European Commission

Artificial intelligence masters' programs - An analysis of curricula building blocks

Dodero, J.M.

Editors: López Cobo, M., De Prato, G.

2021

Joint Research Centre

Contact information
Address: Edificio Expo, C/ Inca Garcilaso 3, Sevilla 41092, Spain
Email: JRC-LIST-B6-SECRETARIAT@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC123713

PDF ISBN 978-92-76-37417-6 doi:10.2760/773615

Luxembourg: Publications Office of the European Union, 2021

How to cite this report: Dodero, J.M., Artificial intelligence masters' programs - An analysis of curricula building blocks, López Cobo, M. and De Prato, G. editors, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-37417-6, doi:10.2760/773615, JRC123713.

Contents

Editors' Foreword

The PREDICT project (Prospective Insights on R&D in ICT) focuses on analysing the supply of Information and Communications Technologies (ICT) and Research and Development (R&D) in ICT in Europe, in comparison with major competitors worldwide. ICTs are indeed the technologies underpinning the digital transformation of the economy and of society. This research aims at supporting the policy making process by providing the evidence needed to analyse strengths and weaknesses of the European ICT industry and of technological take-up in comparison with that of its most important trading partners, over a range of several years and to a significant level of detail. The PREDICT project has been producing comparable statistics and analyses on ICT industries and their R&D in Europe since 2006, covering major world competitors including 40 advanced and emerging countries – the EU27 plus United Kingdom, Norway, Russia and Switzerland in Europe, Canada, the United States and Brazil in the Americas, China, India, Japan, South Korea and Taiwan in Asia, and Australia.

Examples of topics PREDICT addressed in over a decade of research activity are: the shift of the ICT industry, and ICT demand, from manufacturing to services; the rise of the ICT industry in Asia; the international geography of ICT R&D and innovation; the growing problems of the IPR system; the importance of mobile internet, as driving rationale of supply and demand; the deployment of ICT supply-side activities within all sectors of the economy.

PREDICT is presently expanding by analysing techno-economic segments (TES) in the economy, describing the dynamics of their ecosystems with factual data from non-official heterogeneous sources, with the overall objective of contributing to measuring the digital transformation of the economy and providing policy recommendations.

Presently PREDICT is also supporting the work towards the first Digital Europe programme and the Digital Education Action Plan for increasing EU's international competitiveness and developing and reinforcing Europe's strategic digital capacities. PREDICT provides evidence about the availability in the EU27 Member States and six additional countries of adequate advanced digital skills in a number of IT domains, including artificial intelligence. Moreover, the TES analytical approach has been applied to target artificial intelligence and map its worldwide landscape in the EC AI Watch.

PREDICT is a collaboration between the Digital Economy Unit of European Commission (EC) Joint Research Centre (JRC) and the Digital Economy and Skills Unit of the EC Communications Networks, Content and Technology (CNECT) Directorate General.

Acknowledgements

The following researchers constitute the panel of experts who provided valuable comments and useful critiques for this work (in alphabetical order): Stefania Bocconi (Institute for Educational Technology of the National Research Council of Italy), Anna Boyer (University of Lorraine), Asunción Gómez Pérez (Polytechnic University of Madrid), Lynda Hardman (Centrum Wiskunde & Informatica - CWI Amsterdam), Colin de la Higuera (University of Nantes) and Enrico Nardelli (Tor Vergata University of Rome and Informatics Europe). The author would also like to acknowledge the contributions and comments from Silvia Merisio, Lourdes Saltó (DG CNECT), Margherita Bacigalupo, Riina Vuorikari (Joint Research Centre's Human Capital and Employment unit), David Fernández Llorca, Fernando Martínez Plumed, Riccardo Righi and Sofia Samoili (Joint Research Centre's Digital Economy unit). The author finally acknowledges the valuable support provided by Montserrat López Cobo and Giuditta De Prato (Joint Research Centre's Digital Economy unit), co-editors of this report.

Author

Juan Manuel Dodero, Professor of Computer Science, School of Engineering, University of Cádiz

Abstract

This report identifies building blocks of master programs on Artificial Intelligence (AI), on the basis of the existing programs available in the European Union. These building blocks provide a first analysis that requires acceptance and sharing by the AI community. The proposal analyses first, the knowledge contents, and second, the educational competences declared as the learning outcomes, of 45 post-graduate academic masters' programs related with AI from universities in 13 European countries (Belgium, Denmark, Finland, France, Germany, Italy, Ireland, Netherlands, Portugal, Spain, and Sweden in the EU; plus Switzerland and the United Kingdom). As a closely related and relevant part of Informatics and Computer Science, major AI-related curricula on data science have been also taken into consideration for the analysis. The definition of a specific AI curriculum besides data science curricula is motivated by the necessity of a deeper understanding of topics and skills of the former that build up the foundations of strong AI versus narrow AI, which is the general focus of the latter.

The body of knowledge with the proposed building blocks for AI consists of a number of knowledge areas, which are classified as Essential, Core, General and Applied. First, the AI Essentials cover topics and competences from foundational disciplines that are fundamental to AI. Second, topics and competences showing a close interrelationship and specific of AI are classified in a set of AI Core domain-specific areas, plus one AI General area for non-domain-specific knowledge. Third, AI Applied areas are built on top of topics and competences required to develop AI applications and services under a more philosophical and ethical perspective. All the knowledge areas are refined into knowledge units and topics for the analysis. As the result of studying core AI knowledge topics from the master programs sample, machine learning is observed to prevail, followed in order by: computer vision; human-computer interaction; knowledge representation and reasoning; natural language processing; planning, search and optimisation; and robotics and intelligent automation. A significant number of master programs analysed are significantly focused on machine learning topics, despite being initially classified in another domain. It is noteworthy that machine learning topics, along with selected topics on knowledge representation, depict a high degree of commonality in AI and data science programs. Finally, the competence-based analysis of the sample master programs' learning outcomes, based on Bloom's cognitive levels, outputs that understanding and creating cognitive levels are dominant. Besides, analysing and evaluating are the most scarce cognitive levels. Another relevant outcome is that master programs on AI under the disciplinary lenses of engineering studies show a notable scarcity of competences related with informatics or computing, which are fundamental to AI.

Executive Summary

This report identifies building blocks of masters' programs on Artificial Intelligence (AI), on the basis of the existing programs available in the European Union. An analysis of post-graduate academic training related with AI has been carried out to determine the characteristics of existing EU AI master level programs and to help higher education authorities have a common understanding.

The methodology approached for this study begins by the analysis of a sample of 45 masters' program content. Knowledge topics and competence-based skills declared as the learning outcomes of such programs have been subject to a case-by-case study. Then, existing curricula in AI and related areas of Informatics, proposed by main European and US organizations in computing education, have been identified and analysed to form a frame for the competence-based curricula development. After assessing similarities and commonalities regarding AI topics coverage, the building blocks of a possible EU AI master have been delineated. The curriculum and the analysis performed are based first on the knowledge contents, and then on the educational competences compiled from the declared learning outcomes of the sample of masters.

With the overall goal of AI being to develop computational systems capable of human levels of intelligent behaviour, AI is considered as a relevant part of Informatics, built on strong mathematical and computer engineering foundations. Noteworthy efforts on drafts for Data Science curricula are ongoing, putting an emphasis on AI topics and skills. Data Science curricula, however, are more focused on narrow AI knowledge and skills than in those skills that build up the roadmap towards strong AI. That is the principal motivation and need for the development of an AI curriculum that is different to existing data science curricula.

The identified knowledge-based curricular building blocks describes a number of knowledge areas, refined into a set of knowledge units, which are formed by topics on AI. This structure constitutes the body of knowledge for AI education at the master's level, classified in the following core domains:

- Automated reasoning & planning, including knowledge representation, automated reasoning, planning, search and optimization;
- Automated learning, including symbolic and stochastic machine learning;
- Computational linguistics and communication, including natural language processing;
- Computational perception, including computer vision and audio processing;
- Intelligent systems integration, including robotics and intelligent automation, multiagent systems, and connected and automated vehicles;
- Human-machine interaction, including human-computer interaction and non-verbal interaction;
- AI digital services & applications; and
- AI ethics & philosophy

The identified core domains are later complemented by a competence-based design of the AI curriculum's building blocks. The AI-specific knowledge is also accompanied by topics from horizontal areas of Informatics, Mathematics and Statistics disciplines, which are fundamental domains to study a master program on AI, and which are often acquired through a grade-level degree. No specific competence-based study has been carried out to analyse the skills of these AI fundamental grade-level domains.

The results of the knowledge-based analysis of knowledge topics from all masters' programs, considering only core AI domains and excluding AI fundamentals, shows that 27% of all topics have to do with automated learning; between 16 and 18% have to do with computational perception, intelligent systems integration and interaction, and knowledge reasoning and planning; between 8% and 9% have to do with AI digital services and applications and communication; and less than 5% of all topics have to do with AI ethics and philosophy.

Regarding knowledge topics on core AI subdomains plus AI fundamentals on informatics and statistics, the topic coverage outputs the following figures:

- Machine learning (21.4%),
- Fundamental Informatics/Computing (10.9%),
- Computer vision (10.0%),
- Fundamental maths & statistics (8.1%),
- Human-computer interaction (7.1%),
- Knowledge representation and reasoning (7%),
- Natural language processing (6.4%),
- Planning, search and optimisation (5.4%)
- Robotics and intelligent automation (5.4%)

The rest of subdomains (i.e. audio processing, AI services and applications, AI ethics, connected and automated vehicles and philosophy of AI) cover less than 5% of topics.

A significant number of master programs analysed are very focused on topics that are classified under a domain that is different to the principal domain of classification for the master. It is noteworthy that machine learning is the domain most covered by topics of most programs, independently of the initial master program's aim. A significant number of masters about computational linguistics and natural language processing are more focused on machine learning topics than on its own domain's topics. Masters about computational perception, robotics and intelligent automation are also very focused on machine learning. The latter are as much focused on machine learning topics or even more than in their own topics. In general, ethics and philosophy topics are not sufficiently covered, except by some master programs about services and applications.

For the competence-based analysis of AI curricula developed on the sample of masters, we applied a classification of competences by competence level (i.e., knowledge, skill or disposition) and competence type (i.e., transversal competences, general competences of AI, specific competences of an AI domain, and horizontal competences). Horizontal competences are related with either one of the two fundamental fields of AI (i.e. informatics and statistics). The competence-based analysis of competence levels is based on the Bloom's taxonomy, which considers a number of cognitive levels for competences at a knowledge level (i.e. level-1 *remembering* and level-2 *understanding*), skill level (level-3 *applying*, level-4 *analysing*, level-5 *evaluating* and level-6 *creating*) and disposition level, including also transversal skills in the analysis.

The results of the competence-based analysis show that Bloom's understanding and creating cognitive levels are dominant in the explicit declaration of knowledge, skills and dispositions in the master programs' learning outcomes. The most scarce cognitive levels in the learning outcomes are related with analysing and evaluating. A good number of knowledge areas of the analysed programs do not cover all cognitive levels, which often results in an incomplete competence-based description of curricula. Another noteworthy result is that under the disciplinary lenses of engineering studies, master programs on AI show a notable scarcity of horizontal competences, related with informatics or computing, which are fundamental to AI.

Finally, after the knowledge-based and competence-based analysis, a body of knowledge and the building blocks for a competence-based EU AI curriculum is proposed. It consists of the following knowledge areas, for which a respective set of knowledge units and learning competences are also defined:

Group	**Knowledge Area**		**Scope within AI**
AI Essentials	FIC	Fundamentals of Informatics/ Computing	Concepts, theories, methods and techniques of Informatics or Computing, Computer Science and Software Engineering that are at the foundations of building an intelligent system
	FMS	Fundamentals of Maths & Statistics	Concepts, theories, methods and techniques of Mathematics, Probability and Statistics that form the foundations of intelligent systems
AI General	AIG	AI General	General AI competences that are not domain-specific, i.e., the overall knowledge needed to achieve the goal of artificial intelligence, without using specific techniques that characterise core areas or fundamentals of informatics or computing. A generic broad definition of AI would be applicable here: Systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal

Group	Knowledge Area		Scope within AI
AI Core areas	KRR	Knowledge Representation and Reasoning	Representation of information and knowledge in logic and probabilistic formalisms. Application of automated reasoning methods to the represented information and knowledge
	PSO	Planning, Search & Optimisation	Methods for planning and executing solutions by intelligent systems
	ML	Machine Learning	Algorithms that improve through experience to identify patterns in data to build models in order to gain valuable information. It includes the processing, analysis and presentation of data
	NLP	Natural Language Processing	Collection and parsing of text data to generate and understand human languages
	CP	Computational Perception	Interpretation of data in a manner that is similar to the way humans use their senses to relate to the world around them, mainly through vision and audio processing
	RAI	Robotics, Agents & Integration	Distribution, coordination, cooperation, and autonomy of intelligent systems with the environment, as well as the combination of other abilities
	HMI	Human-Machine Interaction	Interaction of humans with computers and intelligent machines and technologies that let humans interact with computers in effective ways
AI Applied areas	AIS	AI Services	Infrastructure, software and platforms provided as digital services or applications to run AI, which are available off-the-shelf and run on demand
	PEA	Philosophy & Ethics of AI	Philosophical and ethical issues associated with AI and related with the compliance of ethical principles and values, including applicable regulation

The building blocks for an AI curriculum that are proposed here should be seen as a first proposal to continue working on, and they need to be sufficiently flexible in order to take into account a future expansion of the body of knowledge in AI.. In order to provide a complete AI curriculum, the sample of masters can be broadened, as well as a revised method should be approached to complement the report with additional studies.

A potential follow-up of this work may be the development of a catalogue that defines and describes a number of levels of expertise in AI linked to the building blocks identified. Based on that, an approach can be defined to help designing a master's program or to classify existing ones according to the eventual EU AI curriculum framework.

1 Introduction

1.1 Policy background

The promotion and support of the digital transformation in Europe is one of the key objectives of the European Commission (EC). A Europe fit for the digital age, one of the six political priorities of the Von der Leyen's Commission, aims at benefiting from digitalisation in a safe an ethical way. While the digital economy is a leading driver of the European economy, digital skills will be in greater demand and their prevalence in society needs to be monitored and further developed.

Some of the EC recent communications target the development of Artificial Intelligence (AI) from multiple perspectives[1], including the skills dimension. The Coordinated Plan on AI proposes joint actions for cooperation to foster the development and use of AI in Europe and provides recommendations for Member States. The Plan enacts that the digital skills that facilitate AI uptake should be included in all education levels and training curricula, and will be particularly supported in Master and PhD programs. The proposed Digital Europe programme[2] aims at increasing the EU's international competitiveness and reinforcing strategic digital capacities, and identifies AI among the key advanced digital skills for a competitive Europe in the digital race. It provides funding for initiatives on advanced digital skills, among which is the development of master's programs in cutting-edge digital technologies.

Additionally, the recently adopted 2021-2027 Digital Education Action Plan[3] proposes stronger cooperation between Member States for a high-performing digital education ecosystem, with enhanced competences and connectivity for the digital transformation. The plan proposes to enhance digital skills at all levels, from basic to advanced.

1.2 Objectives and expectations

The objective of this study is to contribute to the development of policies to encourage the introduction of AI advanced skills in higher education. In particular, this report aims to delimit and define a the building blocks of an AI masters' program.

Developing computational systems capable of human levels of intelligent behaviour is the overall goal of AI (Rosenbloom, 2013). As a topic, it is considered as part of Informatics or Computer Science[4], one of the traditional disciplines within the computing sciences, built on strong mathematical foundations. Informatics also includes topics as Human-Computer Interaction (HCI), with an emphasis on facilitating human use of computers; and graphics, with its focus on visual rendering of both real and imagined scenes. Such topics only illustrate very superficially the conventional topics within computing, but they are highlighted here because they constitute a relevant part of the foundations on which AI is built. This topic list can be completed by other disciplines of Informatics, such as Computer Engineering, Information Science and Computational Sciences. As such, AI brings a major source of skills needed for the digital transformation of the economy. The quantity and diversity of post-graduate academic training related with AI requires a thorough analysis, with the objective of determining the characteristics of an AI curriculum for masters' programs. This should be based on best practices by top universities around Europe, and will help higher education authorities to build their programs on AI.

Having just knowledge is not sufficient to be productive in the changing world of AI. Competences require skills that complement knowledge to achieve professional expectations. The mission of this document is to produce a reference of AI knowledge areas and competences appropriate for master programs that meets the growing demands of the changing technological world and is useful for both industry and academia.

The report compares existing curricula in world-leading institutions in AI and it aims to promote and feed further discussion among relevant stakeholders, with a view of providing a common understanding about the main components of an AI curricula for masters' programs.

---

1 For instance, the European Strategy on Artificial intelligence (Communication "Artificial intelligence for Europe" COM(2018) 237), the Coordinated Plan on AI (COM(2018) 795), the White paper on AI - A European approach to excellence and trust (COM(2020) 65).

2 COM(2018) 434, https://ec.europa.eu/digital-single-market/en/europe-investing-digital-digital-europe-programme

3 COM/2020/624

4 In the US, the term *computer science* has an equivalent meaning to *informatics* in Europe. In the US *informatics* focuses on issues concerning data, particularly the management and analysis of data across the sciences, currently known as *data science*. In this document, *Informatics* is used as the EU term for the discipline known in the UK and other parts of the world as *Computing*.

1.3 Scope of AI

AI includes the methodologies for modelling and simulating several human abilities that are widely accepted as representing intelligence. Perceiving, representing, learning, planning, and reasoning (either with complete or uncertain knowledge and partial evidence) are traditional key themes in AI. Generating knowledge for a useful human-AI communication is also a key theme, though less developed than the former. These human abilities form the core **AI domains** as defined by the AI Watch[5] report that proposes an operational definition of AI (Samoili et al., 2020a).

The operational definition of AI proposed by AI Watch is based on the AI definition developed by the High-Level Expert Group on AI[6]. According to that definition:

> *Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions*

Concepts and methods developed by the AI discipline have been included and analysed in existing curricula recommendations for a diversity of closely related domains of **Informatics**, such as **Computer Science** (CS) **Data Science** (DS), **Information Technology** (IT) and **Cyber-security** (CSEC). Curricular recommendations in these fields that delimit the scope of AI and are thus relevant for an AI curriculum are described below. They are based on the IEEE/ACM Computing Curricula 2020 (CC2020) project, which proposes a philosophical shift in the format and emphasis of curricula through the adoption of a competence-based model for curriculum specification. The report will go beyond curricula on Informatics[7], since we will also consider ethical and philosophical contents that complement Informatics and other information technology-related areas.

1.4 Methodology

The methodology of development of the tasks required for this study has consisted of the following steps:

1. **Analysis of programs' contents**: Starting from a sample of masters, this step consists of the collection and qualitative analysis of the programs' content, in order to identify the main characteristics of the selected programs. It is based on a case-by-case study of the available information included in a sample of master programs, complemented with the information collected from universities' websites. The sample has been taken from the database feeding a JRC report analysing the education offer in advanced digital technologies in European and non-European universities (Righi et al., 2020). A description of the sample selection can be found in subsection 1.5, and a list of the masters considered is available in Annex C: List of analysed masters. This analysis provides an overview of the AI education offer of master courses in terms of:
   - Modules and courses that compose compulsory and optional courses
   - Duration and number of ECTS credits per course/module
   - Students' background and other entrance requirements
   - Departments or research areas in which they are embedded
   - Main education field, academic outcome, potential professional outings and career opportunities
2. **Identification of existing AI curricula**: A desk research is conducted to identify already developed AI curricula in European or non-European institutions. The identification of existing curricula has served to frame the competence-based curriculum, based on curricular frameworks that are globally accepted in the main European and worldwide institutions related with education and training in Artificial Intelligence and Informatics, such as ACM, IEEE, AIS and IFIP.

---

[5] AI Watch is the European Commission knowledge service to monitor the development, uptake and impact of Artificial Intelligence for Europe, launched in December 2018. AI Watch monitors European Union's industrial, technological and research capacity in AI; AI-related policy initiatives in the Member States; uptake and technical developments of AI; and AI impact. AI Watch has a European focus within the global landscape. In the context of AI Watch, the Commission works in coordination with Member States. AI Watch results and analyses are published on the AI Watch Portal (https://ec.europa.eu/knowledge4policy/ai-watch_en).

[6] Appointed by the EC to support the implementation of the European Strategy on AI.

[7] See footnote 4.

3. **Assessment of similarities**: The Master course programs analysed in step 1 are assessed to find similarities and commonalities in order to delineate the building blocks of an AI curriculum. The assessment begins from the AI Watch report (Samoili et al., 2020a) domains, subdomains and keywords, which are then justifiably extended from the programs' content descriptions that are subject of the analysis in step 1 and the outcomes of the desk research carried out in step 2. When assessing similarities between programs from different countries, national specificities are considered, since the structure and definition of master programs depend on the countries' accreditation system.

4. **Definition of building blocks for a draft AI curriculum**: The proposal of the building blocks for an AI curriculum is based on the results from step 1 and 2, and is developed following an adequate competence-based framework. This step has produced the first draft of the building blocks for an AI curriculum. This task is supported by the interaction with academia professors with expertise in different AI areas and curricula building[8]. The related complete works that have served as additional references are the following:

   - The IEEE/ACM Cybersecurity (CSEC) 2017 curricula[9]
   - The IEEE/ACM Information Technology (IT) 2017 curricula[10].
   - The IEEE/ACM Computing Curricula (CC) 2020 in its current draft status[11].
   - The Competence Based Framework for Curriculum Development, focused on ICT training, produced under the TEMPUS project[12].
   - The IEEE/ACM Data Science (DS) 2019 curricula draft 2[13], as proposed and analysed in the desk research.

The proposal of an AI curriculum includes the AI specialised contents to be covered, as well as other characteristics as analysed in the previous subtasks (AI subdomains, duration, number of credits, etc.).

This report does not propose a closed curriculum, but a portfolio of contents and characteristics, building blocks from which education institutions may pick to compose their AI specialised masters. This way, the AI curriculum may be developed covering core topics and horizontal topics, theoretical courses and applied courses, etc.

1.5 Assumptions

The sample of 45 masters used for the study has been drawn from the dataset developed for the JRC study on Academic offer of advanced digital skills in 2019-20 (Righi et al., 2020). That study relies on data from Studyportals[14], a platform offering worldwide information on global study choice. As acknowledged by the referred JRC study, this source is the one providing the widest coverage of programs offered by European universities. However, the source does not cover all European universities[15], and the fact that programs taught in national languages (other than English) are not tracked limits its coverage[16]. This source is used under the assumption that masters that are taught (totally or partially) in English language are representative of the

---

8 The following researchers constitute the panel of experts who participated in the discussions and review of a preliminary version of this report, providing valuable comments and useful critiques (in alphabetical order): Stefania Bocconi (Institute for Educational Technology of the National Research Council of Italy), Anna Boyer (University of Lorraine), Asunción Gómez Pérez (Polytechnic University of Madrid), Lynda Hardman (Centrum Wiskunde & Informatica - CWI Amsterdam), Colin de la Higuera (University of Nantes) and Enrico Nardelli (Tor Vergata University of Rome and Informatics Europe).

9 Cybersecurity Curricula 2017. Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity. ISBN: 978-1-4503-5278-9. DOI: 10.1145/3184594. URL: https://dl.acm.org/citation.cfm?id=3184594

10 Information Technology Curricula 2017. Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology. ISBN: 978-1-4503-6416-4, DOI: 10.1145/3173161. URL: https://dl.acm.org/doi/book/10.1145/3173161

11 Computing Curricula 2020. Paradigm for future Computing Curricula. Version 36, April 2020 URL: https://cc2020.nsparc.msstate.edu/

12 TEMPUS project. PICTET: EQF-based professional ICT training for Russia and Kazakhstan. 543808-TEMPUS-1-2013-1-BE-TEMPUS-JPHES. ISBN: 978-619-185-015-0, ISBN online: 978-619-185-016-7. Publisher: Za bukvite, O'pismeneh, Sofia, 2014

13 Computing Competencies for Undergraduate Data Science Curricula, Draft 2, Dec 2019, URL: http://dstf.acm.org/DSReportDraft2Full.pdf

14 https://studyportals.com

15 Studyportals database feeds from universities' websites and from data reported by universities. Although very complete, it still suffers from some information lags, and as consequence, it is possible that few universities with a strong record in research and academic offer are not covered.

16 The case studies conducted to evaluate the coverage of specialised masters for Spain and France gave satisfactory results. The conclusion was that, even if not covering all the education offer, "the source covers a high percentage of the targeted programmes and that the impact of the teaching language, although not negligible, was somehow limited and not strongly affecting the validity of the source" (Righi et al., 2020).

masters offered by each country. From that source, Righi et al. (2020) derive a list of AI-related programs, from which we have drawn a sample of masters for this analysis.

The masters have been selected from top universities ranked according to a triple quality criteria:

i. the JRC AI TES R&D excellence score, a normalised measure based on the number of AI-related research activities developed (patent applications and frontier research)[17];

ii. the 2020 QS World University Rankings in the subject Engineering and Technology; and

iii. the Webometrics' excellence ranking, based on top cited papers.

The three scores are transformed, normalised and weighted. Higher values of the score represent higher quality of the university (unlike rankings); and higher weight has been given to the JRC AI TES R&D excellence score, since it considers AI-relevant research activity, while the other two rankings represent more general quality criteria of the institutions, which may not be directly related to AI activity. While these criteria seem appropriate to identify top universities in AI in terms of cited papers and AI research activity, it can be argued that they may not necessarily be the best proxy for quality of programs' syllabus and teaching skills. Therefore, in absence of indicators on pedagogical quality, we assume that the referred criteria rightly assist in the selection of a solid sample for the purpose of this work.

Additional principles contemplated for the sample selection are (i) geographical diversity, to capture national specificities: 13 European countries are represented[18]; and (ii) topic variability: the sample includes programs covering a wide range of AI subdomains such as: knowledge representation and reasoning, planning and scheduling, searching, optimisation, machine learning, natural language processing, computational perception, robotics and automation, multiagent systems, connected and automated vehicles, human-computer interaction, AI Services, AI Ethics and Philosophy of AI. The incorporation of less frequent domains, such as the ethics of AI or the philosophy of AI, has meant that some good quality masters on more common domains (e.g. machine learning) are not included in the sample.

Bearing in mind the limitations of the original source, and the multiple criteria followed to draw the sample, the list of masters that serves as the starting point for this study does not pretend to be exhaustive, with the result that many high quality masters offered by prestigious universities have not been included. Overall, we consider that the list of 45 masters analysed for the study sufficiently represents the European educational offer in AI at masters' level.

[17] Detailed information on the score can be consulted in (Samoili et al., 2020b).

[18] Belgium, Denmark, Finland, France, Germany, Italy, Ireland, Netherlands, Portugal, Spain, and Sweden in the EU; plus Switzerland and the United Kingdom.

2 Context

Artificial Intelligence was born in the context of well-established scientific disciplines such as Mathematics and Informatics. In the academic context, AI is currently considered a knowledge area in the broad scope of Informatics that shares the same informational structures that are at the core of Mathematics and Informatics. At the core of academic Informatics in most universities are Computer Science and Computer Engineering departments. Despite the use of the word science in its name, computer science is frequently considered to be an engineering discipline. Therefore, Informatics, Computer Science and Computer Engineering are fundamental disciplines underlying to AI[19]. The quantitative, mathematical approaches of AI as an Informatics and Computer Engineering discipline have their origins in academic departments of Statistics and Operational Research. The knowledge, concepts and methods of all these scientific disciplines have to be taken into account as the principal context in order to propose an AI curriculum.

2.1 AI Watch taxonomy

As basic **taxonomy** for AI, we consider as starting point the one elaborated as part of the operational definition of AI, developed in the AI Watch context (Samoili et al., 2020), as depicted in Figure 1.

Figure 1. Proposed taxonomy in AI Watch report (Source: AI Watch)

	AI taxonomy	
	AI domain	**AI subdomain**
Core	**Reasoning**	Knowledge representation
		Automated reasoning
		Common sense reasoning
	Planning	Planning and Scheduling
		Searching
		Optimisation
	Learning	Machine learning
	Communication	Natural language processing
	Perception	Computer vision
		Audio processing
Transversal	**Integration and Interaction**	Multi-agent systems
		Robotics and Automation
		Connected and Automated vehicles
	Services	AI Services
	Ethics and Philosophy	AI Ethics
		Philosophy of AI

Source: AI Watch (Samoili et al., 2020)

Core **AI domains** are defined by the human abilities and purposes the AI is intended to fulfil. Such human abilities are mainly representing, planning, reasoning, learning, communicating, perceiving and acting (Russell & Norvig, 2016). Besides, traversal domains are common to all core domains.

Due to the terminological coincidence of the AI domains and common language concepts out of the Informatics and AI realms, it is needed to specify further the meaning of the short names used for such domains:

Representation and reasoning refers to computational methods to automate reasoning, planning, scheduling and optimising the solution to a formally represented problem in a machine-understandable knowledge representation.

Learning refers to computational methods and algorithms that improve through experience. It involves both symbolic learning and statistical learning by machines.

Integration and Interaction refers to characteristics such as distribution, coordination, cooperation, and autonomy of intelligent systems when acting with the environment, as well as the combination of other abilities (i.e. Perception, Reasoning, Learning and Interaction).

[19] See footnote 4.

Communication mainly refers to computational linguistics methods and techniques, including natural language processing. But it also involves non-verbal means of communication, which are also a topic of Interaction.

Perception means the capability of a computer system to interpret data in a manner that is similar to the way humans use their senses to relate to the world around them, mainly through computer vision and audio processing.

Services and Applications refers to any infrastructure, software and platform provided as digital services or applications, which are available off-the-shelf and run on demand.

Ethics & Philosophy includes philosophical and ethical issues associated with AI and related with compliance of ethical principles and values, including applicable regulation.

The **AI subdomains** that unfold from the AI Watch taxonomy are the following:

- Knowledge Representation (KR)
- Automated Reasoning (AR)
- Planning and Scheduling (PS)
- Optimisation and Searching (OS)
- Machine Learning (ML)
- Natural Language Processing (NLP)
- Computer Vision (CV)
- Audio Processing (AP)
- Human-Computer Interaction (HCI)
- Multi-Agent Systems (MAS)
- Robotics & Intelligent Automation (RIA)
- Connected and Automated Vehicles (CAV)
- AI Ethics (AIE)
- Philosophy of AI (PAI)

These subdomains are complemented by the **AI Services (AIS)** subdomain, which compiles a number of services and applications of AI in diverse fields.

2.2 Curricula on AI and related areas

The world will witness degree programs for specialized themes with a broad ranging effect across multiple domains, and AI should be one of these specialized themes. However, the context of this report is delimited by the scope of AI as currently treated in post-degree master programs related with the AI domains and subdomains, as initially defined by the AI Watch report. When the AI Watch report does not cover the AI domain completely, it will be enlarged with other domains as detected from the sample of masters that are analysed.

The context in which the proposal of a new AI curriculum should be understood is that of Informatics or Computing[20], which are the subject of the IEEE/ACM CC 2020. Although the CC 2020 draft report does not include any formal professionally endorsed AI curriculum, AI is recognized in CC 2020 as a study area of renewed interest. Furthermore, it acknowledges that a curricular recommendation in AI areas has the potential to emerge in the next few years.

At the time of this writing, the CC2020 consists of a number of disciplines for which curricula proposals exist, with different degrees of development:

- Information systems (IS) curricula as of 2010
- Computer science (CS) curricula as of 2013
- Software engineering (SE) curricula as of 2014
- Computer engineering (CE) curricula as of 2016
- Information technology (IT) curricula as of 2017
- Cybersecurity (CSEC) curricula as of 2017
- Data science (DS) draft curricula as of 2020

From these existing curricula, which form the disciplinary context of AI, those that consider AI knowledge as mostly relevant are CS, DS, and CSEC, which are analysed separately below. The CC 2020 curricula refer to

[20] See footnote 4.

some other areas, such as Internet of Things (IoT), Cloud computing, and Narrow AI, which have not reached a globally recognized curriculum. In particular, narrow AI, also known as **weak AI**, supports specific tasks in a well-defined context to enable and support human decision making; while general artificial intelligence or **strong AI** is focused on forms of AI that mimic and may exceed human capabilities. Narrow AI has been quickly adopted by research and industry, since it represents a huge part of the recent successes of AI, based on statistical machine learning and, more specifically, deep learning techniques. However, the reality is that these techniques only tell a partial story. If the horizon is to tackle strong AI, other aspects of AI should be taught beyond weak AI topics.

An emerging area that is being subject of standardization for their curricula is **data science**. Recently in 2019, the IEEE/ACM DS draft curriculum has been released, and the EDISON Data Science Framework (EDSF) has been published including a DS curriculum proposal and competence framework for DS based on the European e-Competence Framework (e-CF), with the aim of developing data science and analytics-related competences and professional skills. These efforts, though appreciable, put the focus more in weak AI knowledge and skills than in those skills that must build the roadmap towards a strong AI. This is a principal reason why an AI curriculum is needed and it must be differentiated from DS curricula.

2.2.1 IEEE/ACM Data Science 2019 curriculum

The IEEE IS 2010 curriculum provides a competency framework for the description of various **knowledge areas**. Knowledge areas are refined further into a set of **knowledge units**. In all IEEE/ACM curricula based on that framework, each knowledge area represents a significant and coherent body of material, which in the case of the DS 2019 curriculum has to be considered for AI course programs.

AI knowledge domains and AI competences are very relevant for the DS 2019 curricula and vice-versa. AI competences are not only used by the DS curricula, but also produced in the DS curricula. That provides a strong argument in favour of a thorough analysis of the DS 2019 curriculum in the desk research required for this report. For instance, knowledge graphs and ontologies are both used and generated by data scientists; computer vision algorithms can be used and improved for the analysis of image data; speech and natural language processing algorithms can be researched and applied in the analysis of speech or text data; and machine learning algorithms are also applied extensively to extract patterns from data.

Conversely, DS methods are applied extensively in AI systems. For instance, big data systems have boosted AI applications and systems. Due to their centrality in DS, AI competencies related to image and text analysis and machine learning are highlighted in specific knowledge areas of the DS 2019 curricula, such as Data Acquisition, Management and Governance, Data Mining and Machine Learning, which form a separate area from AI in the DS 2019 curricula. The AI area of the DS 2019 curriculum is limited to knowledge representation, reasoning, and planning, because other AI domains, such as machine learning, have been placed as separate areas in the curricula. But they all are part of the extensive AI domain that must be considered here.

The AI area of the DS 2019 curriculum is classified in the following major sub-areas:

- General
- Knowledge Representation and Reasoning (Logic-based models)
- Knowledge Representation and Reasoning (Probability-based models)
- Planning and Search Strategies

The IEEE DS 2019 curriculum classifies ML as a separate knowledge area from AI. Some topics of AI such as Big Data Systems and Data Mining are also classified as separate knowledge areas from AI.

The machine learning area is classified in the following sub-areas:

- General
- Supervised learning
- Unsupervised learning
- Applications that require mixed methods
- Deep learning

The data mining area is classified in the following sub-areas:

- Proximity measurement
- Data preparation
- Information extraction

- Cluster analysis
- Classification and regression
- Pattern mining
- Outlier detection
- Time series data
- Mining Web data
- Information retrieval

The DS 2019 curriculum defines two great knowledge areas that can be shared with the AI domain classification, namely: Programming, Data Structures and Algorithms; and Software Development and Maintenance.

2.2.2 IEEE/ACM Cybersecurity 2017 curriculum

Cybersecurity (CSEC) curriculum proposes crosscutting concepts to help students explore connections among the knowledge areas, and are fundamental to an individual's ability to understand the knowledge area regardless of the disciplinary lens. These concepts "provide an organizational schema for interrelating knowledge" into a coherent view of cybersecurity. The crosscutting concepts also reinforce the security mindset conveyed through each of the knowledge areas. The CSEC model considers crosscutting concepts of confidentiality, integrity, availability, risk, adversarial thinking and systems thinking.

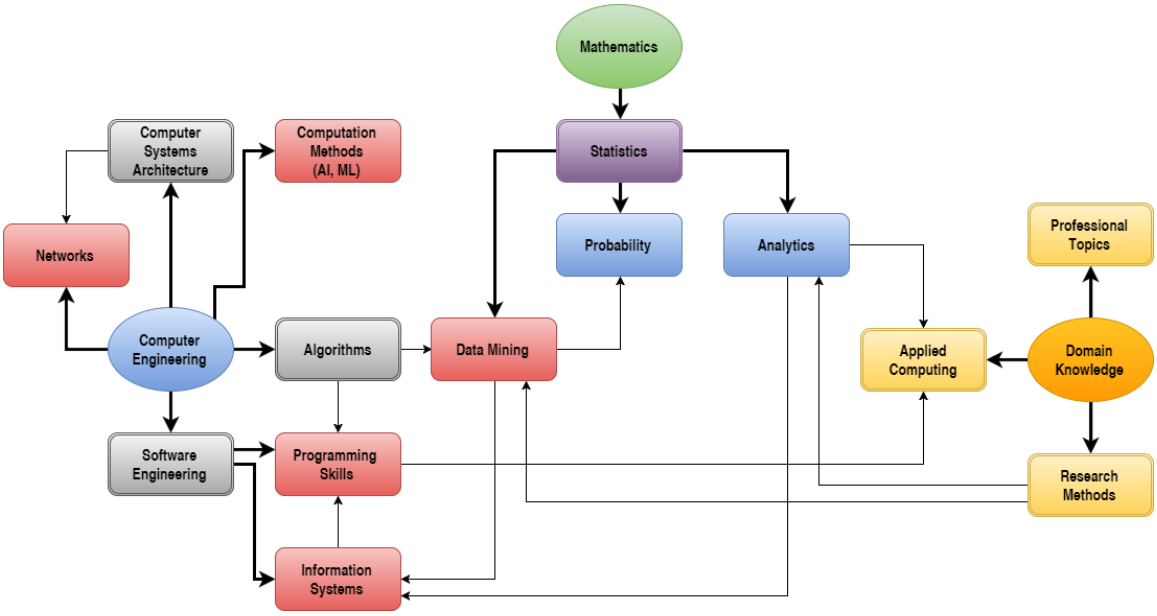
2.2.3 EDISON Data Science Framework

Besides ACM/IEEE DS 2019 curricula, the EDISON European project delivered in 2016 the Data Science Framework (EDSF), which is a comprehensive model to define competence-based curricula in the field of Data Science. All components of the framework are based upon the *Data Science Body of Knowledge* (DS-BoK), which defines the knowledge areas for building Data Science curricula that are required to support Data Science competences. DS-BoK is organised by Knowledge Area Groups corresponding to the CF-DS competence groups. It also incorporates best practices in Computer Science and domain- specific books of knowledge and knowledge areas based on the ACM 2012 Computing Classification System (CCS). The relation between areas in DS-BoK is shown in Figure 2.

2.2.4 Digital Experience domain

Another emerging area in Informatics that has to do with AI is **digital experience**, which involves customized, emotionally intelligent experiences based on individuals' emotions using AI capabilities. The area of interaction technologies is moving to other capabilities that allow augmentation of human experiences with capabilities that naturally do not exist. When the integration with natural human experience is so tight that the technology as a separate entity becomes invisible, the interaction contexts are known as **ambient computing**, where AI has also a great relevance. Related with digital experience, the area of **cognitive technologies** is a label frequently used to refer to a variety of AI capabilities for addressing complex organizational and societal problems.

Figure 2 Relationships between knowledge areas in the EDSF DS-BoK component



Source: EDSF project.

2.3 Existing competence-based curricular frameworks

The competence-based framework for AI will be mainly based on the CC 2020 model, taken from the Knowledge-Skill-Disposition framework model defined by the IT 2017 curricula. Other competence-based curricular frameworks of relevance for AI are the IEEE/ACM Cybersecurity 2017 curricula and the EDISON Data Science Framework, which are described below. Besides, the EQF and e-CF are general competence-based frameworks that are also of interest for AI.

2.3.1 IEEE/ACM IT 2017 competence-based framework

According to IT 2017 curricula, an individual's **competence** is defined as the *knowledge* (know what), *skill* (know how) and *disposition* (know why) in the accomplishment of a task. The definition of the **learning outcomes** for a competence adopts Bloom's taxonomy (Bloom et al., 1956) of cognitive process to specify the skill level expected in successful task accomplishment. The **task** is the construct that frames the skilled application of knowledge and makes dispositions concrete. The IT 2017 volume introduced the notion of *disposition*, a concept that had its origins in the concept of *context* to highlight distinctive situations.

2.3.2 IEEE/ACM Cybersecurity 2017 curricula

For the purpose of this report, the CSEC 2017 curricula is useful in two veins. First, the report structure was the first of the CC 2020 curricula to be based in the competence-based framework originally depicted in the IT 2017 curricula. The competence-based curricular framework is of outmost relevance and has to be considered in new AI curricula. Second, CSEC 2017 curricula deals with cyber security and privacy topics that are also relevant to AI, particularly for the ethical and philosophical domains, related with the knowledge area of social security as defined in CSEC 2017 curricula.

2.3.3 ACM/AIS MSIS 2016 global competency model

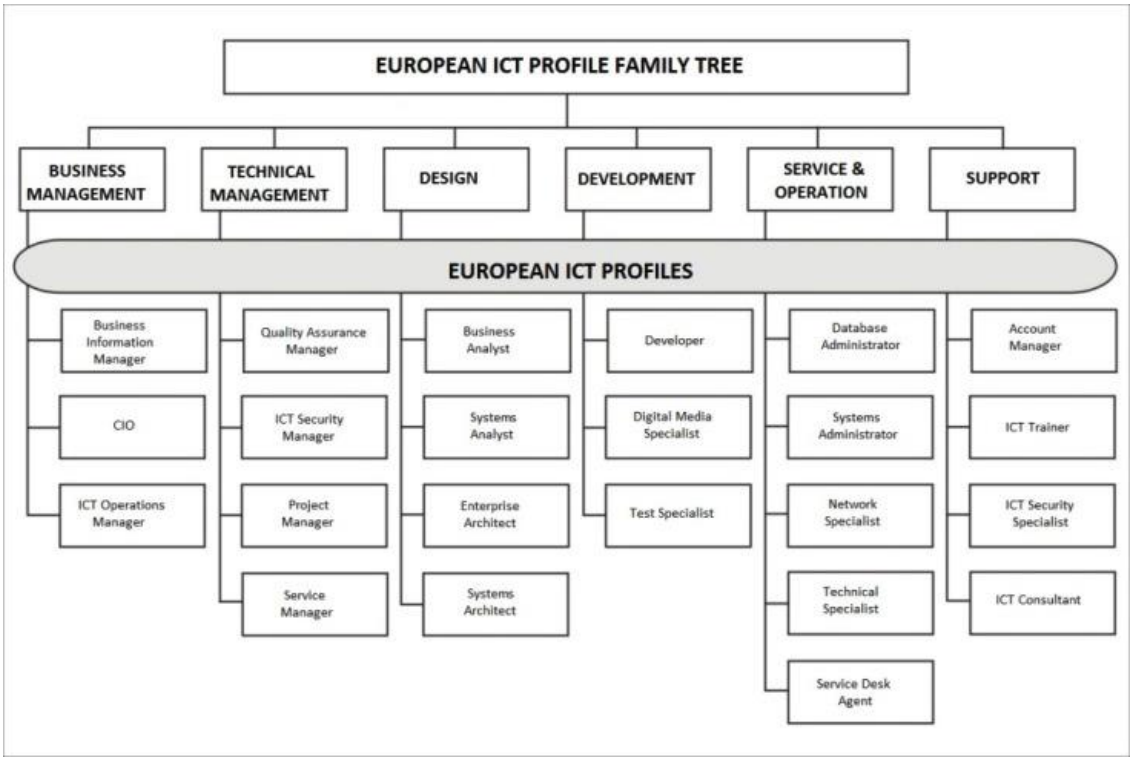
The ACM and AIS defined a competence model and curriculum guidelines (Topi et al., 2017) for master's level degree programs in Information Systems (IS). Beyond the IEEE/ACM IS 2010 curriculum, which is thought to define a body of knowledge for the IS field as the intersection of Informatics/computing and Business/management, the MSIS 2016 is focused on competences at the program level. It develops competences in three realms: IS competences, individual foundational (i.e. transversal) competences and domain-specific competences. It includes the following areas of individual, foundational competences: Critical thinking, Creativity, Collaboration and team work, Ethical analysis, Intercultural competence, Leadership, Mathematical and statistical competences, Negotiation, Oral communication, Problem solving and Written communication.

2.3.4 EQF and e-CF competence framework

The European Qualification Framework (EQF) provides a common European translation tool that facilitates the comparison of different qualifications issued all over Europe. It consists of eight levels that are defined according to **learning outcomes**, which refer to the knowledge, skills and competences to be acquired. The EQF levels go from knowledge of general concepts and practical skills in a field of study to frontier knowledge and specialized skills to solve problems in research and innovation. EQF competences can be mapped to the 5 levels of the e-CF[21] framework, which resemble knowledge areas and knowledge units of the original ACM/IEEE curricula (CS 2013 and IT 2024), which have been superseded by the competence-oriented curricula of IT 2017 and CC 2020.

A useful approach of the EQF is to group ICT profiles into 6 families, as depicted in Figure 3. This classification can be useful to classify the types of master courses according to their professional profile orientation (from business manager to technical manager, designer, developer, service operations or support).

Figure 3. EQF ICT profile family tree



Source: PICTET TEMPUS project (Dolinina et al., 2017)

2.3.5 EDISON Data Science Framework

The EDISON Data Science Framework (EDSF) is a comprehensive model to define competence-based curricula in the field of Data Science. Besides the *Data Science Body of Knowledge* (DS-BoK) component, it includes a *Data Science Competence Framework* (CF-DS) and a *Data Science Model Curriculum* (MC-DS)

The CF-DS is a competence framework defined using the same approach as e-CF version 3. It extends e-CF with a number of competences related to Data Science and the following competence groups:

- Data Science Analytics (including Statistical Analysis, Machine Learning, Data Mining, Business Analytics, others)
- Data Science Engineering (including Software and Applications Engineering, Data Warehousing, Big Data Infrastructure and Tools)

[21] European e-Competence Framework 3.0. A common European Framework for ICT Professionals in all industry sectors. CWA 16234:2014 Part 1 [online] http://ecompetences.eu/wp-content/uploads/2014/02/European-e-Competence-Framework-3.0_CEN_CWA_16234-1_2014.pdf

- Data Management and Governance (including data stewardship, curation, and preservation)
- Research Methods and Project Methods
- Domain Knowledge and Expertise (Subject/Scientific domain related)

The MC-DS is built upon DS-BoK and linked to CF-DS. The definitions of Learning Outcomes are based on CF-DS competences, and learning units are mapped to Knowledge Units of DS-BoK. Three proficiency levels are defined for each Learning Outcome (LO) to allow for flexible curricula development and profiling for different professional profiles.

2.4 Program accreditation standards

Masters programs can be appraised against standard frameworks for accreditation, such as ABET[22] and EUR-ACE[23] for Engineering studies or EQANIE[24] for Informatics, Computer Science and Engineering. The EURO-INF quality label can be awarded to degree programs at BSc or MSc level that comply with a set of standards and accreditation criteria[25]. We must note that none of the master's programs selected for this study are accredited by EURO-INF, and that the applicability and appraisal of the EURO-INF seal is very diverse among different countries. Besides, feeding an accreditation framework is not a goal of this report. All in all, there is a number of criteria in the EURO-INF quality label that can be relevant for analysing a master on AI.

First, one of the main criteria to be assessed in the program design and development are LO definition. The intended LOs for the program must cover the program outcomes for accreditation specified in the EURO-INF Standards. Besides, the curriculum must be adequate to enable the achievement of the program outcomes. LOs must be also consistent with the mission and objectives of the institution and the department or school responsible for the program. There must be a link between the program syllabus, LOs and overall program outcomes.

EURO-INF program outcomes for Informatics degrees can be useful to further analyse MSc programs on AI. EURO-INF defines a set of program outcomes in terms of *underlying conceptual basics for Informatics*, which identifies capabilities that are essential to satisfying other program outcomes, independently from the specific specialisation and application context. Therefore, AI programs could be appraised against the EURO-INF's conceptual basics for Informatics category. Other program outcomes of the EURO-INF framework include analysis, design and implementation criteria, which are specific of studies of Informatics, beyond AI. Another group of outcomes is the category for social or soft competences (i.e. transversal competences, as discussed below in the report), which can be useful to analyse the types of intended LOs. According to EURO-INF, MSc graduates and programs are, in general, expected to have demonstrated their ability to specify and complete tasks that are complex or incompletely defined. Such rationales have been considered in the competence-based curricular analysis and proposal.

[22] https://www.abet.org/accreditation/

[23] https://www.enaee.eu/

[24] https://eqanie.eu/

[25] European Quality Assurance Network for Informatics Education (EQANIE): EURO-INF framework standards and accreditation criteria for informatics degree programmes. Available at: http://eqanie.eu/wp-content/uploads/2019/09/Euro-Inf_Framework_Standards_and_Accreditation_Criteria_V_2017-10-23.pdf

3 AI Curricular framework

The curricular content of an AI program requires the development of theoretical and conceptual knowledge essential for understanding the discipline, as well as practical skills and competences that support the application of that knowledge.

This report and the proposed building blocks for AI curricula will organize the AI discipline around **knowledge areas** (KA), which for analysis purposes will be initially defined on the basis of the AI domains of the AI Watch report. Each KA consists of critical knowledge within the AI discipline and across other related Informatics-based disciplines. Each knowledge area is divided in **knowledge units** (KU), which consist of **topics**.

Besides this knowledge-based curricular framework, for each topic, a number of **learning outcomes** are defined to measure the skills and **competences** of the competence-based framework described below. The learning outcomes are descriptions of what students should know or be able to do. The content of topics and learning outcomes for a specific curriculum would be influenced by the **disciplinary lens** and the type of institution that will define the master program. The competence-based framework and related curriculum proposal are explained in a separate section below.

3.1 Knowledge areas

Knowledge areas must be designed to allow the sufficient flexibility needed from a potential contraction of the curricular requirements or an expansion of the body of knowledge in AI. The knowledge areas of this curricular framework have been based on the AI domains of Figure 1 and broken down in the following nine KAs:

- Reasoning
- Planning and Optimization
- Learning
- Communication
- Perception
- Integration
- Interaction
- Services
- Ethics and Philosophy

3.2 Knowledge units

Knowledge units are thematic groups within one or more knowledge areas that encompass related topics. Knowledge areas are not structured to be mutually exclusive. Some knowledge units could be situated in multiple knowledge areas. The placement of a knowledge unit under one knowledge area should not preclude its coverage by other areas.

The knowledge units of the curricular framework for analysis purposes is initially based on the AI subdomains and on the related keywords defined by the AI Watch report. The following is the unfolded list of AI subdomains coverer by AI Watch:

- Knowledge Representation
- Automated Reasoning
- Planning and Scheduling
- Optimisation and Searching
- Machine Learning
- Natural Language Processing
- Computer Vision
- Audio Processing
- Human-Computer Interaction
- Multi-Agent Systems
- Robotics & Intelligent Automation
- Connected and Automated Vehicles
- AI Ethics
- Philosophy of AI

The AI Watch report also proposes a keyword list to analyse the content and topics of each AI subdomain. The keywords of some subdomains (e.g. Knowledge Representation and Automated Reasoning) are not separately classified in one of the two subdomains. Hence both subdomains have to be grouped in a single unit corresponding to the Knowledge Representation and Reasoning subdomain. The same occurs with the Planning & scheduling, Searching and Optimization subdomains, which are grouped in a single Planning, Search and Optimization subdomain.

Therefore, the AI subdomains that are feasible to be used to analyse the master course programs are the following

- Knowledge Representation & Reasoning (KRR)
- Planning & Scheduling, Search and Optimization (PSO)
- Machine Learning (ML)
- Natural Language Processing (NLP)
- Computer Vision (CV)
- Audio Processing (AP)
- Multi-Agent Systems (MAS)
- Robotics & Intelligent Automation (RIA)
- Human-Computer Interaction (HCI)
- Connected and Automated Vehicles (CAV)
- AI Ethics (AIE)
- Philosophy of AI (PAI)

Based on the previous subdomains, the result of the analysis will eventually help to define the KA and KU building blocks of the curricular framework. In the following we will use the acronyms to refer to each AI subdomain for the sake of analysis. Note that the analysis subdomains may or may not share their name, and should not be confused, with the eventually resulting KAs and KUs.

3.3 Horizontal areas

Foundational requirements on Informatics, Mathematics and Statistics underlie and support all of the curricular content of an AI program. These requirements include competencies which are often jointly developed through basic degrees in the Informatics discipline:

- AI master students should have acquired some basic grade-level education in an **Informatics** or **Computing** discipline[26], including algorithms and data structures; be able to program on their own with one or two common languages; be aware of the advantages of using programming libraries and data repositories; be able to manage large-scale data and apply high-performance computing techniques; and be able to learn new languages and new libraries when needed.
- They should also be familiar with concepts in applied **Mathematics**, covering multi-variate calculus, linear algebra, optimization, and graph theory, in addition to concepts in probability and basic methods in **Probability and Statistics**.

As a consequence, the list of unfolded AI Watch subdomains will be augmented with the following that cover horizontal, transversal topics:

- Fundamental Informatics/Computing (FIC)
- Fundamental Maths & Statistics (FMS)

3.4 Disciplinary lenses

The disciplinary lenses represent the underlying disciplines from which the AI curriculum can be developed. The disciplinary lens drives the approach, depth of content and learning outcomes expected for the AI topics and skills. The disciplinary lenses encompass the disciplines identified by the IEEE/ACM curricula. Besides, other disciplines, such as Cognitive Sciences, Computational Linguistics, Applied Mathematics and diverse Engineering degrees, may constitute also valid disciplinary lenses for an AI program designed on the basis of the proposed curriculum. AI content can be also taught in other disciplines that can be disciplinary lenses as well, such as

[26] See footnote 4.

Health and Medicine (e.g. Medical Informatics); Biosciences (e.g. Biotech and Bioinformatics); Business and Administration (e.g. Fintech); and Arts and Humanities (e.g. computational creativity in Fine Arts).

3.5AI topics

The topics of AI have been classified according to the AI Watch **keywords**, depicted in the Annex A: AI keywords and topics. These keywords have been extended with frequent terms occurring in the sample of master programs.

Since AI Watch keywords were more crowded in some domains (e.g. machine learning) than in others, some keywords and **topics** have been clustered in order to balance the number of topics per domain, subdomain and the eventual KAs and KUs. Clustering has been carried out only for the sake of clarity of the analysis. It does not mean that the number of keywords has been reduced for, e.g., machine learning, just because it has many more than others; it means that some classification topics are fed by more target keywords than other topics. Thus, the number of topics is balanced among different domains, but they still count all their clustered keyword occurrences. Some keywords have been clustered in the same topic by semantic similarity, according to the author's criteria. When a topic should fit more than one subdomain, it is classified in the subdomain that suits a greater number of keywords. The resulting **body of knowledge**, structured in KA/domains, KU/subdomains and topics, is listed in the Annex B: Body of knowledge.

4 Competence-based AI curriculum framework

The knowledge-based content of the AI curricular framework represents the body of knowledge that teachers should teach and students should learn. It refers to the AI concepts, facts, theories, principles, algorithms, methods and techniques of specific master courses. The concept of *knowledge* has been traditionally the focus of curricular reports through knowledge areas, knowledge units, topics and learning outcomes. However, the traditional knowledge-based learning paradigm may be less effective and may not be useful when technical skills and human behaviour occur in a changing computing and engineering world.

Within the broader context of industry, professions and society, a curriculum description centred on competences must be focused on an individual's capability to perform and to apply their education in a practical and professional service to society. We have to consider the range of AI domains in contexts that include industry, economic and academic markets and provide an education that includes technical skills and human attitudes in such contexts. To meet industry requirements, AI education needs to focus on both what students know and what they should be able to do within a context.

4.1 Purpose of the competence-based framework

For education providers, there is the opportunity to reduce the distance between the competencies associated with a program and the targeted jobs and careers by that program. The following is an example of the kind of questions the analysis of the next section should help to answer:

- How closely aligned is a given University's current AI MSc program to the competence-based curriculum enacted by this report?
- How well does an AI MSc degree from a given University prepare someone to be a *data scientist*?
- How well does a given University's AI MSc program prepare a current (e.g., *Computer Science*) student to develop a career as a given professional role (e.g., *ontology engineer*)?

4.2 Definition of competence

The competence-based framework that will be used for the analysis of learning outcomes published by masters in the selection will follow a set of guidelines common to existing curricula. The competence **level** will be defined as *knowledge* (know what), *skill* (know how) or *disposition* (know why). For a further classification of the **cognitive processes**, described in the learning outcomes, the Bloom's taxonomy will be used. Bloom's cognitive processes to remember, understand, apply, analyse, evaluate and create will be the values of classification. The cognitive processes and the usual verbs used to express them are summarized in Table 1.

Table 1. Bloom's taxonomy levels of cognitive processes and verbs

Cognitive process	Verbs	Definition
Remember	Recognize: identify Recall: retrieve	Exhibit memory of previously learned materials by recalling facts, terms, basic concepts, and answers
Understand	Interpret: clarify, paraphrase, represent, translate Exemplify: illustrate, instantiate Summarise: generalise Infer: conclude, extrapolate, interpolate, predict Compare: contrast, map, match Explain	Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions
Apply	Execute: carry out Implement: use, solve	Solve problems to new situations by applying acquired knowledge, facts, techniques, and rules in a different way
Analyse	Differentiate: discriminate, distinguish, focus, select, make informed choices Organize: find, make coherent, integrate, outline, parse, structure Attribute: decompose	Examine and break information into parts by identifying motives or causes; make inferences and find evidence to support solutions
Evaluate	Check: coordinate, detect, monitor, test Critique judge, critically review	Present and defend opinions be making judgments about information, validity of ideas, or quality of material

Create	Generate: hypothesize, derive, construct models, abstract, classify Plan: design Produce: construct, derive	Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions

Source: (Anderson & Krathwohl, 2001)

Most learning outcomes in the analysed sample do not describe currently a specific **task** to frame the application of knowledge or skills. Therefore, the current version of the framework cannot consider specific tasks yet. The classification of **dispositions** will serve to frame the **context** of application of skills in distinctive situations, although these cannot be currently concretized as specific tasks.

4.3 Competence types

The competences used by the framework will belong to the following kinds:

- **Specific** competences of one AI domain
- **General** competences of AI, useful for but unspecific of any AI domain
- **Transversal** competences, which are transferable between jobs, and are not specific of AI or an AI domain; they are often called *soft skills*.

The transversal or transferable competences of the framework are based on the areas of the foundational competences defined in the ACM/AIS MSIS 2016 curricula, namely:

- Critical thinking
- Creativity
- Collaboration and team work
- Ethical analysis
- Intercultural competence
- Leadership
- Mathematical and statistical competences
- Negotiation
- Oral communication
- Problem solving
- Written communication

Besides the former competences, we have considered also the following abilities as relevant transversal competences for AI programs:

- **Systems thinking** can consider the interplay between social and technical constraints to enable a given operation or application.
- **Anticipatory thinking** is the ability to prepare oneself in time for future events, problems and opportunities.
- **Computational thinking** is a set of abilities that refer to thinking processes required in understanding problems and formulating solutions in ways that a computer can execute. It can be summarized as the capacity of abstraction that can be automated (Wing, 2008). Computational thinking defines a specific set of transversal competences that can complement mathematical and statistical ones.

Although mathematical and statistical competences, as well as computational thinking abilities can be and usually are considered as transversal competences, the proposed body of knowledge for AI includes two separate blocks for AI fundamentals, devoted to Informatics/Computing (FIC), and Mathematics & Statistics (FMS), as **horizontal** knowledge areas. Therefore, they may be also considered as domain-specific competences. For the sake of analysis and to avoid misunderstandings, we have separately classified such groups of competences.

5 Analysis of master courses

5.1 Analysis framework

As explained above, the domains for the analysis of master programs have been based on the AI Watch domains, subdomains and keywords of Figure 1. The seven **core** domains and subdomains for the analysis are grouped under the following names:

- **Reasoning & Planning**: Automated reasoning & planning, including KRR and PSO
- **Learning**: Automated learning, including ML
- **Communication**: Computational linguistics and communication, including NLP
- **Perception**: Computational perception, including CV and AP
- **Integration & Interaction**: Computer systems integration & interaction, including RIA, MAS, HCI and CAV
- **AI Services**: Digital services & applications, including AIS
- **AI Ethics**: AI ethics & philosophy, including AIE and PAI

Other domains that are pertinent for analysis are out of the specific scope of AI but are essential to AI as a discipline. These two **fundamentals** domains are the following:

- Informatics/Computing Fundamentals, including FIC
- Maths & Statistics Fundamentals, including FMS

The FIC and FMS subdomains have not been subdivided, as argued in section 1.2, because the analysis of Informatics or Computing areas involved in AI is out of the scope of this report. For the same reason, the analysis in this section is developed on the basis of the seven AI-specific core domains, namely Reasoning & Planning, Learning, Communication, Perception, Integration & Interaction, AI Services and AI Ethics; and extended when pertinent with the two non-specific domains for fundamentals.

The Integration & Interaction domain includes two groups of topics that can be clearly separated. On the one hand, it involves a group of topics related with distribution, coordination and autonomy of either physical (i.e. robots) or virtual (i.e. agents) intelligent systems when perceiving and acting with the environment. On the other hand, it involves a group of topics related with human-computer interaction and, in particular, non-verbal communication such as multi-modal human-AI interaction. These two groups of topics would correspond to the Integration and the Interaction (sub)domains, respectively. The latter could have been classified as part of the Communication domain. Nevertheless, we have decided to keep Interaction as part of the original AI Watch's Integration & Interaction domain. Nonetheless, in order to permit users to classify the Interaction domain otherwise, that choice is reflected in the analysis, when source data allows for it, by separating the Integration and the Interaction domains. Otherwise, Integration and Interaction topics will be treated as a unit. Thus, the eventual list of domains for the analysis is formed by seven or eight AI-specific core domains plus two non-specific domains for AI fundamentals.

5.1.1 Disciplinary lenses

The classification of master programs, according to the department/school or research group/area in charge of the master, includes the following values as disciplinary lenses:

- Business and management
- Electrical & Electronic Engineering
- Engineering (general)
- Health & Life Sciences
- Humanities & Social Sciences
- Linguistics
- Mechanical Engineering
- Informatics/Computing
- Psychology, Cognitive & Behavioural Sciences
- Laws

5.1.2 Orientation

The research or professional orientation of the master courses includes the following options:

- **MSc** – Generic or professional orientation
- **MScR** – Masters by Research: Research-oriented; Part of a PhD program; Usually first year of a PhD
- **MPhil** – Master of Philosophy: Research-oriented; Part of a PhD program; Usually first 2 years of a PhD

5.1.3 Duration and credits

Masters' programs are organised to be completed in 1 or 2 years, depending on the country, the link between MSc and BSc degree studies in each country, and the professional or research orientation of the master. The general rule is that countries with regular 3-year BSc degrees usually offer 2-year, 120-credit MSc courses; and countries with 4-year BSc degrees usually offer 60-credit, 1-year MSc courses. There are exceptions to this rule, with 90-credit masters that are completed in 2 years (e.g. ETHZ Data Science and UB Artificial Intelligence masters).

Masters in France and Italy are often closely linked with the BSc studies, so that the MSc is a continuation of the BSc during 1 or 2 additional years. This is the case of masters offered by Ecoles d'Ingénieurs as GINP, which spans 7th to 9th semesters (for courses) and 10th semester (for the final project) of a complete 5-year BSc+MSc program. In some cases, the 7th and 8th semesters are common to other non-AI degrees; thus, only the last AI-specific MSc-level 60 credits have been taken into account for this study in such cases.

Duration and credits are not comparable for research masters of UK institutions. They are part of a PhD program and their duration range from 1-2 years (MScR) to 2-3 years (MPhil) to 3-4 years (Complete PhD). They are often offered as 180-credit courses, which can be completed entirely (as a PhD) or partly (as a MScR or MPhil), either completing 60 or 120 credits. Therefore, credits and duration cannot be seamlessly compared between UK masters and those from other European countries.

5.2 Overall assessment of domain/subdomain topic coverage

As depicted in Figure 4, from the sample of all masters, the topics that are most covered are the following:

- 27% of all topics have to do with **Learning**
- 16-18% of all topics have to do with **Perception**, **Integration & Interaction** and **Reasoning & Planning**
- 8-9% of all topics have to do with **Services & Applications** and **Communication**
- 4.7% of all topics have to do with **Ethics & Philosophy**

In general for all the programs (see Figure 5), the topics that are most covered are within the following subdomains:

- ML - Machine Learning (21.4%),
- FIC - Fundamental Informatics/Computing (10.9%),
- CV - Computer Vision (10.0%),
- FMS - Fundamental Maths & Statistics (8.1%),
- HCI - Human-Computer Interaction (7.1%),
- KRR - Knowledge Representation & Reasoning (7%),
- NLP - Natural Language Processing (6.4%),
- PSO - Planning & Scheduling, Search and Optimisation (5.4%)
- RIA - Robotics & Intelligent Automation (5.4%)

Topics from each of other subdomains (e.g. Audio Processing, AI Services, AI Ethics, Multi-Agent Systems and Connected and Automated Vehicles and Philosophy of AI) cover less than 5% of all topics. Other topics that cannot be classified as part of an AI domain cover 1.6% of all topics.

Figure 4. Coverage of domain topics in the sample of masters. The vertical axis represents the AI domains; the horizontal axis represents the percentage of all topics that are related with each AI domain for all masters.

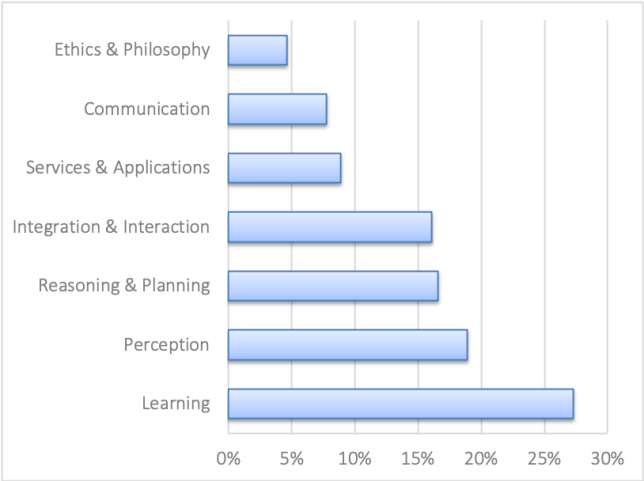
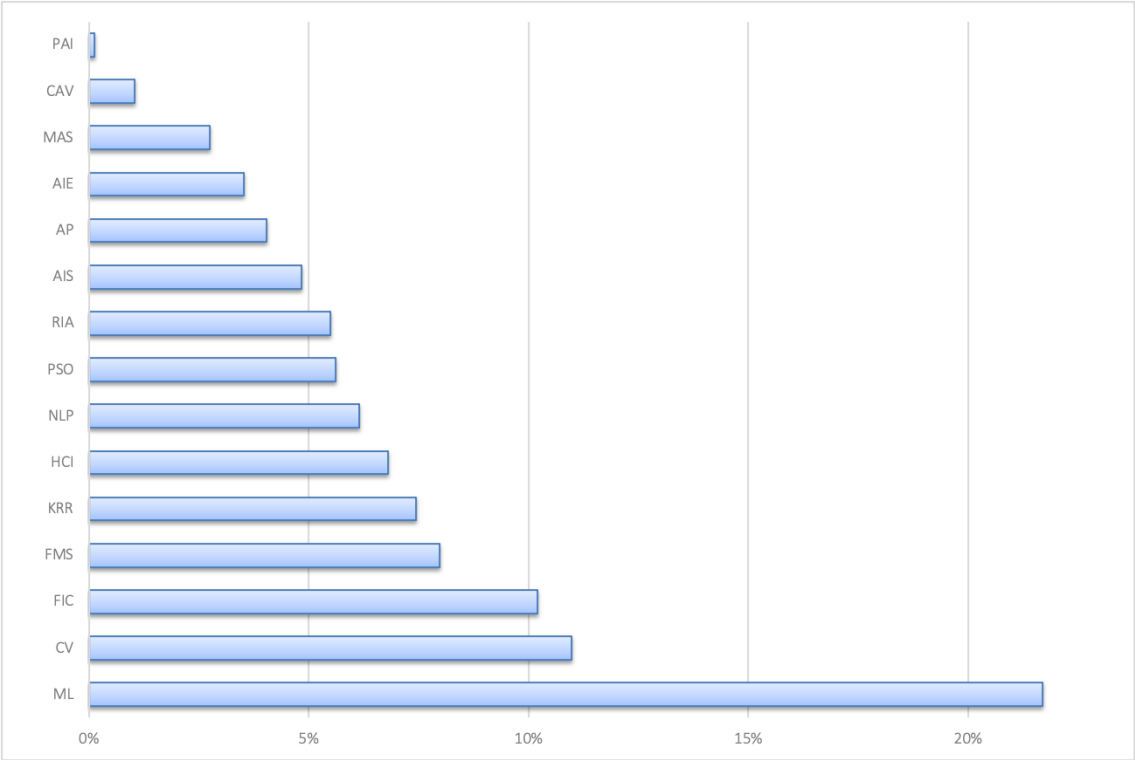


Figure 5. Coverage of subdomain topics in the sample of masters. The vertical axis represents the AI subdomains; the horizontal axis represents the percentage of all topics that are related with each AI subdomain for all masters.



Note: The acronyms used for the subdomains are the following: AI Ethics (AIE); AI Services (AIS); Audio Processing (AP); Connected and Automated Vehicles (CAV); Computer Vision (CV); Fundamentals of Informatics/Computing (FIC); Fundamentals of Maths & Statistics (FMS); Human-Computer Interaction (HCI); Knowledge Representation and Reasoning (KRR); Multi-Agent Systems (MAS); Machine Learning (ML); Natural Language Processing (NLP); Philosophy of AI (PAI); Planning, Search and Optimisation (PSO); Robotics and Intelligent Automation (RIA).

5.3Assessment by AI domain

The assessment by domain may serve an educator to answer how does a program fit within an international curricular guideline, or if there is a particular area where a given curriculum is different from the guidelines, in order to consider eventual changes. Besides, educational authorities can use this information to find out if a given curriculum complies to the guidelines, and/or to assess universities/departments based on their AI curricula.

The domains used in the analysis are the defined in the analysis framework explained above, mainly based on AI Watch domains.

5.3.1 Reasoning & Planning domain

The following masters are in the Reasoning & Planning domain of the sample:

- UEDIN: Informatics – AIAI
- UCARDIFF: Artificial Intelligence

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 6. Accordingly, the most covered topics are from the Reasoning & Planning domain, followed by the Integration & Integration domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 7. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 8.

Figure 6. Distribution of topics of all masters classified in the Reasoning & Planning domain

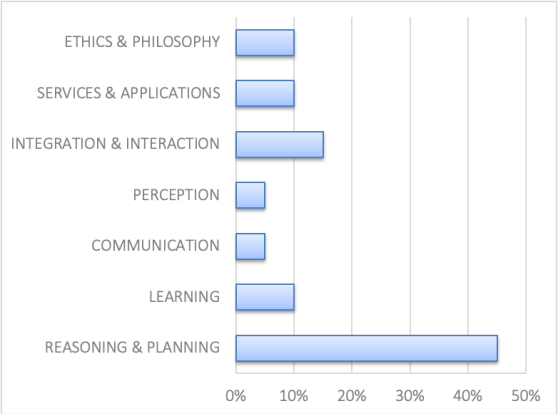


Figure 8. Topic coverage of the programs of masters in the Reasoning & Planning domain represented in a 0-5 scale

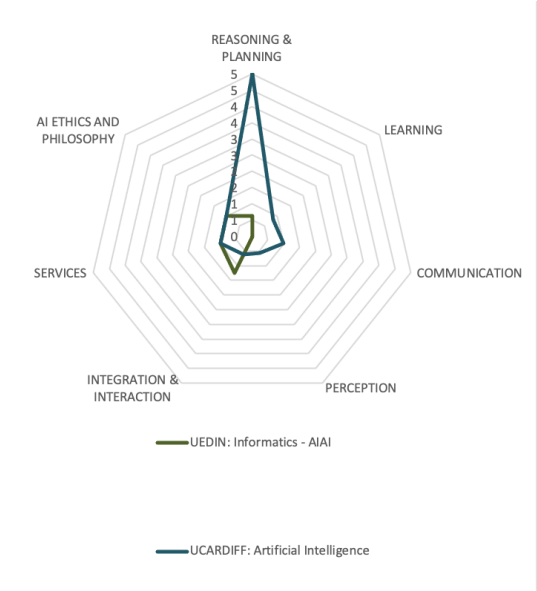
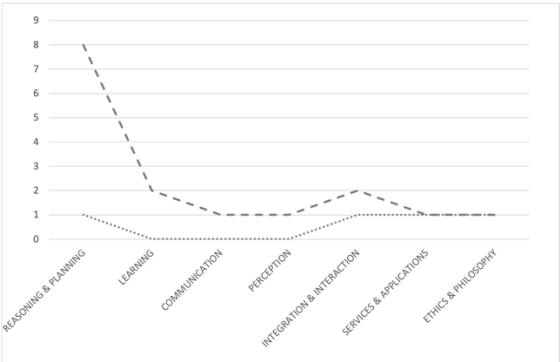


Figure 7. Maximum and minimum number of topics in each domain for all masters of the Reasoning & Planning domain



The analysis of similarities of the masters in the Reasoning & Planning domain of the master sample outputs the following:

- The coverage of topics in the Reasoning & Planning domain in the program of UEDIN is much lesser than the maximum of all masters in that domain (see Figure 9). Therefore, it insufficiently covers Reasoning & Planning topics compared to other masters in its domain.
- The program of UEDIN fulfils the minimum number of topics classified as Integration & Interaction for all masters in the Reasoning & Planning domain. The program of UCARDIFF defines the minimum of the Integration & Interaction topics for its domain (see Figure 10). All the masters in the Reasoning & Planning domain have a moderate and balanced component of topics of Integration & Interaction.

Figure 9. Topic coverage for each AI domain of the UEDIN course program

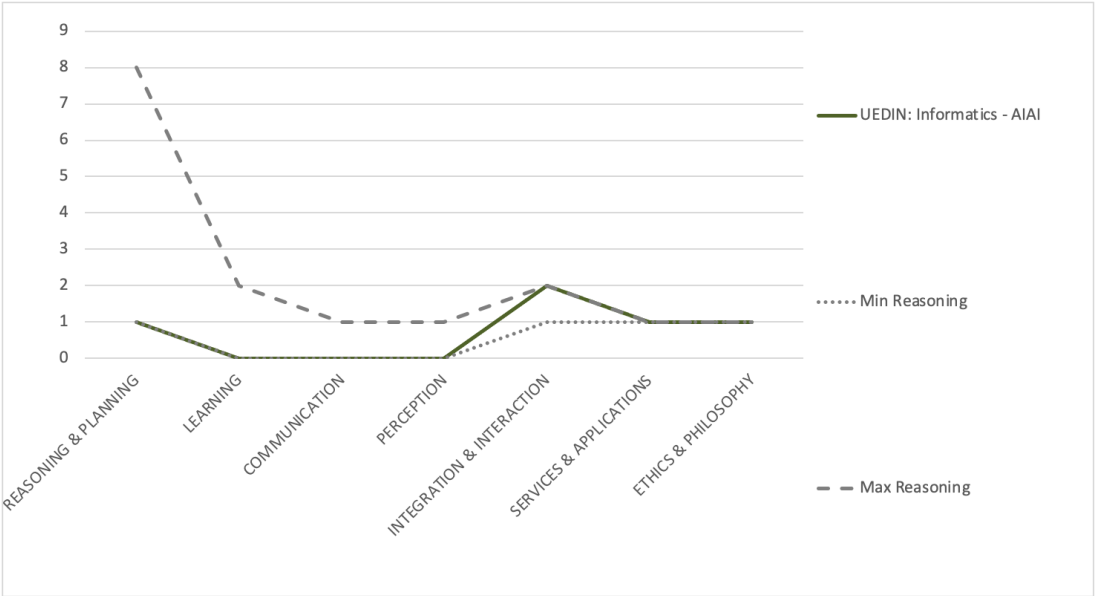
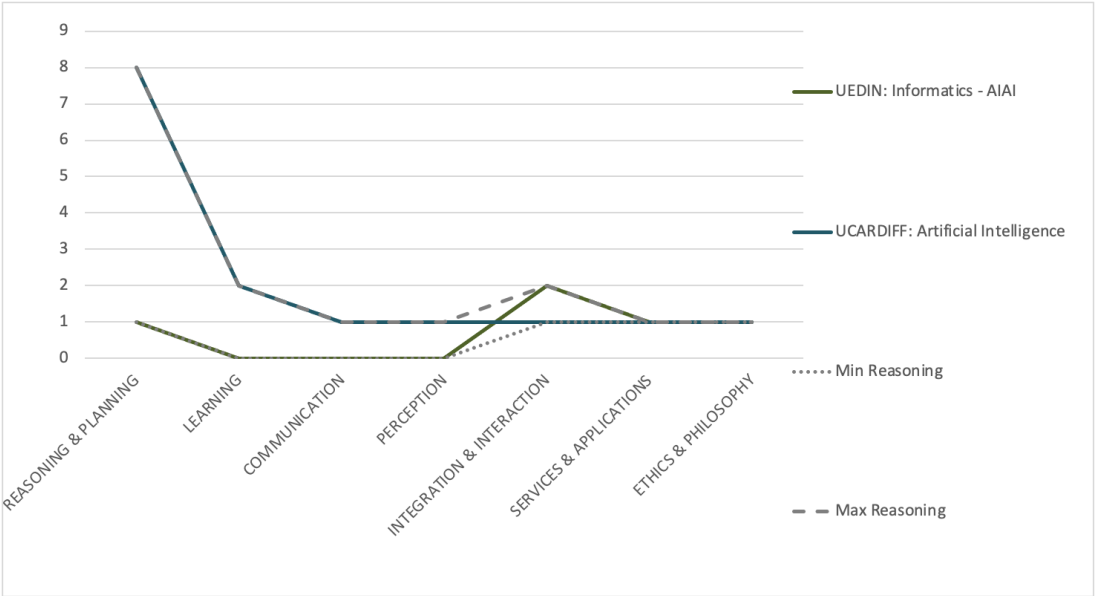


Figure 10. Topic coverage for each AI domain of the masters in the Reasoning and Planning category



5.3.2 Learning domain

The following masters are in the Learning domain of the sample:

- UCAMB: Machine Learning and Machine Intelligence
- UCL 1: Data Science and Machine Learning
- UCL 2: Computational Statistics and Machine Learning
- ETHZ: Data Science
- EPFL: Data Science
- KTH: Machine Learning
- AALTO: Computer, Communication and Information Sciences - Machine Learning, Data Science and Artificial Intelligence

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 11. Accordingly, the most covered topics are from the Learning domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 12. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 13.

Figure 11. Distribution of topics of all masters classified in the Learning domain

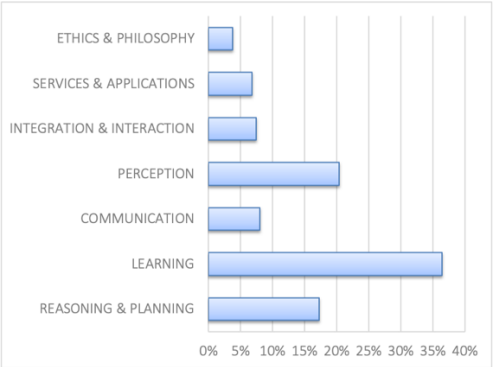


Figure 12. Maximum and minimum number of topics in each domain for all masters of the Learning domain

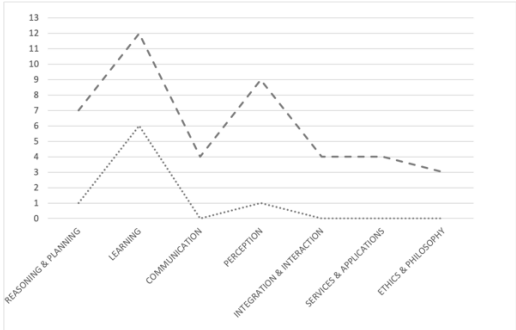
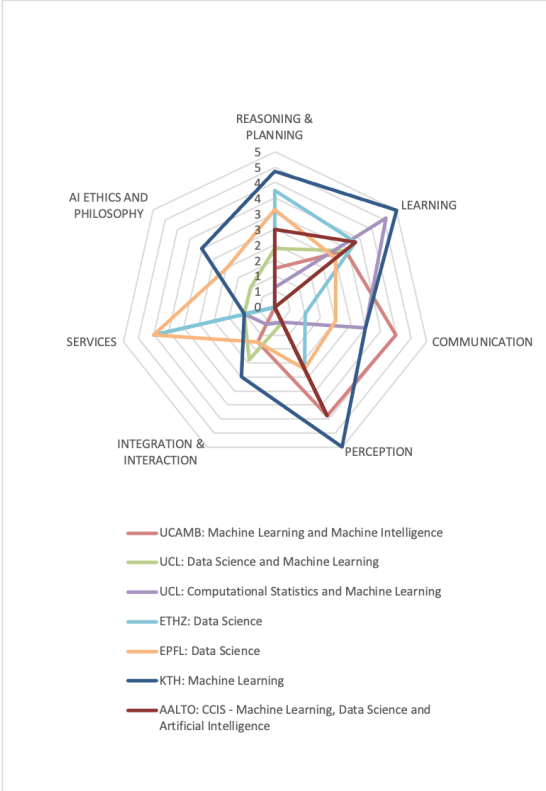


Figure 13. Topic coverage of the programs of masters in the Learning domain represented in a 0-5 scale



The analysis of similarities of the masters in the Learning domain of the master sample outputs the following:

- Most masters in the Learning domain encompass topics from other domains, being significant the number of topics from the Perception domain (see Figure 14), notably UCAMB, KTH and AALTO. They are very close to the number of topics in its domain of classification, i.e. Learning.
- The program of UCL 1 provides an average coverage of Learning topics compared to the rest of masters in the Learning domain (see Figure 15). It also covers a significant number of topics of the Integration & Interaction domain.

- The programs of ETHZ and EPFL have a strong component of topics from the *Services & Applications* domain (see Figure 16). Arguably, such master programs can be considered as very applied compared to the rest of masters in their category. Despite sharing part of its name with the former, AALTO's master program topic coverage is not so applied.
- KTH master program has a strong focus on the Ethics & Philosophy topic. This is even greater than in other master programs classified in such domain.

Figure 14. Topic coverage of the programs of UCAMB, KTH and AALTO

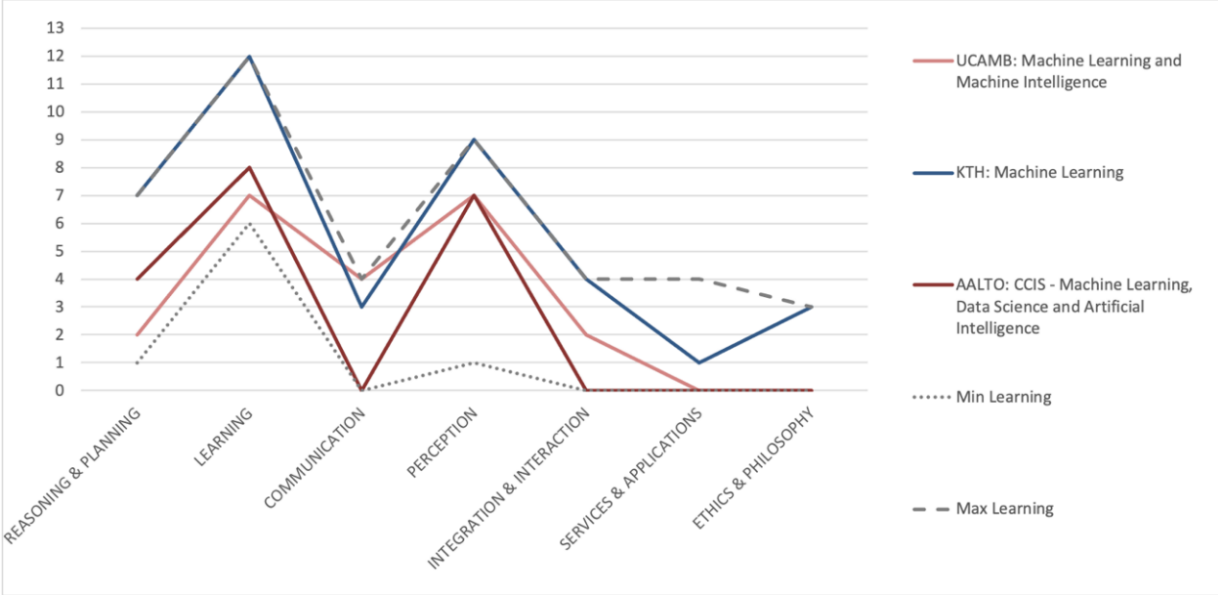


Figure 15. Topic coverage of the programs of UCL 1 and UCL 2

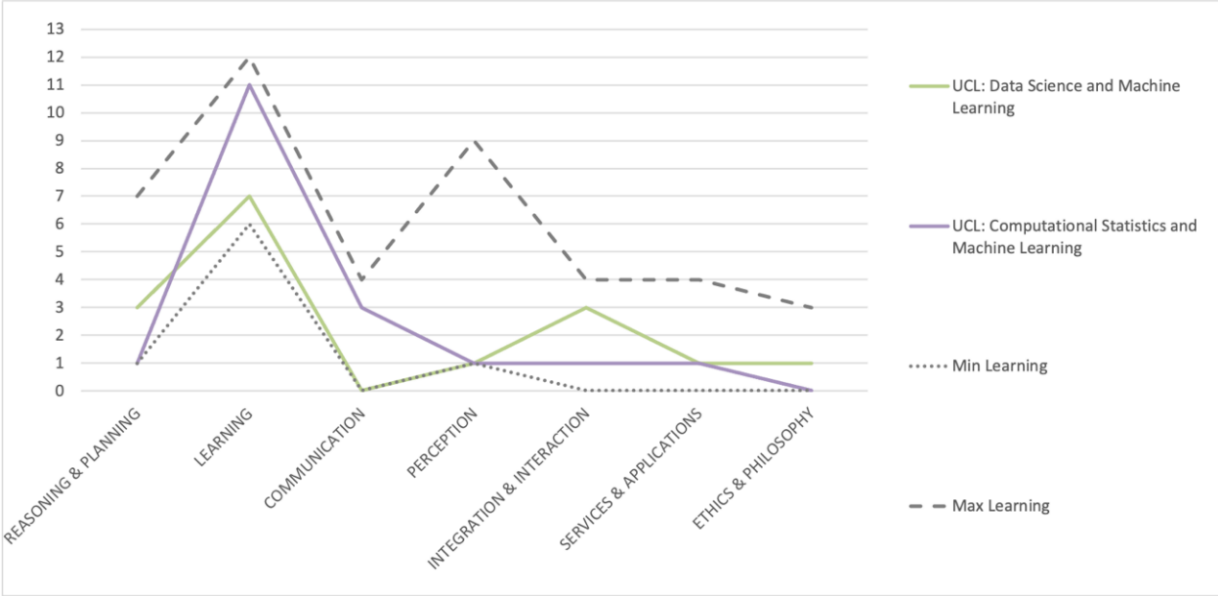
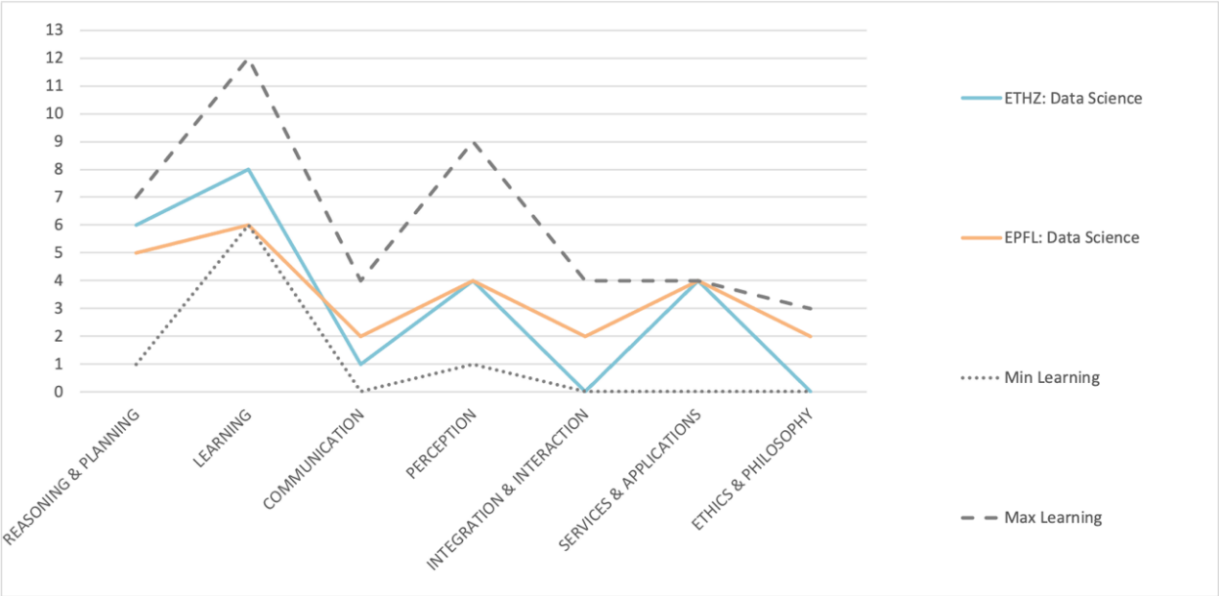


Figure 16. Topic coverage of the programs of ETHZ and EPFL



5.3.3 Communication domain

The following masters are in the Communication domain of the sample:

- UEDIN 1: Speech and Language Processing
- UEDIN 2: Cognitive Science
- SHEFFIELD: Computer Science with Speech and Language Processing
- VUA: Linguistics - Text Mining
- USG: Computational Linguistics
- AAU: Sound and Music Computing

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 17. Accordingly, the most covered topics are from the Communication domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 18. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 19.

The analysis of similarities of the masters in the Communication domain of the master sample outputs the following:

- As depicted in Figure 18 and Figure 20, some master programs in the Communication domain have a significant coverage of topics from other domains, notably of Perception (e.g., UEDIN 1, UEDIN 2 and USG) and Learning (e.g., UEDIN 1 and UEDIN 2).
- The focus on Perception topics for some masters (e.g., UEDIN 1, UEDIN 2 and USG), is sometimes greater or equal than on Communication topics (e.g., UEDIN 1 and UEDIN 2). It shows a frequent relationship between such categories (see Figure 20).
- Certain masters in the Communication category are more focused on topics from the Learning domain than on topics from its own domain of classification, i.e., Communication. This is general for all Learning domain topics, which are more significantly covered in a lot of masters of all categories.
- The AAU program has a greater focus on Integration & Interaction topics than in those from its domain of Communication (see Figure 21). Notably, it does not cover sufficiently Communication topics.

Figure 17. Distribution of topics of all masters classified in the Communication domain

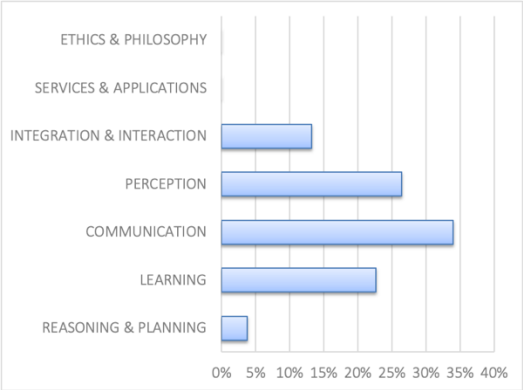


Figure 18. Maximum and minimum number of topics in each domain for all masters of the Communication domain

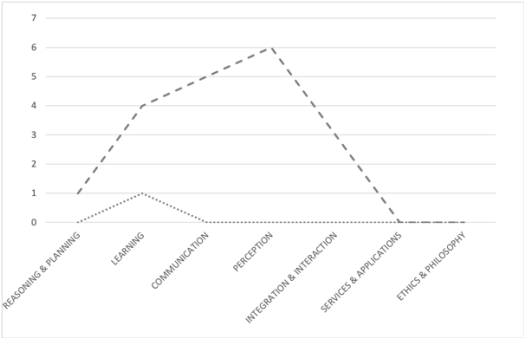


Figure 19. Topic coverage of the programs of masters in the Communication domain represented in a 0-5 scale

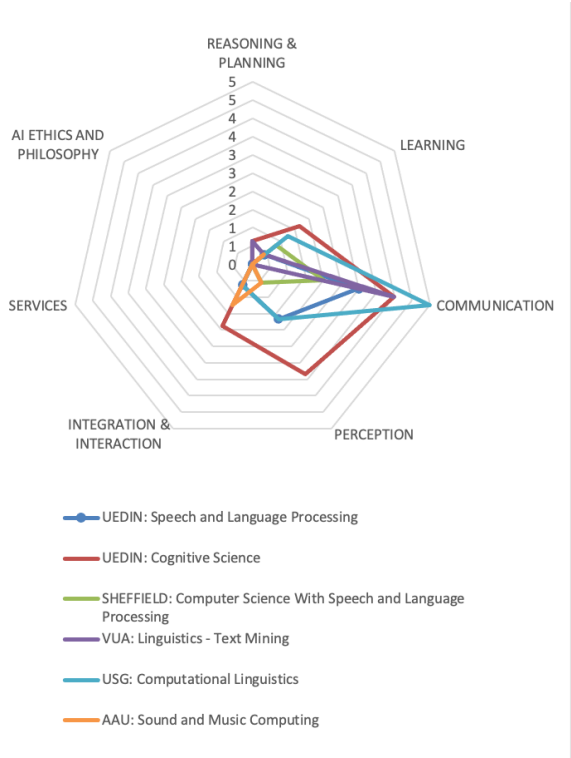


Figure 20. Topic coverage of the program of UEDIN 1, UEDIN 2 and USG

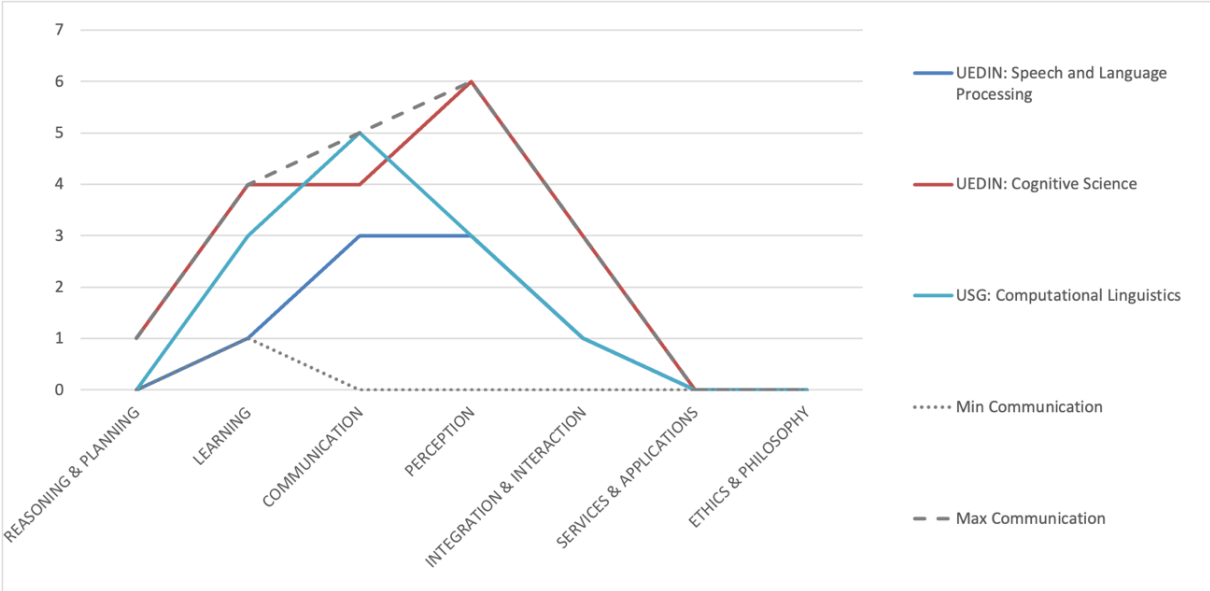
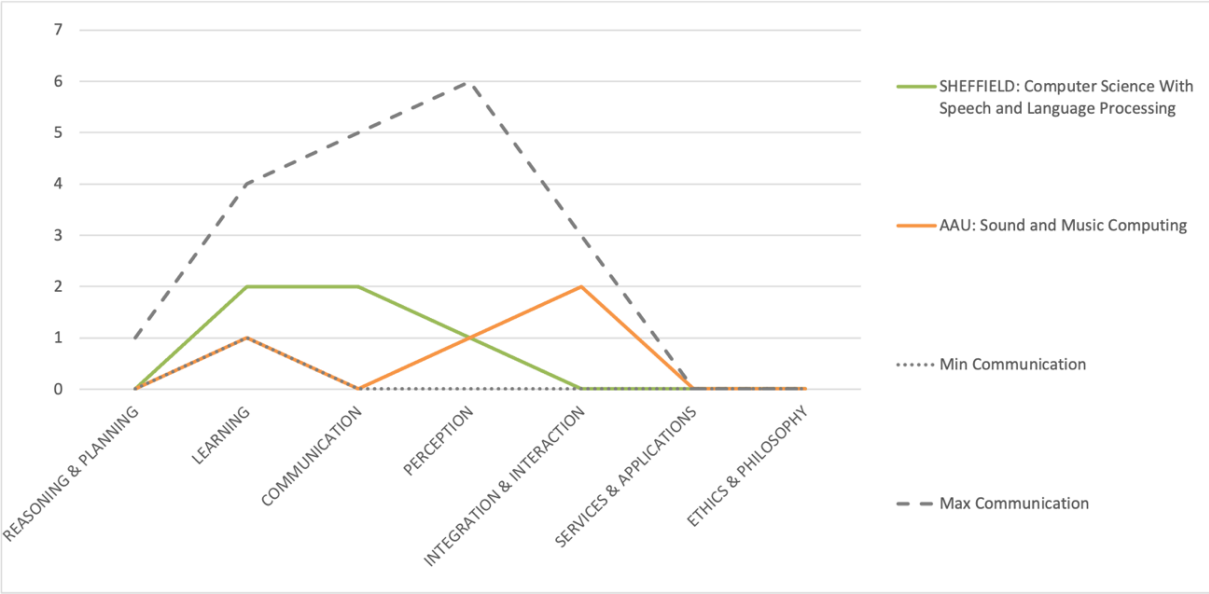


Figure 21. Topic coverage of the program of SHEFFIELD and AAU



5.3.4 Perception domain

The following masters are in the Perception domain of the sample:

- UPC: Computer Vision
- AAU: Vision, Graphics and Interactive Systems
- AALTO: ICT Innovation - EIT - Visual Computing and Communication
- TUM: Biomedical Computing
- GINP: Signal and ImaGe processing Methods and Applications

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 22. Accordingly, the most covered topics are from the Perception domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 23. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 24.

The analysis of similarities of the masters in the Perception domain of the master sample outputs the following:

- UPC, AAU and GIMP programs stress on Perception topics first and then on Learning (Figure 25). This bias towards Learning is very frequent accompanying other domains, such as Perception and Communication.
- AAU, UPC and TUM put also a focus in the more applied Services & Applications domain topics.
- AALTO covers only a few topics from Perception, comparable to the coverage of other domains as Integration & Interaction. This is possibly due to missing information in its program's description.

Figure 22. Distribution of topics of all masters classified in the Perception domain

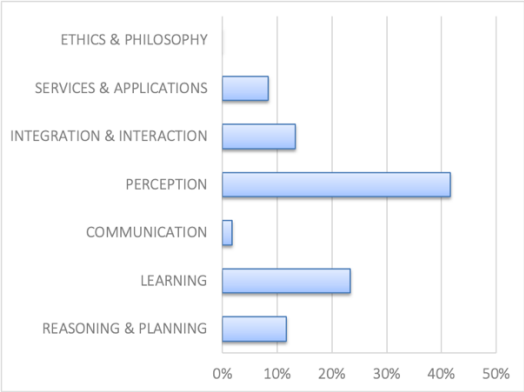


Figure 23. Maximum and minimum number of topics in each domain for all masters of the Perception domain

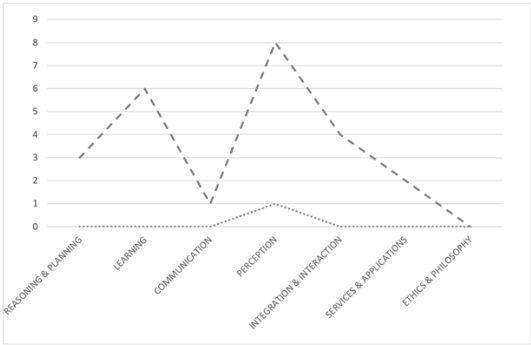


Figure 24. Topic coverage of the programs of masters in the Perception domain represented in a 0-5 scale

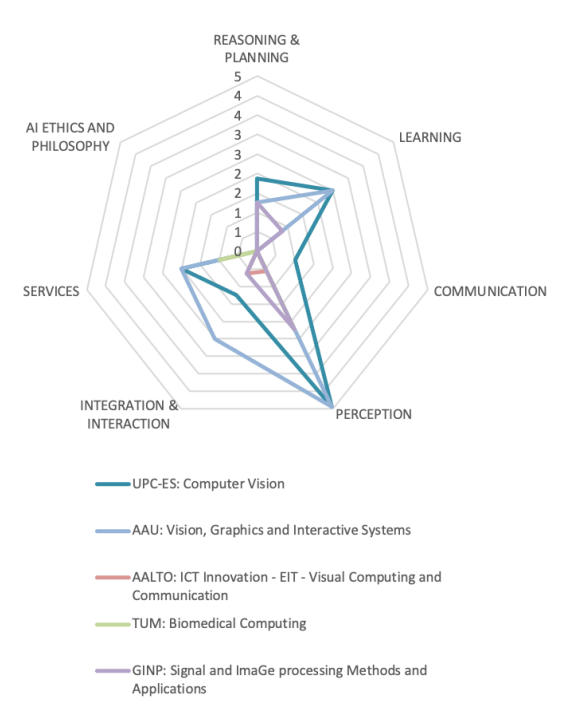
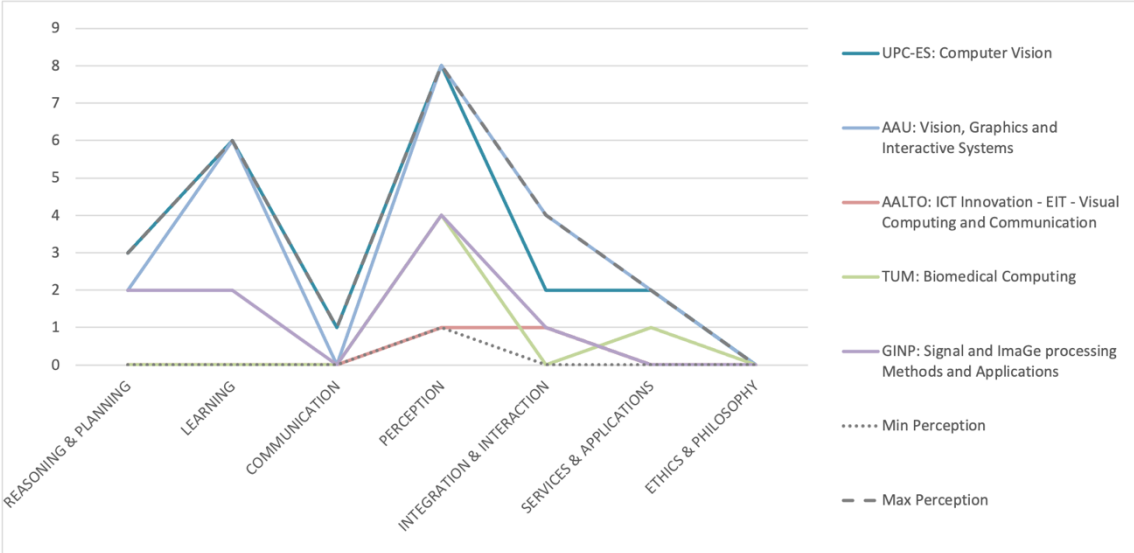


Figure 25. Topic coverage of the program of UPC, AAU, AALTO, TUM and GINP



5.3.5 Integration & Interaction

The following masters are in the Integration & Interaction domain of the sample:

- ICL: Control Systems
- RWTHA: Robotic Systems Engineering
- UPC: Automatic Control and Robotics
- UBIR: Human Computer Interaction
- SAPIENZA: Multimedia Computing and Interaction
- UPF: Intelligent Interactive Systems
- UBATH: Robotics and Autonomous Systems
- UTRECHT: Human Computer Interaction
- GINP: MARS
- UNITN: Human Computer Interaction
- CRANFIELD: Autonomous Vehicle Dynamics and Control

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 26. Accordingly, the most covered topics are from the Perception domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 27. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 28.

Figure 26. Distribution of topics of all masters classified in the Integration & Interaction domain

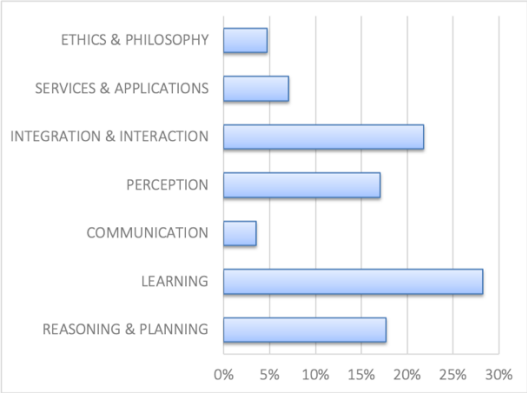


Figure 27. Maximum and minimum number of topics in each domain for all masters of the Integration & Interaction domain

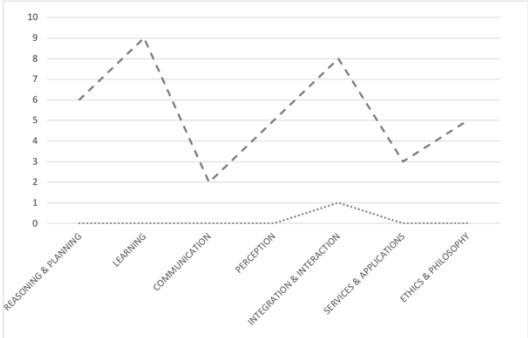
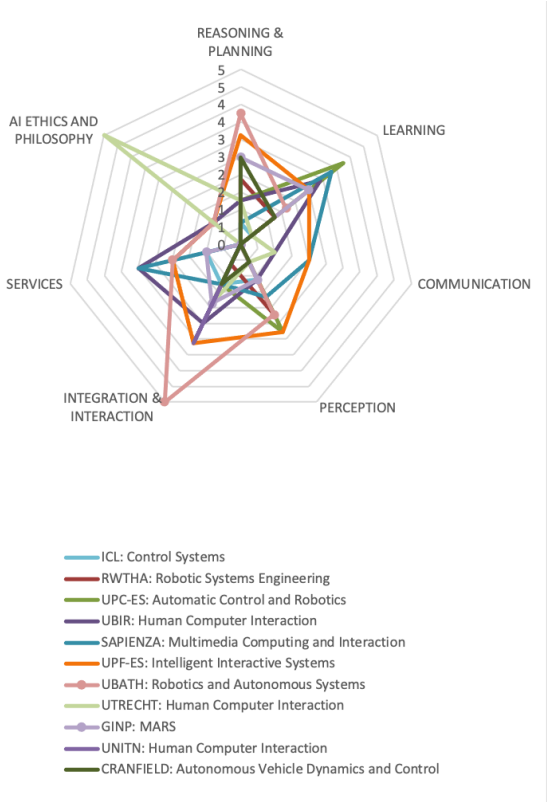


Figure 28. Topic coverage of the programs of masters in the Integration & Interaction domain represented in a 0-5 scale



The analysis of similarities of the masters in the Integration & Interaction domain of the master sample outputs the following:

- For the masters covering Integration topics, they are also significantly focused on Learning (e.g., UPC, GINP, UBATH), Perception (e.g., UPC, UBATH, RWTHA) and Reasoning (e.g., UBATH, GINP and CRANFIELD). The focus on topics from other categories is residual –see Figure 29.
- For the masters covering Interaction topics, besides the interest on Learning (e.g., SAPIENZA, UBIR and UPF) and Perception (e.g., UPF and SAPIENZA), there is a common focus on Communication, shared by all except UNITN –see Figure 30.
- UBATH, UNITN, SAPIENZA and UPF have a significant component of interest on the Services & Applications domain, compared with the average in the Integration & Interaction category.

Figure 29. Topic coverage of the programs of ICL, RWTHA, UPC, UBATH, GINP and CRANFIELD

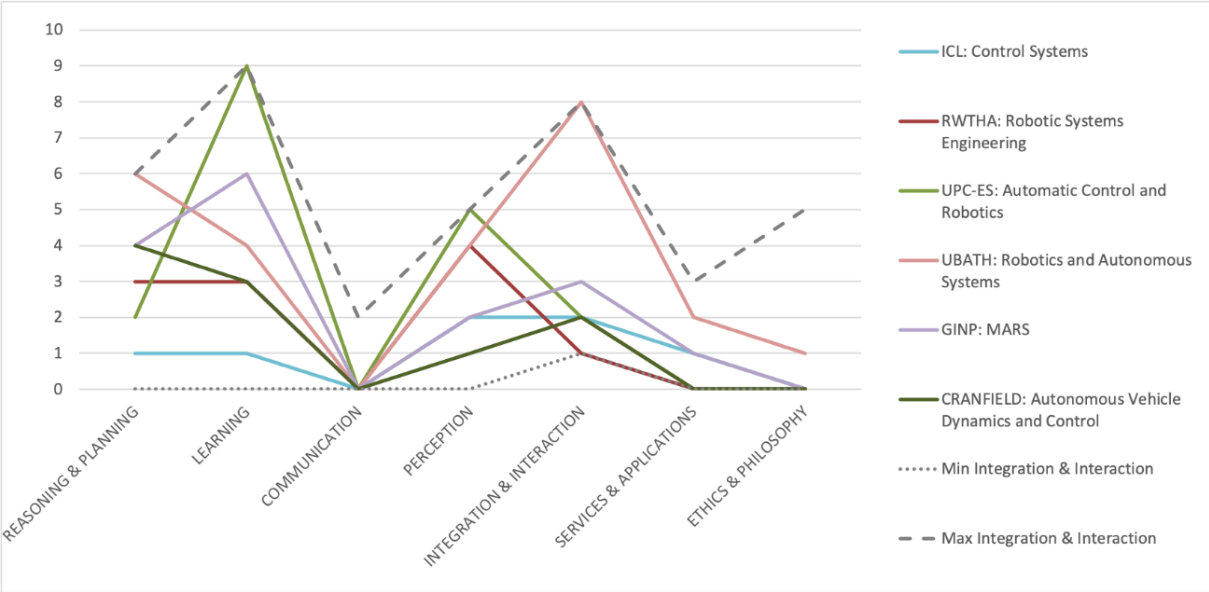
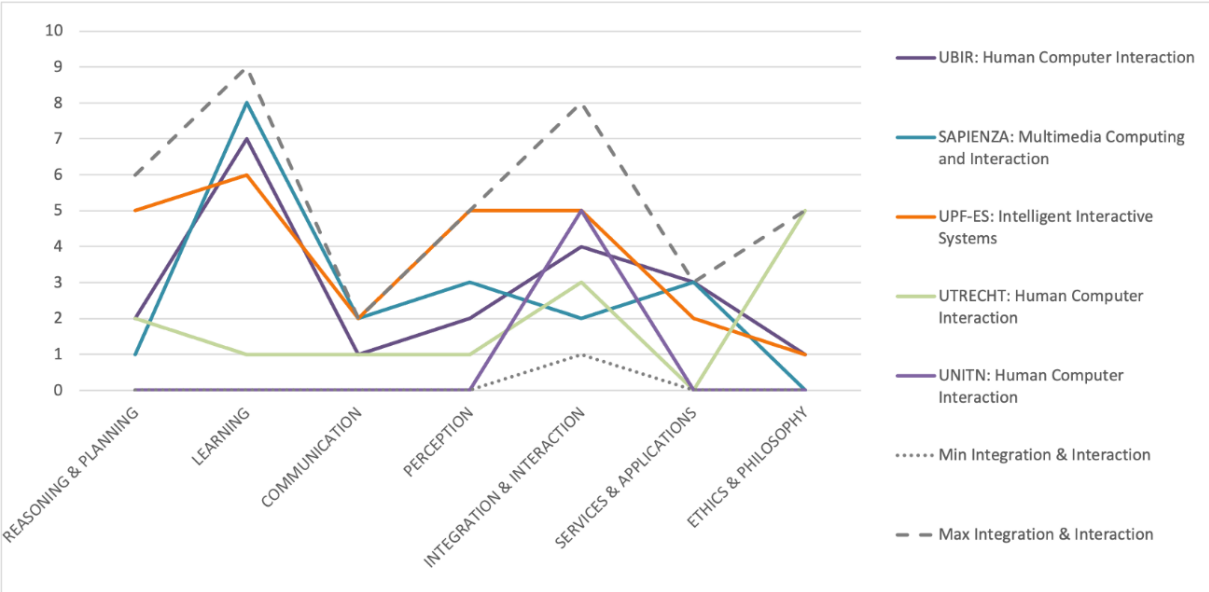


Figure 30. Topic coverage of the programs of UBIR, SAPIENZA, UPF, UTRECHT and UNITN



5.3.6 Services & Applications

The following masters are in the Services & Applications domain of the sample:

- UCL: AI Enabled Healthcare
- KUL 1: Artificial Intelligence
- KUL 2: Digital Humanities
- RWTHA: DDS
- POLIMI: Computer Science and Engineering
- UMAAS: Business Intelligence and Smart Services
- USTRATH: Digital Health Systems
- UYORK: Computer Science with Data Analytics

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 31. Accordingly, the most covered topics are from the Perception domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 32. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 33.

Figure 31. Distribution of topics of all masters classified in the Services & Applications domain

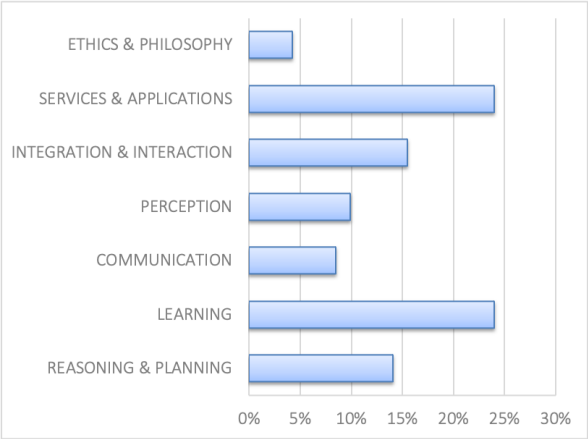


Figure 32. Maximum and minimum number of topics in each domain for all masters of the Services & Applications domain

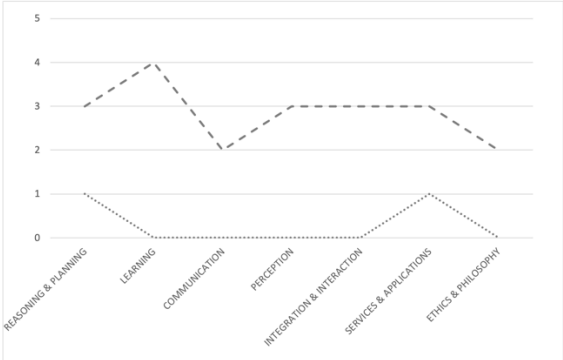
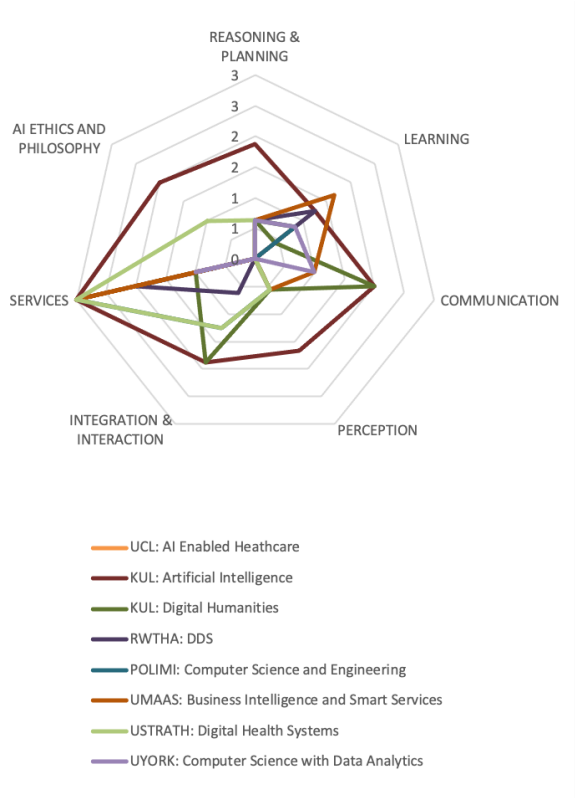


Figure 33. Topic coverage of the programs of masters in the Services & Applications domain represented in a 0-5 scale



In the Services & Applications domain, some masters are very focused on Learning, either strongly (see Figure 34) or more slightly (see Figure 35). Other masters are focused on Integration & Interaction, besides Services & Applications (see Figure 36).

Figure 34. Topic coverage of the programs of RWTHA, POLIMI and UMAAS

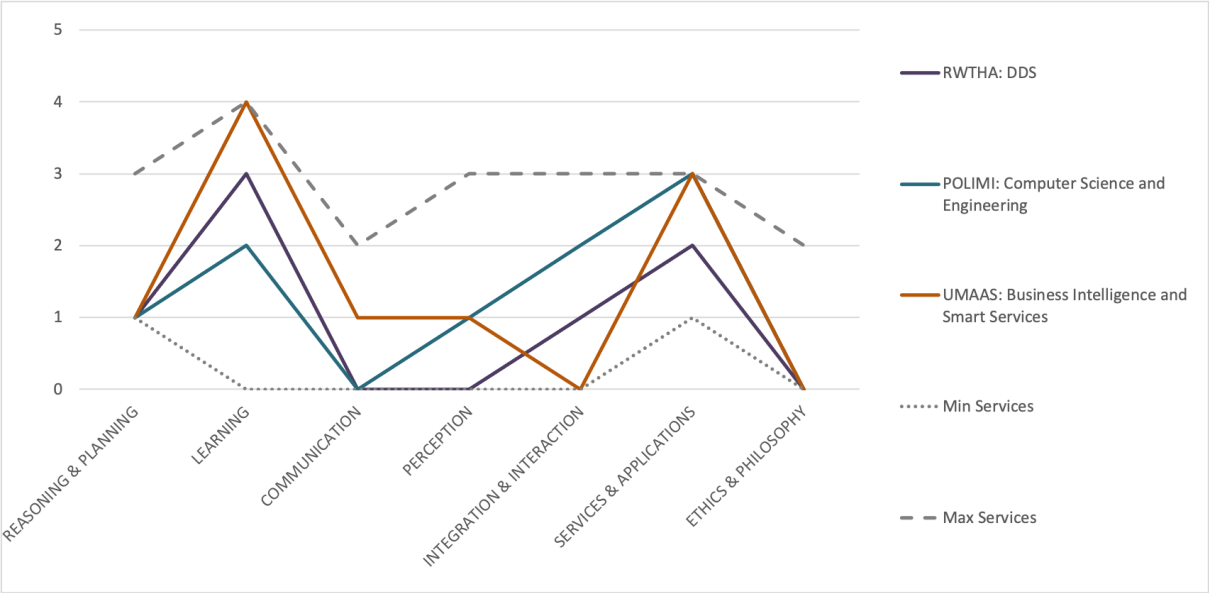


Figure 35. Topic coverage of the programs of UCL, KUL 1 and USTRATH

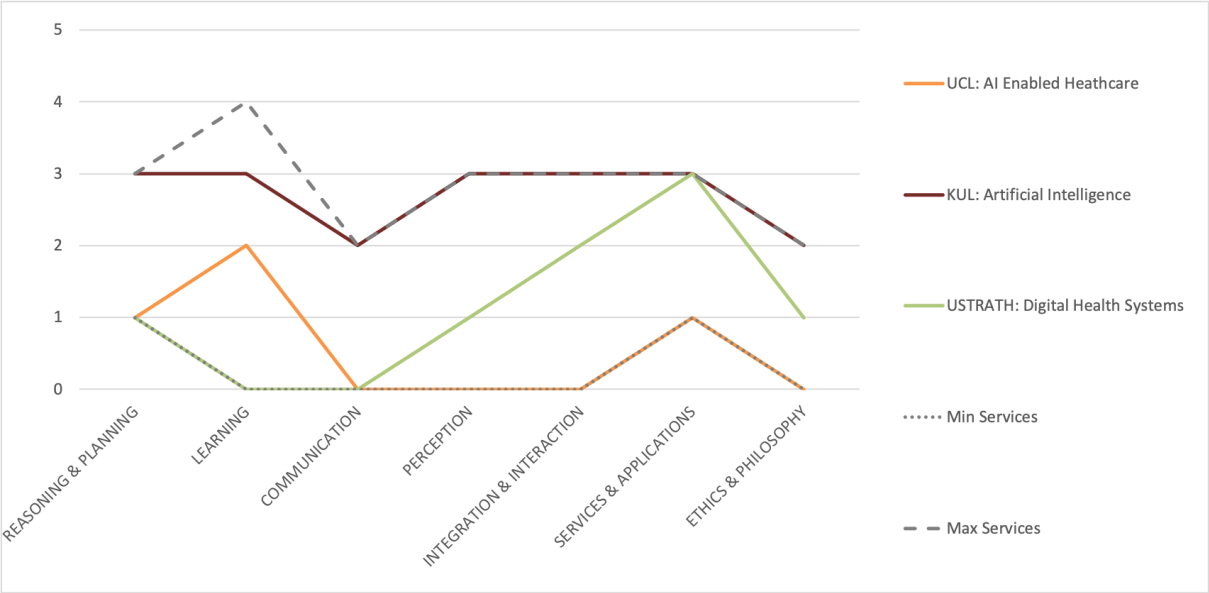
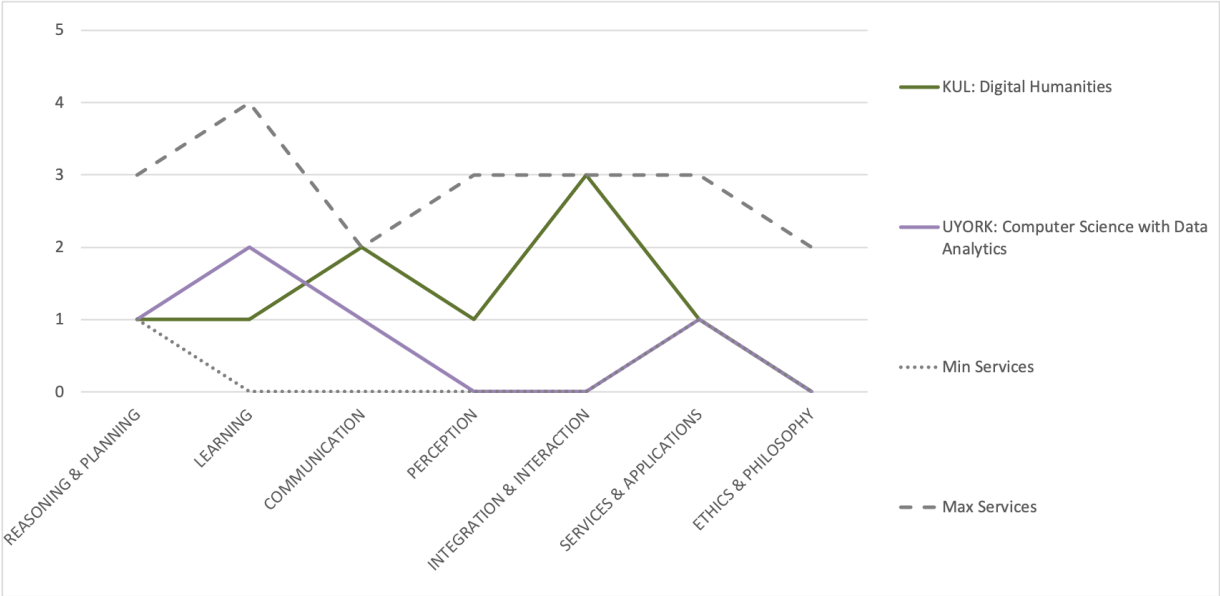


Figure 36. Topic coverage of the programs of KUL 2 and UYORK



5.3.7 Ethics and Philosophy of AI

The following masters are in the Ethics & Philosophy domain of the sample:

- ICL: Artificial Intelligence
- UB: Artificial Intelligence
- UCD: Cognitive Science
- UNL: Law and Technology
- VUA 1: Artificial Intelligence - Cognitive Science
- VUA 2: International Technology Law

All the topics covered in the programs of this group of master courses are distributed in AI domains as shown in Figure 37. Accordingly, the most covered topics are from the Perception domain. The maximum and minimum topic coverage of master programs in this domain is shown in Figure 38. The distribution of topics in the different domains, represented in a 0-5 scale, is depicted in Figure 39.

Figure 37. Distribution of topics of all masters classified in the Ethics & Philosophy domain

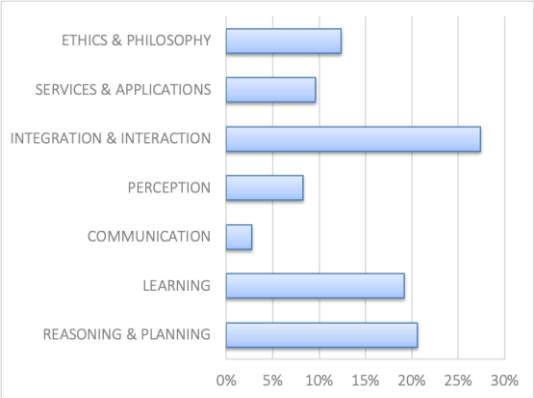


Figure 38. Maximum and minimum number of topics in each domain for all masters of the Ethics & Philosophy domain

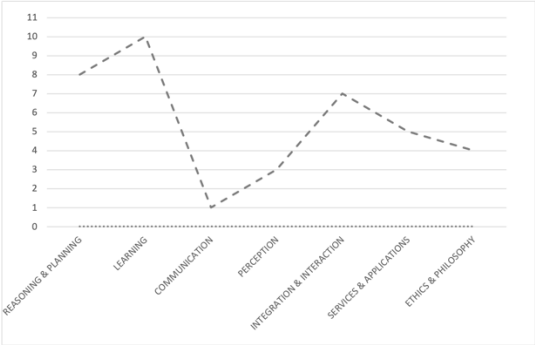
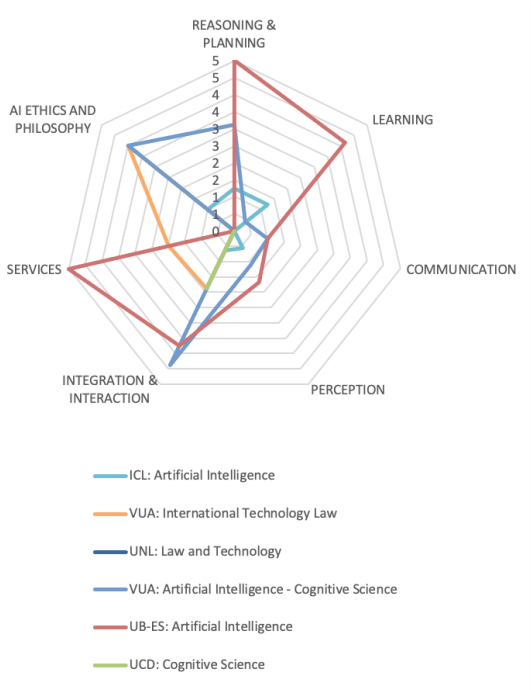
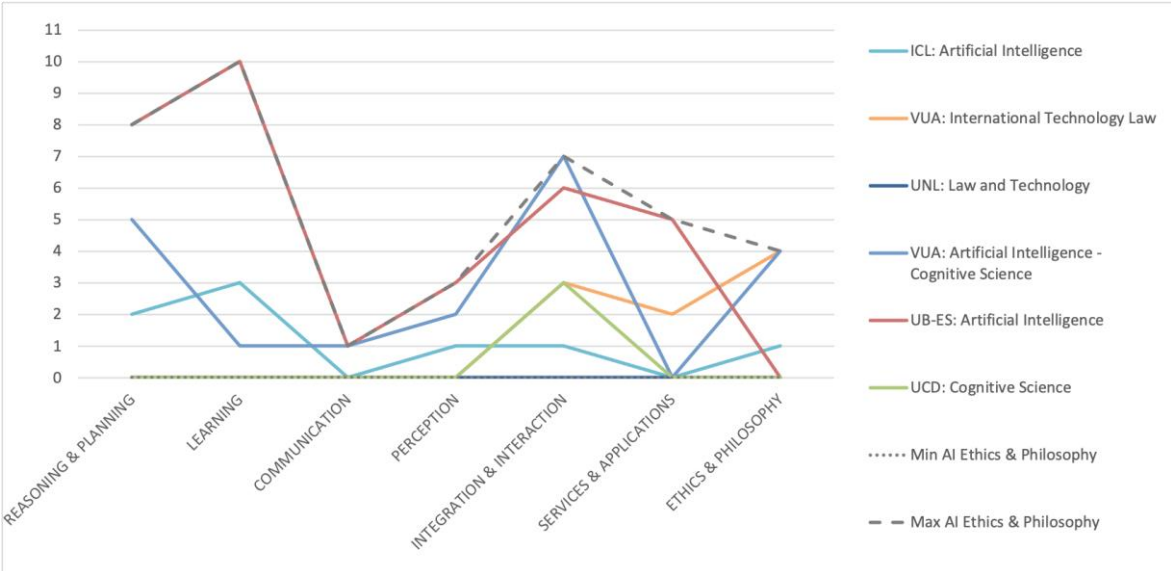


Figure 39. Topic coverage of the programs of masters in the Ethics & Philosophy domain represented in a 0-5 scale



As depicted in Figure 40, Ethics & Philosophy topics are not sufficiently covered, except for the masters of VUA. A few masters of the Services & Applications domain have a broad coverage of all AI topics, as well as have a greater focus on Ethics & Philosophy topics than the masters in the Ethics & Philosophy domain though (see e.g. KUL in Figure 35).

Figure 40. Topic coverage of the programs of ICL, UB, UCD, UNL, VUA 1 and VUA 2



5.4Assessment by competences

All the competences compiled from the selection of masters have been analysed within the general framework of knowledge, skills and dispositions described above. Competences have been compiled and classified according to Bloom's taxonomy (see Annex E: Classification of competences). From that collection, the following analysis of competence types, level, cognitive process and domain specificity has been carried out.

5.4.1 Analysis by competence type and level

The competences published by all masters' programs analysed are summarized in Table 2. Competences have been classified by competence level (i.e., knowledge, skill or disposition) and type (i.e., transversal; general of AI, specific of an AI domain; and horizontal of one of the fundamental fields of AI, namely informatics and statistics). As discussed before, horizontal competences can be considered transversal as well, but they have been depicted separately here for the analysis. The figures in the table are graphically depicted in Figure 41 and Figure 42.

Table 2. Number of competences per level and type

	Competence level			
Type	1-knowledge	2-skill	3-disposition	**Total**
transversal	4	92	40	**136**
specific	80	178	28	**286**
horizontal	19	97	3	**119**
general	6	14	2	**22**
Total	**109**	**381**	**73**	**563**

Figure 41. Number of competences per level and type

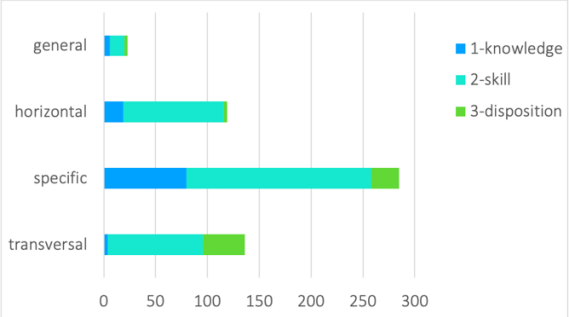
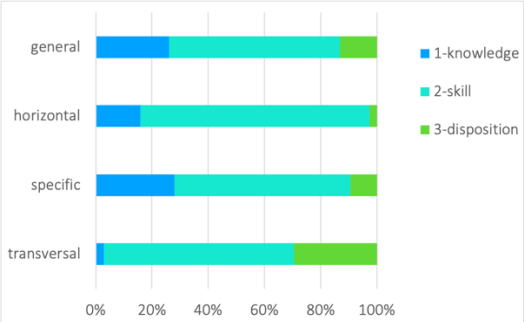


Figure 42. Percentage distribution of competences per level and type



5.4.2 Analysis of domain-specific competences by level and AI domain

The analysis of AI domain-specific competences is focused on the eight core domains of the analysis framework described in section 5.1. The distribution of AI domain-specific competences found in the analysed master programs is shown in Table 3. Figure 43 and Figure 44 graphically depict the distribution of specific competences by each AI domain.

Table 3. Number of competences per level and AI domain

	Competence level			
Domain	1-knowledge	2-skill	3-disposition	**Total**
Communication	3	14	0	**17**
Ethics & philosophy	4	17	9	**30**
Integration	4	18	0	**22**

Interaction	14	32	1	**47**
Learning	26	32	10	**68**
Perception	6	20	3	**29**
Reasoning	7	15	2	**24**
Services & applications	16	30	3	**49**
Total	**80**	**178**	**28**	**286**

Figure 43. Number of specific competences per level and AI domain

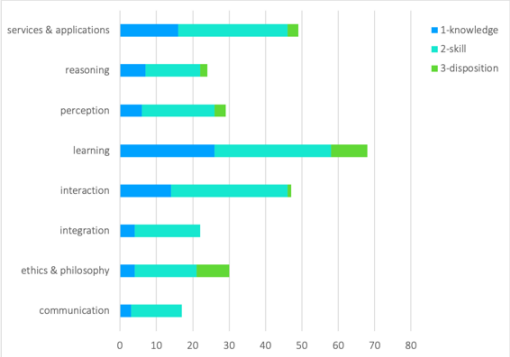
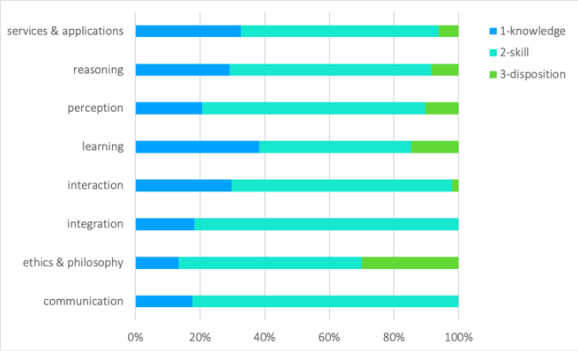


Figure 44. Percentage distribution of specific competences per level and AI domain



5.4.3 Analysis by Bloom's cognitive processes taxonomy

Besides the competence level, the Bloom's taxonomy defines 6 cognitive processes that are involved in the definition of knowledge and skills. Figure 45 summarizes the kind of cognitive process involved in all the competences observed in the masters' sample. The distribution of cognitive processes after classifying by competence type (i.e., general, specific, horizontal and transversal) are shown in Figure 46.

Figure 45. Distribution of competences from all masters by cognitive process

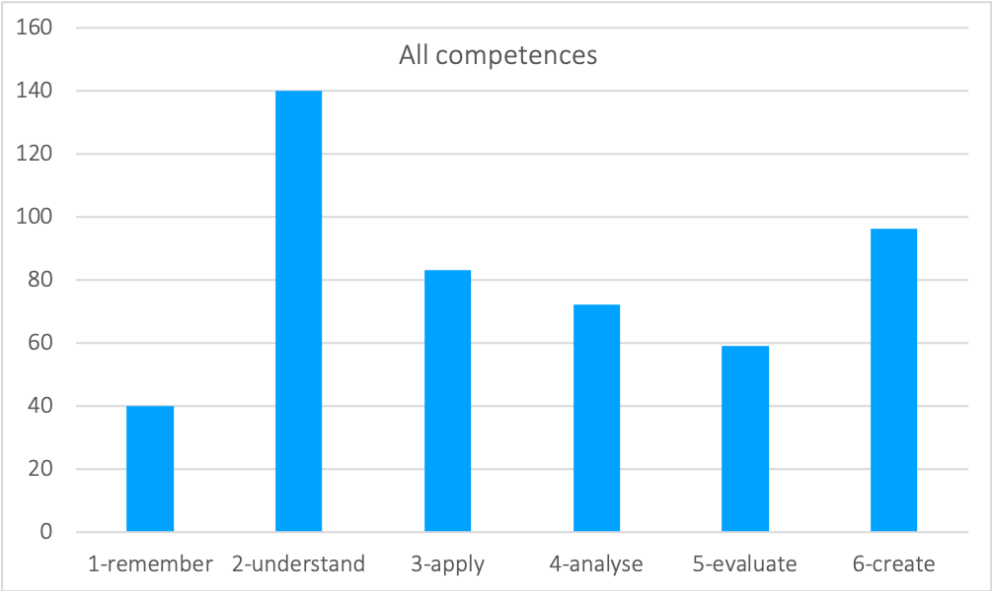
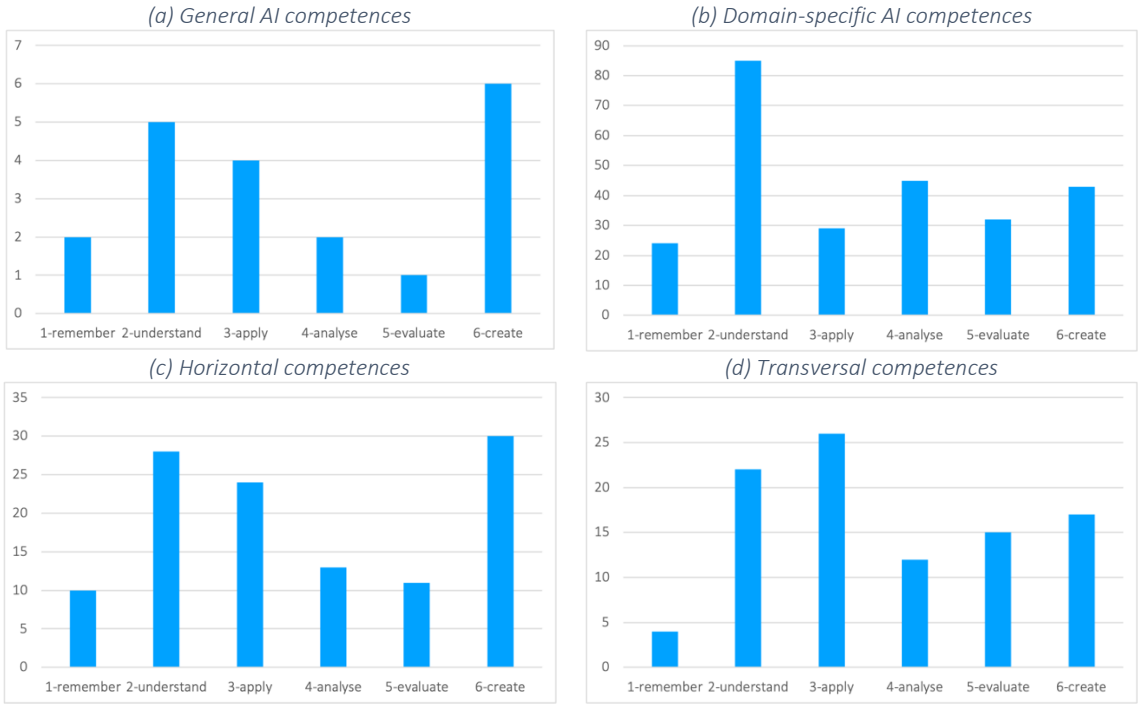


Figure 46. Distribution of competences from all masters' sample by competence type and cognitive process involved



Finally, the distribution of competences by AI domain and Bloom's cognitive process kind is shown in Table 4. They are graphically depicted by number of competences (Figure 47) and percentage distribution (Figure 48).

Table 4. Number of competences per AI domain and Bloom's cognitive process taxonomy level

	Cognitive process level						
Domain	1 remember	2 understand	3 apply	4 analyse	5 evaluate	6 create	**Total**
communication	3	4	2	1	2	5	**17**
ethics & philosophy	1	6	2	1	4	7	**21**
integration	2	6	4	2	3	5	**22**
interaction		15	6	12	8	5	**46**
learning	8	20	7	10	6	7	**58**
perception		8	2	8	1	7	**26**
reasoning	3	11		5	2	1	**22**
services & applications	7	15	6	6	6	6	**46**
Total	**24**	**85**	**29**	**45**	**32**	**43**	**258**

Figure 47. Number of competences from all masters' sample by AI domain and cognitive process involved

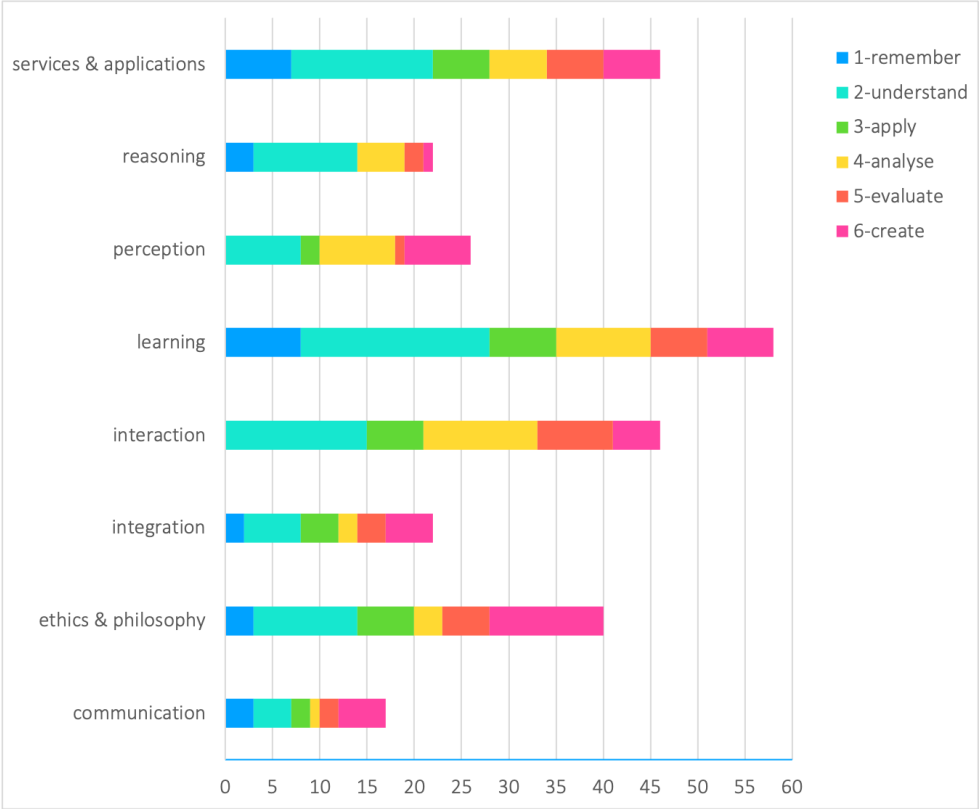
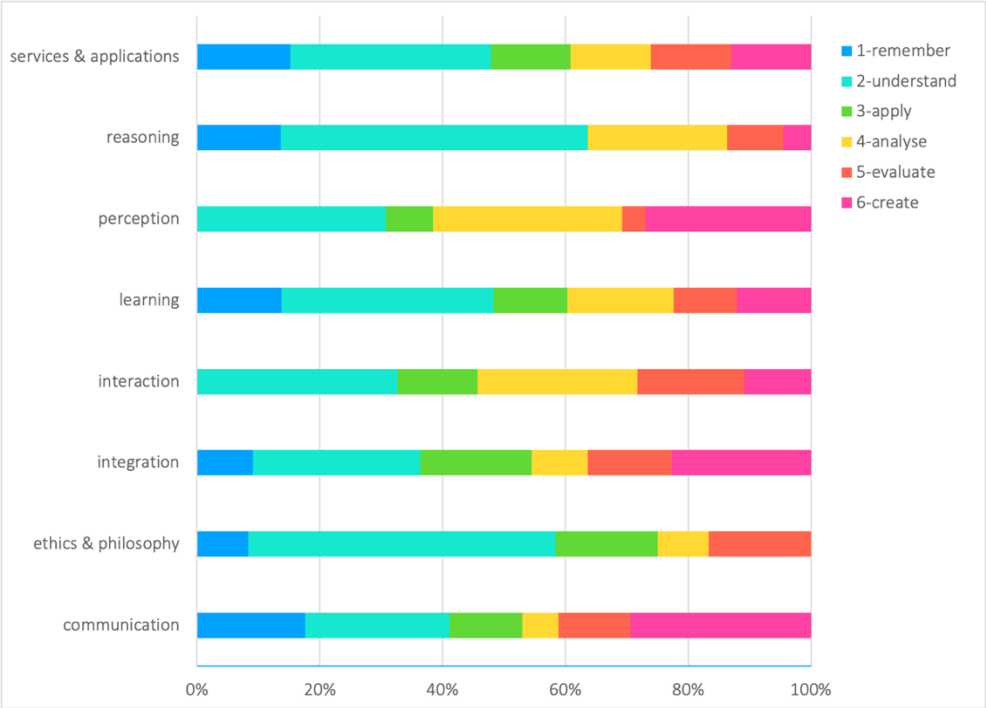


Figure 48. Percentage distribution of competences from all masters' sample by AI domain and cognitive process involved



5.4.4 Analysis by disciplinary lenses

A number of disciplines have been found to have a close relation to the masters programs and the departments, schools and research areas that are in charge of teaching in their institutions. Since not all disciplines cover in a balanced way all types of competences, they have been grouped in three main disciplinary lenses, namely:

- *Humanities and Social Sciences*, including: Humanities, Linguistics, Laws, Business and management, Psychology, Cognitive Science and Behavioural Sciences (see Figure 49);
- *Engineering*, including: Electrical & Electronic Engineering, Computer Engineering, Mechanical Engineering and other Engineering areas (Figure 50); and
- *Informatics*, including: Computer Science and Information Sciences (see Figure 51).

Figure 49. Distribution of competences through the disciplinary lenses of Humanities and Social Sciences disciplines.

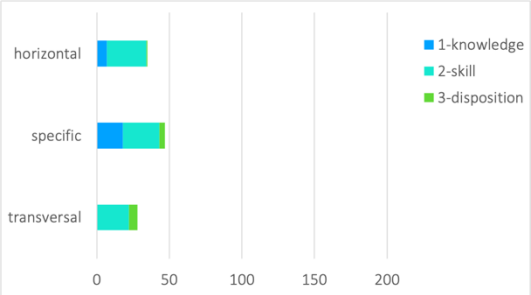


Figure 50. Distribution of competences through the disciplinary lenses of Engineering disciplines.

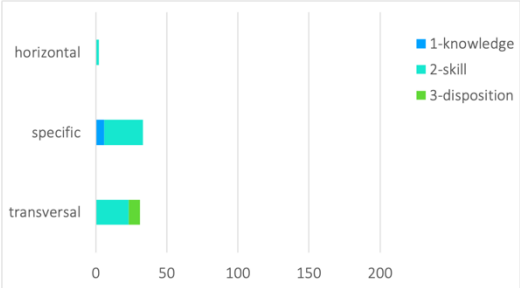
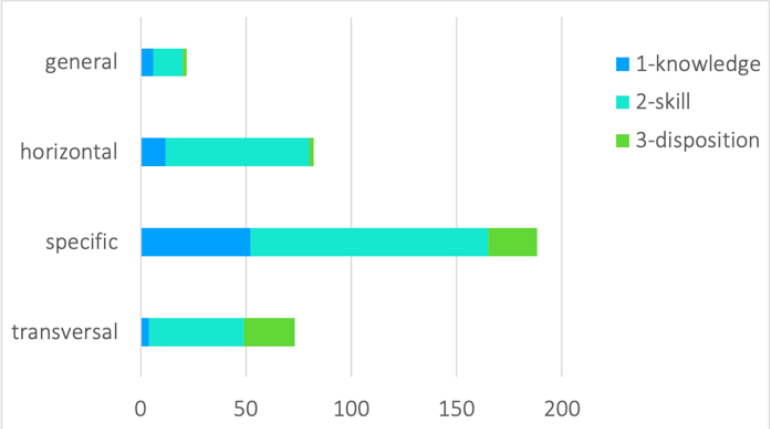


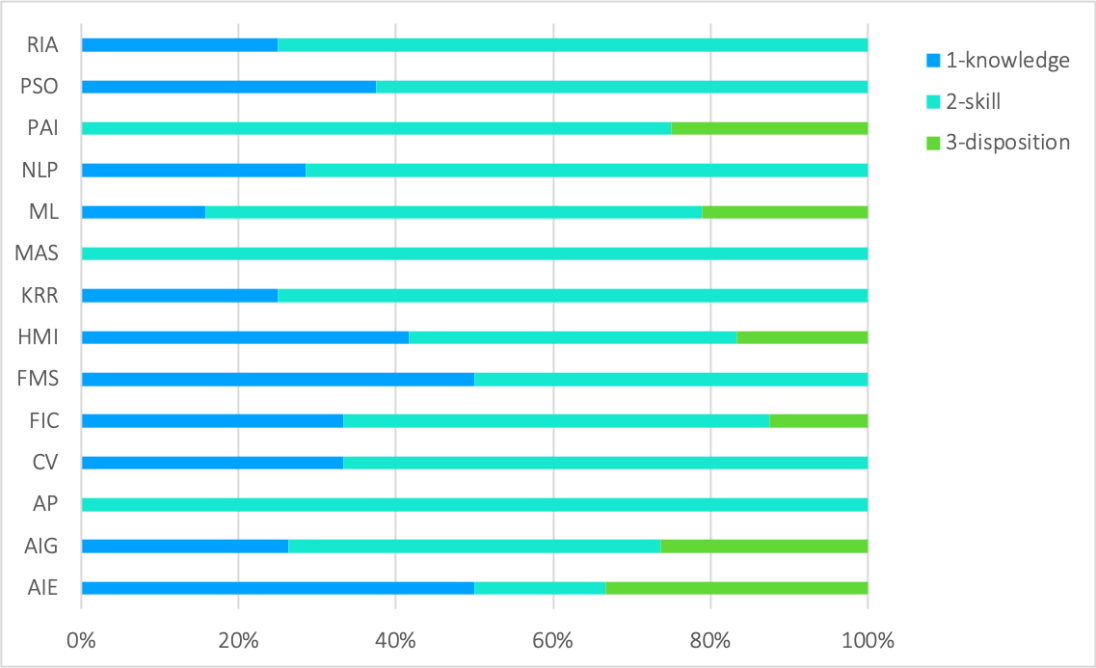
Figure 51. Distribution of competences through the disciplinary lenses of Informatics and Computer Science disciplines.



5.5 Conclusions of the analysis

After the quantitative analysis of the competences expressed by the masters selection, a thorough qualitative inspection was carried out. The objective of this inspection was to identify pairs of similar competences across different master programs that could subsume one another. A competence subsumes another if the former can be considered a generalization of the latter. Subsumption has been considered only when both competences are referred to the same level and cognitive process. The resulting distribution of competences is depicted in Figure 52.

Figure 52. Distribution of the percentage of competence level per AI subdomain after the qualitative inspection



The list of competences before and after the qualitative inspection are respectively depicted in Figure 53 and Figure 54. Some examples of competences that were clustered are provided in Table 5.

Figure 53. Distribution of the number of competences per AI subdomain before the qualitative inspection

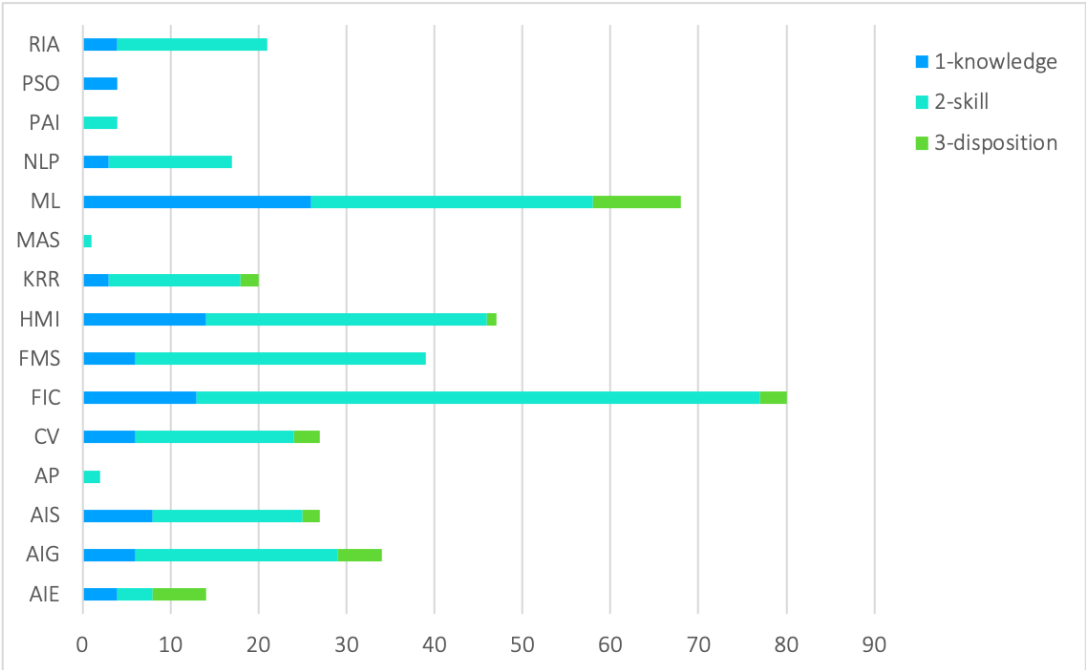


Figure 54. Distribution of the number of competences per AI subdomain after the qualitative inspection

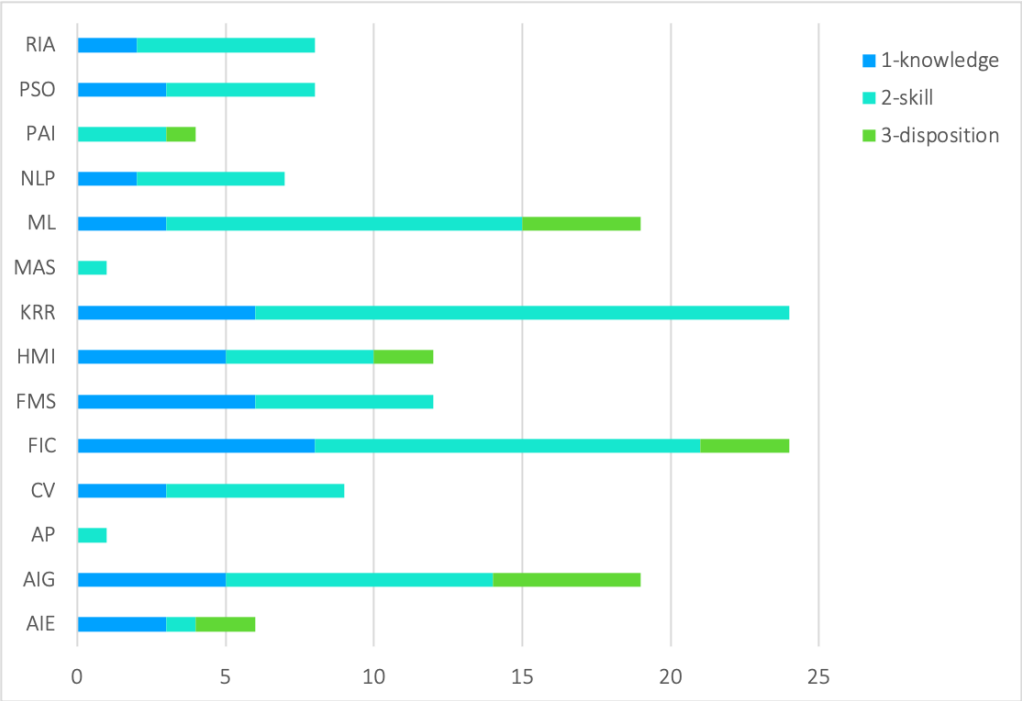


Table 5. Examples of proposed competences that subsume others of the master programs.

Competence	**Cognitive process**	**Subsumed competence**
Formulate the fundamental concepts of information theory and signal processing	2-Understand	Formulate the fundamental concepts of signal processing such as basis representations and sampling
Explain how a solution to a problem can be viewed as a state in a space of possible solutions	2-Understand	For a given problem, model it as search in a multidimensional state space.
Have knowledge on an advanced level in speech signal processing	2-Understand	Have a solid background in speech signal processing
Apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems.	3- Apply	Identify and apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems.
Choose appropriate tools and implement efficient solutions to problems in AI	3-Apply	Apply AI techniques and tools in the development of an AI-application
		Apply AI techniques in technological and industrial environments to improve quality and productivity
Analyse and apply appropriate theories, methods and tools for computer vision problems within e.g. surveillance, robotics, etc.	3-Analyse	Analyse and apply state-of-the-art methods in Computer Vision
Discuss advantages with and limitations of machine learning for different applications	4-Analyse	Discuss the advantages and disadvantages of machine learning techniques
		Characterize trade-offs between time, data and accuracy, for machine learning methods
Evaluate the suitability of different machine learning methods for solving a new problem encountered, and apply the methods to the problem	5-Evaluate	Implement machine learning methods to real-world problems, and rigorously evaluate their performance using cross-validation
		Assess and Evaluate the most important algorithms, function classes, and algorithm convergence guarantees

Competence	Cognitive process	Subsumed competence
Critical appraisal of the ethical implications and societal risks associated with the deployment of AI methods	5-Evaluate	Exercise a basic, critical set of best practices for handling sensitive information
Implement search algorithms	6-Create	Model a small problem as a constraint satisfaction problem.
Engineer a NLP application in a rigorous and principled manner	6-Create	Build some NLP applications such as corpora storage and searching using the learned technologies

As can be seen, the number of competences were very much reduced for some of the subdomains, while others provided a large number of the competences, not balanced with other domains. This occurs either before or after the qualitative inspection. Therefore, some subdomains have been merged with others, while other domains have been split, in order to form the final *knowledge areas* of the curricula, as explained next:

- The MAS subdomain provides a scarce number of competences to the Integration domain, and the CAV does not provide any competence. Therefore, they are integrated with RIA in the **Robotics, Agents & Integration** (RAI) knowledge area in the proposed curriculum.
- The HMI subdomain provides a quantitatively significant number of competences that are qualitatively different from RIA competences in the Integration & Interaction domain. Therefore, a **Human-Machine Interaction** (HMI) knowledge area is defined for the curriculum.
- The AP subdomain provides a scarce number of competences. Along with CV competences, they form up the **Computational Perception** (CP) of the curriculum.
- The KRR and PSO subdomains of the Reasoning domain have a large number of competences, which can be qualitatively differentiated. Therefore, two separate knowledge areas are defined for **Knowledge Representation and Reasoning** (KRR) and **Planning, Search and Optimisation** (PSO) in the curriculum.
- The AIE and PAI subdomains of the Ethics & Philosophy domain are merged in a new Philosophy & Ethics of AI (PEA) knowledge area, which has a more balanced number of competences with respect to other areas.

The resulting knowledge areas of the curriculum are summarized in Table 6. They have been clustered in four main groups, including:

- AI Essentials: cover horizontal topics of disciplines that are fundamental to AI
- AI General: includes general AI competences that are not domain-specific
- AI Core areas: include AI domain-specific competences
- AI Applied areas: define a set of competences, built on top of domain-specific competences of AI core areas, aimed at providing applied AI applications and services under an ethical, philosophical perspective.

Table 6. Knowledge areas and their scope as the building blocks towards defining a competence-based AI curriculum

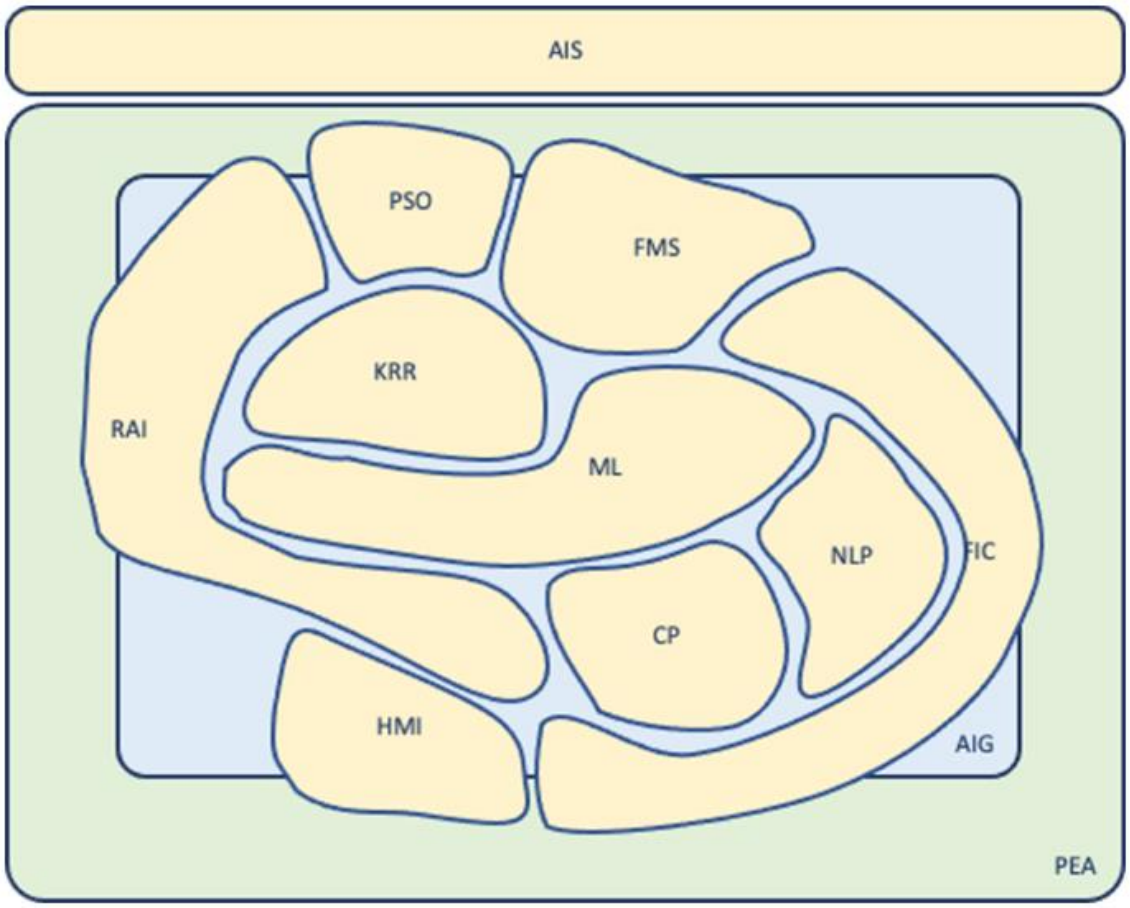
	Knowledge Area		Scope within AI
AI Essentials	FIC	Fundamentals of Informatics/Computing	Concepts, theories, methods and techniques of Informatics or Computing, Computer Science and Software Engineering that are at the foundations of building an intelligent system
	FMS	Fundamentals of Maths & Statistics	Concepts, theories, methods and techniques of Mathematics, Probability and Statistics that form the foundations of intelligent systems
AI General	AIG	AI General	Systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal
AI Core areas	KRR	Knowledge Representation and Reasoning	Representation of information and knowledge in logic and probabilistic formalisms. Application of automated reasoning methods to the represented information and knowledge.
	PSO	Planning, Search & Optimisation	Methods for planning and executing solutions by intelligent systems
	ML	Machine Learning	Algorithms that improve through experience to identify patterns in data to build models in order to gain valuable information. It includes the processing, analysis and presentation of data.
	NLP	Natural Language Processing	Collection and parsing of text data to generate and understand human languages
	CP	Computational Perception	Interpretation of data in a manner that is similar to the way humans uses their senses to relate to the world around them, mainly through vision and audio processing
	RAI	Robotics, Agents & Integration	Distribution, coordination, cooperation, and autonomy of intelligent systems with the environment, as well as the combination of other abilities
	HMI	Human-Machine Interaction	Interaction of humans with computers and intelligent machines and technologies that let humans interact with computers in effective ways
AI Applied areas	AIS	AI Services	Infrastructure, software and platforms provided as digital services or applications to run AI, which are available off-the-shelf and run on demand
	PEA	Philosophy & Ethics of AI	Philosophical and ethical issues associated with AI and related with the compliance of ethical principles and values, including applicable regulation

Figure 55 raws a graphical description of the proposed building blocks for the knowledge areas identified in AI, illustrating the close relationship between many of them. Two shapes with a shared border means their areas have a stronger relationship in scope and topics (even might have an intersection, which for clarity sake has been not graphically depicted). Although the bi-dimensional representation has some limitations, the most relevant relationships between knowledge areas have been included.

The set of AI Essentials and AI Core areas depict the shape of a brain, situated on top of the AI General area. AI Applied areas (AIS and PEA) are built on top of AI core areas, with PEA mediating the dependence of AIS with respect to all other AI areas. ML occupies a central position, illustrating their strong involvement in all the other areas. FIC and RAI are situated at both sides and have also an extensive border with many other areas, meaning their essential competences can be acquired through grade studies in other disciplines (namely, Informatics and

Computer Engineering) that are foundational for AI. KRR and ML form a combined shape, meaning that both areas are very closely related, even sharing a significant part of their knowledge bodies. HMI has a close relationship with RAI regarding interaction devices. FMS can be seen as a lengthening to FIC (or reversely, FIC can be seen as a prolongation of FMS) to form the combined body of knowledge in Mathematics and Informatics that originally gave birth to AI.

Figure 55. Graphical description of knowledge areas in AI illustrating the close relationship between them.



Keys for interpretation:
- A border shared between two shapes reflects a strong relationship in scope and topics (it could even be an intersection, which for sake of clarity has not been graphically depicted). The most relevant relationships between knowledge areas have been included, despite the limitations of a bi-dimensional representation.
- The location of PEA behind the union of all knowledge areas plus AIG means that PEA is built on the basis of certain level of knowledge of all the rest.
- The location of AIS on top illustrates its dependency on knowledge areas, and this knowledge is conveyed through PEA.

Source: Author's elaboration.

6 Building blocks towards an EU AI curriculum

This section describes the competence building blocks related with AI discipline towards providing an EU AI curriculum, which covers as many competence levels as possible, according to Bloom's taxonomy. Since Bloom's cognitive level 1 (i.e. *remembering*) and level 2 (i.e. *understanding*) competences represent the same knowledge topics than the knowledge-based AI curricular framework (see section 3 and Annex B: Body of knowledge), there is no need to consider them again in this section.

The building blocks are based on: (a) the selected sample of analysed masters and (b) existing competence-based curricula related to AI. They have been obtained by applying the methodology of section 1.4. Due to such methodological and technical limitations, some competence levels can be empty, as explained below.

6.1 Knowledge area: AI General

The knowledge area of AI General includes all the competences in the realm of AI that involve knowledge, skills and dispositions that cannot be classified as specific of a given domain. The scope is that of AI and no specific KUs are defined.

The broad scope of AI General is that of systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best actions to take to achieve the given goal.

6.1.1 Competences

SKILLS	
3-apply	
	Choose appropriate tools and implement efficient solutions to problems in AI
4-analyse	
	Choose an appropriate AI method to address the needs of a given application setting
6-create	
	Design, conduct and publish original AI research
	Design new tools and new techniques of Artificial Intelligence in professional practice
	Design, conduct and critique original research to address questions and challenges in the design and use of systems involving humans and AI
DISPOSITIONS	
	Possess an attitude of approaching and investigating AI and AI-problems from a multi-disciplinary perspective
	Insight of what the major areas of concern are in AI, as well as the types of problems they address, in order to know where to look for approaches when needed, thus avoiding rediscovery of existing methods
	Reflect on and discuss current social and ethical aspects of AI

6.2 Knowledge area: Knowledge Representation & Reasoning (KRR)

6.2.1 Scope	**6.2.2 Knowledge Units**
Representation of information and knowledge in logic and probabilistic formalisms. Application of automated reasoning methods to the represented information and knowledge.	Case-based reasoning Causal models & inference Common sense reasoning Expert systems Probabilistic models Information theory Knowledge representation & reasoning Latent & factor analysis

	Semantics & ontologies Soft computing & uncertainty

6.2.3 Competences

SKILLS	
3-apply	
	Demonstrate how Bayesian networks can be used to make inferences; describe approaches for efficient reasoning (Belief Propagation)
	Apply a learning algorithm to construct a Bayesian network for a small- or medium-sized problem
	Apply a reinforcement learning algorithm to an appropriate problem
	Apply a probabilistic logic model to a small- or medium-sized problem
4-analyse	
	Choose an appropriate knowledge representation approach to address the needs of a given application setting
	Choose an appropriate automated reasoning approach to address the needs of a given application setting
	Demonstrate contexts in which Markov Decision Processes can be useful (e.g., optimization or control problems)
5-evaluate	
	Critically evaluate knowledge representation alternatives to solve a given task
	Implement and evaluate automated reasoning approaches to solve a given task

6.3 Knowledge area: Planning, Search & Optimization (PSO)

6.3.1 Scope	6.3.2 Knowledge Units
Methods for planning and executing solutions by intelligent systems. [The scope of this area may have an overlap with FIC fundamental concepts, such as programming methodologies.]	Bayesian optimisation Constraint satisfaction Evolutionary & genetic algorithms Energy formulation Heuristics & metaheuristics Planning graph & activities Stochastic optimisation

6.3.3 Competences

SKILLS	
3-apply	
	Apply a stochastic search approach (e.g., genetic algorithms, simulated annealing)
	Apply a knowledge representation formalism to a problem
	Apply a constraint-satisfaction algorithm to a small- or medium-sized problem
6-create	
	Formalize simple problems with a given knowledge representation approach
	Implement search algorithms
DISPOSITIONS	
	Appreciate that there may be multiple acceptable solutions in a state space, as well as multiple problem-solving approaches, depending on the need for optimality, time constraints, etc.
	Appreciate the relationship between algorithm, heuristics, and optimality of solution to a problem

6.4Knowledge area: Machine Learning (ML)

6.4.1 Scope	6.4.2 Knowledge Units
Algorithms that improve through experience to identify patterns in data to build models in order to gain valuable information. It includes the processing, analysis and presentation of data.	Active & adaptive machine learning Adversarial & generative machine learning Anomaly detection Artificial neural networks Automated machine learning Ensemble methods Classification & supervised learning Clustering & unsupervised learning Collaborative filtering Data mining & information retrieval Deep learning Feature & information extraction Multi-task learning Recommender system Recurrent neural networks Reinforcement learning Semi-supervised learning Statistical learning Transfer learning

6.4.3 Competences

SKILLS	
3-apply	
	Optimize the main trade-offs such as overfitting, and computational cost vs accuracy
	Apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems
	Identify software to support classification and regression and apply the software
4-analyse	
	Discuss advantages with and limitations of machine learning for different applications
	Choose an appropriate machine learning method and data pre-processing strategy to address the needs of a given application setting
	Recognize the type of learning problem and select appropriate algorithms
	Compare clustering approaches, highlighting relative benefits and shortcomings
5-evaluate	
	Evaluate the suitability of different machine learning methods for solving a new problem encountered, and apply the methods to the problem
6-create	
	Derive, explain and apply practical machine learning methods and algorithms
	Design, implementation, deployment and analysis of deep learning architectures addressing complex problems in several applicative areas
	Select and program pattern recognition methods and learning based on the type of problem, after distinguishing if the situation so requires
DISPOSITIONS	
	Critically appraise the ethical implications and societal risks associated with the deployment of machine learning methods
	Reflect on the importance of data representation for the success of machine learning methods

	Depicting links between classification and regression, and more generally statistics, as well as machine learning
	Understanding the limits and potentials of advanced machine learning models

6.5 Knowledge area: Natural Language Processing (NLP)

6.5.1 Scope	6.5.2 Knowledge Units
Collection and parsing of text data to generate and understand human languages	Computational linguistics Dialog systems Machine translation Natural language generation Natural language understanding Question answering Sentiment analysis Text classification Text mining

6.5.3 Competences

SKILLS	
3-apply	
	Understand the basic operation principles of NLP techniques in an intelligent system
	Combine dependency parsing with data-driven statistical methods
5-evaluate	
	Critically evaluate and select software tools appropriate for building NLP applications
6-create	
	Engineer an NLP application in a rigorous and principled manner
	Implement a dependency parser

6.6 Knowledge area: Computational Perception (CP)

6.6.1 Scope	6.6.2 Knowledge Units
Interpretation of data in a manner that is similar to the way humans uses their senses to relate to the world around them, mainly through vision and audio processing	Action, gesture & motion recognition Image processing Image retrieval: content-based & visual search Pattern & object recognition Sensors Music & sound processing Speech processing Speech recognition Speech synthesis

6.6.3 Competences

SKILLS	
4-analyse	
	Analyse and apply appropriate theories, methods and tools for computer vision problems within e.g. surveillance, robotics, etc.

	Identify scientific problems within control and auto computer vision, graphics and interactive systems and select and apply proper scientific theories, methods and tools for their solution
5-evaluate	
	Evaluate and select among the scientific theories, methods, tools and general skills within the fields of computer vision and graphics and, on a scientific basis, advance new analyses and solutions
	Select, plan, and evaluate different techniques to detect, extract and analyse data an image or sequence of images
6-create	
	Derive, explain, and apply practical computer vision algorithms
	Plan, develop, evaluate and manage solutions for projects in the different areas of computer vision

6.7 Knowledge area: Robotics, Agents & Integration (RAI)

6.7.1 Scope	6.7.2 Knowledge Units
Distribution, coordination, cooperation, and autonomy of intelligent systems with the environment, as well as the combination of other abilities [This area has a very close relationship with the other areas of KRR, PSO, ML, NLP, CP and HMI, as well as with other domains that are beyond the scope of this report, such as Mechatronics]	Intelligent multi-agent systems Computational economics Negotiation & agreement Collective intelligence Cognitive systems Control theory Distributed computing Robotics Autonomous vehicles

6.7.3 Competences

SKILLS	
3-apply	
	Apply user-centred design methods to design, implement and test multimodal user interaction strategies, including virtual and augmented reality
4-analyse	
	Select and apply appropriate methods for solving a given problem within interactive systems
5-evaluate	
	Evaluate competing proposals for interface design and implementation
	Conduct research with the prerequisite of care and ethical responsibility, and to process, analyse, interpret and evaluate empirical data or other findings obtained in the process appropriately
6-create	
	Design, simulation, real-time implementation, test, evaluation, and documentation of systems within the field of user interaction
DISPOSITIONS	
	Understand the potential dilemmas related to ethics (scientific integrity, privacy and security) in HCI research
	Critically reflect on research efforts in the field of HCI from a societal perspective, including ethical perspectives such as privacy, scientific integrity, and information security

6.8 Knowledge area: Human-Machine Interaction (HMI)

6.8.1 Scope	6.8.2 Knowledge Units
Interaction of humans with computers and intelligent machines and technologies that let humans interact with computers in effective ways	Intelligent user interfaces Virtual environments & reality Multi-modal interaction Human-robot interaction Affective computing Interaction & User Experience

6.8.3 Competences

SKILLS	
3-apply	
	Apply user-centered design methods to design, implement and test multimodal user interaction strategies, including virtual and augmented reality
4-analyse	
	Select and apply appropriate methods for solving a given problem within interactive systems
5-evaluate	
	Evaluate competing proposals for interface design and implementation
	Conduct research with the prerequisite of care and ethical responsibility, and to process, analyse, interpret and evaluate empirical data or other findings obtained in the process appropriately
6-create	
	Design, simulation, real-time implementation, test, evaluation, and documentation of systems within the field of user interaction
DISPOSITIONS	
	Understand the potential dilemmas related to ethics (scientific integrity, privacy and security) in HCI research
	Critically reflect on research efforts in the field of HCI from a societal perspective, including ethical perspectives such as privacy, scientific integrity, and information security

6.9 Knowledge area: Philosophy & Ethics of AI (PEA)

6.9.1 Scope	6.9.2 Knowledge Units
Philosophical and ethical issues associated with AI and related with the compliance of ethical principles and values, including applicable regulation	Accountability Explainability Fairness Privacy Safety Security Transparency Artificial general intelligence Strong artificial intelligence Weak artificial intelligence

6.9.3 Competences

SKILLS	
5-evaluate	

	Critical appraisal of the ethical implications and societal risks associated with the deployment of AI methods
	Critically compare, relate and evaluate the relative merits of general and data-driven approaches to AI applications
6-create	
	Contribute to the plan, design and construction of AI applications
DISPOSITIONS	
	Respect the surrounding environment and design and develop sustainable intelligent systems
	Apply ethical guidelines to analyse organizational data collection, storage and utilization
	Be aware about how machine learning is utilised and the consequences this has for the society and the professional responsibilities
	Be aware of the tradeoffs about gains and losses made when massive data about people is made available to AI applications
	Appreciate that AI is not a new field, but rather one with a long and rich history within the history of Informatics

6.10 Knowledge area: AI Services (AIS)

6.10.1 Scope	**6.10.2 Knowledge Units**
Infrastructure, software and platforms provided as digital services or applications to run AI, which are available off-the-shelf and run on demand	AI Software toolkits Big data Business Intelligence Computational creativity Computational neuroscience Decision support Intelligent control Machine learning toolkits Personal assistant

6.10.3 Competences

SKILLS	
3-apply	
	Apply AI techniques and tools in the development of a big data analytics application
4-analyse	
	Critically compare, relate and evaluate the relative merits of different approaches to certain classes of big data analytics applications
	Analyse, validate and design cognitive systems
	Understand, analyse and solve challenges in medical and life science environment with the support of AI methods and techniques
5-evaluate	
	Extract a big data analytics problem from a real-world situation, resolve the problem using big data analytics techniques, evaluate the solution method and test the solution
	To write a well-structured and well-argued legal analysis on the use of big data and modern technologies
6-create	
	Develop a small-scale big data analytics system,
	Write small-scale programs in a programming language to perform a big data analytics task
	Transform challenges in medical and life science environment to formal mathematical models and transfer these into efficient algorithms and suitable data structures.
DISPOSITIONS	

	Contribute to the academic and public debate as to whether and to what extent legal responses to human security threats are undergoing a fundamental shift through the use of modern technologies

6.11 Knowledge area: Fundamental Informatics/Computing (FIC)

6.11.1 Scope	6.11.2 Knowledge Units
Concepts, theories, methods and techniques of Informatics or Computing, Computer Science and Software Engineering that are at the foundations of building an intelligent system	Data representation Information structures and management Operating system functions Cybersecurity, data protection Database and file organization Network structure and communication Programming and scripting Algorithms and programming methodologies Software development techniques Compilers and interpreters Formal modelling and verification

6.11.3 Competences

SKILLS	
3-apply	
	Have practical skills in a programming language used to build AI applications
	Perform data acquisition and wrangling from different data formats
	Use the techniques and software development tools required to manage data
	Apply the functional and logic programming paradigms to solve a given problem
	Know how to use a statistical programming environment (R, Python)
4-analyse	
	Select appropriately a programming paradigm to implement the solution for a problem
	Configure the parameters of database systems and applications
	Analyse the trade-offs between various approaches to large-scale data management and analytics
	Analyse the defined specific requirements and select an architecture for computing application
6-create	
	Develop data-parallel analytics programs that scale up to very large workloads
	Design and implement intelligent systems
	Devise suitable strategic plans when developing an intelligent service or application
DISPOSITIONS	
	Appreciate the needs of end-users and issues related to design, management and performance of software
	Recognise and integrate different points of view, even in cases where parties lack expert knowledge in the field of informatics
	Recognize the importance of the choice of data types for encoding information, the challenges brought by heterogeneous data sources and know the role of AI in data integration

6.12 Knowledge area: Fundamental Mathematics & Statistics (FMS)

6.12.1 Scope	**6.12.2 Knowledge Units**
Concepts, theories, methods and techniques of Mathematics, Probability and Statistics that form the foundations of intelligent systems	Discrete mathematics and graph theory Information theory Complexity and decidability Logic formalisms Operations research Stochastic simulation Probability & Statistics Regression Time series Exploratory data analysis Factorization and dimensionality reduction

6.12.3 Competences

SKILLS	
2-understand	
	Summarise a data set using descriptive statistics
	Define fundamental concepts of probability
3-apply	
	Implement operational research models and algorithms using computing tools
	Use probability and perform statistical hypothesis tests in the context of data analysis problems
4-analyse	
	Analyse and select from a range of operational research techniques
6-create	
	Estimate a model and the model parameters from empirical observations using statistical software

7 Conclusions

This document describes and analyses a sample of European masters in the field of AI, and identifies the building blocks for a competence-based curriculum on AI.

The curriculum has to be designed to allow for sufficient flexibility, such that a potential contraction of the curricular requirements of an AI master program, or a future expansion of the body of knowledge in AI, would not require a complete redesign of the curriculum.

The study builds on existing curricula of neighbouring Informatics or Computing domains such as Computer Science, Data Science, Information Technology, and Cybersecurity, and fills a gap that these do not completely fill in relation with knowledge and competences required by strong AI.

The competence building blocks provided in this study do not aim at a complete coverage for all the Bloom's competence levels, for two reasons. First reason is methodological, insofar as the inputs used for the analysis are limited to: (a) the selected sample of analysed masters and (b) the existing competence-based curricula related to AI that have been studied. The second reason for the limited results is due to the lack of details in the published master's syllabi, which do not always include an explicit declaration of their learning outcomes. Actually, for only 39 of the 45 masters in the sample an explicit declaration of competences, skills or learning outcomes was found. In many cases, the list of competences declared is overly vague or scarce, as can be observed in Annex D: Summary of data from masters' analysis. In the learning outcome declaration, most programs under analysis did not observe some soft skills related with entrepreneurship and other transferable competences as proposed by the ACM/AIS MSIS 2016 curricula, such as creativity, leadership and negotiation.

In order to provide a more complete overview of existing AI curricula, a revised method should be approached to complement the report with additional studies. This does not preclude broadening the sample of masters with data from, e.g., EU open or national databases about academic offering, consultations with the national accreditation agencies with responsibility in higher education in the EU, additional programs of accredited master degrees approved through the national accreditation systems, and consultations with key stakeholders in academia and industry, among other inputs.

The building blocks for an AI curriculum that are identified here should therefore be seen as a first proposal on which to continue working. It has been developed to fuel and promote discussion among relevant stakeholders and to assist them in the development of AI curricula, while facilitating comparison with the curricula of leading institutions around the world. To develop an AI curriculum that can be widely accepted, this report can be seen as a starting point for a discussion and validation process involving higher education institutions, research networks, industry, and domain professionals.

Based on an eventual EU AI curriculum that reconciles a wide acceptance degree, future works would be to develop a catalogue that defines and describes a number of levels of expertise in AI linked to the building blocks identified in this document. Based on that, an approach can be defined to help designing a master's program or to classify an existing one according to the framework provided by the eventual EU AI curriculum.

References

ACM Data Science Task Force, *Computing Competencies for Undergraduate Data Science Curricula, Draft 2*, Association for Computing Machinery, New York, Dec 2019, URL: http://dstf.acm.org/DSReportDraft2Full.pdf

Anderson, L. W., and Krathwohl, D. R. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Addison Wesley Longman, 2001.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., and Krathwohl, D. R. *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York: David McKay Company, 1956.

CC2020 Task Force, *Computing Curricula 2020. Paradigm for future Computing Curricula*. *Version 36*, Association for Computing Machinery and IEEE Computer Society, New York, April 2020, URL: https://cc2020.nsparc.msstate.edu/

CEN Workshop Agreement, *European e-Competence Framework 3.0. A common European Framework for ICT Professionals in all industry sectors*. CWA 16234:2014 Part 1 [online] http://ecompetences.eu/wp-content/uploads/2014/02/European-e-Competence-Framework-3.0_CEN_CWA_16234-1_2014.pdf

Dolinina, O., Bobrov, L., Brovko, A., and Cherchimtseva, D. *Enhancement of IT-professional education: Russian-Kazakh network of the IT-training centers*, Proceedings of the International Conference Internet and Modern Society, June 21-24, 2017, pp. 90-93, Association for Computing Machinery, DOI: 10.1145/3143699.3143742

European Quality Assurance Network for Informatics Education (EQANIE), *EURO-INF framework standards and accreditation criteria for informatics degree programmes*, 2017, Available at: http://eqanie.eu/wp-content/uploads/2019/09/Euro-Inf_Framework_Standards_and_Accreditation_Criteria_V_2017-10-23.pdf

Joint Task Force on Cybersecurity Education, *Cybersecurity Curricula 2017. Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity*, Association for Computing Machinery, New York, 2017, ISBN: 978-1-4503-5278-9. DOI: 10.1145/3184594. URL: https://dl.acm.org/citation.cfm?id=3184594

Nikolov, R., Shoikova, E., and Kovatcheva, E., *Competence based framework for curriculum development*, TEMPUS project PICTET: EQF-based professional ICT training for Russia and Kazakhstan (543808-TEMPUS-1-2013-1-BE-TEMPUS-JPHES). Za bukvite, O'pismeneh, Sofia, 2014, ISBN: 978-619-185-015-0, ISBN online: 978-619-185-016-7.

Righi, R., López-Cobo, M., Alaveras, G., Samoili, S., Cardona, M.., Vázquez-Prada Baillet, M., Ziemba, L.W., and De Prato, G., *Academic offer of advanced digital skills in 2019-20. International comparison. Focus on Artificial Intelligence, High Performance Computing, Cybersecurity and Data Science*, EUR 30351 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21541-9, doi:10.2760/225355, JRC121680.

Rosenbloom, P., *On Computing. The Fourth Great Scientific Domain*, MIT Press, 2013.

Russell, S. and Norvig, P. *Artificial Intelligence: A modern approach*, 3rd edition, Pearson, 2016.

Samoili, S., Lopez Cobo, M., Gomez Gutierrez, E., De Prato, G., Martinez-Plumed, F. and Delipetrev, B., *AI WATCH. Defining Artificial Intelligence*, EUR 30117 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17045-7, doi:10.2760/382730, JRC118163.

Samoili S., Righi R., Cardona M., López Cobo M., Vázquez-Prada Baillet M., and De Prato G., *TES analysis of AI Worldwide Ecosystem in 2009-2018*, EUR 30109 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-16661-0, doi:10.2760/85212, JRC120106.

Task Group on Information Technology Curricula, *Information Technology Curricula 2017. Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology*, Association for Computing Machinery, New York, 2017, ISBN: 978-1-4503-6416-4, DOI: 10.1145/3173161. URL: https://dl.acm.org/citation.cfm?id=3173161

Topi, H., Karsten, H., Brown, S. A., Carvalho, J. A., Donnellan, B., Shen, J., Tan, B. C.Y. and Thouin, M. F., 'MSIS 2016 Global Competency Model for Graduate Degree Programs in Information Systems', *Communications of the Association for Information Systems*, Vol. 40, Article No. 18, 2017, Available at: http://aisel.aisnet.org/cais/vol40/iss1/18

Wing, J., 'Computational thinking and thinking about computing', *Philosophical Transactions of the Royal Society*, Vol. 366, No. 1881, 2018, pp. 3717–3725, DOI:10.1098/rsta.2008.0118

List of abbreviations

ACM	Association for Computing Machinery
AI	Artificial Intelligence
AIE	Artificial Intelligence Ethics
AIG	AI General
AIS	AI Services
AP	Audio Processing
AR	Automated Reasoning
BSc	Bachelor in Sciences
BoK	Body of Knowledge
CAV	Connected and Automated Vehicles
CC	Computing Curriculum/Curricula
CCS	Computing Classification System
CE	Computer Engineering
CF-DS	Competence Framework
CP	Computational Perception
CS	Computer Science
CSEC	Cyber-Security
CV	Computer Vision
DS	Data Science
DS-BoK	Data Science Body of Knowledge
EC	European Commission
e-CF	European e-Competence Framework
ECTS	European Credit Transfer System
EDSF	EDISON Data Science Framework
EQF	European Qualification Framework
FIC	Fundamentals of Informatics & Computing
FMS	Fundamentals of Maths & Statistics
HCI	Human-Computer Interaction
HMI	Human-Machine Interaction
IEEE	Institute of Electrical and Electronic Engineers
IoT	Internet of Things
IT	Information Technology
IS	Information Systems
KA	Knowledge Area
KR	Knowledge Representation
KRR	Knowledge Representation and Reasoning
KU	Knowledge Unit
LO	Learning Outcome

MAS	Multi-Agent Systems
MC-DS	Model Curriculum - Data Science
ML	Machine Learning
MPhil	Master in Philosophy
MSc	Master in Sciences
MScR	Master in Science Research
NLP	Natural Language Processing
OS	Optimisation and Searching
PAI	Philosophy of Artificial Intelligence
PEA	Philosophy & Ethics of AI
PhD	Philosophy Doctorate
PS	Planning and Scheduling
PSO	Planning, Search & Optimisation
RAI	Robotics, Agents & Integration
RIA	Robotics and Intelligent Automation
SE	Software Engineering

List of figures

List of tables

Annexes

Annex A: AI keywords and topics

AI domain	AI subdomain	Keywords
Reasoning	Knowledge Representation	case-based reasoning causal inference causal models common-sense reasoning expert system fuzzy logic graphical models inductive programming information theory knowledge representation & reasoning latent variable models semantic web uncertainty in artificial intelligence
	Automated Reasoning	
Planning	Planning and Scheduling	bayesian optimisation constraint satisfaction evolutionary algorithm genetic algorithm gradient descent hierarchical task network metaheuristic optimisation planning graph stochastic optimisation
	Searching	
	Optimization	
Learning	Machine learning	active learning adaptive learning adversarial machine learning adversarial network anomaly detection artificial neural network automated machine learning automatic classification automatic recognition bagging bayesian modelling boosting classification clustering collaborative filtering convolutional neural network content-based filtering data mining deep learning deep neural network feature extraction ensemble method generative adversarial network generative model multi-task learning neural network pattern recognition probabilistic learning probabilistic model recommender system recurrent neural network recursive neural network reinforcement learning semi-supervised learning statistical learning statistical relational learning supervised learning

AI domain	AI subdomain	Keywords
		support vector machine transfer learning unstructured data unsupervised learning
Communication	Natural Language Processing	chatbot computational linguistics conversation model coreference resolution information extraction information retrieval machine translation natural language generation natural language understanding question answering sentiment analysis text classification text mining
Perception	Computer Vision	action recognition face recognition gesture recognition image processing image retrieval object recognition recognition technology sensor network visual search
	Audio Processing	computational auditory scene analysis music information retrieval sound description sound event recognition sound source separation sound synthesis speaker identification speech processing speech recognition speech synthesis
Integration and Interaction	Multi-agent Systems	agent-based modelling agreement technologies computational economics game theory intelligent agent negotiation algorithm network intelligence q-learning swarm intelligence
	Robotics and Automation	cognitive system control theory human-ai interaction industrial robot robot system service robot social robot
	Connected and Automated Vehicles	autonomous driving autonomous system autonomous vehicle self-driving car unmanned vehicle
Services	AI Services	ai application ai benchmark ai competition ai software toolkit analytics platform big data business intelligence

AI domain	AI subdomain	Keywords
		central processing unit computational creativity computational neuroscience data analytics decision analytics decision support distributed computing graphics processing unit intelligence software intelligent control intelligent control system intelligent hardware development intelligent software development intelligent user interface internet of things machine learning framework machine learning library machine learning platform personal assistant platform as a service tensor processing unit virtual environment virtual reality
AI Ethics and Philosophy	AI Ethics	accountability explainability fairness privacy safety security transparency
	Philosophy of AI	artificial general intelligence strong artificial intelligence weak artificial intelligence narrow artificial intelligence

Annex B: Body of knowledge

Knowledge Area / AI domain	Knowledge Unit / AI subdomain	AI Topic	Keywords
Reasoning & Planning	**Knowledge Representation & Automated Reasoning**	Case-based reasoning	case-based reasoning
		Causal models & inference	causal inference causal models
		Common sense reasoning	common-sense reasoning
		Expert systems	expert system
		Probabilistic models	graphical models bayesian modelling bayesian network probabilistic learning probabilistic model markov network
		Information theory	information theory
		Knowledge representation & reasoning	knowledge representation automated reasoning
		Latent & factor analysis	latent variable model factorization principal component analysis
		Semantics & ontologies	semantic web ontology knowledge graph linked data
		Soft computing & uncertainty	fuzzy logic uncertainty in AI
	Planning & Scheduling & Searching & Optimisation	Bayesian optimisation	bayesian optimisation
		Constraint satisfaction	constraint satisfaction
		Evolutionary & genetic algorithms	evolutionary algorithm genetic algorithm
		Energy formulation	energy formulation gradient descent
		Heuristics & metaheuristics	heuristic optimisation metaheuristic optimisation
		Planning graph & activities	hierarchical task network planning graph planning & activity management
		Stochastic optimisation	stochastic optimisation simulation
Learning	**Machine learning**	Active & adaptive machine learning	active learning adaptive learning
		Adversarial & generative machine learning	adversarial machine learning adversarial network generative adversarial network generative model
		Anomaly detection	anomaly detection
		Artificial neural networks	artificial neural network neural network
		Automated machine learning	automated machine learning automatic classification automatic recognition
		Ensemble methods	bagging boosting ensemble method
		Classification & supervised learning	classification supervised learning

Knowledge Area / AI domain	Knowledge Unit / AI subdomain	AI Topic	Keywords
			support vector machine
		Clustering & unsupervised learning	clustering
		Collaborative filtering	collaborative filtering
		Data mining & information retrieval	data mining information retrieval
		Deep learning	convolutional neural network deep learning deep neural network recursive neural network q-learning
		Feature & information extraction	feature extraction information extraction
		Multi-task learning	multi-task learning
		Recommender system	recommender system
		Recurrent neural networks	Recurrent neural network LTSM
		Reinforcement learning	reinforcement learning
		Semi-supervised learning	semi-supervised learning
		Statistical learning	statistical learning statistical relational learning
		Transfer learning	transfer learning
Communication	**Natural Language Processing**	Computational linguistics	computational linguistics linguistic linked data data-driven language engineering
		Dialog systems	chatbot conversation model dialogue system
		Coreference resolution	coreference resolution
		Information extraction	information extraction
		Machine translation	machine translation
		Natural language generation	natural language generation
		Natural language understanding	natural language processing natural language understanding
		Question answering	question answering
		Sentiment analysis	sentiment analysis
		Text classification	text classification
		Text mining	text mining unstructured data
Perception	**Computer Vision**	Action, gesture & motion recognition	action recognition gesture recognition motion recognition
		Image processing	image processing unstructured data
		Image retrieval	content-based filtering image retrieval visual search
		Pattern & object recognition	face recognition pattern recognition object recognition recognition technology
		Sensors	sensor network
	Audio Processing	Music & sound processing	computational auditory scene analysis
			music information retrieval
			sound description
			sound event recognition
			sound source separation
			sound synthesis
			speaker identification
		Speech processing	speech processing

Knowledge Area / AI domain	Knowledge Unit / AI subdomain	AI Topic	Keywords
		Speech recognition	speech recognition
		Speech synthesis	speech synthesis
Integration and Interaction	**Multi-agent Systems**	Intelligent multi-agent systems	agent-based modelling intelligent agent
		Computational economics	computational economics game theory
		Negotiation & agreement	agreement technologies negotiation algorithm
		Collective intelligence	network intelligence swarm intelligence
	Robotics & Intelligent Automation	Cognitive systems	cognitive system
		Control theory	control theory
		Distributed computing	distributed computing IoT
		Robotics	industrial robot robot system robotics service robot social robot
	Connected and Automated Vehicles	Autonomous vehicles	autonomous driving
			autonomous system
			autonomous vehicle
			self-driving car
			unmanned vehicle
	Human-Machine Interaction	Intelligent user interfaces	intelligent user interface
		Virtual environments & reality	virtual environment
			virtual reality
			augmented reality
		Multi-modal interaction	extended reality
			multi-modal interaction
		Human-robot interaction	human-robot interaction
			human-ai interaction
		Affective computing	affective computing
		Interaction & User Experience	usability
			user experience
Services & Applications	**AI Services**	AI Software toolkits	ai application
			ai benchmark
			ai competition
			ai software toolkit
		Big data	big data
		Business Intelligence	analytics platform
			business intelligence
		Computational creativity	computational creativity
		Computational neuroscience	computational neuroscience
		Decision support	data analytics
			decision analytics
			decision support
		Intelligent control	intelligence software
			intelligent control
			intelligent control system
		Machine learning toolkit	machine learning framework
			machine learning library
			machine learning platform
		Personal assistant	personal assistant
AI Ethics and Philosophy	**AI Ethics**	Accountability	accountability
		Explainability	explainability
		Fairness	fairness
		Privacy	privacy
		Safety	safety
		Security	security
		Transparency	transparency

Knowledge Area / AI domain	Knowledge Unit / AI subdomain	AI Topic	Keywords
	Philosophy of AI	Artificial general intelligence	artificial general intelligence
		Strong artificial intelligence	strong artificial intelligence
		Weak artificial intelligence	weak artificial intelligence
			narrow artificial intelligence

Annex C: List of analysed masters

Masters' program name	University	University short name	Country
Artificial Intelligence	KU Leuven	KUL	BE
Artificial Intelligence	University of Barcelona	UB	ES
Artificial Intelligence	Cardiff University	UCARDIFF	UK
Artificial Intelligence	Imperial College London	ICL	UK
Artificial Intelligence - Cognitive Science	Vrije Universiteit Amsterdam	VUA	NL
Artificial Intelligence Enabled Healthcare	University College London	UCL	UK
Automatic Control and Robotics	Polytechnic University of Catalonia	UPC	ES
Autonomous Vehicle Dynamics and Control	Cranfield University	CRANFIELD	UK
Biomedical Computing	Technical University of Munich	TUM	DE
Business Intelligence and Smart Services	Maastricht University	UMAAS	NL
Cognitive Science	University College Dublin	UCD	IE
Cognitive Science	The University of Edinburgh	UEDIN	UK
Computational Linguistics	University of Stuttgart	USG	DE
Computational Statistics and Machine Learning	University College London (UCL)	UCL	UK
Computer Science and Engineering	Politecnico Di Milano	POLIMI	IT
Computer Science with Data Analytics	University of York	UYORK	UK
Computer Science With Speech and Language Processing	University of Sheffield	SHEFFIELD	UK
Computer Vision	Polytechnic University of Catalonia	UPC	ES
Computer, Communication and Information Sciences - Machine Learning, Data Science and Artificial Intelligence	Aalto University	AALTO	FI
Control Systems	Imperial College London	ICL	UK
Data Analytics and Decision Science (DDS)	RWTH Aachen University	RWTHA	DE
Data Science	ETH Zurich - Swiss Federal Institute of Technology	ETHZ	CH
Data Science	Swiss Federal Institute of Technology Lausanne	EPFL	CH
Data Science and Machine Learning	University College London (UCL)	UCL	UK
Digital Health Systems	University of Strathclyde	USTRATH	UK
Digital Humanities	KU Leuven	KUL	BE
Human Computer Interaction	University of Trento	UNITN	IT
Human Computer Interaction	Utrecht University	UTRECHT	NL
Human Computer Interaction	University of Birmingham	UBIR	UK
ICT Innovation (EIT Digital Master School) - Visual Computing and Communication	Aalto University	AALTO	FI
Informatics - AIAI: Foundations and Applications of Artificial Intelligence, Automated Reasoning, Agents, Data Intensive Research	The University of Edinburgh	UEDIN	UK
Intelligent Interactive Systems	Pompeu Fabra University	UPF	ES
Law - International Technology Law	Vrije Universiteit Amsterdam	VUA	NL
Law and Technology	Universidade Nova de Lisboa	UNL	PT
Linguistics - Text Mining	Vrije Universiteit Amsterdam	VUA	NL

Masters' program name	University	University short name	Country
Machine Learning	KTH Royal Institute of Technology	KTH	SE
Machine Learning and Machine Intelligence	University of Cambridge	UCAMB	UK
Mobile Autonomous and Robotic Systems - MARS	Grenoble INP Institute of engineering Univ. Grenoble Alpes	GINP	FR
Multimedia Computing and Interaction	Sapienza University of Rome	SAPIENZA	IT
Robotic Systems Engineering	RWTH Aachen University	RWTHA	DE
Robotics and Autonomous Systems	University of Bath	UBATH	UK
Signal and ImaGe processing Methods and Applications	Grenoble INP Institute of engineering Univ. Grenoble Alpes	GINP	FR
Sound and Music Computing	Aalborg University	AAU	DK
Speech and Language Processing	The University of Edinburgh	UEDIN	UK
Vision, Graphics and Interactive Systems	Aalborg University	AAU	DK

Annex D: Summary of data from masters' analysis

1 UCL: AI Enabled Healthcare

1.1 School/Research area

Health Sciences

1.2 Syllabus

CORE:

- Scientific Software Development with Python for Health Research

ELECTIVE:

- Principles of Health Data Science
- Data Methods for Health Research
- Machine Learning in Healthcare and Biomedicine
- Advanced Statistical Analysis
- Advanced Statistics for Records Research
- Principles of Epidemiology Applied to Electronic Health Records Research
- Information Retrieval and Data Mining
- Graphical Models
- Advanced Machine Learning for Healthcare
- Computational Genetics of Healthcare

1.3 Project/thesis

52.5 ECTS (105 module course units)

2 KUL: Artificial Intelligence

2.1 School/Research area

Informatics

2.2 Syllabus

CORE:

- Fundamentals of Artificial Intelligence
- Programming Languages and Programming Methodologies
- Machine Learning and Inductive Inference
- Uncertainty in Artificial Intelligence
- Artificial Neural Networks and Deep Learning
- Scripting languages
- Speech Science
- Speech Recognition
- Natural Language Processing
- Linguistics and Artificial Intelligence
- Language Engineering Applications
- Data and Statistical Modelling
- Privacy and Big Data
- Big Data Analytics Programming
- Data Mining

ELECTIVE:

- Cognitive Science
- Philosophy of Mind and Artificial Intelligence
- Basic Programming

- Genetic Algorithms and Evolutionary Computing
- Neural Computing
- Cybernetics and its Applications in Physiology and Biological Sciences
- Topics in Psychonomic Science
- Knowledge Representation
- Biometrics System Concepts
- Information Retrieval and Search Engines
- Support Vector Machines: Methods and Applications
- Foundations of Formal Theories of Language
- Robotics
- Computer Vision
- Advanced Programming Languages for A.I.
- Multi-Agent Systems
- Bio-informatics
- Brain Computer Interfaces
- Analysis of Large Scale Social Networks
- AI Ethics & Regulation

2.3 Competences

Knowledge level:

- Understand the concepts, the methods, and the applicability of the fundamentals of AI, including:
    - knowledge representation formalisms,
    - search and problem solving techniques,
    - basics of machine learning,
    - constraint processing and planning,
    - at least one broadening theme in AI: either in Cognitive Science or in Philosophy of Mind and AI or in Privacy issues in AI.
- Be familiar with the concepts and techniques of an Object Oriented programming language and either of an AI-programming language or of specific issues required for Big Data programming.
- Be familiar with the basics of several advanced areas of AI and with the current research directions taken in these areas.

Additional end terms specific for the ECS option:

- Be familiar with the more advanced issues in AI, including:
    - logic for representation and problem solving,
    - neural networks, their basic techniques and applications,
    - machine learning techniques,
    - the treatment of uncertainty in knowledge systems,
- Be familiar with an AI-programming language.
- Be familiar with the basics of several advanced methodologies and/or application areas of AI and with the current research directions taken in these areas.

Additional end terms specific for the SLT option:

- Successful students should have a solid background in
    - linguistics
    - speech science
    - natural language processing
    - speech signal processing
    - pattern recognition

Additional end terms specific for the BDA option:

- Be familiar with the more advanced issues in AI, including:
    - optimization in constraint processing and local search,
    - data and statistical modelling,
    - machine learning techniques,
    - data mining techniques.
- Be familiar with issues involving programming for big data.

- Be familiar with the basics of several advanced methodologies and/or application areas of Big Data Analysis and with the current research directions taken in these areas.

Skills:

General:

- Be able to formulate research goals, determine trajectories that achieve these goals, collect and select information relevant to achieve the research goals and interpret collected information on the basis of a critical research attitude.
- Be able to read and comprehend the international scientific literature on AI (in English).
- Be able to write a scientific paper on AI (in English).

Specific:

- Be able to write small-scale programs in an Object Oriented programming language and in either an AI-programming language or in the context of Big Data programming.

Additional end terms specific for the ECS option:

- Be able to
    - apply AI techniques and tools in the development of an AI-application,
    - develop a small-scale AI-system,
    - write small-scale programs in an AI-programming language,
    - critically compare, relate and evaluate the relative merits of different approaches to certain classes of AI-applications,
    - perform research in one of the research areas of Artificial Intelligence.
- Be able to extract an AI problem from a real world situation, resolve the problem using AI techniques, evaluate the solution method and test the solution.

Additional end terms specific for the SLT option:

- Have experience with the technological and scientific activities performed in companies or research centres in the speech and language technology area.
- Be able to
    - critically compare, relate and evaluate the relative merits of scientific techniques used in companies or research centres in speech and language technology,
    - actively participate in the research activities of such centres.

Additional end terms specific for the BDA option:

- Be able to
    - apply AI techniques and tools in the development of an BDA-application,
    - develop a small-scale BDA-system,
    - write small-scale programs for programming with big data,
    - critically compare, relate and evaluate the relative merits of different approaches to certain classes of BDA-applications,
    - perform research in one of the research areas of Big Data Analytics.
- Be able to solve problems using these fundamentals of BDA, i.e. be able to extract an BDA problem from a real world situation, resolve the problem using BDA techniques, evaluate the solution method and test the solution.

Attitudes:

- Possess an attitude of approaching and investigating AI and AI-problems from a multi-disciplinary perspective.

2.4 Project/thesis

15 ECTS

3 KUL: Digital Humanities

3.1 School/Research area

Humanities, Social and Behavioural Sciences

3.2 Syllabus

CORE:

- Introduction to Digital Humanities
- Information Structures and Implications
- Scripting Languages
- Management and Information Technology

ELECTIVE:

- Design Thinking and Making
- Human-Computer Interaction
- Data Visualisation
- Web Information Systems
- Introduction to Data Mining
- Methods of Corpus Linguistics
- Linked Data Scholarship
- Linguistics and Artificial Intelligence
- Speech Science
- Natural Language Processing
- Online Publishing
- Multimodality in Interaction
- Digital Cultural Heritage

3.3 Competences

Knowledge:

- Understand the basic concepts of Digital Humanities. Appreciate its history and understand the controversies concerning Digital Humanities and traditional Humanities research.
- Understand the concepts underlying a range of basic digital techniques applied in Digital Humanities, with an emphasis on databases, web and scripting languages.
- Understand the concepts and organizational issues of the use of IT for managerial decision in Digital Humanities.
- Have in-depth knowledge and understanding of the techniques used in a selection of tools for Digital Humanities and are able to critically evaluate them.
- Have in-depth understanding of the problem settings and solutions for a selection of applications in Digital Humanities and are able to critically evaluate and assess them.

Skills:

General level:

- Are able to independently formulate research goals, determine research methods that achieve these goals, collect and select information from different research sources relevant to achieve the research goals and interpret collected information on the basis of a critical research attitude, in the context of Digital Humanities.
- Are able to communicate scientifically, both in written and oral communication, on topics related to novel technologies and applications in Digital Humanities.
- Have a critical insight in the interdisciplinary and international dimensions of Digital Humanities and its research.

Specific level:

- Are able to use a range of basic digital techniques applied in Digital Humanities, with an emphasis on modelling, querying, encoding and scripting.
- Are able to assess the potential contributions and pitfalls of the use of IT in research project in Digital Humanities.
- Are able to follow-up and critically situate new scientific developments in Digital Humanities and situate them in a broader context.
- Are able to independently select and apply appropriate tools and techniques for Digital Humanities problems, for a selection of tools and techniques depending on the interests of the graduate.

- Have the ability to independently analyse, model and design solutions for Digital Humanities problems and to critically analyse and interpret the results, for types of problems depending on the interests of the graduate.

3.4 Project/thesis

15 ECTS

4 RWTHA: DDS

4.1 School/Research area

Business

4.2 Syllabus

CORE:

- DDS Essentials: mathematics, statistics, algorithms and data structures
- Data Analytics: predictive modelling, data handling, data quality, machine learning, deep learning
- Decision Science: optimization, decision models, networks, algorithm analysis & design, game theory, uncertainty in decision making, heuristic optimization, metaheuristics, complex planning tasks
- Analytics Project: formalization, modelling, understanding, data gathering, data cleaning, algorithm selection and development, implementation, computational solution, visualization and interpretation, documentation
- Application Areas: supply chain, logistics, economic modelling of energy and climate systems

ELECTIVE:

- Management Electives: management
- Data Analytics & Technology Electives: advanced machine learning, data mining, intelligent monitoring of engineering systems

4.3 Project/thesis

30 ECTS

5 POLIMI: Computer Science and Engineering

5.1 School/Research area

Informatics & Engineering

5.2 Syllabus

CORE:

- Foundations of operations research
- Formal languages and compilers
- Data bases
- Software engineering
- Advanced Computer Architectures
- Computing infrastructures
- Computer security

ELECTIVE:

- Ambient and data intelligence, Pervasive Computing
- Artificial Intelligence, Machine Learning and Soft Computing
- Big data and data science, Advanced Databases
- Cybersecurity
- Design for Safety-critical, Concurrent and Real-time Systems

- Distributed Systems and Middleware Technologies
- High Performance Computer Architectures, Design of Embedded Systems
- Robotics and Image Analysis
- Interactive applications, Mobile Applications, Web and Multimedia Technologies, Videogames Design
- Advanced software engineering for complex systems, Internet engineering
- Business informatics, analytics and intelligence
- Networked Enterprises and Services, Business Information Systems
- Bioinformatics and e-health

5.3 Competences

Skills:

- design devices and systems;
- create hardware and software systems;
- use information technology to plan, design, manage, decide, produce and supervise;
- design and create corporate information systems;
- design and create the automation of services using modern technologies, including Internet-based ones;
- develop multimedia and hypermedia systems;
- develop IT systems based on joint Hw/Sw project techniques;
- develop robotics systems and applications;
- develop systems based on artificial intelligence;
- designing networked computer architectures and systems, infrastructures and software for "smart" environments.

5.4 Project/thesis

20 ECTS

6 UMAAS: Business Intelligence and Smart Services

6.1 School/Research area

Business

6.2 Syllabus

CORE:

- Business Analytics: data-intensive decision support, predictive modelling, data mining, programming/scripting, uncertainty modelling
- Service Design: design thinking, smart services, business intelligence, decision making, data analytics,
- Business Intelligence Systems: Business intelligence and ETL, data and file management systems (RDBM, NoSQL databases, Hadoop HDFS), GDPR, CCPA
- Machine Learning for Smart Services: intelligent system, predictive maintenance, recommender system
- Smart Services Skills: statistical and programming environment R

ELECTIVE:

- Analysing Unstructured Data: decision support systems, unstructured data (text and image),
- Smart Service Management
- Data Visualisation
- Descriptive and Predictive Analytics: causal factors, statistical models, time series
- Application areas: operations, manufacturing, supply-chain, customer behaviour, marketing campaign performance, workflow procedures

6.3 Competences

General skills:

- List several data analytics methods
- Analyse data by using data science concepts.
- Understand and develop how data can be used to provide new insights into business and create value for the business.
- Translate business problems into canonical data mining tasks and study business problems from a data perspective.
- Interpret and communicate application results from data science concepts in a business context.
- Demonstrate knowledge and understanding of the role service design, principles, processes and methods play in developing smart services
- Leverage / use service design as a practical approach to generate stakeholder insights needed for smart services
- Integrate academic knowledge on service, interaction and business design to develop new ideas and innovative services
- Demonstrate academic reasoning and critical thinking based on evidence and theory
- Communicate in a clear and effective manner
- Successfully work together and manage tasks in interdisciplinary innovation teams
- Understand the diverse data landscape of modern organizations
- Be familiar with different data and file management systems such as RDBM, Data Warehouses, NoSQL and HDFS
- Analyse and design organizational data infrastructure using data modelling
- Apply ethical guidelines to analyse organizational data collection, storage and utilization
- Develop insights with respect to the BI lifecycle in organizations, ranging from ETL to end user applications
- Know the relationship between machine learning, artificial intelligence and smart services.
- Be able to design and implement intelligent systems.
- Be able to reflect on and evaluate intelligent systems.
- Be familiar with the statistical and programming environment R, and are able to run basic (pre- or self-programmed) routines;
- Be familiar with several practical service design principles and tools; and
- Be more aware of the expectations of the labour market and have identified ways to improve their own employability.

Analysing unstructured data:

- Explain and work with the basic concepts of several structured and unstructured data types
- Explain and understand existing models and methods to analyse structured and unstructured data types published in the academic literature
- Evaluate existing models and methods published in the academic literature
- Identify suitable methods to analyse structured and unstructured data types
- Estimate a suitable model using empirical data and statistical software
- Interpret an estimated model, and draw managerial implications
- Develop their own models and provide interpretations thereof based on the learned methods and available data

Smart Service Management:

- devise suitable strategic plans when developing new smart service;
- design an appropriate organizational configuration for implementing new smart services;
- take into account human resource considerations when designing and executing new services.

Descriptive and Prescriptive Analytics:

- Use several statistical and econometric models for time series data, discrete choice data and panel data.
- Evaluate the applicability of different econometric models for a given business problem.
- Translate business problems to canonical time series, discrete choice or panel data models.

- Understand and use fundamental concepts of hypothesis testing and model comparison in analyzing business data.
- Apply time series, discrete choice and panel data models for describing and summarizing business data and for evaluating the potential future outcomes in a business problem.
- Interpret and communicate the numerical results of time series, discrete choice and panel data models in a business context.

6.4 Project/thesis

5 ECTS

7 USTRATH: Digital Health Systems

7.1 School/Research area

Health Sciences & Information Sciences

7.2 Syllabus

CORE:

- Design of Usable Health and Care Systems: usable systems
- Health Literacy
- Information Systems Architecture
- Health Information Governance: ethical behaviour, cybercrime, data protection
- Digital Health Implementation: monitoring systems, wearable and sensors,
- Decision Support & Health Analytics: data analytics, visualization, multimodal output, information structures, interoperability, decision support
- Database Fundamentals: SQL, data models, relational DBMS, big data
- Research Methods

7.3 Project/thesis

60 ECTS

8 UYORK: Computer Science with Data Analytics

8.1 School/Research area

Informatics

8.2 Syllabus

CORE:

- Algorithms and Data Structures
- Big Data Analytics
- Data Mining and Text Analysis
- Advanced Programming
- Computer Architecture and Operating Systems
- Artificial Intelligence and Machine Learning
- Computer and Mobile Networks
- Software engineering
- Research methods

8.3 Project/thesis

30 ECTS

9 ICL: Artificial Intelligence

9.1 School/Research area

Informatics

9.2 Syllabus

CORE:

- Ethics, Privacy, AI in Society
- Introduction to Machine Learning
- Introduction to Symbolic Artificial Intelligence
- MSc Software Engineering Practice and Group Project
- Python Programming

ELECTIVE:

- Advanced Databases
- Advanced Robotics
- Advanced Security in Smartphone and IoT Systems
- Complexity
- Computational Finance
- Computer Vision
- Databases
- Deep Learning
- Knowledge Representation
- Logic-Based Learning
- Machine Arguing
- Machine Learning for Imaging
- Maths for Machine Learning
- Modal Logic
- Network and Web Security
- Operations Research
- Optimisation
- Performance Engineering
- Principles of Distributed Ledgers
- Privacy Engineering
- Probabilistic Inference
- Probabilistic Programming
- Prolog
- Quantum Computing
- Reinforcement Learning
- Robotics
- Scalable Systems for the Cloud
- Separation Logic: Local Reasoning about Programs
- Systems Verification

9.3 Competences

Knowledge and Understanding of:

- Practical programming skills;
- The detail and essential topics relevant to the students' chosen option and project areas, such as Software Engineering;
- Communication skills, including project design, teamwork, written and oral reports and presentations and literature search, both web-based and hard copy;
- Emerging trends in Computing and an awareness of how these techniques can be adapted in industrial applications;

- Practical programming skills in Prolog and Matlab;
- Research skills, including time management, research effectiveness, personal effectiveness, writing skills, presentation and communication skills, technical presentation and critical reading of literature.

Intellectual Skills:

- Match problems to tools and techniques most suitable for solving them;
- Analyse computing and computing related problems and devise solutions to them;
- Develop an understanding and practice of more advanced computing topics, including databases, concurrent programming, artificial intelligence and distributed systems –in particular Architecture; Artificial Intelligence; Biomedical Applications; Computational Management Science; Creative Industries; Distributed Systems; Software Engineering and Visual Information Processing;
- Plan, conduct and write-up a programme of software development conducted in a team;
- Plan, conduct and write-up a programme of original research and software development.

Practical Skills:

- Design and develop programs of varying levels of complexity using Prolog, Matlab and other languages;
- Use computing tools and techniques, for instance software development tools;
- Analyse computing and computing related problems and devise solutions to them;
- Give technical presentations;
- Appreciate the needs of end-users and issues related to design, management and performance of large scale software;
- Prepare technical reports;
- Conduct detailed literature searches;
- Conduct in-depth research on tools and languages available on line.

Transferable Skills:

- Communicate effectively through oral presentations, computer presentations and written reports;
- Program in the major computer programming paradigms;
- Integrate and evaluate information from multiple and diverse sources;
- Work within and contribute to a team, apply management skills such as coordination, project design and evaluation and decision processes as applied in software engineering;
- Manage resources and time;
- Transfer techniques and solutions from one area to another;
- Learn independently with open mindedness and critical enquiry;
- Learn effectively for the purpose of continuing professional development.

9.4 Project/thesis

36 ECTS

10 VUA: International Technology Law

10.1 School/Research area

Laws

10.2 Syllabus

CORE:

- Technology Law: data protection, privacy, human-robot relationships, autonomous decision making, liability and discrimination, sharing economy, climate change, medical innovation
- Legal Methodology
- Big Data, Human Rights and Human Security

ELECTIVE:

- Law and Ethics on Robots and Artificial Intelligence: autonomous intelligent vehicles, social robots, ambient technology, IoT

- Blockchain and Other Disruptive Business-tech Challenges to the Law
- Bioethics, Technology and Law
- European Consumer Law in a Digital Society
- International Weapons Law

10.3 Competences

- Acquire knowledge of the legal framework which is applicable to the most important new technologies.
- Research and discover which laws are relevant to a new situation, and how to extend legal ideas to situations which have not yet been addressed by courts.
- Map an overview of the main sources of EU and international data protection law;
- Apply the principles of data protection law to the use of big data and modern technologies in each of the three human rights and human security fields discussed in the course;
- Identify and explain weaknesses and gaps in the international and EU legal framework regulating data protection and privacy and other fundamental rights such as procedural justice, when it comes to the use of big data and new technologies to address threats to human security;
- Contribute to the academic and public debate as to whether and to what extent legal responses to human security threats are undergoing a fundamental shift through the use of modern technologies;
- To write a well-structured and well-argued legal analysis on the use of big data and modern technologies in the domains discussed in the course.
- Have a clear understanding of legal research methods and be able to apply them in your research;
- Be able to apply the ”doctrinal method“, understand the process of legal reasoning, understand the role of (non-legal) factual statements in legal discourse and be able identify ideologically biased claims, understand the role of “storytelling“ in legal discourse and identify different analytical approaches to doctrinal research.
- Have a basic understanding of non-doctrinal legal research methods.
- Be able to map a research area, draft research questions appropriate for a master thesis, develop a functional analytical structure, access relevant academic research resources, identify and avoid plagiarism, and pursue a functional writing strategy.
- Be able to analyse legal academic texts from a methodical perspective, and identify methodical problems.

Elective:

- Acquire an advanced knowledge of legal and ethical issues related to robots and artificial intelligence;
- Explain their own well-founded opinion on the tasks and challenges for the law related to robots and artificial intelligence;
- Be able to critically reflect on the state of the law in the light of technical topics related to robots and artificial intelligence, and to formulate their own well-founded opinion in current academic debates in this field.
- Be aware of the contextual demands (not to stifle technological development by enacting restrictive legislation, while at the same time protecting fundamental rights and freedoms of a democratic society) law has to deal with;
- Be able to assess the legal and societal aspects of a problem in an integrated way and critically reflect on possible approaches and solutions;
- Be able to formulate their own well-founded opinion on the challenges posed by particular applications of robots and AI.
- Understand, at a functional level, how disruptive technologies work, how they circumvent or defeat tradition regulation.
- Understand and critically evaluate the traditional legal approaches in the areas covered by these disruptive technologies.
- Explain their own well-founded opinion on the tasks and challenges for the law.

10.4 Project/thesis

12 ECTS

11 UNL: Law and Technology

11.1 School/Research area

Laws

11.2 Syllabus

CORE:

- Methodology of Legal Research

ELECTIVE:

- Intellectual Property Law
- Law & Technology
- Programming
- Start-up Life Cycle
- Emerging Technologies: Governance and Regulation
- Data Protection and Management Law
- Digital Contracts
- Competition Law
- International Commercial Law
- International Tax Law
- Fintech
- Life Sciences Law
- Cybersecurity

11.3 Project/thesis

60 ECTS

12 UPC: Computer Vision

12.1 School/Research area

Electronics & Telecommunications

12.2 Syllabus

CORE:

- Video Analysis: segmentation, tracking, model-based, gesture recognition, action recognition, video retrieval, traffic monitoring
- Computational Learning/Machine Learning for Computer Vision: image classification, deep learning, bag of words, convolutional neural networks,
- Introduction to Human and Computational Vision: image perception, acquisition and processing, Fourier analysis, multiscale representations, extraction of features, image description, grouping, segmentation, classification, object recognition, content-based image retrieval,
- Optimization and Inference for Computer Vision: energy formulation, gradient descent optimization, deep learning, convex optimization, graphical models, image restoration
- Visual Recognition: deep learning, automatic image understanding, deep convolutional neural networks, detection, segmentation, recognition, programming, autonomous driving, ML frameworks (Theano, TensorFlow, Keras), MLP feed forward networks (supervised), convolutional neural networks,
- 3D Vision: stereoscopic videos, projective geometry, sensors, augmented reality, object scanning, motion capture, robotics, urban planification, architectural design, traffic

- Dissemination of Research
- Research Methods and Technology Transfer

12.3 Competences

- Accept responsibilities for information and knowledge management.
- Choose the most suitable software tools and training sets for developing solutions to problems in computer vision.
- Conceptualise alternatives to complex solutions for vision problems and create prototypes to show the validity of the system proposed.
- Continue the learning process, to a large extent autonomously
- Identify concepts and apply the most appropriate fundamental techniques for solving basic problems in computer vision.
- Plan, develop, evaluate and manage solutions for projects in the different areas of computer vision.
- Solve problems in new or little-known situations within broader (or multidisciplinary) contexts related to the field of study.
- Understand, analyse and synthesise advanced knowledge in the area, and put forward innovative ideas.
- Use acquired knowledge as a basis for originality in the application of ideas, often in a research context.
- Work in multidisciplinary teams

12.4 Project/thesis

12 ECTS

13 AAU: Vision, Graphics and Interactive Systems

13.1 School/Research area

Information Technology (Informatics) & Design

13.2 Syllabus

CORE:

- Computer graphics programming: augmented and virtual reality
- User experience design for multi-modal interaction: system design methods including the social and cultural contexts of use; user behaviour research; qualitative research methods involving end users in the field, such as interview techniques and analysis and experience sampling; scenario-based design methods; principles for multi modal interaction design; methods for multi modal evaluation and field studies
- Machine learning: supervised learning methods: support vector machines, neural networks; unsupervised learning methods: K-means, Gaussian mixture model, hidden Markov model, EM algorithm, and principal component analysis; probabilistic graphical models, variational Bayesian methods, belief propagation, and mean-field approximation; Bayesian decision theory, bias and variance trade-off, and cross-validation; reinforcement learning
- Image processing and computer vision: camera system; representation and compression of digital images and video signal; basic point and neighbourhood operations; invariant feature point descriptors; motion analysis methods; tracking frameworks such as the Kalman filter, mean-shift and the particle filter; shape analysis methods.

ELECTIVE:

- Interactive Systems: user involvement; methods and architectures for fusion of information; context-aware interaction; methods for multi-modal systems.
- Research in vision, graphics and interactive systems: theories for automatic detection and recognition of objects in natural scenes; theories for statistical user modelling and profiling;

methods for automatic detection and recognition of objects in natural scenes; methods for advanced realistic graphics rendering of natural scenes; methods for theories for data mining.

- Robot vision: robotics; vision and other sensors; design of intelligent machines (artificial intelligence);flexible and integrated automation technologies; business potential of intelligent manufacturing.
- Platforms and Methods for Multi Modal Systems: integration of sensory information from non-standard signal sources; methods and architectures for fusion of multi modal information from e.g. speech, gaze, sound and gesture modalities; context-aware multimodal interaction.
- Algorithms, data structures and software engineering for media technology: fundamentals of algorithm design and analysis; time and space complexity; data structures used in various computational problems; algorithmic techniques such as recursion and dynamic programming; machine learning algorithms and techniques; software engineering concepts and programming techniques
- Numerical scientific computing: software platforms for scientific computing; parallelization; message and data passing in distributed computing; programming techniques, profiling, benchmarking, code optimization etc.; numerical accuracy; software development methods of relevance to development of scientific computing software
- Research in Vision, Graphics and Interactive Systems: automatic detection and recognition of objects in natural scenes; real-time and non-real-time techniques for computer graphics rendering; theories for statistical user modelling and profiling; methods for automatic detection and recognition of objects in natural scenes; methods for advanced realistic graphics rendering of natural scenes; methods for theories for data mining, statistical user modelling and profiling

13.3 Competences

Knowledge:

- Has knowledge on an advanced level in computer vision, computer graphics and interactive systems based on the highest international research in these areas
- Can understand and, on a scientific basis, reflect over the aforementioned subject area's key knowledge and can identify scientific problems and propose solutions within these
- Has a comprehensive knowledge of the core subjects for computer vision, such as image recognition, visual scene analysis, object tracking, etc.
- Has knowledge about methods for computer graphics, augmented reality, 3D rendering, etc.
- Has knowledge about interactive systems design, in particular multi modal user interaction and user experience design.
- Has knowledge about machine learning methods and techniques and pattern recognition
- Has knowledge of the theories and methods for realizing complex software systems for vision, graphic and interactive systems

Skills:

- Excels in scientific methods, tools and general skills related to design, simulation, real-time implementation, test, evaluation, and documentation of systems within the fields of computer vision, graphics and user interaction
- Can evaluate and select among the scientific theories, methods, tools and general skills within the fields of computer vision, graphics and user interaction and, on a scientific basis, advance new analyses and solutions
- can communicate research-based knowledge and discuss professional and scientific problems with both peers and non-specialists
- Can apply methods and tools for solving complex problems within the aforementioned domains
- Can analyse and apply state-of-the-art methods in Computer Vision
- Can analyse and apply state-of-the-art methods in Computer Graphics
- Can apply user cantered design methods to design, implement and test multimodal user interaction strategies

Competences (Attitudes):

- Can manage work and development situations that are complex, unpredictable and require new solutions.
- Can independently initiate and implement discipline-specific and interdisciplinary cooperation and assume professional responsibility.
- Can independently take responsibility for own professional development and specialization
- Can analyse and apply appropriate theories and methods for computer vision problems within e.g. surveillance, robotics, etc.
- Can select and apply appropriate methods for solving a given problem within computer vision, graphics and interactive systems and evaluate the results regarding their accuracy and validity
- Can identify scientific problems within control and auto computer vision, graphics and interactive systems and select and apply proper scientific theories, methods and tools for their solution
- Can develop and advance new analyses and solutions within computer vision, graphics and interactive systems
- Can take responsibility for own professional development and specialization.
- Work according to a scientific method and present results in the form of a scientific article and at a seminar/scientific conference
- Formulate and explain scientific hypotheses and results achieved through scientific work
- Analyse results and draw conclusions on a scientific basis

13.4 Project/thesis

30 ECTS

14 AALTO: ICT Innovation - EIT - Visual Computing and Communication

14.1 School/Research area

Technology (Informatics) & Engineering

14.2 Syllabus

- Web Services
- Web Software Development
- WWW Applications
- Special Assignment in WWW and Knowledge Technology
- Explorative Information Visualization
- User Interface Construction
- Seminar in Computer Science
- Seminar on Media Technology
- Mobile Cloud Computing
- Cloud Software and Systems
- Multimedia Services in Internet
- Social Media
- Complex Networks
- Computer Vision

14.3 Project/thesis

30 ECTS

15 TUM: Biomedical Computing

15.1 School/Research area

Informatics & Health Sciences

15.2 Syllabus

CORE:

- Informatics: Computer Aided Medical Procedures; Project Management and Software Development for Medical Applications, software project management and development, software engineering, version control, deployment, testing and documentation
- Medicine: Medical Instrumentation and Computer Aided Surgery, Imaging in Radiology, Nuclear Medicine and Radiation Therapy, Medical Information Processing and Pathophysiology

ELECTIVE:

- Imaging
- Mathematical methods and scientific computing
- Programming and software engineering
- Image processing, computer vision, and pattern recognition
- Computer graphics, augmented reality, and visualization
- Professional and transferrable skills

15.3 Competences

Formal, computational, mathematical skills:

- Be able to understand, analyse and solve challenges in medical and life science environment.
- Be able to transform these to formal mathematical models and transfer these into efficient algorithms and suitable data structures.
- Master the concept of formal proofs and are able to verify and evaluate resulting solutions and therefore hold ambitious mathematical competences.

Analysis, design, implementation and project management skills:

- Be able to analyse specific requirements defined by clinical and life science processes, understand their overall context and apply and evaluate appropriate computational methods in order to enhance efficiency of these processes.
- Be able to plan and manage ambitious projects and, even with limited resources
- Be able to develop solutions that comply with quality standards defined by health systems.

Technological skills:

- Understand the interaction between biomedical soft- and hard-ware and are familiar with the theoretical foundations of medical imaging systems.
- Be able to analyse, validate and design cognitive systems, know the different paradigms of artificial intelligence and the characteristics of intelligent systems and are able to validate them.
- Know models and methods in computer graphics, image understanding/processing, and visualization
- Analysing and judging the efficiency of related computational methods for proper validation and testing

Interdisciplinary skills:

- Given technical, economic and social contexts, be able to solve problems in demanding interdisciplinary projects in medical/biological fields of application
- Be able to use methods of computer science to develop demanded systems and to manage corresponding projects.
- Use document systems in written form and are able to present their findings.
- Be able to work in multi-national and multi-cultural teams
- Understand ethical standards and the impact of their work on future users, patients and society.

Methodological skills:

- Be able to work according to research orientated scientific principles, to conduct independent research to advanced knowledge in their challenging field and to introduce new methods in informatics into an existing corporate environment.
- Understand decision-making processes within a corporate context and can make valuable contributions to them.
- Be able to further develop existing methods of computer science and increase current knowledge in the discipline.

Social and personal skills:

- Be equipped with communicative skills and are able to convincingly present their ideas and findings both verbally and in writing.
- Be able to recognise and integrate different points of view, even in cases where parties lack expert knowledge in the field of informatics.
- Be able to recognise and resolve misunderstandings between different parties involved in the creative process.
- Argue with specific objectives in mind and to deal open-mindedly with criticism.
- Appraise the social, economic, organisational, psychological and legal effects of informatics on its environment.

Scientific skills:

- Be able to perform self-guided literature research and critical reading of scientific publications, define and evaluate experiments and prepare documents according to scientific standards.

15.4 Project/thesis

30 ECTS

16 GINP: Signal and ImaGe processing Methods and Applications

16.1 School/Research area

Electrical Engineering & Informatics

16.2 Syllabus

CORE:

- Initiation to experiment design and research
- Computational statistics and statistical learning
- Signals and systems
- Scientific programming
- Image processing
- Dynamic systems and control theory
- Data challenge
- Object-oriented programming (Arduino)

ELECTIVE:

- Bayesian methods for data image analysis
- Convex Optimisation
- Factorization of multidimensional observation
- Detection estimation
- Image Analysis and Segmentation
- Machine Learning
- Hyperspectral imaging for astrophysics
- Satellite Imaging and remote sensing
- Data science geo-sciences
- Bio and neuro imaging methods
- Energy Monitoring and Diagnostics
- Signal Representations and Models
- Audio Compression
- Multimedia Indexing
- Speech Processing
- Wireless Communications
- Image and Video Compression
- Signal and Coding for Communications

16.3 Project/thesis

24 ECTS

17 UEDIN: Informatics – AIAI

17.1 School/Research area

Informatics

17.2 Syllabus

- Interpretable and Explainable AI
- Autonomous and Multi-agents Systems
- Mathematical/Probabilistic and Logical Reasoning
- Formal Modelling and Verification
- Planning and Activity Management
- Data-Intensive Research

17.3 Project/thesis

Unspecified number of ECTS

18 UCARDIFF: Artificial Intelligence

18.1 School/Research area

Informatics

18.2 Syllabus

- Knowledge Representation: fundamentals, logical representation, complexity and decidability, description logics
- Automated Reasoning: fundamental algorithms for reasoning, planning, constraint satisfaction problem, satisfiability, first order logic, argumentation theory, automated reasoning with uncertainty
- Principles of Machine Learning: learning theory, machine learning algorithms
- Applications of Machine Learning: Natural Language Processing/Computer Vision: decision trees, support vector machines, neural networks, implementation of machine learning techniques, ethical considerations: biases, Natural Language Processing (NLP) and Computer Vision (CV).
- Human Centric Computing: platforms and devices, multimodal user interfaces
- Programming Paradigms: programming language paradigms
- Foundations of Operational Research and Analytics: Simulation (Monte Carlo, Discrete Event, System Dynamics, and Agent Base), linear and integer programming, dynamic programming, scheduling, heuristics.
- Foundations of Statistics and Data Science
- Developing Secure Systems and Applications
- Malware Analysis and Vulnerability Assessment
- Distributed and Cloud Computing
- Computer and Network Forensics
- Cybersecurity Operations

18.3 Competences

Knowledge & Understanding:

- Understanding of the importance of how data is represented for the success of artificial intelligence methods
- Knowledge of the key concepts and algorithms underlying artificial intelligence methods
- Understanding of the theoretical properties of different artificial intelligence methods
- Insight and foresight of how artificial intelligence methods influence the success of a given task

Intellectual Skills:

- An ability to implement and evaluate artificial intelligence methods to solve a given task
- An ability to explain and communicate the basic principles underlying common artificial intelligence methods
- Critical appraisal of the ethical implications and societal risks associated with the deployment of artificial intelligence methods

Professional Practical Skills:

- Capacity to formalize real-world problems in relation to chosen artificial intelligence methods
- Ability to choose an appropriate artificial intelligence method (and data pre-processing strategy if needed) to address the needs of a given application setting
- Competence in implementing artificial intelligence methods, taking advantage of existing libraries where appropriate

Transferable/Key Skills:

- Critical appraisal of your own and other's work through written and verbal means
- Clear and efficient communication of complex ideas, principles and theories by oral, written and practical means, to a range of audiences
- Appreciation of opportunities for career development
- An ability to undertake independent study and critical reflection

KRR

- Critically evaluate knowledge representation alternatives to solve a given task
- Formalize simple problems with a given knowledge representation approach
- Discuss the theoretical properties of different knowledge representation formalisms
- Explain the basic principles underlying common knowledge representation approaches
- Choose an appropriate knowledge representation approach to address the needs of a given application setting
- Compare how knowledge representation approaches influence the success of a given task
- Explain the nature, strengths and limitations of knowledge representation technique to an audience of non-specialists

AR

- Implement and evaluate automated reasoning approaches to solve a given task
- Explain the basic principles underlying common automated reasoning approaches
- Choose an appropriate automated reasoning approach to address the needs of a given application setting
- Reflect on the importance of data representation for the success of automated reasoning methods
- Critically appraise the ethical implications and societal risks associated with the deployment of automated reasoning methods
- Explain the nature, strengths and limitations of automated reasoning technique

ML principles:

- Describe basic principles underlying machine learning.
- Assess the key concepts and algorithms widely used in machine learning.
- Apply basic algorithms to toy examples.
- Critically reflect and evaluate different approaches for learning.
- Determine a suitable machine learning approach given an application.

ML Applications:

- Implement and evaluate machine learning methods to solve a given task
- Explain the fundamental principles underlying common machine learning methods
- Choose an appropriate machine learning method and data pre-processing strategy to address the needs of a given application setting
- Reflect on the importance of data representation for the success of machine learning methods
- Critically appraise the ethical implications and societal risks associated with the deployment of machine learning methods

- Explain the nature, strengths and limitations of an implemented machine learning technique to an audience of non-specialists
- Explain the fundamentals and modern principles of natural language processing or computer vision

HCI:

- Understand the complex nature of users and apply heuristics to create and evaluate inclusive and multimodal user experiences.
- Evaluate competing proposals for interface design and implementation.
- Apply human centric design methodologies in the context of current and emerging interaction technologies such as virtual and augmented reality.
- Demonstrate competency in the method of scientific analysis, the control of variables, analysis, and the presentation of outcomes.
- Understand experimental design for the subjective assessment of user experience
- Select and apply suitable methodologies for the conduct and analysis of a subjective experiment.

Programming:

- Evaluate and apply the functional and logic programming paradigms to solve a given problem.
- Evaluate and apply a suitable programming paradigm and language from a selection of them to solve a given problem.
- Discuss and contrast the issues, features, design and concepts of a range of programming paradigms and languages, such as imperative, functional, declarative, logic, scripting, filter-based programming, pattern matching and quantum computing.
- Explain the conceptual foundations of various programming paradigms.

Operational Research:

- Know when it is appropriate to apply a range of fundamental OR techniques, based on an understanding of their theoretical underpinnings.
- Construct both deterministic and stochastic models of real-life situations using simulation, mathematical programming and other optimisation techniques.
- Use optimisation algorithms to solve practical problems.
- Implement OR models and algorithms using different commercial computer packages.
- Present findings and recommendations in a concise manner.

Statistics & Data Science:

- Formulate problems involving uncertainty within the framework of probability theory.
- Understand the conditions under which various statistical methods can be applied.
- Summarise a data set using descriptive statistics.
- Calculate confidence intervals and perform hypothesis tests.
- Identify the sources of variation in data.
- Fit linear models to data and evaluate the accuracy of these models.
- Perform variable selection and dimension reduction.
- Write technical reports to communicate the results of data analysis procedures.

18.4 Project/thesis

60 ECTS

19 UCAMB: Machine Learning and Machine Intelligence

19.1 School/Research area

Engineering

19.2 Syllabus

CORE:

- Introduction to Machine Learning: probabilistic modelling and fitting, regression and classification, clustering and time series, parameter estimation
- Deep Learning and Structured Data

- Probabilistic Machine Learning: probabilistic inference, Gaussian processes, TrueSkill ranking system, latent Dirichlet allocation model
- Speech Recognition: automatic speech recognition, Markov models, N-gram language models, neural network acoustic models
- Computer Vision: stereo vision, motion and object detection and recognition, visual navigation for autonomous robots, robot hand-eye coordination, man-machine interfaces, feature detectors
- Natural Language Processing: morphological processing, parsing, word sense disambiguation
- Advanced Machine Learning
- Reinforcement Learning and Decision Making: uncertainty
- Neural Machine Translation and Dialogue Systems
- Designing Intelligent Interactive Systems: human-computer interaction, intelligent interactive systems, human behavioural theory, verification and validation for interactive systems.
- Spoken Language Processing and Generation

19.3 Competences

- Knowledge of the fundamental techniques in machine learning and how to apply these techniques to a range of practical problems;
- A deep understanding of fundamental problems in machine intelligence, including speech and language processing and computer vision, and the technologies that form the current state of the art;
- A comprehensive understanding of techniques, and a thorough knowledge of the literature, applicable to the area of their chosen research topic;
- Presentation skills through presenting their research in progress;
- Methodological and other technical skills necessary for research in their chosen area;
- Ability to critically assess the technical literature in machine learning and machine intelligence and related topics;
- Directly marketable skills in computing, machine intelligence, machine learning, and the data sciences;
- Collaborative skills through working with other students on the practical exercises and with PhD students and research assistants while carrying out their research project;
- Experience in large-scale computing for machine learning and machine intelligence; and
- An understanding of how to define and conduct a research project.

19.4 Project/thesis

Unspecified number of ECTS

20 UCL: Data Science and Machine Learning

20.1 School/Research area

Informatics

20.2 Syllabus

CORE:

- Applied Machine Learning: Large Scale Linear Systems, Conjugate Gradients; Regression and Classification, linear and logistic regression; Clustering Methods for Unsupervised Learning; Fast Nearest Neighbours; Matrix and Tensor Factorisation; Visualisation methods; Ensemble, Gradient Boosting Machines; Data Ethics; Fairness in Machine Learning.
- Introduction to Statistical Data Science

ELECTIVE:

- Introduction to Machine Learning
- Supervised Learning
- Complex Networks and Web

- Information Retrieval and Data Mining
- Introduction to Deep Learning
- Machine Vision
- Multi-agent Artificial Intelligence
- Reinforcement Learning
- Statistical Natural Language Processing
- Affective Computing and Human-Robot Interaction
- Applied Bayesian Methods
- Bioinformatics
- Computational Modelling for Biomedical Imaging
- Decision and Risk
- Forecasting
- Graphical Models
- Statistical Design of Investigations

20.3 Competences

Machine Learning:

- have a good understanding of practical issues arising in implementing machine learning in practice, including engineering challenges as well as the data ethics considerations;
- become familiar with techniques used in practice to solve real world machine learning problems and will be able to apply these techniques
- understand machine learning at both the theoretical and practical level;
- solve real-world machine learning problems using the right tools
- Gain in-depth familiarity with various classical and contemporary supervised learning algorithms;
- Understand the underlying limitations and principles that govern learning algorithms and ways of assessing and improving their performance.

Statistics:

- have an understanding of the fundamental aspects of probability and statistics sufficient to follow other taught postgraduate level modules in Statistical Science
- Be equipped to lead basic data analysis projects in industry and research.
- To use probability as a language to express uncertainty, ways of visualizing and preparing data for statistical analysis, estimation techniques in the context of applied data analysis problems, the role of algorithms in the computation of estimators
- To express uncertainty in estimation via confidence intervals and hypothesis testing, predictive analysis from the point of view of regression

20.4 Project/thesis

60 ECTS

21 UCL: Computational Statistics and Machine Learning

21.1 School/Research area

Informatics

21.2 Syllabus

CORE:

- Statistical Models and Data Analysis: Multiple Linear Regression.
- Supervised Learning: Nearest Neighbours; Linear Regression; Kernels and Regularisation; Support Vector Machines; Gaussian Processes; Decision Trees; Ensemble Learning; Sparsity Methods; Multi-task Learning; Proximal Methods; Semi-supervised Learning; Neural Networks; Matrix Factorization; Online Learning; Statistical Learning Theory

ELECTIVE:

- Investigating Research
- Advanced Topics in Machine Learning
- Applied Bayesian Methods
- Approximate Inference and Learning in Probabilistic Models
- Graphical Models
- Information Retrieval and Data Mining
- Introduction to Deep Learning
- Introduction to Machine Learning
- Inverse Problems in Imaging
- Machine Vision
- Multi-agent Artificial Intelligence
- Probabilistic and Unsupervised Learning
- Reinforcement Learning
- Researcher Professional Development
- Selected Topics in Statistics
- Statistical Computing
- Statistical Inference
- Statistical Natural Language Processing: Machine Translation; Text Classification

21.3 Project/thesis

60 ECTS

22 ETHZ: Data Science

22.1 School/Research area

Informatics

22.2 Syllabus

CORE:

- Introduction to Estimation and Machine Learning: Mathematical basics, applications in signal processing, probability theory; statistical estimation; least squares and linear learning; Hilbert spaces; Gaussian random variables; singular-value decomposition; kernel methods, neural networks, and more

ELECTIVE:

Hardware:

- Machine Learning on Microcontrollers: - Sensors, supervised learning (Bayes Decision Theory, Decision Trees, Random Forests, kNN-Methods, Support Vector Machines, Convolutional Networks and Deep Learning)

Computer Vision:

- Computer Vision: Camera models and calibration, invariant features, Multiple-view geometry, Model fitting, Stereo Matching, Segmentation, 2D Shape matching, Shape from Silhouettes, Optical flow, Structure from motion, Tracking, Object recognition, Object category recognition

Neural Information Processing:

- Learning in Deep Artificial and Biological Neuronal Networks: ANN
- Neuromorphic Engineering

Statistics:

- Applied Analysis of Variance and Experimental Design: experimental design, one-way analysis of variance, contrasts and multiple comparisons, multi-factor designs and analysis of variance, complete block designs, Latin square designs, random effects and mixed effects models, split-plot designs, incomplete block designs, two-series factorials and fractional designs, power.
- Applied Statistical Regression: linear modelling, parameter estimation, tests, confidence intervals, residual analysis, model choice, and prediction, generalized linear models

- Stochastic Simulation: Monte Carlo, Markov chains
- Fundamentals of Mathematical Statistics
- Statistical Modelling
- Bayesian Statistics: Laplace approximation, Monte Carlo and Markov chain Monte Carlo methods
- Time Series Analysis: Stationarity, Autocorrelation, Trend estimation, Elimination of seasonality, Spectral analysis, spectral densities, Forecasting, ARMA, ARIMA, Introduction into GARCH models

ML and AI:

- System Identification
- Advanced Machine Learning: Bayesian Learning, Computational learning theory, Supervised learning, Ensembles: Bagging and Boosting, Max Margin methods, Neural networks, Unsupervised learning, Dimensionality reduction techniques, Clustering, Mixture Models, Non-parametric density estimation, Learning Dynamical Systems
- Reliable and Interpretable Artificial Intelligence: Adversarial Attacks on Deep Learning, gradient-based optimization, deep neural networks, automated reasoning, Probabilistic Programming
- Deep Learning
- Probabilistic Artificial Intelligence: Probability, Probabilistic inference, Bayesian learning (Gaussian, Bayesian), Probabilistic planning, Bayesian optimization, Reinforcement learning
- Natural Language Processing

Big Data:

- Design of Parallel and High-Performance Computing
- Big Data: distributed file systems (HDFS), object storage(S3), key-value stores - logical storage: document stores (MongoDB), column stores (HBase), graph databases (neo4j), data warehouses (ROLAP), data formats and syntaxes (XML, JSON, RDF, Turtle, CSV, XBRL, YAML, protocol buffers, Avro), data shapes and models (tables, trees, graphs, cubes), type systems and schemas: atomic types, structured types (arrays, maps), set-based type systems, functional, declarative programming languages across data shapes (SQL, XQuery, JSONiq, Cypher, MDX), query paradigms (selection, projection, joining, grouping, ordering, windowing), parallel processing (MapReduce, DAG-based)
- Information Systems for Engineers: relational databases, SQL, relational algebra, database design, Indices and optimization, database architecture and storage, relational database analytics, data cubes

22.3 Project/thesis

30 ECTS

23 EPFL: Data Science

23.1 School/Research area

Informatics

23.2 Syllabus

CORE:

- Advanced algorithms
- Applied data analysis: Data wrangling: Data acquisition (scraping, crawling, parsing, etc.), Data manipulation, array programming, dataframes, Schema alignment, data reconciliation, Data quality testing with crowdsourcing. Data Interpretation: Distribution fitting, statistical significance, design of observational studies, regression analysis, machine learning in practice (supervised and unsupervised, feature engineering, more data vs. advanced algorithms, curse of dimensionality, etc.), Text mining, Social network analysis. Data Visualization: layout best practices, network and geographical data. Reporting: Anonymization, ethical concerns.

- Foundations of data science (information theory): Signal Representations, Measures of Information, Compression and Quantization, Sparsity, Exponential Families, Maximum Entropy, Detection and Estimation Theory
- Information security and privacy: vulnerabilities, authentication, access control, compartmentalization, Basic applied cryptography, Data anonymization and de-anonymization techniques, Privacy enhancing technologies, Blockchain and decentralization
- Machine learning: regression, classification, unsupervised learning, clustering, dimensionality reduction: PCA and matrix factorization, word embeddings, generalized linear models, SVMs and Kernel methods, Neural networks and deep learning
- Optimization for machine learning: Convexity, Gradient Methods
- Statistics for data science
- Systems for data science: Big data, Distributed systems, Data structures: File systems, Key-value stores, DBMS, Concurrent access to data, Consistency models, NoSQL and NewSQL systems, Transactions, Parallel processing, Streaming Processing, Online Processing, Graph Processing

ELECTIVE:

- Advanced cryptography
- Advanced probability and applications
- Advanced topics on privacy enhancing technologies
- Applied biostatistics
- Artificial neural networks
- Automatic speech processing
- Biological modelling of neural networks
- Computational linear algebra
- Computational complexity
- Computational photography
- Computer vision
- Concurrent algorithms
- Cryptography and security
- Data visualization
- Deep learning
- Digital education & learning analytics
- Distributed algorithms
- Distributed information systems
- Distributed intelligent systems
- Formal verification
- Graph theory
- Image analysis and pattern recognition
- Information theory and coding
- Intelligent agents
- Interaction design
- Introduction to natural language processing
- Learning theory
- Linear models
- Machine learning for behavioural data
- Markov chains and algorithmic applications
- Mathematical foundations of signal processing
- Mathematics of data: from theory to computation
- Networks out of control
- Robust and nonparametric statistics
- Software security
- Statistical mechanics and Gibbs measures
- Statistical theory

- Sublinear algorithms for big data analysis
- Time Series
- Topics in theoretical computer science
- Virtual reality

23.3 Competences

Algorithms:

- Use a suitable analysis method for any given algorithm
- Prove correctness and running-time bounds
- Design new algorithms for variations of problems studied in class
- Select appropriately an algorithmic paradigm for the problem at hand
- Define formally an algorithmic problem

Applied data analysis:

- Construct a coherent understanding of the techniques and software tools required to perform the fundamental steps of the Data Science pipeline
- Perform data acquisition (data formats, dataset fusion, Web scrapers, REST APIs, open data, big data platforms, etc.)
- Perform data wrangling (fixing missing and incorrect data, data reconciliation, data quality assessments, etc.)
- Perform data interpretation (statistics, knowledge extraction, critical thinking, team discussions, ad-hoc visualizations, etc.)
- Perform result dissemination (reporting, visualizations, publishing reproducible results, ethical concerns, etc.)

Transversal skills:

- Evaluate one's own performance in the team, receive and respond appropriately to feedback.
- Give feedback (critique) in an appropriate fashion.
- Demonstrate the capacity for critical thinking
- Write a scientific or technical report.

Data science (information theory):

- Formulate the fundamental concepts of signal processing such as basis representations and sampling
- Formulate the fundamental concepts of information theory such as entropy and mutual information
- Analyze problems in statistical settings using fundamental bounds from information theory
- Formulate problems using robust and universal techniques

Information security and privacy:

- Understand the most important classes of information security/privacy risks in today's "Big Data" environment
- Exercise a basic, critical set of "best practices" for handling sensitive information
- Exercise competent operational security practices in their home and professional lives
- Understand at overview level the key technical tools available for security/privacy protection

Machine learning:

- Define the following basic machine learning problems: Regression, classification, clustering, dimensionality reduction, time-series
- Explain the main differences between them
- Implement algorithms for these machine learning models
- Optimize the main trade-offs such as overfitting, and computational cost vs accuracy
- Implement machine learning methods to real-world problems, and rigorously evaluate their performance using cross-validation. Experience common pitfalls and how to overcome them
- Explain and understand the fundamental theory presented for ML methods

Optimization for machine learning:

- Assess / Evaluate the most important algorithms, function classes, and algorithm convergence guarantees
- Compose existing theoretical analysis with new aspects and algorithm variants.
- Formulate scalable and accurate implementations of the most important optimization algorithms for machine learning applications
- Characterize trade-offs between time, data and accuracy, for machine learning methods

Transversal skills:

- Use both general and domain specific IT resources and tools
- Summarize an article or a technical report.

Statistics:

- Derive properties of fundamental statistical procedures
- Estimate model parameters from empirical observations
- Test hypotheses related to the structural characteristics of a model
- Construct confidence bounds for model parameters and predictions
- Contrast competing models in terms of fit and parsimony

Systems:

- Choose systems parameters, data layouts, query plans, and application designs for database systems and applications.
- Develop data-parallel analytics programs that make use of modern clusters and cloud offerings to scale up to very large workloads.
- Analyze the trade-offs between various approaches to large-scala data management and analytics, depending on efficiency, scalability, and latency needs
- Choose the most appropriate existing systems architecture and technology for a task

23.4 Project/thesis

30 ECTS

24 KTH: Machine Learning

24.1 School/Research area

Informatics

24.2 Syllabus

CORE:

- Introduction to the Philosophy of Science and Research Methodology
- Machine learning: nearest neighbour classifier, decision trees, bias and the trade-off of variance, regression, probabilistic methods, Bayesian learning, support vector machines, artificial neural networks, ensemble methods, dimensionality reduction, subspace methods, probabilistic modelling, graphical models, Markov models
- Artificial intelligence: problem-solving with search algorithms, heuristics, knowledge representations (logic), planning, representation of uncertainty and inference (Bayesian networks, HMM), decision theory and utility theory, diction (NLP).

ELECTIVE:

- Visualization
- Neuroscience
- Computational Biology
- Robotics and autonomous systems
- Probabilistic graphical models: gradient ascent
- Image analysis and computer vision: Basic image analysis: signal theoretical methods, filtering, image enhancement, image reconstruction, segmentation, classification, representation; Basic computer vision: multiscale representation, detection of edges and other distinctive features. Stereo and multi-camera systems. Object recognition, morphology.

- Deep learning: deep networks, probabilistic deep learning, deep transfer and sharing of knowledge, unsupervised deep representation learning, higher order learning, adversarial learning, clustering, supervised learning, convolutional networks and recurrent networks
- Language engineering: Morphological analysis, generation and language statistics and corpus processing, parsing, generation, part-of-speech tagging, named entity recognition, probabilistic parsing and statistical lexical semantics
- Artificial Neural Networks and Deep Architectures
- Artificial intelligence and multi-agent systems: Cooperative path planning, Cooperative task assignment, Formation keeping, Motion coordination
- Statistical Methods in Applied Computer Science
- Search Engines and Information Retrieval Systems
- Speech Technology
- Speech and Speaker Recognition
- Music Informatics
- Applied Estimation
- Reinforcement Learning
- Pattern Recognition and Machine Learning
- Analysis and Search of Visual Data
- Data Mining
- Scalable Machine Learning and Deep Learning
- Optimization
- Regression Analysis
- Probability Theory
- Time Series Analysis
- Speech technology: Linguistic theory and phonetics, Speech production by humans (speech physiology and acoustics) and computers (text-to-speech synthesis), Speech perception by humans (hearing and psycholinguistics) and computers (speech recognition), Multimodal dialogue systems for human-computer interaction with speech and vision
- Program Integrating Course in Machine Learning: Privacy, security and ethical issues around "big data"
- Program System Construction Using C++
- Algorithms and Complexity
- Computer Security
- Foundations of Cryptography
- Interaction Programming and the Dynamic Web
- Logic Programming
- Data-intensive Computing
- Parallel Computations for Large-scale Problems

24.3 Competences

General:

- present the foundational issues in the methodology and philosophy of science, especially as regards the natural, technological and computational sciences.
- present the history of computation and computers
- do a library search within the subject
- write a technical report within the subject
- be aware about how machine learning is used and be utilised outside the academic world and the consequences this has for the society and the professional responsibilities as a machine learning practitioners.
- be more aware of workplaces and professions available for them as machine learning graduates.
- apply different principles of Artificial Intelligence (AI)

- choose appropriate tools and implement efficient solutions to problems in AI
- integrate tools to design computer programs that show different properties that are expected by an intelligent system
- present, analyse, and entitle an own solution to an AI problem
- reflect on and discuss current social and ethical aspects of AI
- draw use of methods of artificial intelligence in analysis, design and implementation of computer programs
- contribute to design of an intelligent system in both academic and industrial applications.

ML:

- describe the most important algorithms and the theory that constitutes the basis for machine learning and artificial intelligence
- explain the principle for machine learning and how the algorithms and the methods can be used
- discuss advantages with and limitations of machine learning for different applications
- to be able to identify and apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems.
- describe the most important algorithms and the theory that constitutes the basis for machine learning and artificial intelligence
- explain the principle for machine learning and how the algorithms and the methods can be used
- discuss advantages with and limitations of machine learning for different applications
- to be able to identify and apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems.

Project:

- show advanced knowledge within the main field of study/the specialisation for the education, including advanced insight into current research and development work,
- show methodological knowledge within the main field of study/the specialisation for the education,
- participate in research and development work and thereby contribute to the knowledge development,
- with a holistic approach, critically, independently and creatively identify, formulate, analyse, assess and deal with complex phenomena and issues, even with limited information,
- plan and with adequate methods carry out qualified assignments within given frames, and evaluate this work,
- integrate knowledge critically and systematically and identify the need of additional knowledge
- in Swedish or in English, in speech and writing clearly report and discuss their conclusions and the knowledge and arguments on which they are based,
- within the frames of the degree project identify the role of the scholarship and the engineer in the society,
- within the frame of the specific degree project identify which issues that need to be answered in order to observe relevant dimensions of sustainable development,
- within the frames of the degree project assess and show awareness of ethical aspects of research and development work, with respect to methods, working methods and results of the degree project

Ethical:

- be aware of the ethical issues that are associated with "big data" and the choices about the gains and losses made when mass data about people is made available
- be aware of the responsibilities when presenting machine learning results/algorithms to the public
- be aware of the responsibilities of drawing conclusions from experimental results.
- be aware about how machine learning is used and be utilised outside the academic world and the consequences this has for the society and the professional responsibilities as a machine learning practitioners.
- be more aware of workplaces and professions available for them as machine learning graduates.

24.4 Project/thesis

30 ECTS

25 AALTO: CCIS – Machine Learning, Data Science and Artificial Intelligence

25.1 School/Research area

Informatics & Electrical Engineering

25.2 Syllabus

CORE:

- Machine Learning - Supervised Methods: Generalization error analysis and estimation; Model selection; Optimization and computational complexity; Linear models; Support vector machines and kernel methods; Boosting; Feature selection and sparsity; Multi-layer perceptrons; Multi-class classification; Ranking; Multi-output learning
- Bayesian Data Analysis: Bayesian probability theory and bayesian inference. Bayesian models and their analysis. Computational methods, Markov-Chain Monte Carlo.
- Deep Learning: python programming
- Machine Learning - Advanced Probabilistic Methods: independence, conditional independence, mixture models, EM algorithm, Bayesian networks, latent linear models, exact and approximate inference, variational inference, probabilistic modelling in practice.
- Methods of Data Mining: pattern discovery, graph mining, and clustering
- Kernel Methods in Machine Learning: Inner product spaces, Kernels, Empirical Risk Minimization, Uniform Convergence and Rademacher Complexity, Kernel Ridge Regression and Logistic Regression, Optimization and Duality, Margin-based methods and Support vector machines, Unsupervised learning including clustering, PCA.

ELECTIVE:

- Information Visualization
- Computational Methods in Stochastics
- Computer Vision: Image formation and processing, feature detection and matching, motion estimation, structure-from-motion, object recognition, image-based 3D reconstruction, automatic analysis of visual data.
- Artificial Intelligence: (deep) machine learning, reinforcement learning, graphical models, decision under uncertainty, knowledge representation and reasoning, logical representations, declarative problem solving, solver technology
- Speech Processing: audio signal processing, psychoacoustics and perceptually motivated signal processing, acoustic theory of speech production, time-frequency analysis of speech signals, speech coding, linear prediction, speech synthesis and speech recognition.
- Speech Recognition: Preprocessing and feature extraction for speech, phoneme models, decoding, lexicon and language models, continuous speech.
- Statistical Natural Language Processing
- Speech and Language Processing Methods

25.3 Competences

- is able to define data-intensive problems in data science and artificial intelligence and understand their underlying statistical and computational principles.
- is able to evaluate the suitability of different machine learning methods for solving a new problem encountered in industry or academia, and apply the methods to the problem.
- can effectively interpret the results of a machine learning algorithm, assess its credibility, and communicate the results to experts of other fields.
- can implement common machine learning methods and design and implement novel algorithms by modifying the existing approaches.
- understands the theoretical foundations of the machine learning field to the extent required to be able to follow research in the field.

- understands the opportunities that machine learning offers in data science and artificial intelligence

25.4 Project/thesis

30 ECTS

26 UEDIN: Speech and Language Processing

26.1 School/Research area

Philosophy, Psychology & Language

26.2 Syllabus

CORE:

- Computer Programming
- Speech and Language Processing
- Univariate Statistics and Methodology
- Accelerated Natural Language Processing
- Research Ethics

ELECTIVE:

- Automatic Speech Recognition
- The Human Factor
- Natural Language Understanding, Generation, and Machine Translation
- Introductory Applied Machine Learning
- Speech Synthesis
- Simulating Language
- Phonetics and Laboratory Phonology
- Machine Learning in Signal Processing

26.3 Project/thesis

60 ECTS

27 UEDIN: Cognitive Science

27.1 School/Research area

Philosophy, Psychology & Language

27.2 Syllabus

CORE:

- Informatics Research review

ELECTIVE:

- Human Computer Interaction
- Automatic Speech Recognition
- Computational Cognitive Neuroscience
- Accelerated Natural Language Processing
- The Human Factor
- Natural Language Understanding, Generation, and Machine Translation
- Speech Synthesis
- Speech Processing
- Simulating Language
- Programming Skills
- Introduction to Practical Programming with Objects
- Computer Programming for Speech and Language Processing

- Algorithmic Game Theory and its Applications
- Automatic Speech Recognition
- Robotics: Science and Systems
- Accelerated Natural Language Processing
- Image and Vision Computing
- Text Technologies for Data Science
- Natural Computing
- Bioinformatics
- Data Mining and Exploration
- Machine Learning and Pattern Recognition
- Machine Learning Practical
- Introductory Applied Machine
- Parallel Architectures
- Introduction to Quantum Computing
- Computational Complexity
- Introduction to Modern Cryptography
- Blockchains and Distributed Ledgers
- Internet of Things Systems, Security, and the Cloud (IoTSSC)
- Principles and Design of IoT Systems
- Advanced Database Systems

27.3 Competences

General:

- Select literature appropriate for the review subject , and critically evaluate research literature in the chosen area
- Search and use appropriately databases of scientific literature
- Evaluate and search traditional library resources
- Discuss a research topic in detail leading to new hypotheses
- Deliver a detailed and balanced report on a research topic
- Critically evaluate research literature or other prior work appropriate for their project subject
- Use existing research literature or other prior work to justify choices in experimental design, theoretical goals, and/or implementation
- Develop a structured project proposal
- Outline project/research management issues and potential legal, social, ethical or professional issues

Project:

- Structure, summarise and critically evaluate a body of knowledge relating to a substantial project topic in Informatics
- Conduct a programme of work in further investigation of issues related to the topic
- Discuss and solve conceptual problems which arise during the investigation
- Critically evaluate the investigation, including design choices made
- Present their work orally and visually, with demonstration of working artifacts where appropriate

27.4 Project/thesis

60 ECTS

28 SHEFFIELD: Computer Science with Speech and Language Processing

28.1 School/Research area

Informatics

28.2 Syllabus

CORE:

- Text Processing
- Speech Processing
- Speech Technology
- Machine Learning and Adaptive Intelligence
- Natural Language Processing
- Research Methods and Professional Issues
- Team Software Project
- Dissertation Project

ELECTIVE:

- Software Development for Mobile Devices
- Object-Oriented Programming and Software Design

28.3 Competences

- The ability to function in a computer-based learning environment, making full use of email, the internet and electronic media;
- The ability to engineer a human language processing application in a rigorous and principled manner, through processes of analysis, design, implementation and evaluation;
- The ability to critically evaluate and select software tools appropriate for building particular human language technology applications;
- Written communication skills, including the ability to summarise and present coherently an argument, the ability to expose technical information systematically and clearly, the ability to comprehend, summarise, synthesize and properly cite material as part of an integrated argument;
- Oral communication skills, specifically the ability to present and defend a substantial piece of work, to engage with enquirers and respond effectively to questions.
- The ability to identify material, from multiple published sources, relevant to a chosen topic, to comprehend and filter such material and from it synthesize principles or designs pertinent to a problem-solving project;
- Individual initiative, self-motivation and problem-solving skills, fostered through the selection and taking through to completion of a practical, problem-solving project, leading to a dissertation and poster session.

28.4 Project/thesis

60 ECTS

29 VUA: Linguistics – Text Mining

29.1 School/Research area

Humanities

29.2 Syllabus

CORE:

- Introduction Human Language Technology
- Linguistic Research
- Programming in Python for Text Analysis
- Language as Data
- Machine Learning for NLP
- Applied Text Mining: sentiment analysis
- Text Mining Domains
- NLP Technology: ontologies
- Text Mining Domains
- Master Thesis Linguistics: Text Mining

29.3 Project/thesis

18 ECTS

30 USG: Computational Linguistics

30.1 School/Research area

Linguistics & Informatics

30.2 Syllabus

CORE:

- Computational Linguistics Team Laboratory
- Methods in Computational Linguistics
- Computational Linguistics Research Module

ELECTIVE:

- Computational Linguistics - Core: Parsing, Topics in Computational Semantics, Grammar Formalisms and Grammar Engineering, Advanced Computational Syntax, Advanced Semantics, Advanced Computational Semantics, Foundations of Computational Linguistics, Statistical Machine Translation, Meaning and Interpretation, Resources for Lexical Semantics: Theoretical Foundations and their Applications, Cognitive and Computational Models for Lexical Semantics
- Computational Linguistics - Applied Natural Language Processing: Information Retrieval and Text Mining, Distributional and Statistical Approaches to Semantics, Statistical Dependency Parsing, Text Technology, Topics in Natural Language Processing, Advanced Natural Language Processing, Ethics and NLP, Introduction and Application of Programming in R, Empirical Approaches to Lexical Semantics, Deep Learning for Speech and Language Processing
- Computational Linguistics - Speech Processing: Speech recognition and synthesis, Dialog Modelling, Speech Signal Processing and Microphone Array Processing, Topics in Phonetics, Spoken Language Understanding, Speech Signal Processing and Speech Enhancement
- Cognitive Science: Language and Speech in the Human Brain: Advanced Methods in Neurolinguistics and Neurophonetics, Topics in Cognitive Science, Foundations of Cognitive Science, Cognitive Computing
- Computer Science: Artificial Intelligence, Machine learning, Software development
- Linguistics
- Mathematical Foundations of Machine Learning

30.3 Competences

- Become familiar with the main concepts, research questions and methodological frameworks of Computational Linguistics
- Know what methodological and practical tool basis to start from if they want to do research or technological development in a particular subarea.
- Be equipped with the most recent text technologies that are commonly used, to get ready for both research and development.
- Know about technologies such as XML and JSON, organizing and storing text corpora in databases including relational and NoSQL databases, basic knowledge about big data.
- Be able to build some NLP applications such as corpora storage and searching using the learned technologies.
- Be familiar with the main approaches in dependency parsing.
- Know how to combine dependency parsing algorithms with statistical methods to create data-driven dependency parsers.
- Have implemented their own dependency parser.

30.4 Project/thesis

30 ECTS

31 AAU: Sound and Music Computing

31.1 School/Research area

Electronics & Information Technology

31.2 Syllabus

- Sound Processing
- New Interfaces for Musical Expression
- Music Perception and Cognition
- Sonic Interaction Design
- Sound and Music Signal Analysis
- Modelling Physical Systems
- Embodied Interaction
- Research in Sound and Music Computing
- Multimodal Perception and Cognition
- Prototyping and Fabrication Techniques
- Machine Learning for Media Technology
- Multivariate Statistics and Pattern Recognition
- Real-time Interaction and performance

31.3 Project/thesis

30 ECTS

32 VUA: Artificial Intelligence – Cognitive Science

32.1 School/Research area

Cognitive Psychology

32.2 Syllabus

CORE:

- Knowledge Representation: propositional logic, description Logic, constraint solving, qualitative reasoning
- Multi agent systems: Beliefs desires and intentions, non-cooperative game theory, coalitional game theory for teams of selfish agents, Principles of Mechanism Design, Exploration versus Exploitation, Markov Decision Processes Reinforcement learning for a single agent, multi-agent reinforcement learning
- Social Robotics: user-centered design of social robots, AI techniques for developing a social robot that can interact with human users, visual perception, face recognition, speech recognition and dialogue, emotional expression through body language, architecture.
- Evolutionary computing: evolutionary programming, genetic programming, differential evolution, particle swarm optimization - Applications in optimisation, constraint handling, machine learning, and robotics.
- AI & Society: AI for the labour market and (in)equality, ethical considerations around autonomous systems, the risks of biases and misuse of algorithms, legal aspects of AI, questions about the control over AI systems.
- Experimental Design & Analysis
- Brain Imaging: signal analysis, statistics, pattern classification analysis, connectivity modelling, state network analysis
- Natural Language Processing Technology
- Seminar Cognitive Neurosciences
- Neural Models of Cognitive Processes for AI

ELECTIVE:

- Cognitive psychology and its applications: human factors, human-computer systems
- Skils for AI: linear algebra, logic and probability, python, propositional logic and first order predicate logic, probability theory, Gradients and derivative,
- Data Mining Techniques
- Machine Learning for the Quantified Self

32.3 Project/thesis

30 ECTS

33 UB: Artificial Intelligence

33.1 School/Research area

Informatics

33.2 Syllabus

CORE:

- Computational intelligence: Introduction to neural computation: biological inspiration, neural network models, architectures and training algorithms. Learning and generalization, Introduction to evolutionary computation: evolutionary processes in nature, genetic operators, evolutionary optimization algorithms, Genetic algorithms, Evolution Strategies and CMA, Introduction to fuzzy computation: fuzzy sets and systems, fuzzy inference systems and hybrid. Applications and case studies on real problems in regression, classification, identification and system optimization.
- Computational vision: Image Processing, Edges and contours detection, Feature detection, Feature Matching, Face detection, Face recognition, Segmentation, Texture analysis, Video Segmentation, Object Recognition, Image classification with CNNs
- Introduction to human language technology: Document Structure and Language, Text selection, Tokenization, Sentence splitting, Language Identifiers, Morphology, Finite States Automata, Finite States Transducers, PoS tagging, Hidden Markov Models, Lexical semantics, Semantic resources, Word Sense Disambiguation, Recognition and classification of word sequences with meaning, BIO discriminative models. Conditional Random Fields (CRF), Named Entity Recognition and Classification (NERC), Noun-phrase Chunking, Syntactic grammars, typology, Context free grammars, Probabilistic context free grammars, Chomsky normal form grammars, Syntactic parsers, properties and strategies, CKY and probabilistic CKY parsers, Coreference resolution, Mention detection, Types of techniques for the generation of coreference chains, Mention-pair model, Entity-mention model, Rankers model
- Introduction to multiagent systems: Intelligent agents. Intelligent agents architectures: reactive, deliberative, hybrid. Properties: reasoning, learning, autonomy, proactivity, etc. Intelligent agent typology: interface agents, information agents, heterogeneous systems. Distributed intelligent systems. Communication. Standards. Coordination. Negotiation. Distributed planning. Voting. Auctions. Coalition formation. Application of multi-agent systems to industrial problems.
- Introduction to machine learning: Machine learning, Unsupervised learning, Clustering, Classification of clustering algorithms: K-Means and EM, Factor Analysis: PCA (Principal Components Analysis) and ICA (Independent Component Analysis), Self-Organized Maps (SOM) and Multi-dimensional Scaling, Recommender Systems, Supervised learning, Lazy Learning, Introduction to feature selection, Model selection, Supervised learning taxonomy, Linear decision, Non-linear decision learning: Kernel methods, Non-linear decision learning: Ensemble Learning, Bayesian Learning
- Planning and approximate reasoning: Probabilistic models, Fuzzy Logic and Fuzzy expert systems, Models based on the Theory of Evidence, PDDL language, STRIPS, Linear planners, Graph plan, MDP, Reinforcement Learning.

ELECTIVE:

- Assistive and Health-Care Technologies
- Advanced Human Language Technologies

- Artificial Intelligence Seminar
- Advanced Topics in Computational Intelligence
- Complex Networks
- Cognitive Robotics
- Deep Learning
- Human-Computer Interaction
- Knowledge Representation and Engineering
- Logics for Artificial Intelligence
- Multi-Agent Systems Design
- Minds, Brains and Machines
- Object Recognition
- Probabilistic Graphical Models
- Personalized Multi-Criteria Decision Support Systems
- Professional Practice in Artificial Intelligence
- Self Organizing Agent Systems
- Supervised and Experiential Learning
- Unsupervised and Reinforcement Learning
- Artificial Intelligence in Health Care
- Artificial Vision and Pattern Recognition
- Big Data Analytics
- Cognitive Interaction with Robots
- Constraint Processing and Programming
- Human Language Engineering
- Intelligent Data Analysis Applications in Business
- Intelligent Data Analysis and Data Mining
- Intelligent Decision Support Systems
- Intelligent System Project
- Multi-Robot Systems
- Normative and Dynamic Virtual Worlds
- New Trends in Robotics

33.3 Competences

Specific:

- Capability to understand the basic principles of the Multiagent Systems operation main techniques , and to know how to use them in the environment of an intelligent service or system.
- Capability to understand the basic operation principles of Planning and Approximate Reasoning main techniques, and to know how to use in the environment of an intelligent system or service.
- Capability to understand the basic operation principles of Machine Learning main techniques, and to know how to use on the environment of an intelligent system or service.
- Capability to understand the basic operation principles of Computational Intelligence main techniques, and to know how to use in the environment of an intelligent system or service.
- Capability to understand the basic operation principles of Natural Language Processing main techniques, and to know how to use in the environment of an intelligent system or service.
- Capability to understand the problems, and the solutions to problems in the professional practice of Artificial Intelligence application in business and industry environment
- Capability to research in new techniques, methodologies, architectures, services or systems in the area of Artificial Intelligence.
- Capability to solve the analysis of information needs from different organizations, identifying the uncertainty and variability sources
- Capability to solve the decision making problems from different organizations, integrating intelligent tools.

- Capacity for applying Artificial Intelligence techniques in technological and industrial environments to improve quality and productivity.
- Capability to design, write and report about computer science projects in the specific area of Artificial Intelligence.
- Capability to design new tools and new techniques of Artificial Intelligence in professional practice
- Capability to assimilate and integrate the changing economic, social and technological environment to the objectives and procedures of informatic work in intelligent systems.
- Capability to respect the legal rules and deontology in professional practice.
- Capability to respect the surrounding environment and design and develop sustainable intelligent systems.

Generic:

- Capability to plan, design and implement products, processes, services and facilities in all areas of Artificial Intelligence.
- Capability to lead, plan and supervise multidisciplinary teams.
- Capacity for modelling, calculation, simulation, development and implementation in technology and company engineering centres, particularly in research, development and innovation in all areas related to Artificial Intelligence.
- Capacity for general management, technical management and research projects management, development and innovation in companies and technology centres in the area of Artificial Intelligence.

Transversal:

- Teamwork: Being able to work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.
- Effective use of information resources: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.
- Appropriate attitude towards work: Capability to be motivated for professional development, to meet new challenges and for continuous improvement. Capability to work in situations with lack of information.
- Reasoning: Capability to evaluate and analyse on a reasoned and critical way about situations, projects, proposals, reports and scientific-technical surveys. Capability to argue the reasons that explain or justify such situations, proposals, etc
- Analysis and synthesis: Capability to analyse and solve complex technical problems

33.4 Project/thesis

18 ECTS

34 UCD: Cognitive Science

34.1 School/Research area

Psychology & Philosophy

34.2 Syllabus

- Introduction to Cognitive Science
- Introduction to Cognitive Psychology
- Consciousness, Agency and the Self
- Fundamentals of Cognitive Neuropsychology
- Connectionism and Dynamical Systems
- Cognitive Modelling
- Readings in Visual and Social Cognition
- Embodied and Enactive Approaches to Cognitive Science

- The Cultural mind
- Computational Creativity
- Human-Computer Interaction: Human cognition and models of interaction, Usability and user experience, Experimental design and statistics for HCI, Interface design using user-centred and iterative methods, Design thinking and rapid prototyping, Qualitative and quantitative evaluation strategies
- Merleau-Ponty Phenomenology of Perception

34.3 Project/thesis

Unspecified number of ECTS

35 ICL: Control Systems

35.1 School/Research area

Electrical & Electronic Engineering

35.2 Syllabus

CORE:

- C1 Lab

ELECTIVE:

- industrial automation
- robotics
- mechanical systems
- biomedical control
- control engineering
- linear multivariable control
- discrete-time control
- optimization
- predictive control
- non-linear systems
- systems identification
- coding theory
- discrete-event systems
- distributed computation
- game theory
- information theory
- intelligent data and probabilistic inference
- machine learning for computer vision
- pattern recognition

35.3 Competences

Knowledge and Understanding:

- Fundamental concepts and principles underpinning control system theory and design, including those associated with linear and non-linear deterministic systems, stochastic systems, modelling, optimisation, control system design, on-line control.
- The essential facts, concepts, principles and theories relevant to the student's chosen area of research for the individual project;
- Information retrieval as a research technique;
- Management and communication skills, including problem definition, project design, decision processes, written reports, scientific publications.

Intellectual (thinking) skills:

- (Analysis) model systems mathematically and apply relevant theory to study their properties and performance;
- (Synthesis) apply control concepts and theory to the solution of control problems;
- (Computing) apply computational principles and techniques to control problems;
- (Evaluative) plan, conduct and report on a programme of original research.

Practical skills:

- Formulate mathematical models of systems and identify the parameters of such models from observations using appropriate statistical techniques;
- Solve control analysis and synthesis problems using appropriate statistical, frequency-response and state-space methods;
- Analyse and interpret computed results;
- Write programs using at least one common language (Matlab);
- Understand the literature so personal knowledge and skills can be kept up-to-date;
- Define problems and design /manage associated projects;
- Write effective technical reports

Transferable skills:

- Communicate effectively, as a result of clear and precise thinking, using presentations, web-pages and written reports;
- Apply knowledge skills to new control problems;
- (Management skills) formulate problem definitions; design and evaluate projects using objective criteria;
- Transfer techniques and solutions from one discipline to another;
- Use Information and Communications Technology;
- Manage resources and time;
- Learn independently with open-mindedness and critical enquiry;
- Learn effectively for the purpose of continuing professional development

35.4 Project/thesis

40 ECTS

36 RWTHA: Robotic Systems Engineering

36.1 School/Research area

Mechanical Engineering

36.2 Syllabus

CORE:

- Robotics Systems
- Multibody Dynamics
- Simulation of Robotic Systems, Sensors and Environment
- Advanced Robot Kinematics and Dynamics
- Computer Vision I: Image Processing Basics: linear filters, edge detection, structure extraction, radiometry, color. Image Segmentation: Segmentation as clustering, k-means, EM, mean-shift, segmentation as energy minimization, normalized cuts, graph cuts. Object Recognition: Histogram based approaches, subspace representations. Local Invariant Features: Invariant feature extraction, local descriptors, efficient matching and indexing, recognition with local features. Object Categorization: Sliding-window approaches, Bag-of-visual-word approaches, part-based approaches. 3D Reconstruction: Epipolar geometry, camera calibration, multi-view stereo, structure-from-motion. Motion & Tracking: Optical flow, tracking with linear dynamic models, Kalman filter.
- Control Engineering
- Robotic Sensor Systems

- Electrical Drives
- Machine Learning: Bayes decision theory. Probability density estimation: non-parametric vs. parametric methods. Maximum Likelihood vs. Bayesian estimation. Linear classifiers, least-squares classification, generalized linear classifiers, Fisher linear discriminant analysis, logistic regression. Empirical/structural Risk minimization, VC dimension. Support Vector Machine. Ensemble methods, Boosting, AdaBoost. Decision trees: attribute selection, Random Forests, extremely randomized trees, ferns. Probabilistic Graphical Models: Bayesian Networks, Markov Random Fields, and Factor Graphs; factorization; conditional independence. Exact inference: belief propagation; junction tree algorithm; graph cuts algorithm.
- Computer Science in Mechanics Engineering II

ELECTIVE:

- Computer Vision II
- Introduction to Artificial Intelligence
- Production Metrology
- Advanced Machine Learning
- Machine Dynamics of Rigid Systems
- Power Electronics
- Industrial Logistics
- Processes and Principles for Lightweight Design
- Artificial Intelligence and Data Analytics for Engineers
- Applied Numerical Optimization Engineering
- Factory Planning
- Numerical Methods in Mechanical Engineering
- Strategic Technology Management
- Advanced Finite Element Methods for Engineers
- Mechatronics and Control Techniques for Production Plants
- Advanced Control System

36.3 Competences

Machine Learning Skills:

- Derive, explain and apply practical machine learning methods and algorithms
- Discuss the advantages and disadvantages of machine learning techniques;
- Find practical solutions to complex real-world machine learning problems;

Computer Vision Skills:

- Derive, explain, and apply practical computer vision algorithms
- Discuss the advantages and disadvantages of computer vision techniques:
- Find practical solutions to complex real-world computer vision problems

General:

- Work on practical problems in a team.

36.4 Project/thesis

10 ECTS

37 UPC: Automatic Control and Robotics

37.1 School/Research area

Electronic Engineering

37.2 Syllabus

CORE:

- Industrial Scheduling
- Linear Multivariable Control Systems

- Computer Vision: Digital image processing, Segmentation and feature extraction, Feature detection and descriptors, Classification and Recognition, Boosting, Motion detecttion
- Optimization in Control & Robotics
- Robotics, Kinematics, Dynamics and Control
- Modelling, Identification and Simulation of Dynamical Systems
- Mobile Robots & Navigation
- Business Administration
- Pattern Recognition & Machine Learning: Visualization of multidimensional data. Data clustering algorithms. Dimensionality reduction and Principal Component Analysis. Data imputation algorithms. Feature extraction. Independent Component Analysis. Probabilistic Models: Discriminant analysis. Probabilistic models for classification. Mixture Models and the Expectation-Maximization algorithm. Parameter estimation in probabilistic models. Classification and Regression Trees. Neural Networks and Deep Learning. Support Vector Machines and Kernel methods: Statistical Learning Theory, Kernel trick. Learning by demonstration. Reinforcement Learning, Applications in robotics.
- Non Linear Control Systems
- Human Resources Management
- Technological Innovation
- Planning and Implementation of Robotic Systems
- Embedded & Real Time Systems

ELECTIVE:

- Model Predictive Control
- Sensors, Instrumentation and Communications
- Advanced Topics in Computer Vision
- Introduction to ROS
- Scientific Python for Engineers
- Hybrid Systems
- Fault Diagnosis & Supervisory Control
- Robot Learning
- Human Robot Interaction & Teleoperation
- Robust Control
- Medical Robotics

37.3 Competences

Specific:

- Select appropriate software and hardware elements to implement a solution in a system wardrobe.
- Be able to recognize and represent problems in the area by automatic and robotic techniques optimization, and then apply analytical methods / numerical resolution.
- Be able to select, plan, and evaluate different techniques to detect, extract and analyse data an image or sequence of images
- Be able to model, formulate and solve problems of control, taking into account its uncertainty, by fuzzy logic based controllers.
- Be able to select and program pattern recognition methods and learning based on the type of problem, after distinguishing if the situation so requires

Generic:

- Have adequate mathematical skills, analytical, scientific, instrumental, technological, and management information
- Ability to conduct research, development and innovation in the field of systems engineering, control and robotics, and as to direct he development of engineering solutions in new or unfamiliar environments, linking creativity, innovation and transfer of technology
- Ability to reason and act based on the so-called culture of safety and sustainability

- Have adequate mathematical skills, analytical, scientific, instrumental, technological, and management information.

Transversal:

- Teamwork: Being able to work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.
- Effective use of information resources: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.
- Sustainability and social commitment: Being aware of and understanding the complexity of the economic and social phenomena typical of a welfare society, and being able to relate social welfare to globalisation and sustainability and to use technique, technology, economics and sustainability in a balanced and compatible manner.

37.4 Project/thesis

12 ECTS

38 UBIR: Human Computer Interaction

38.1 School/Research area

Informatics

38.2 Syllabus

CORE:

- Research Topics in HCI
- Mobile and Ubiquitous Computing: Mobile development and programming platforms. Wireless technologies: sensor networks. Mobile computing and applications. Embedded devices, m-commerce, location-aware applications, mobile games and multimedia, the Internet of Things. Sensing technologies, mobile phone sensing systems. Context detection and inference, machine learning techniques for mobile systems design. Privacy and security issues related to mobile computing. Mobile HCI. Programming mobile devices.
- Human Computer Interaction Theory and Practice
- Mini Project
- Research Skills
- Evaluation Methods, and Statistics: R programming, regression analysis, inferential statistics,

ELECTIVE:

- Intelligent Robotics; control theory, reinforcement learning for control, planning visual search
- Machine Learning: Supervised learning, Generative algorithms, Discriminative algorithms, Computational learning theory basics, Boosting and ensemble methods, Unsupervised learning, Clustering, Learning for structure discovery, Reinforcement learning basics
- Intelligent Data Analysis: Dimensionality reduction techniques, Clustering techniques, Classification and regression techniques, Analysing structured data, Mining textual data, Other structured data types.
- Neural computation: Neural Networks, Artificial Neurons, Networks of Artificial Neurons, Perceptrons, Hebbian Learning, Gradient Descent Learning, Under-Fitting and Over-Fitting, Generalization, Multi-Layer Perceptrons, Recurrent Neural Networks, Radial Basis Function Networks, Self Organizing Maps, Learning Vector Quantization, Committee Machines, Model Selection and Evolutionary Optimization
- Software Workshop: Java object-oriented programming
- Network security
- Secure programming
- Teaching Computer Science in Schools

38.3 Competences

Knowledge and Understanding

- Principles of HCI, usability and user experience, designing, building and evaluating interactive systems.
- The psychology of the user, the social context of design, and the potentials and issues of next-generation interactive systems.
- Research tools and methods used in HCI.

Skills & Other Attributes

- Practical experience in HCI: usability and user experience, designing, building and evaluating interactive systems.
- Applying knowledge of the psychology of the user, the social context of design, and the potentials and issues of next-generation interactive systems.
- Selecting and using research tools and methods used in HCI.

HCI:

- Explain and discuss the key capabilities and limitations in human cognitive performance and relate this to the design of HCI systems
- Select appropriate HCI design methodologies and apply them in the solution of real world design problems
- Select appropriate methodologies for the evaluation of HCI systems. Implement these methodologies on real systems and analyse and discuss the results produced
- Participate in a user-centred design process
- Demonstrate an understanding of the scope and importance of HCI systems across a range of application domains

38.4 Project/thesis

60 ECTS

39 SAPIENZA: Multimedia Computing and Interaction

39.1 School/Research area

Informatics

39.2 Syllabus

ELECTIVE:

- Biometric Systems
- Computer Vision: feature extraction, tracking, scene analysis, object recognition, event analysis, emotion analysis
- Fundamentals of Computer Graphics: path tracing, monte carlo methods, bidirectional reflectance distribution function, microfacet models, importance sampling, multiple importance sampling, subdivision surfaces, bump and normal mapping, volumetric scattering
- Deep Learning and Applied Artificial Intelligence
- Human-Computer Interaction on the Web
- Machine Learning: Supervised learning: decision trees, instance-based learning, naïve Bayes, support vector machine, neural networks, deep learning, ensemble methods. Unsupervised learning: clustering, association rules. Semi-supervised learning. Reinforcement learning. Genetic algorithms and genetic programming. Issues in machine learning: underfitting, overfitting, model selection, error analysis, Weka ML software Weka, Tensor Flow, scikit-learn.
- Multimodal Interaction
- Natural Language Processing: machine translation
- Web and Social Information Extraction
- Advanced Software Engineering
- Big Data Computing: data streaming, MapReduce, Hadoop,

- Cloud Computing
- Computer Networks Performance
- Concurrent Systems
- Distributed Systems
- Formal Methods in Software Development

39.3 Competences

CV:

- Introductions of the fundamental principles and different areas of Computer Vision and knowledge on problem solving such as feature extraction, tracking, scene analysis, object recognition, event analysis, emotion analysis.
- The successful student will be able to exploit the portfolio of techniques and the different approaches shown in the course for the design and the successful implementation of vision systems.
- Students will learn techniques that have proven to be useful by first-hand experience and a wide range of mathematical methods in the design of vision system.
- Students will be able to interact proficiently with other Computer Vision researchers on a wide set of AI topics.
- Students will be able to extend their skills in the subjects of this course, by the autonomous reading of the scientific literature on Computer Vision.

ML:

- Knowledge and understanding of how neural networks work and their mathematical interpretation as universal approximators. Understanding the limits and potentials of advanced machine learning models.
- Design, implementation, deployment and analysis of deep learning architectures addressing complex problems in several applicative areas.
- To be able to evaluate the performance of different architectures, and to assess their generalization capabilities.
- To be able to communicate clearly how to formulate an advanced machine learning problem as well as its implementation, its applicability in realistic settings, and specific architectural and regularization choices.
- Understanding alternative and more complex techniques such as generative models based on optimal transportation, scattering transforms and the energetic profile of neural networks. To be able to implement existing techniques efficiently, robustly and reliably.

39.4 Project/thesis

36 ECTS

40 UPF: Intelligent Interactive Systems

40.1 School/Research area

Telecommunications Engineering

40.2 Syllabus

CORE:

- Research Methodology
- Natural Language Interaction: human-computer interaction, conversational analysis, cooperative systems, machine learning, stochastic generation, dialogue systems, text-to-speech synthesis
- Machine Learning: linear models, optimization and gradient descent, supervised learning, unsupervised learning, clustering, PCA, Bayesian machine learning, probabilistic graphical models, reinforcement learning

- Autonomous Systems: classical planning, Markov decision processes, heuristic search, multi-agent models, game theory, multi-agent planning
- Web Intelligence: information retrieval, social networks, data mining

ELECTIVE:

- Cognitive Science & Psychology: Mind, Brain and Behaviour
- Audio Signal Processing for Music Applications
- Computational Semantics: data analysis, ML, basic programming
- Data-driven Social Analytics: tools and libraries for SNA, hierarchical clustering, fake news, bias, statistical modelling of online discussions,
- Mobile Robotics: sensors, vision, Kalman filter, planning and navigation, agent architectures
- Virtual Communication Environments: virtual environment, Javascript OOP, WebGL, 3D apps for virtual environments
- Face and Gesture Analysis: face recognition, feature extraction from images and video, facial expressions and emotions, 3D sensors, affective computing.
- Adaptive Behaviour: learning design, digital learning environments, learning analytics, learning technologies
- Computer Vision: feature detection, segmentation, image processing, colorization, face recognition, object recognition
- Optimization Techniques: energy minimization, PCA, convex optimization, non-convex problems, application to machine learning
- Education, Games and Entertainment: technology-enhanced learning, full-body interaction learning environments, location-based entertainment, cultural heritage and ICT

40.3 Competences

Research:

- Formulation of research questions;
- Ability to search and distinguish the types of information sources and their impact;
- Selection of the techniques and methods that can be applied to different types of research work;
- Communication skills in the context of research;
- Understanding the context and role of professional researchers, including the tasks of writing and reviewing papers and projects.

Machine Learning:

- Understand the mathematical principles that form the basis of machine learning.
- Solve basic mathematical exercises related to machine learning theory.
- Recognize the type of learning problem and select appropriate algorithms.
- Implement machine learning algorithms in a common programming language and test them on actual learning problems.
- Evaluate and interpret the outcome of learning on a given problem and compare the outcome for different algorithms.
- Select appropriate values of hyperparameters through validation.

40.4 Project/thesis

15 ECTS

41 UBATH: Robotics and Autonomous Systems

41.1 School/Research area

Informatics & Electronic Engineering & Mechanical Engineering

41.2 Syllabus

CORE:

- Robotic platform engineering: land based robotic platforms, marine based robotic platforms, UAV

- Robotics software: ROS
- Autonomous systems engineering: Autonomy and control algorithms, advanced automation, safety and fault tolerance, guidance, navigation, command and control, intelligent systems (e.g. sense and avoid, sense and follow), energy storage and management for vehicle platforms, object detection and recognition, basic imaging and signal processing.
- Humans and intelligent machines: human-machine interaction, robots, ethics and safety, cyborgs
- Autonomous systems navigation, guidance and communications

ELECTIVE:

- Embedded systems design
- Intelligent agents: multi-agency, logic, reasoning, negotiation, game theory, argumentation, institutions and norms, auctions, agent architectures, agent platforms, standards, ontologies and communication and content languages, decision making, trust and reputation.
- Intelligent control and cognitive systems: Sensing, action, perception and learning, cognition, agent-based modelling, evolution and cognitive control, animation and virtual reality, motion capture, segment smoothing, motion planning, basic AI for games, complex planning systems, ethics and philosophy of AI
- Artificial intelligence: heuristic, adversarial search, constraint satisfaction, logical reasoning, propositional logic, first-order logic, logic programming, probabilistic reasoning, probability models, bayesian networks, machine learning, reinforcement learning, neural networks, support vector machines, boosting
- Reinforcement learning: dynamic programming, Monte Carlo methods, temporal-difference algorithms, integration of planning and learning, value function approximation, policy gradient methods.
- Electronic control systems design
- Sensors and instrumentation
- Electronic communications systems

41.3 Competences

Robotics:

- Design, critically appraise and validate robotic systems hardware and platforms
- Compare, contrast and evaluate practical robotic platform design techniques and technologies
- Use a range of established and new techniques to design robotic platforms
- Demonstrate an understanding of current practice and developments in systems involving humans and intelligent machines;
- Show awareness of intelligent systems design issues;
- Critically evaluate examples of the design and deployment of intelligent systems;
- Recognize and challenge advances in the state of the art of intelligent systems;
- Design, conduct and critique original research to address questions and challenges in the design and use of systems involving humans and machine intelligence.

General:

- Demonstrate detailed knowledge and understanding of the technical and design processes when working in a multidisciplinary group
- Understand the interaction of different skills when analysing unfamiliar multi-disciplinary engineering problems
- Show originality in tackling and solving problems and dealing with inter-disciplinary issues.
- Effectively analyse and communicate within a technical team structure.

41.4 Project/thesis

30 ECTS

42 UTRECHT: Human Computer Interaction

42.1 School/Research area

Information Science

42.2 Syllabus

CORE:

- Advanced Cognitive and Social Psychology for HCI
- Advanced HCI Qualitative Research Methods
- Interaction Technology Innovation
- Advanced HCI Quantitative Research Methods

ELECTIVE:

- Technologies for learning
- Machine learning for human vision and language
- Adaptive interactive systems
- Sound and music technology
- Multimedia discourse interaction: linked data, semantic web
- Cognitive modelling
- Multimodal interaction
- Natural language generation
- Mobile interaction
- Serious gaming

42.3 Competences

Knowledge and understanding:

- is capable of making an essential contribution to the development and/or application of scientific concepts and methods, predominantly in relation to research in HCI;
- is capable of considering recent developments within HCI (e.g., novel sensor-based interfaces) and of specifying the implications of those developments for the discipline;
- is capable of appropriately utilising and interpreting specialist professional literature relevant to HCI, using systematic reviews (e.g., PRISMA);
- understands the potential dilemmas related to ethics (scientific integrity, privacy and security) in the research field of HCI.
- understands the psychological aspects underlying human behaviour that are relevant to HCI
- understands the computing and information science aspects underlying system behaviour that are relevant to HCI
- is capable of explaining and advocating where and how human-centred design and user experience research fits within organizations, and howit needs to consider and influence organizational and business strategies.

Applying knowledge and understanding:

- is capable of critically analysing, defining, and using a problem within the HCI domain and use this to formulate relevant appropriate research questions for either HCI educational, scientific, or engineering purposes;
- is capable of formulating a research design, which is appropriate for that research question and is in line with the HCI methodological and scientific standards,
- is capable of conducting that research with the prerequisite degree of care and ethical responsibility, and to process, analyse, interpret and evaluate empirical data or other findings obtained in the process appropriately;
- is capable of analysing the computing and information science aspects underlying system behaviour and apply these in HCI research and design;
- is capable of analysing the psychological aspects underlying human behaviour and apply these in HCI research and design;
- is capable of analysing possible future HCI designs and methods, critically analyse their pros and cons, conduct a requirement analysis, and suggest implementation strategies, taking the latest HCI developments in consideration.

Making judgements:

- is capable of discussing the findings of HCI research, relating it to the state of the art and relevant literature, and participating critically and constructively in the scientific debate;
- is capable of specifying the relevance of such research for the resolution of questions and problems in the field of HCI, both from a research and a societal point of view;
- is capable of critically reflecting on their own efforts as a researcher in the field of HCI and that of others from a societal perspective, including ethical perspectives such as privacy, scientific integrity, and information security.

Communication:

- is able to clearly communicate research findings in both written and oral form to an audience of specialists as well as people other than professional experts within an international context;
- is able to function effectively and creatively as part of possibly multidisciplinary teams, lead such teams, and communicate effectively with clients, end-users and other stakeholders (e.g., engineers);
- is able to showcase a portfolio of industrial and research projects in which their competencies have been applied;
- is able to implement prototype systems that support effective and efficient communication of HCI solutions.

Learning skills:

- has the skills to evaluate their own learning and development process, and to motivate and correct themselves during their studies where necessary;
- has developed their own effective, performance-oriented methodology to enable them to perform independently in the field of Interaction Technology;
- has the qualifications to enrol in a PhD programme in the field of Information Science;
- Is qualified to acquire a position as a professional in the field of Information Technology;
- has a realistic idea of the career opportunities after graduating, and of the skills that they need to successfully start a career.

42.4 Project/thesis

43 ECTS

43 GINP: MARS

43.1 School/Research area

Electrical & Electronic Engineering

43.2 Syllabus

CORE:

- Artificial Intelligence: Automated Planning: State Space Planning. Plan Space Planning. Planning-Graph Techniques. Heuristics in Planning. Hierarchical Task Network Planning; Machine and statistical learning: classification/regression, Supervised/unsupervised, cost functions, training error/testing, complexity: variance bias trade-off, scourge of the dimension; Generative Approaches: Discriminant analysis (linear/quadratic, regularization, size reduction); Naive Bayesian (parametric and non-parametric). Discriminatory approaches: generalized linear statistical models for regression and classification (logistic regression). ridge regulation, lasso (parsimony bet). Complexity and validation (cross-validation) of models. Data transformation (kernel move); Data representation (Unsupervised): BCP, standardization, small visualization; (Convolutional) Neural Nets: neuronal learning, gradient stoch. Neural networks. Deep, convolutional aspects: scikit-learn, kheras/tensorflow; Random trees and forests; Clustering: K-means, Gaussian mixture model, EM algorithm. Ex MNIST data and comparison with CNN. Hierarchical patterns
- Robotics: Modeling (mobile and Aerial robots. Perception for robots: detection of motion, detection of moving objects, tracking of moving objects. Control for robots: UAVs control. ROS
- Advanced control

- Research project

ELECTIVE:

- Smart transportation
- Cyber-security and embedded systems for robotics
- Distributed optimization and estimation
- Diagnostic, reliability and prognostic

43.3 Project/thesis

30 ECTS

44 UNITN: Human Computer Interaction

44.1 School/Research area

Psychology & Informatics

44.2 Syllabus

CORE:

- Design experience: Cognitive ergonomics, interaction design, cognitive models of interaction, participatory design
- Social interaction: social cognition
- Mind-Brain interaction and cognitive constraints: brain-computer interfaces
- Research methodology – quantitative: statistical and computational analyses, statistical analysis and modelling, R statistical package, social network analysis, inferential statistics
- Research methodology – qualitative
- Cognitive Neuroscience and Neurotechnology: interactive technologies

ELECTIVE:

- Multisensory interactive systems: physical and tangible interactions, usable and engaging interactive systems
- Prototyping interactive systems: interaction design, cognition and user behaviour
- Educational technologies
- Affective computing
- Visual design
- Design for social inclusion
- Design epistemology and ethics
- Assistive technology for neurological disorders

44.3 Project/thesis

18 ECTS

45 CRANFIELD: Autonomous Vehicle Dynamics and Control

45.1 School/Research area

Mechanical Engineering

45.2 Syllabus

- Introduction to Unmanned Aircraft Systems (UAS)
- UAS Modelling and Simulation
- Sensor Fusion: Statistical Analysis, Sensor Integration architectures, multiple sensor fusion
- Artificial Intelligence for Autonomous Systems: Imaging, Supervised Learning, Neural Networks, Unsupervised Learning, Clustering, Automated Reasoning, Bayesian Networks
- Guidance and Navigation for UAS

- Autonomous Vehicle Control Systems
- UAS Dynamics and Control
- Logic and Automated Reasoning: Introduction to logical representation and reasoning, Logical Agents, Propositional Logic, First-order Logic, Inference, Engineering domain knowledge representation

45.3 Project/thesis

Unspecified number of ECTS

Annex E: Classification of competences

	institution	level	bloom	domain	subdomain	name	election
General							
AIG							
	KUL: Artificial Intelligence	1-knowledge	1-remember	general	AIG	Be familiar with the basics of several advanced areas of AI and with the current research directions taken in these areas.	optional
	KUL: Artificial Intelligence	1-knowledge	1-remember	general	AIG	Be familiar with the basics of several advanced methodologies and or application areas of AI and with the current research directions taken in these areas.	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	general	AIG	Understand the concepts, the methods, and the applicability of the fundamentals of AI	core
	KUL: Artificial Intelligence	1-knowledge	2-understand	general	AIG	Read and comprehend the international scientific literature on AI.	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	general	AIG	Understand of the theoretical properties of different artificial intelligence methods	core
	UB: Artificial Intelligence	1-knowledge	2-understand	general	AIG	Understand the problems, and the solutions to problems in the professional practice of Artificial Intelligence application in business and industry environment	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	general	AIG	Explain and communicate the basic principles underlying common artificial intelligence methods	core
	KTH: Machine Learning	2-skill	3-apply	general	AIG	choose appropriate tools and implement efficient solutions to problems in AI	core
	KTH: Machine Learning	2-skill	3-apply	general	AIG	Draw use of methods of artificial intelligence in analysis, design and implementation of computer programs	core
	UB: Artificial Intelligence	2-skill	3-apply	general	AIG	Apply Artificial Intelligence techniques in technological and industrial environments to improve quality and productivity.	core
	KUL: Artificial Intelligence	2-skill	3-apply	general	AIG	Apply AI techniques and tools in the development of an AI-application,	optional
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	general	AIG	Choose an appropriate artificial intelligence method (and data pre-processing strategy if needed) to address the needs of a given application setting	core
	KTH: Machine Learning	2-skill	4-analyse	general	AIG	Present, analyse, and entitle an own solution to an AI problem	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	general	AIG	Implement and evaluate artificial intelligence methods to solve a given task	core
	KUL: Artificial Intelligence	2-skill	5-evaluate	general	AIG	Critically compare, relate and evaluate the relative merits of different approaches to certain classes of AI-applications,	optional
	KUL: Artificial Intelligence	2-skill	5-evaluate	general	AIG	Extract an AI problem from a real world situation, resolve the problem using AI techniques,	optional

	institution	level	bloom	domain	subdomain	name	election
						evaluate the solution method and test the solution	
	UCARDIFF: Artificial Intelligence	2-skill	6-create	general	AIG	Formalize real-world problems in relation to chosen artificial intelligence methods	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	2-skill	6-create	general	AIG	Define data-intensive problems in data science and artificial intelligence	core
	UB: Artificial Intelligence	2-skill	6-create	general	AIG	Research in new techniques, methodologies, architectures, services or systems in the area of Artificial Intelligence.	core
	UB: Artificial Intelligence	2-skill	6-create	general	AIG	Design, write and report about computer science projects in the specific area of Artificial Intelligence.	core
	UB: Artificial Intelligence	2-skill	6-create	general	AIG	Design new tools and new techniques of Artificial Intelligence in professional practice	core
	UB: Artificial Intelligence	2-skill	6-create	general	AIG	Plan, design and implement products, processes, services and facilities in all areas of Artificial Intelligence.	core
	UB: Artificial Intelligence	2-skill	6-create	general	AIG	Model, calculate, simulate, develop and implement in technology and company engineering centres, particularly in research, development and innovation in all areas related to Artificial Intelligence.	core
	UB: Artificial Intelligence	2-skill	6-create	general	AIG	General management, technical management and research projects management, development and innovation in companies and technology centres in the area of Artificial Intelligence.	core
	KUL: Artificial Intelligence	2-skill	6-create	general	AIG	Write a scientific paper on AI.	core
	KUL: Artificial Intelligence	2-skill	6-create	general	AIG	Develop a small-scale AI-system,	optional
	KUL: Artificial Intelligence	2-skill	6-create	general	AIG	Write small-scale programs in an AI-programming language,	optional
	UBATH: Robotics and Autonomous Systems	2-skill	6-create	general	AIG	Design, conduct and critique original research to address questions and challenges in the design and use of systems involving humans and machine intelligence.	core
	KTH: Machine Learning	2-skill	6-create	general	AIG	Contribute to design of an intelligent system in both academic and industrial applications.	core
	KUL: Artificial Intelligence	3-disposition	-	general	AIG	Possess an attitude of approaching and investigating AI and AI-problems from a multi-disciplinary perspective.	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	general	AIG	Understand of the importance of how data is represented for the success of artificial intelligence methods	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	general	AIG	Insight and foresight of how artificial intelligence methods influence the success of a given task	core

	institution	level	bloom	domain	subdomain	name	election
	UB: Artificial Intelligence	3-disposition	-	general	AIG	Respect the surrounding environment and design and develop sustainable intelligent systems.	core
	UMAAS: Business Intelligence and Smart Services	3-disposition	-	general	AIG	Apply ethical guidelines to analyse organizational data collection, storage and utilization	core
Fundamentals							
FMS							
	KUL: Artificial Intelligence	1-knowledge	1-remember	fundamentals	FMS	Be familiar with the more advanced issues in AI, including data and statistical modelling,	optional
	UCARDIFF: Artificial Intelligence	1-knowledge	1-remember	fundamentals	FMS	Identify the sources of variation in data.	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	1-remember	fundamentals	FMS	List several data analytics methods	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	1-knowledge	2-understand	fundamentals	FMS	Understand the underlying statistical and computational principles of data-intensive problems in data science and artificial intelligence	core
	TUM: Biomedical Computing	1-knowledge	2-understand	fundamentals	FMS	Master the concept of formal proofs	core
	UCL: Data Science and Machine Learning	1-knowledge	2-understand	fundamentals	FMS	Have an understanding of the fundamental aspects of probability and statistics sufficient to follow other taught postgraduate level modules in Statistical Science	core
	UCL: Data Science and Machine Learning	1-knowledge	6-create	fundamentals	FMS	Be equipped to lead basic data analysis projects in industry and research.	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FMS	Understand and develop how data can be used to provide new insights into business and create value for the business.	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FMS	Interpret and communicate application results from data science concepts in a business context.	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FMS	Translate business problems to canonical time series, discrete choice or panel data models.	optional
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FMS	Interpret and communicate the numerical results of time series, discrete choice and panel data models in a business context.	optional

	institution	level	bloom	domain	subdomain	name	election
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FMS	Summarise a data set using descriptive statistics.	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FMS	Write technical reports to communicate the results of data analysis procedures.	core
	EPFL: Data Science	1-knowledge	2-understand	fundamentals	FMS	Contrast competing models in terms of fit and parsimony	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FMS	Present findings and recommendations in a concise manner.	core
	UMAAS: Business Intelligence and Smart Services	2-skill	3-apply	fundamentals	FMS	Use several statistical and econometric models for time series data, discrete choice data and panel data.	optional
	UMAAS: Business Intelligence and Smart Services	2-skill	3-apply	fundamentals	FMS	Understand and use fundamental concepts of hypothesis testing and model comparison in analyzing business data.	optional
	UMAAS: Business Intelligence and Smart Services	2-skill	3-apply	fundamentals	FMS	Apply time series, discrete choice and panel data models for describing and summarizing business data and for evaluating the potential future outcomes in a business problem.	optional
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	fundamentals	FMS	Use optimisation algorithms to solve practical problems.	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	fundamentals	FMS	Implement operational research models and algorithms using different commercial computer packages.	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	fundamentals	FMS	Calculate confidence intervals and perform hypothesis tests.	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	fundamentals	FMS	Perform variable selection and dimension reduction.	core
	UCL: Data Science and Machine Learning	2-skill	3-apply	fundamentals	FMS	To use probability as a language to express uncertainty, ways of visualizing and preparing data for statistical analysis, estimation techniques in the context of applied data analysis problems, the role of algorithms in the computation of estimators	core
	UCL: Data Science and Machine Learning	2-skill	3-apply	fundamentals	FMS	To express uncertainty in estimation via confidence intervals and hypothesis testing, predictive analysis from the point of view of regression	core
	EPFL: Data Science	2-skill	3-apply	fundamentals	FMS	Perform data interpretation (statistics, knowledge extraction, critical thinking, team discussions, ad-hoc visualizations, etc.)	core
	EPFL: Data Science	2-skill	3-apply	fundamentals	FMS	Perform result dissemination (reporting, visualizations, publishing reproducible results, ethical concerns, etc.)	core

	institution	level	bloom	domain	subdomain	name	election
	UMAAS: Business Intelligence and Smart Services	2-skill	4-analyse	fundamentals	FMS	Analyse data by using data science concepts.	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	fundamentals	FMS	Know when it is appropriate to apply a range of fundamental operational research techniques, based on an understanding of their theoretical underpinnings.	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	fundamentals	FMS	Understand the conditions under which various statistical methods can be applied.	core
	TUM: Biomedical Computing	2-skill	5-evaluate	fundamentals	FMS	Verify and evaluate resulting solutions and therefore hold ambitious mathematical competences.	core
	UMAAS: Business Intelligence and Smart Services	2-skill	5-evaluate	fundamentals	FMS	Evaluate the applicability of different econometric models for a given business problem.	optional
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	fundamentals	FMS	Fit linear models to data and evaluate the accuracy of these models.	core
	EPFL: Data Science	2-skill	5-evaluate	fundamentals	FMS	Test hypotheses related to the structural characteristics of a model	core
	UCARDIFF: Artificial Intelligence	2-skill	6-create	fundamentals	FMS	Construct both deterministic and stochastic models of real-life situations using simulation, mathematical programming and other optimisation techniques.	core
	UCARDIFF: Artificial Intelligence	2-skill	6-create	fundamentals	FMS	Formulate problems involving uncertainty within the framework of probability theory.	core
	EPFL: Data Science	2-skill	6-create	fundamentals	FMS	Derive properties of fundamental statistical procedures	core
	EPFL: Data Science	2-skill	6-create	fundamentals	FMS	Estimate model parameters from empirical observations	core
	EPFL: Data Science	2-skill	6-create	fundamentals	FMS	Construct confidence bounds for model parameters and predictions	core
	ICL: Control Systems	2-skill	6-create	fundamentals	FMS	Formulate mathematical models of systems and identify the parameters of such models from observations using appropriate statistical techniques,	core
FIC							
	KUL: Artificial Intelligence	1-knowledge	1-remember	fundamentals	FIC	Be familiar with an AI-programming language.	optional
	UCARDIFF: Artificial Intelligence	1-knowledge	1-remember	fundamentals	FIC	Knowledge of the key concepts and algorithms underlying artificial intelligence methods	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	1-remember	fundamentals	FIC	Be familiar with the statistical and programming environment R,	core
	UMAAS: Business Intelligence	1-knowledge	1-remember	fundamentals	FIC	Be familiar with different data and file management systems such as	core

	institution	level	bloom	domain	subdomain	name	election
	and Smart Services					RDBM, Data Warehouses, NoSQL and HDFS	
	UMAAS: Business Intelligence and Smart Services	1-knowledge	1-remember	fundamentals	FIC	Know the relationship between machine learning, artificial intelligence and smart services.	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	1-remember	fundamentals	FIC	Be familiar with several practical service design principles and tools, and	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	1-remember	fundamentals	FIC	Identify suitable methods to analyse structured and unstructured data types	optional
	ICL: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	The detail and essential topics relevant to the students' chosen option and project areas, such as Software Engineering,	core
	ICL: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Emerging trends in Computing and an awareness of how these techniques can be adapted in industrial applications,	core
	ICL: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Develop an understanding and practice of more advanced computing topics, including databases, concurrent programming, artificial intelligence and distributed systems –in particular Architecture, Artificial Intelligence, Biomedical Applications, Computational Management Science, Creative Industries, Distributed Systems, Software Engineering and Visual Information Processing	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Understand the underlying statistical and computational principles of data-intensive problems in data science and artificial intelligence	core
	TUM: Biomedical Computing	1-knowledge	2-understand	fundamentals	FIC	Understand the overall context of specific requirements defined by clinical and life science processes	core
	USG: Computational Linguistics	1-knowledge	2-understand	fundamentals	FIC	Know about technologies such as XML and JSON, organizing and storing text corpora in databases including relational and NoSQL databases, basic knowledge about big data.	core
	ICL: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Practical programming skills,	core
	ICL: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Practical programming skills in Prolog and Matlab,	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Discuss and contrast the issues, features, design and concepts of a range of programming paradigms and languages, such as imperative, functional, declarative, logic, scripting, filter-based programming, pattern matching and quantum computing.	core

	institution	level	bloom	domain	subdomain	name	election
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	fundamentals	FIC	Explain the conceptual foundations of various programming paradigms.	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FIC	Demonstrate knowledge and understanding of the role service design, principles, processes and methods play in developing smart services	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FIC	Understand the diverse data landscape of modern organizations	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FIC	Develop insights with respect to the BI lifecycle in organizations, ranging from ETL to end user applications	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FIC	Explain and work with the basic concepts of several structured and unstructured data types	optional
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FIC	Explain and understand existing models and methods to analyse structured and unstructured data types published in the academic literature	optional
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	fundamentals	FIC	Interpret an estimated model, and draw managerial implications	optional
	EPFL: Data Science	1-knowledge	2-understand	fundamentals	FIC	Construct a coherent understanding of the techniques and software tools required to perform the fundamental steps of the Data Science pipeline	core
	UMAAS: Business Intelligence and Smart Services	2-skill	3-apply	fundamentals	FIC	Run basic (pre-programmed or self-programmed) routines with the statistical and programming environment R	core
	ICL: Artificial Intelligence	2-skill	3-apply	fundamentals	FIC	Conduct in-depth research on tools and languages available on line.	core
	UMAAS: Business Intelligence and Smart Services	2-skill	3-apply	fundamentals	FIC	Leverage and use service design as a practical approach to generate stakeholder insights needed for smart services	core
	TUM: Biomedical Computing	2-skill	3-apply	fundamentals	FIC	Use methods of computer science to develop demanded systems and to manage corresponding projects.	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	fundamentals	FIC	Implement artificial intelligence methods, taking advantage of existing libraries where appropriate	core
	TUM: Biomedical Computing	2-skill	3-apply	fundamentals	FIC	Apply appropriate computational methods in order to enhance efficiency of clinical and life science processes	core

	institution	level	bloom	domain	subdomain	name	election
	ICL: Artificial Intelligence	2-skill	3-apply	fundamentals	FIC	Design and develop programs of varying levels of complexity using Prolog, Matlab and other languages,	core
	ICL: Artificial Intelligence	2-skill	3-apply	fundamentals	FIC	Use computing tools and techniques, for instance software development tools,	core
	EPFL: Data Science	2-skill	3-apply	fundamentals	FIC	Use a suitable analysis method for any given algorithm	core
	EPFL: Data Science	2-skill	3-apply	fundamentals	FIC	Prove correctness and running-time bounds	core
	EPFL: Data Science	2-skill	3-apply	fundamentals	FIC	Perform data acquisition (data formats, dataset fusion, Web scrapers, REST APIs, open data, big data platforms, etc.)	core
	EPFL: Data Science	2-skill	3-apply	fundamentals	FIC	Perform data wrangling (fixing missing and incorrect data, data reconciliation, data quality assessments, etc.)	core
	TUM: Biomedical Computing	2-skill	3-apply	fundamentals	FIC	Work according to research orientated scientific principles, to conduct independent research to advanced knowledge in their challenging field and to introduce new methods in informatics into an existing corporate environment.	core
	UMAAS: Business Intelligence and Smart Services	2-skill	4-analyse	fundamentals	FIC	Integrate academic knowledge on service, interaction and business design to develop new ideas and innovative services	core
	ICL: Artificial Intelligence	2-skill	4-analyse	fundamentals	FIC	Analyse computing and computing related problems and devise solutions to them,	core
	ICL: Artificial Intelligence	2-skill	4-analyse	fundamentals	FIC	Analyse computing and computing related problems and devise solutions to them,	core
	UMAAS: Business Intelligence and Smart Services	2-skill	4-analyse	fundamentals	FIC	Estimate a suitable model using empirical data and statistical software	optional
	TUM: Biomedical Computing	2-skill	4-analyse	fundamentals	FIC	Analyse specific requirements defined by clinical and life science processes	core
	EPFL: Data Science	2-skill	4-analyse	fundamentals	FIC	Select appropriately an algorithmic paradigm for the problem at hand	core
	EPFL: Data Science	2-skill	4-analyse	fundamentals	FIC	Define formally an algorithmic problem	core
	EPFL: Data Science	2-skill	4-analyse	fundamentals	FIC	Choose systems parameters, data layouts, query plans, and application designs for database systems and applications.	core
	EPFL: Data Science	2-skill	4-analyse	fundamentals	FIC	Analyse the trade-offs between various approaches to large-scala data management and analytics, depending on efficiency, scalability, and latency needs	core
	EPFL: Data Science	2-skill	4-analyse	fundamentals	FIC	Choose the most appropriate existing systems architecture and technology for a task	core

	institution	level	bloom	domain	subdomain	name	election
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	fundamentals	FIC	Evaluate and apply the functional and logic programming paradigms to solve a given problem.	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	fundamentals	FIC	Evaluate and apply a suitable programming paradigm and language from a selection of them to solve a given problem.	core
	UMAAS: Business Intelligence and Smart Services	2-skill	5-evaluate	fundamentals	FIC	Reflect on and evaluate intelligent systems.	core
	TUM: Biomedical Computing	2-skill	5-evaluate	fundamentals	FIC	Analyse and judge the efficiency of related computational methods for proper validation and testing	core
	UEDIN: Cognitive Science	2-skill	5-evaluate	fundamentals	FIC	Structure, summarise and critically evaluate a body of knowledge relating to a substantial project topic in Informatics	core
	TUM: Biomedical Computing	2-skill	5-evaluate	fundamentals	FIC	Evaluate appropriate computational methods in order to enhance efficiency of clinical and life science processes	core
	UMAAS: Business Intelligence and Smart Services	2-skill	5-evaluate	fundamentals	FIC	Evaluate existing models and methods published in the academic literature	optional
	ICL: Control Systems	2-skill	6-create	fundamentals	FIC	Write programs using at least one common language (Matlab),	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Design devices and systems,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Create hardware and software systems,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Design and create corporate information systems,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Design and create the automation of services using modern technologies, including Internet-based ones,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Develop IT systems based on joint hardware and software project techniques,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Develop systems based on artificial intelligence,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Design networked computer architectures and systems, infrastructures and software for smart environments.	core
	UMAAS: Business Intelligence	2-skill	6-create	fundamentals	FIC	Analyse and design organizational data infrastructure using data modelling	core

	institution	level	bloom	domain	subdomain	name	election
	and Smart Services						
	UMAAS: Business Intelligence and Smart Services	2-skill	6-create	fundamentals	FIC	Design and implement intelligent systems.	core
	TUM: Biomedical Computing	2-skill	6-create	fundamentals	FIC	Plan and manage ambitious projects and, even with limited resources	core
	TUM: Biomedical Computing	2-skill	6-create	fundamentals	FIC	Develop solutions that comply with quality standards defined by health systems.	core
	TUM: Biomedical Computing	2-skill	6-create	fundamentals	FIC	Further develop existing methods of computer science and increase current knowledge in the discipline.	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Develop multimedia and hypermedia systems,	core
	POLIMI: Computer Science and Engineering	2-skill	6-create	fundamentals	FIC	Develop robotics systems and applications,	core
	UMAAS: Business Intelligence and Smart Services	2-skill	6-create	fundamentals	FIC	Develop their own models and provide interpretations thereof based on the learned methods and available data	optional
	UMAAS: Business Intelligence and Smart Services	2-skill	6-create	fundamentals	FIC	Devise suitable strategic plans when developing new smart service,	optional
	UMAAS: Business Intelligence and Smart Services	2-skill	6-create	fundamentals	FIC	Design an appropriate organizational configuration for implementing new smart services,	optional
	ICL: Artificial Intelligence	2-skill	6-create	fundamentals	FIC	Plan, conduct and write-up a programme of software development conducted in a team,	core
	EPFL: Data Science	2-skill	6-create	fundamentals	FIC	Design new algorithms for variations of problems studied in class	core
	EPFL: Data Science	2-skill	6-create	fundamentals	FIC	Develop data-parallel analytics programs that make use of modern clusters and cloud offerings to scale up to very large workloads.	core
	ICL: Artificial Intelligence	2-skill	6-create	fundamentals	FIC	Program in the major computer programming paradigms,	core
	ICL: Artificial Intelligence	2-skill	6-create	fundamentals	FIC	Plan, conduct and write-up a programme of original research and software development.	core
	ICL: Artificial Intelligence	3-disposition	-	fundamentals	FIC	Appreciate the needs of end-users and issues related to design, management and performance of large scale software,	core
	UMAAS: Business Intelligence	3-disposition	-	fundamentals	FIC	Take into account human resource considerations when designing and executing new services.	optional

	institution	level	bloom	domain	subdomain	name	election
	and Smart Services						
	TUM: Biomedical Computing	3-disposition	-	fundamentals	FIC	Recognise and integrate different points of view, even in cases where parties lack expert knowledge in the field of informatics.	core
Ethics & Philosophy							
AIE							
	KTH: Machine Learning	1-knowledge	1-remember	ethics & philosophy	AIE	Be more aware of workplaces and professions available for them as machine learning graduates.	core
	EPFL: Data Science	1-knowledge	2-understand	ethics & philosophy	AIE	Understand the most important classes of information security and privacy risks in today's Big Data environment	core
	EPFL: Data Science	1-knowledge	2-understand	ethics & philosophy	AIE	Understand at overview level the key technical tools available for security and privacy protection	core
	VUA: International Technology Law	1-knowledge	2-understand	ethics & philosophy	AIE	Acquire an advanced knowledge of legal and ethical issues related to robots and artificial intelligence,	optional
	EPFL: Data Science	2-skill	3-apply	ethics & philosophy	AIE	Exercise competent operational security practices in their home and professional lives	core
	KTH: Machine Learning	2-skill	4-analyse	ethics & philosophy	AIE	Reflect on and discuss current social and ethical aspects of AI	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	ethics & philosophy	AIE	Critical appraisal of the ethical implications and societal risks associated with the deployment of artificial intelligence methods	core
	EPFL: Data Science	2-skill	5-evaluate	ethics & philosophy	AIE	Exercise a basic, critical set of best practices for handling sensitive information	core
	KTH: Machine Learning	3-disposition	-	ethics & philosophy	AIE	Be aware about how machine learning is used and be utilised outside the academic world and the consequences this has for the society and the professional responsibilities as a machine learning practitioners.	core
	KTH: Machine Learning	3-disposition	-	ethics & philosophy	AIE	Be aware of the ethical issues that are associated with big data and the choices about the gains and losses made when mass data about people is made available	core
	KTH: Machine Learning	3-disposition	-	ethics & philosophy	AIE	Be aware of the responsibilities when presenting machine learning results and algorithms to the public	core
	KTH: Machine Learning	3-disposition	-	ethics & philosophy	AIE	Be aware of the responsibilities of drawing conclusions from experimental results.	core
	KTH: Machine Learning	3-disposition	-	ethics & philosophy	AIE	Be aware about how machine learning is used and be utilised outside the academic world and the consequences this has for the society and the professional responsibilities as a machine learning practitioners.	core

	institution	level	bloom	domain	subdomain	name	election
	KTH: Machine Learning	3-disposition	-	ethics & philosophy	AIE	Be more aware of workplaces and professions available for them as machine learning graduates.	core
PAI							
	KTH: Machine Learning	1-knowledge	2-understand	ethics & philosophy	PAI	Present the foundational issues in the methodology and philosophy of science, especially as regards the natural, technological and computational sciences.	core
	KTH: Machine Learning	1-knowledge	2-understand	ethics & philosophy	PAI	Present the history of computation and computers	core
	VUA: International Technology Law	1-knowledge	2-understand	ethics & philosophy	PAI	Understand, at a functional level, how disruptive technologies work, how they circumvent or defeat tradition regulation.	optional
	KTH: Machine Learning	2-skill	3-apply	ethics & philosophy	PAI	Apply different principles of Artificial Intelligence (AI)	core
Reasoning							
PSO							
	KUL: Artificial Intelligence	1-knowledge	1-remember	reasoning	PSO	Be familiar with the more advanced issues in AI, including optimization in constraint processing and local search,	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	reasoning	PSO	Understand the concepts, the methods, and the applicability of the fundamentals of AI, including search and problem solving techniques,	core
	KUL: Artificial Intelligence	1-knowledge	2-understand	reasoning	PSO	Understand the concepts, the methods, and the applicability of the fundamentals of AI, including constraint processing and planning,	core
	UB: Artificial Intelligence	1-knowledge	2-understand	reasoning	PSO	understand the basic operation principles of Planning and Approximate Reasoning main techniques, and to know how to use in the environment of an intelligent system or service.	core
KRR							
	KUL: Artificial Intelligence	1-knowledge	1-remember	reasoning	KRR	Be familiar with the more advanced issues in AI, including logic for representation and problem solving,	optional
	KUL: Artificial Intelligence	1-knowledge	1-remember	reasoning	KRR	Be familiar with the more advanced issues in AI, including the treatment of uncertainty in knowledge systems,	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	reasoning	KRR	Understand the concepts, the methods, and the applicability of the fundamentals of AI, including knowledge representation formalisms,	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	reasoning	KRR	Explain the basic principles underlying common knowledge representation approaches	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	reasoning	KRR	Compare how knowledge representation approaches influence the success of a given task	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	reasoning	KRR	Explain the nature, strengths and limitations of knowledge representation technique to an audience of non-specialists	core

	institution	level	bloom	domain	subdomain	name	election
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	reasoning	KRR	Explain the basic principles underlying common automated reasoning approaches	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	reasoning	KRR	Explain the nature, strengths and limitations of automated reasoning technique	core
	EPFL: Data Science	1-knowledge	2-understand	reasoning	KRR	Formulate the fundamental concepts of signal processing such as basis representations and sampling	core
	EPFL: Data Science	1-knowledge	2-understand	reasoning	KRR	Formulate the fundamental concepts of information theory such as entropy and mutual information	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	reasoning	KRR	Discuss the theoretical properties of different knowledge representation formalisms	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	reasoning	KRR	Choose an appropriate knowledge representation approach to address the needs of a given application setting	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	reasoning	KRR	Choose an appropriate automated reasoning approach to address the needs of a given application setting	core
	EPFL: Data Science	2-skill	4-analyse	reasoning	KRR	Analyse problems in statistical settings using fundamental bounds from information theory	core
	EPFL: Data Science	2-skill	4-analyse	reasoning	KRR	Formulate problems using robust and universal techniques	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	reasoning	KRR	Critically evaluate knowledge representation alternatives to solve a given task	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	reasoning	KRR	Implement and evaluate automated reasoning approaches to solve a given task	core
	UCARDIFF: Artificial Intelligence	2-skill	6-create	reasoning	KRR	Formalize simple problems with a given knowledge representation approach	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	reasoning	KRR	Reflect on the importance of data representation for the success of automated reasoning methods	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	reasoning	KRR	Critically appraise the ethical implications and societal risks associated with the deployment of automated reasoning methods	core
Learning							
ML							
	KUL: Artificial Intelligence	1-knowledge	1-remember	learning	ML	Be familiar with the more advanced issues in AI, including machine learning techniques,	optional
	UCL: Data Science and Machine Learning	1-knowledge	1-remember	learning	ML	become familiar with techniques used in practice to solve real world machine learning problems and will be able to apply these techniques	core
	UCL: Data Science and Machine Learning	1-knowledge	1-remember	learning	ML	Gain in-depth familiarity with various classical and contemporary supervised learning algorithms,	core

	institution	level	bloom	domain	subdomain	name	election
	KUL: Artificial Intelligence	1-knowledge	1-remember	learning	ML	Be familiar with the more advanced issues in AI, including machine learning techniques,	optional
	KUL: Artificial Intelligence	1-knowledge	1-remember	learning	ML	Be familiar with the more advanced issues in AI, including data mining techniques	optional
	KUL: Artificial Intelligence	1-knowledge	1-remember	learning	ML	Be familiar with the more advanced issues in AI, including neural networks, their basic techniques and applications,	optional
	UCARDIFF: Artificial Intelligence	1-knowledge	1-remember	learning	ML	Describe basic principles underlying machine learning.	core
	EPFL: Data Science	1-knowledge	1-remember	learning	ML	Define the following basic machine learning problems: Regression, classification, clustering, dimensionality reduction, time-series	core
	KUL: Artificial Intelligence	1-knowledge	2-understand	learning	ML	Understand the concepts, the methods, and the applicability of the fundamentals of AI, including basics of machine learning,	core
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	learning	ML	Translate business problems into canonical data mining tasks and study business problems from a data perspective.	core
	KTH: Machine Learning	1-knowledge	2-understand	learning	ML	describe the most important algorithms and the theory that constitutes the basis for machine learning and artificial intelligence	core
	KTH: Machine Learning	1-knowledge	2-understand	learning	ML	explain the principle for machine learning and how the algorithms and the methods can be used	core
	KTH: Machine Learning	1-knowledge	2-understand	learning	ML	describe the most important algorithms and the theory that constitutes the basis for machine learning and artificial intelligence	core
	KTH: Machine Learning	1-knowledge	2-understand	learning	ML	explain the principle for machine learning and how the algorithms and the methods can be used	core
	UPF: Intelligent Interactive Systems	1-knowledge	2-understand	learning	ML	Understand the mathematical principles that form the basis of machine learning.	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	learning	ML	Explain the fundamental principles underlying common machine learning methods	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	learning	ML	Explain the nature, strengths and limitations of an implemented machine learning technique to an audience of non-specialists	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	learning	ML	Explain the fundamentals and modern principles of natural language processing or computer vision	core
	UCAMB: Machine Learning and Machine Intelligence	1-knowledge	2-understand	learning	ML	Knowledge of the fundamental techniques in machine learning and how to apply these techniques to a range of practical problems,	core
	UCL: Data Science and	1-knowledge	2-understand	learning	ML	have a good understanding of practical issues arising in implementing machine learning in	core

	institution	level	bloom	domain	subdomain	name	election
	Machine Learning					practice, including engineering challenges as well as the data ethics considerations,	
	UCL: Data Science and Machine Learning	1-knowledge	2-understand	learning	ML	understand machine learning at both the theoretical and practical level,	core
	UCL: Data Science and Machine Learning	1-knowledge	2-understand	learning	ML	Understand the underlying limitations and principles that govern learning algorithms and ways of assessing and improving their performance.	core
	UB: Artificial Intelligence	1-knowledge	2-understand	learning	ML	understand the basic operation principles of Machine Learning main techniques, and to know how to use on the environment of an intelligent system or service.	core
	SAPIENZA: Multimedia Computing and Interaction	1-knowledge	2-understand	learning	ML	Knowledge and understanding of how neural networks work and their mathematical interpretation as universal approximators. Understanding the limits and potentials of advanced machine learning models.	core
	SAPIENZA: Multimedia Computing and Interaction	1-knowledge	2-understand	learning	ML	Understanding alternative and more complex techniques such as generative models based on optimal transportation, scattering transforms and the energetic profile of neural networks.	core
	UCAMB: Machine Learning and Machine Intelligence	1-knowledge	2-understand	learning	ML	A deep understanding of fundamental problems in machine intelligence, including speech and language processing and computer vision, and the technologies that form the current state of the art,	core
	UCAMB: Machine Learning and Machine Intelligence	1-knowledge	2-understand	learning	ML	A comprehensive understanding of techniques, and a thorough knowledge of the literature, applicable to the area of their chosen research topic,	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	1-knowledge	2-understand	learning	ML	understands the opportunities that machine learning offers in data science and artificial intelligence	core
	EPFL: Data Science	1-knowledge	2-understand	learning	ML	Explain the main differences between them	core
	EPFL: Data Science	2-skill	3-apply	learning	ML	Optimize the main trade-offs such as overfitting, and computational cost vs accuracy	core
	KTH: Machine Learning	2-skill	3-apply	learning	ML	to identify and apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems.	core
	KTH: Machine Learning	2-skill	3-apply	learning	ML	to identify and apply appropriate machine learning technique for classification, pattern recognition, regression and decision problems.	core
	SAPIENZA: Multimedia Computing and Interaction	2-skill	3-apply	learning	ML	communicate clearly how to formulate an advanced machine learning problem as well as its implementation, its applicability in realistic settings, and specific	core

	institution	level	bloom	domain	subdomain	name	election
						architectural and regularization choices.	
	SAPIENZA: Multimedia Computing and Interaction	2-skill	3-apply	learning	ML	implement existing machine learning techniques efficiently, robustly and reliably.	core
	UPF: Intelligent Interactive Systems	2-skill	3-apply	learning	ML	Solve basic mathematical exercises related to machine learning theory.	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	learning	ML	Apply basic algorithms to toy examples.	core
	UCL: Data Science and Machine Learning	2-skill	4-analyse	learning	ML	solve real-world machine learning problems using the right tools	core
	EPFL: Data Science	2-skill	4-analyse	learning	ML	Characterize trade-offs between time, data and accuracy, for machine learning methods	core
	KTH: Machine Learning	2-skill	4-analyse	learning	ML	discuss advantages with and limitations of machine learning for different applications	core
	RWTHA: Robotic Systems Engineering	2-skill	4-analyse	learning	ML	Discuss the advantages and disadvantages of machine learning techniques,	core
	RWTHA: Robotic Systems Engineering	2-skill	4-analyse	learning	ML	Find practical solutions to complex real-world machine learning problems,	core
	UPF: Intelligent Interactive Systems	2-skill	4-analyse	learning	ML	Recognize the type of learning problem and select appropriate algorithms.	core
	UPF: Intelligent Interactive Systems	2-skill	4-analyse	learning	ML	Select appropriate values of hyperparameters through validation.	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	learning	ML	Determine a suitable machine learning approach given an application.	core
	UCAMB: Machine Learning and Machine Intelligence	2-skill	4-analyse	learning	ML	critically assess the technical literature in machine learning and machine intelligence and related topics,	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	learning	ML	Choose an appropriate machine learning method and data pre-processing strategy to address the needs of a given application setting	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	2-skill	5-evaluate	learning	ML	evaluate the suitability of different machine learning methods for solving a new problem encountered in industry or academia, and apply the methods to the problem.	core
	EPFL: Data Science	2-skill	5-evaluate	learning	ML	Implement machine learning methods to real-world problems, and rigorously evaluate their performance using cross-validation. Experience common pitfalls and how to overcome them	core

	institution	level	bloom	domain	subdomain	name	election
	EPFL: Data Science	2-skill	5-evaluate	learning	ML	Assess and Evaluate the most important algorithms, function classes, and algorithm convergence guarantees	core
	SAPIENZA: Multimedia Computing and Interaction	2-skill	5-evaluate	learning	ML	evaluate the performance of different architectures, and to assess their generalization capabilities.	core
	UPF: Intelligent Interactive Systems	2-skill	5-evaluate	learning	ML	Implement machine learning algorithms in a common programming language and test them on actual learning problems.	core
	UPF: Intelligent Interactive Systems	2-skill	5-evaluate	learning	ML	Evaluate and interpret the outcome of learning on a given problem and compare the outcome for different algorithms.	core
	EPFL: Data Science	2-skill	6-create	learning	ML	Implement algorithms for these machine learning models	core
	EPFL: Data Science	2-skill	6-create	learning	ML	Compose existing theoretical analysis with new aspects and algorithm variants.	core
	EPFL: Data Science	2-skill	6-create	learning	ML	Formulate scalable and accurate implementations of the most important optimization algorithms for machine learning applications	core
	RWTHA: Robotic Systems Engineering	2-skill	6-create	learning	ML	Derive, explain and apply practical machine learning methods and algorithms	core
	SAPIENZA: Multimedia Computing and Interaction	2-skill	6-create	learning	ML	Design, implementation, deployment and analysis of deep learning architectures addressing complex problems in several applicative areas.	core
	UPC: Automatic Control and Robotics	2-skill	6-create	learning	ML	select and program pattern recognition methods and learning based on the type of problem, after distinguishing if the situation so requires	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	2-skill	6-create	learning	ML	implement common machine learning methods and design and implement novel algorithms by modifying the existing approaches.	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	learning	ML	Critically appraise the ethical implications and societal risks associated with the deployment of machine learning methods	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	learning	ML	Assess the key concepts and algorithms widely used in machine learning.	core
	UB: Artificial Intelligence	3-disposition	-	learning	ML	understand the basic operation principles of Computational Intelligence main techniques, and to know how to use in the environment of an intelligent system or service.	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	learning	ML	Reflect on the importance of data representation for the success of machine learning methods	core
	KTH: Machine Learning	3-disposition	-	learning	ML	discuss advantages with and limitations of machine learning for different applications	core

	institution	level	bloom	domain	subdomain	name	election
	UCARDIFF: Artificial Intelligence	3-disposition	-	learning	ML	Critically reflect and evaluate different approaches for learning.	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	learning	ML	Implement and evaluate machine learning methods to solve a given task	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	3-disposition	-	learning	ML	effectively interpret the results of a machine learning algorithm, assess its credibility, and communicate the results to experts of other fields.	core
	AALTO: CCIS - Machine Learning, Data Science and Artificial Intelligence	3-disposition	-	learning	ML	understands the theoretical foundations of the machine learning field to the extent required to be able to follow research in the field.	core
	EPFL: Data Science	3-disposition	-	learning	ML	Explain and understand the fundamental theory presented for ML methods	core
Communication							
NLP							
	KUL: Artificial Intelligence	1-knowledge	1-remember	communication	NLP	Be familiar with the concepts and techniques of an Object Oriented programming language and of an AI-programming language	optional
	USG: Computational Linguistics	1-knowledge	1-remember	communication	NLP	Become familiar with the main concepts, research questions and methodological frameworks of Computational Linguistics	core
	USG: Computational Linguistics	1-knowledge	1-remember	communication	NLP	Be familiar with the main approaches in dependency parsing.	core
	KUL: Artificial Intelligence	1-knowledge	2-understand	communication	NLP	Have a solid background in linguistics	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	communication	NLP	Have a solid background in natural language processing	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	communication	NLP	Have a solid background in pattern recognition	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	communication	NLP	Have experience with the technological and scientific activities performed in companies or research centres in the speech and language technology area	optional
	USG: Computational Linguistics	2-skill	3-apply	communication	NLP	Be equipped with the most recent text technologies that are commonly used, to get ready for both research and development.	core
	UB: Artificial Intelligence	2-skill	3-apply	communication	NLP	Understand the basic operation principles of Natural Language Processing main techniques, and to know how to use in the environment of an intelligent system or service.	core
	KUL: Artificial Intelligence	2-skill	4-analyse	communication	NLP	Critically compare and relate the relative merits of scientific techniques used in companies or research centres in speech and language technology	optional

	institution	level	bloom	domain	subdomain	name	election
	KUL: Artificial Intelligence	2-skill	5-evaluate	communication	NLP	Critically evaluate the relative merits of scientific techniques used in companies or research centres in speech and language technology	optional
	SHEFFIELD: Computer Science with Speech and Language Processing	2-skill	5-evaluate	communication	NLP	Critically evaluate and select software tools appropriate for building particular human language technology applications,	core
	USG: Computational Linguistics	2-skill	6-create	communication	NLP	Know how to combine dependency parsing algorithms with statistical methods to create data-driven dependency parsers.	core
	KUL: Artificial Intelligence	2-skill	6-create	communication	NLP	Write small-scale programs in an Object Oriented programming language and in an AI-programming language	optional
	USG: Computational Linguistics	2-skill	6-create	communication	NLP	Have implemented their own dependency parser.	core
	SHEFFIELD: Computer Science with Speech and Language Processing	2-skill	6-create	communication	NLP	Engineer a human language processing application in a rigorous and principled manner, through processes of analysis, design, implementation and evaluation,	core
	USG: Computational Linguistics	2-skill	6-create	communication	NLP	Build some NLP applications such as corpora storage and searching using the learned technologies.	core
Perception							
AP							
	KUL: Artificial Intelligence	1-knowledge	2-understand	perception	AP	Have a solid background in speech science	optional
	KUL: Artificial Intelligence	1-knowledge	2-understand	perception	AP	Have a solid background in speech signal processing	optional
CV							
	TUM: Biomedical Computing	1-knowledge	2-understand	perception	CV	Know models and methods in computer graphics, image understanding or processing, and visualization	core
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	perception	CV	Have knowledge on an advanced level in computer vision and computer graphics based on the highest international research in these areas	core
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	perception	CV	Have a comprehensive knowledge of the core subjects for computer vision, such as image recognition, visual scene analysis, object tracking, etc.	core
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	perception	CV	Have knowledge of the theories and methods for realizing complex software systems for vision and graphic systems	core
	SAPIENZA: Multimedia Computing and Interaction	1-knowledge	2-understand	perception	CV	Introductions of the fundamental principles and different areas of Computer Vision and knowledge on problem solving such as feature extraction, tracking, scene analysis,	core

	institution	level	bloom	domain	subdomain	name	election
						object recognition, event analysis, emotion analysis.	
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	perception	CV	Have knowledge about machine learning methods and techniques and pattern recognition	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	3-apply	perception	CV	Identify scientific problems and propose solutions within computer vision and computer graphics	core
	UPC: Computer Vision	2-skill	3-apply	perception	CV	Identify concepts and apply the most appropriate fundamental techniques for solving basic problems in computer vision.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	perception	CV	Analyse and apply state-of-the-art methods in Computer Vision	core
	RWTHA: Robotic Systems Engineering	2-skill	4-analyse	perception	CV	Discuss the advantages and disadvantages of computer vision techniques:	core
	RWTHA: Robotic Systems Engineering	2-skill	4-analyse	perception	CV	Find practical solutions to complex real-world computer vision problems	core
	UPC: Computer Vision	2-skill	4-analyse	perception	CV	Choose the most suitable software tools and training sets for developing solutions to problems in computer vision.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	perception	CV	Analyse and apply appropriate theories and methods for computer vision problems within e.g. surveillance, robotics, etc.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	perception	CV	Select and apply appropriate methods for solving a given problem within computer vision and graphics and evaluate the results regarding their accuracy and validity	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	perception	CV	Identify scientific problems within control and auto computer vision, graphics and interactive systems and select and apply proper scientific theories, methods and tools for their solution	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	perception	CV	Develop and advance new analyses and solutions within computer vision and graphics	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	5-evaluate	perception	CV	Evaluate and select among the scientific theories, methods, tools and general skills within the fields of computer vision and graphics and, on a scientific basis, advance new analyses and solutions	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	6-create	perception	CV	Design, simulation, real-time implementation, test, evaluation, and documentation of systems within the field of computer vision and graphics	core
	RWTHA: Robotic	2-skill	6-create	perception	CV	Derive, explain, and apply practical computer vision algorithms	core

	institution	level	bloom	domain	subdomain	name	election
	Systems Engineering						
	SAPIENZA: Multimedia Computing and Interaction	2-skill	6-create	perception	CV	Exploit the portfolio of techniques and the different approaches shown in the course for the design and the successful implementation of vision systems.	core
	SAPIENZA: Multimedia Computing and Interaction	2-skill	6-create	perception	CV	Learn techniques that have proven to be useful by first-hand experience and a wide range of mathematical methods in the design of vision systems	core
	UPC: Automatic Control and Robotics	2-skill	6-create	perception	CV	Select, plan, and evaluate different techniques to detect, extract and analyse data an image or sequence of images	core
	UPC: Computer Vision	2-skill	6-create	perception	CV	Conceptualise alternatives to complex solutions for vision problems and create prototypes to show the validity of the system proposed.	core
	UPC: Computer Vision	2-skill	6-create	perception	CV	Plan, develop, evaluate and manage solutions for projects in the different areas of computer vision.	core
	SAPIENZA: Multimedia Computing and Interaction	2-skill	learning	perception	CV	Extend their skills by the autonomous reading of the scientific literature on Computer Vision.	core
	AAU: Vision, Graphics and Interactive Systems	3-disposition	-	perception	CV	Apply methods and tools for solving complex problems within the computer vision and graphics domains	core
	SAPIENZA: Multimedia Computing and Interaction	3-disposition	-	perception	CV	Interact proficiently with other Computer Vision researchers on a wide set of AI topics.	core
Services & applications							
AIA							
	KUL: Artificial Intelligence	1-knowledge	1-remember	services & applications	AIA	Be familiar with the concepts and techniques of an Object Oriented programming language and of specific issues required for Big Data programming	optional
	TUM: Biomedical Computing	1-knowledge	2-understand	services & applications	AIA	Understand the interaction between biomedical software and hardware and are familiar with the theoretical foundations of medical imaging systems.	core
	TUM: Biomedical Computing	1-knowledge	2-understand	services & applications	AIA	Understand ethical standards and the impact of their work on future users, patients and society.	core
	TUM: Biomedical Computing	2-skill	3-apply	services & applications	AIA	Given technical, economic and social contexts, be able to solve problems in demanding interdisciplinary projects in medical or biological fields of application	core
	TUM: Biomedical Computing	2-skill	4-analyse	services & applications	AIA	Understand, analyse and solve challenges in medical and life science environment.	core

	institution	level	bloom	domain	subdomain	name	election
	TUM: Biomedical Computing	2-skill	6-create	services & applications	AIA	Transform challenges in medical and life science environment to formal mathematical models and transfer these into efficient algorithms and suitable data structures.	core
AIS							
	KUL: Digital Humanities	1-knowledge	1-remember	services & applications	AIS	Appreciate the history of Digital Humanities and understand the controversies concerning Digital Humanities and traditional Humanities research.	core
	KUL: Artificial Intelligence	1-knowledge	1-remember	services & applications	AIS	Be familiar with issues involving programming for big data	optional
	KUL: Artificial Intelligence	1-knowledge	1-remember	services & applications	AIS	Be familiar with the basics of several advanced methodologies and or application areas of Big Data Analysis and with the current research directions taken in these areas.	optional
	KUL: Digital Humanities	1-knowledge	2-understand	services & applications	AIS	Understand the basic concepts of Digital Humanities	core
	KUL: Digital Humanities	1-knowledge	2-understand	services & applications	AIS	Understand the concepts underlying a range of basic digital techniques applied in Digital Humanities, with an emphasis on databases, web and scripting languages.	core
	KUL: Digital Humanities	1-knowledge	2-understand	services & applications	AIS	Understand the concepts and organizational issues of the use of IT for managerial decision in Digital Humanities.	core
	KUL: Digital Humanities	1-knowledge	2-understand	services & applications	AIS	Have in-depth knowledge and understanding of the techniques used in a selection of tools for Digital Humanities	core
	KUL: Digital Humanities	1-knowledge	2-understand	services & applications	AIS	Have in-depth understanding of the problem settings and solutions for a selection of applications in Digital Humanities	core
	KUL: Digital Humanities	1-knowledge	2-understand	services & applications	AIS	Communicate scientifically, both in written and oral communication, on topics related to novel technologies and applications in Digital Humanities.	core
	KUL: Artificial Intelligence	2-skill	3-apply	services & applications	AIS	Apply AI techniques and tools in the development of an Big Data Analytics application,	optional
	KUL: Digital Humanities	2-skill	3-apply	services & applications	AIS	Use a range of basic digital techniques applied in Digital Humanities, with an emphasis on modelling, querying, encoding and scripting.	core
	KUL: Artificial Intelligence	2-skill	4-analyse	services & applications	AIS	Critically compare, relate and evaluate the relative merits of different approaches to certain classes of Big Data Analytics applications,	optional
	TUM: Biomedical Computing	2-skill	4-analyse	services & applications	AIS	Analyse, validate and design cognitive systems, know the different paradigms of artificial intelligence and the characteristics of intelligent systems and validate them.	core
	KUL: Digital Humanities	2-skill	4-analyse	services & applications	AIS	Independently select and apply appropriate tools and techniques for	core

	institution	level	bloom	domain	subdomain	name	election
						Digital Humanities problems, for a selection of tools and techniques depending on the interests of the graduate.	
	KUL: Digital Humanities	2-skill	4-analyse	services & applications	AIS	Independently analyse solutions for Digital Humanities problems	core
	KUL: Digital Humanities	2-skill	5-evaluate	services & applications	AIS	Critically evaluate the techniques used in a selection of tools for Digital Humanities	core
	KUL: Digital Humanities	2-skill	5-evaluate	services & applications	AIS	Critically evaluate and assess solutions for a selection of applications in Digital Humanities	core
	KUL: Artificial Intelligence	2-skill	5-evaluate	services & applications	AIS	Extract an Big Data Analytics problem from a real world situation, resolve the problem using Big Data Analytics techniques, evaluate the solution method and test the solution	optional
	KUL: Digital Humanities	2-skill	5-evaluate	services & applications	AIS	Assess the potential contributions and pitfalls of the use of IT in research project in Digital Humanities.	core
	KUL: Digital Humanities	2-skill	5-evaluate	services & applications	AIS	Critically analyse and interpret the results, for types of problems of Digital Humanities.	core
	KUL: Artificial Intelligence	2-skill	6-create	services & applications	AIS	Develop a small-scale Big Data Analytics system,	optional
	KUL: Artificial Intelligence	2-skill	6-create	services & applications	AIS	Write small-scale programs for programming with big data,	optional
	KUL: Digital Humanities	2-skill	6-create	services & applications	AIS	Independently formulate research goals, determine research methods that achieve these goals, collect and select information from different research sources relevant to achieve the research goals and interpret collected information on the basis of a critical research attitude, in the context of Digital Humanities.	core
	KUL: Digital Humanities	2-skill	6-create	services & applications	AIS	Independently model and design solutions for Digital Humanities problems	core
	KUL: Artificial Intelligence	2-skill	6-create	services & applications	AIS	Write small-scale programs in an Object Oriented programming language and in the context of Big Data programming	optional
	KUL: Digital Humanities	3-disposition	-	services & applications	AIS	Have a critical insight in the interdisciplinary and international dimensions of Digital Humanities and its research.	core
	KUL: Digital Humanities	3-disposition	-	services & applications	AIS	Follow-up and critically situate new scientific developments in Digital Humanities and situate them in a broader context.	core
Unspecified subdomain							
	VUA: International Technology Law	1-knowledge	1-remember	services & applications		Acquire knowledge of the legal framework which is applicable to the most important new technologies.	core
	VUA: International	1-knowledge	1-remember	services & applications		Identify ideologically biased claims	core

	institution	level	bloom	domain	subdomain	name	election
	Technology Law						
	VUA: International Technology Law	1-knowledge	1-remember	services & applications		Identify different analytical approaches to doctrinal research	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Have a clear understanding of legal research method	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Understand the process of legal reasoning	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Understand the role of (non-legal) factual statements in legal discourse	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Understand the role of storytelling in legal discourse	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Have a basic understanding of non-doctrinal legal research methods.	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Map an overview of the main sources of EU and international data protection law,	core
	VUA: International Technology Law	1-knowledge	2-understand	services & applications		Identify and explain weaknesses and gaps in the international and EU legal framework regulating data protection and privacy and other fundamental rights such as procedural justice, when it comes to the use of big data and new technologies to address threats to human security,	core
	VUA: International Technology Law	2-skill	3-apply	services & applications		Apply legal research methods in research,	core
	VUA: International Technology Law	2-skill	3-apply	services & applications		Apply the doctrinal method	core
	VUA: International Technology Law	2-skill	3-apply	services & applications		Apply the principles of data protection law to the use of big data and modern technologies in each of the three human rights and human security fields discussed in the course,	core
	VUA: International Technology Law	2-skill	4-analyse	services & applications		Research and discover which laws are relevant to a new situation, and how to extend legal ideas to situations which have not yet been addressed by courts.	core
	VUA: International Technology Law	2-skill	5-evaluate	services & applications		To write a well-structured and well-argued legal analysis on the use of big data and modern technologies.	core

	institution	level	bloom	domain	subdomain	name	election
	VUA: International Technology Law	3-disposition	-	services & applications		Contribute to the academic and public debate as to whether and to what extent legal responses to human security threats are undergoing a fundamental shift through the use of modern technologies,	core
Interaction							
HMI							
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	interaction	HMI	Have knowledge about methods for computer graphics, augmented reality, 3D rendering, etc.	core
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	interaction	HMI	Have knowledge about interactive systems design, in particular multi modal user interaction and user experience design.	core
	AAU: Vision, Graphics and Interactive Systems	1-knowledge	2-understand	interaction	HMI	Have knowledge of the theories and methods for realizing complex software systems for interactive systems	core
	UCARDIFF: Artificial Intelligence	1-knowledge	2-understand	interaction	HMI	Understand experimental design for the subjective assessment of user experience	core
	UBIR: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Principles of HCI, usability and user experience, designing, building and evaluating interactive systems.	core
	UBIR: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	The psychology of the user, the social context of design, and the potentials and issues of next-generation interactive systems.	core
	UBIR: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Research tools and methods used in HCI.	core
	UBIR: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Explain and discuss the key capabilities and limitations in human cognitive performance and relate this to the design of HCI systems	core
	UBIR: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Demonstrate an understanding of the scope and importance of HCI systems across a range of application domains	core
	UTRECHT: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Consider recent developments within HCI (e.g., novel sensor-based interfaces) and specify the implications of those developments for the discipline,	core
	UTRECHT: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Understand the psychological aspects underlying human behaviour that are relevant to HCI	core
	UTRECHT: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Understands the computing and information science aspects underlying system behaviour that are relevant to HCI	core
	UTRECHT: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Understand the potential dilemmas related to ethics (scientific integrity, privacy and security) in the research field of HCI.	core
	AAU: Vision, Graphics and	1-knowledge	2-understand	interaction	HMI	Have knowledge on an advanced level in interactive systems based on	core

	institution	level	bloom	domain	subdomain	name	election
	Interactive Systems					the highest international research in these areas	
	UTRECHT: Human Computer Interaction	1-knowledge	2-understand	interaction	HMI	Explain and advocating where and how human-centred design and user experience research fits within organizations, and how it needs to consider and influence organizational and business strategies.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	3-apply	interaction	HMI	Apply user-centered design methods to design, implement and test multimodal user interaction strategies	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	3-apply	interaction	HMI	Identify scientific problems and propose solutions within interactive systems	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	3-apply	interaction	HMI	Apply methods and tools for solving complex problems within the interactive system domain	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	interaction	HMI	Apply human centric design methodologies in the context of current and emerging interaction technologies such as virtual and augmented reality.	core
	UBIR: Human Computer Interaction	2-skill	3-apply	interaction	HMI	Apply knowledge of the psychology of the user, the social context of design, and the potentials and issues of next-generation interactive systems.	core
	UTRECHT: Human Computer Interaction	2-skill	3-apply	interaction	HMI	Implement prototype systems that support effective and efficient communication of HCI solutions.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	interaction	HMI	Analyse and apply state-of-the-art methods in Computer Graphics	core
	UCARDIFF: Artificial Intelligence	2-skill	4-analyse	interaction	HMI	Select and apply suitable methodologies for the conduct and analysis of a subjective experiment.	core
	UBIR: Human Computer Interaction	2-skill	4-analyse	interaction	HMI	Select and use research tools and methods used in HCI.	core
	UBIR: Human Computer Interaction	2-skill	4-analyse	interaction	HMI	Select appropriate HCI design methodologies and apply them in the solution of real world design problems	core
	UBIR: Human Computer Interaction	2-skill	4-analyse	interaction	HMI	Select appropriate methodologies for the evaluation of HCI systems and Implement these methodologies on real systems and analyse and discuss the results produced	core
	UTRECHT: Human Computer Interaction	2-skill	4-analyse	interaction	HMI	Critically analyse, define, and use a problem within the HCI domain and use this to formulate relevant appropriate research questions for either HCI educational, scientific, or engineering purposes,	core
	UTRECHT: Human	2-skill	4-analyse	interaction	HMI	Analyse the computing and information science aspects underlying system behaviour and	core

	institution	level	bloom	domain	subdomain	name	election
	Computer Interaction					apply these in HCI research and design,	
	UTRECHT: Human Computer Interaction	2-skill	4-analyse	interaction	HMI	Analyse the psychological aspects underlying human behaviour and apply these in HCI research and design,	core
	UTRECHT: Human Computer Interaction	2-skill	4-analyse	interaction	HMI	Analyse possible future HCI designs and methods, critically analyse their pros and cons, conduct a requirement analysis, and suggest implementation strategies, taking the latest HCI developments in consideration.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	interaction	HMI	Select and apply appropriate methods for solving a given problem within interactive systems and evaluate the results regarding their accuracy and validity	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	interaction	HMI	Identify scientific problems within control and auto computer vision, graphics and interactive systems and select and apply proper scientific theories, methods and tools for their solution	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	interaction	HMI	Develop and advance new analyses and solutions within interactive systems	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	5-evaluate	interaction	HMI	Evaluate and select among the scientific theories, methods, tools and general skills within the field of user interaction and, on a scientific basis, advance new analyses and solutions	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	interaction	HMI	Understand the complex nature of users and apply heuristics to create and evaluate inclusive and multimodal user experiences.	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	interaction	HMI	Evaluate competing proposals for interface design and implementation.	core
	UTRECHT: Human Computer Interaction	2-skill	5-evaluate	interaction	HMI	Appropriately utilise and interpret specialist professional literature relevant to HCI, using systematic reviews (e.g., PRISMA),	core
	UTRECHT: Human Computer Interaction	2-skill	5-evaluate	interaction	HMI	Discuss the findings of HCI research, relating it to the state of the art and relevant literature, and participating critically and constructively in the scientific debate,	core
	UTRECHT: Human Computer Interaction	2-skill	5-evaluate	interaction	HMI	Specify the relevance of such research for the resolution of questions and problems in the field of HCI, both from a research and a societal point of view,	core
	UTRECHT: Human Computer Interaction	2-skill	5-evaluate	interaction	HMI	Critically reflect on their own efforts as a researcher in the field of HCI and that of others from a societal perspective, including ethical perspectives such as privacy, scientific integrity, and information security.	core
	UTRECHT: Human	2-skill	5-evaluate	interaction	HMI	Conduct research with the prerequisite degree of care and ethical responsibility, and to process,	core

	institution	level	bloom	domain	subdomain	name	election
	Computer Interaction					analyse, interpret and evaluate empirical data or other findings obtained in the process appropriately,	
	AAU: Vision, Graphics and Interactive Systems	2-skill	6-create	interaction	HMI	Design, simulation, real-time implementation, test, evaluation, and documentation of systems within the field of user interaction	core
	UBIR: Human Computer Interaction	2-skill	6-create	interaction	HMI	Practical experience in HCI: usability and user experience, designing, building and evaluating interactive systems.	core
	UBIR: Human Computer Interaction	2-skill	6-create	interaction	HMI	Participate in a user-centred design process	core
	UTRECHT: Human Computer Interaction	2-skill	6-create	interaction	HMI	Make an essential contribution to the development and or application of scientific concepts and methods, predominantly in relation to research in HCI,	core
	UTRECHT: Human Computer Interaction	2-skill	6-create	interaction	HMI	Formulate a research design, which is appropriate for that research question and is in line with the HCI methodological and scientific standards,	core
	UTRECHT: Human Computer Interaction	3-disposition	-	interaction	HMI	Develop their own effective, performance-oriented methodology to enable them to perform independently in the field of Interaction Technology,	core
Integration							
RIA							
	UBATH: Robotics and Autonomous Systems	1-knowledge	1-remember	integration	RIA	Show awareness of intelligent systems design issues,	core
	UBATH: Robotics and Autonomous Systems	1-knowledge	1-remember	integration	RIA	Recognize and challenge advances in the state of the art of intelligent systems,	core
	ICL: Control Systems	1-knowledge	2-understand	integration	RIA	Fundamental concepts and principles underpinning control system theory and design, including those associated with linear and non-linear deterministic systems, stochastic systems, modelling, optimisation, control system design, on-line control.	Core
	ICL: Control Systems	1-knowledge	2-understand	integration	RIA	Information retrieval as a research technique,	core
	UBATH: Robotics and Autonomous Systems	1-knowledge	2-understand	integration	RIA	Demonstrate an understanding of current practice and developments in systems involving humans and intelligent machines,	core
	UPC: Automatic Control and Robotics	1-knowledge	2-understand	integration	RIA	Recognize and represent problems in the area by automatic and robotic techniques optimization, and then apply analytical methods and numerical resolution.	Core
	VUA: International Technology Law	1-knowledge	2-understand	integration	RIA	Explain their own well-founded opinion on the tasks and challenges for the law related to robots and artificial intelligence,	optional

	institution	level	bloom	domain	subdomain	name	election
	UBATH: Robotics and Autonomous Systems	2-skill	3-apply	integration	RIA	Use a range of established and new techniques to design robotic platforms	core
	ICL: Control Systems	2-skill	3-apply	integration	RIA	Solve control analysis and synthesis problems using appropriate statistical, frequency-response and state-space methods,	core
	ICL: Control Systems	2-skill	3-apply	integration	RIA	Apply control concepts and theory to the solution of control problems,	core
	ICL: Control Systems	2-skill	3-apply	integration	RIA	Apply computational principles and techniques to control problems,	core
	UPC: Automatic Control and Robotics	2-skill	4-analyse	integration	RIA	Select appropriate software and hardware elements to implement a solution in a system wardrobe.	Core
	ICL: Control Systems	2-skill	4-analyse	integration	RIA	Analyse and interpret computed results,	core
	UBATH: Robotics and Autonomous Systems	2-skill	5-evaluate	integration	RIA	Compare, contrast and evaluate practical robotic platform design techniques and technologies	core
	UBATH: Robotics and Autonomous Systems	2-skill	5-evaluate	integration	RIA	Critically evaluate examples of the design and deployment of intelligent systems,	core
	VUA: International Technology Law	2-skill	5-evaluate	integration	RIA	Critically reflect on the state of the law in the light of technical topics related to robots and artificial intelligence, and to formulate their own well-founded opinion in current academic debates in this field.	Optional
	UPC: Automatic Control and Robotics	2-skill	6-create	integration	RIA	Conduct research, development and innovation in the field of systems engineering, control and robotics, and as to direct he development of engineering solutions in new or unfamiliar environments, linking creativity, innovation and transfer of technology	core
	UBATH: Robotics and Autonomous Systems	2-skill	6-create	integration	RIA	Design, critically appraise and validate robotic systems hardware and platforms	core
	VUA: International Technology Law	2-skill	6-create	integration	RIA	Formulate their own well-founded opinion on the challenges posed by particular applications of robots and AI.	Optional
	UPC: Automatic Control and Robotics	2-skill	6-create	integration	RIA	Model, formulate and solve problems of control, taking into account its uncertainty, by fuzzy logic based controllers.	Core
	ICL: Control Systems	2-skill	6-create	integration	RIA	Model systems mathematically and apply relevant theory to study their properties and performance,	core
MAS							
	UB: Artificial Intelligence	1-knowledge	2-understand	integration	MAS	Understand the basic principles of the Multiagent Systems operation main techniques , and to know how to use them in the environment of an intelligent service or system.	Core
Unspecified domain							

	institution	level	bloom	domain	subdomain	name	election
	KTH: Machine Learning	1-knowledge	1-remember	-	-	Within the frames of the degree project identify the role of the scholarship and the engineer in the society,	core
	KTH: Machine Learning	1-knowledge	1-remember	-	-	Within the frame of the specific degree project identify which issues that need to be answered in order to observe relevant dimensions of sustainable development,	core
	SHEFFIELD: Computer Science with Speech and Language Processing	1-knowledge	1-remember	-	-	Identify material, from multiple published sources, relevant to a chosen topic, to comprehend and filter such material and from it synthesize principles or designs pertinent to a problem-solving project,	core
	UCARDIFF: Artificial Intelligence	1-knowledge	1-remember	-	-	Appreciation of opportunities for career development	core
	KTH: Machine Learning	1-knowledge	2-understand	-	-	Show advanced knowledge within the main field of study and the specialisation for the education, including advanced insight into current research and development work,	core
	KTH: Machine Learning	1-knowledge	2-understand	-	-	Show methodological knowledge within the main field of study and the specialisation for the education,	core
	ICL: Artificial Intelligence	1-knowledge	2-understand	-	-	Match problems to tools and techniques most suitable for solving them,	core
	UPC: Computer Vision	1-knowledge	2-understand	-	-	Understand advanced knowledge in the area, and put forward innovative ideas.	core
	SHEFFIELD: Computer Science with Speech and Language Processing	1-knowledge	2-understand	-	-	Expose technical information systematically and clearly	core
	SHEFFIELD: Computer Science with Speech and Language Processing	1-knowledge	2-understand	-	-	Comprehend, summarise, synthesize and properly cite material as part of an integrated argument,	core
	UB: Artificial Intelligence	1-knowledge	2-understand	-	-	Argue the reasons that explain or justify situations, projects, proposals, reports and scientific-technical surveys	core
	UPF: Intelligent Interactive Systems	1-knowledge	2-understand	-	-	Communication skills in the context of research,	core
	UPF: Intelligent Interactive Systems	1-knowledge	2-understand	-	-	Understand the context and role of professional researchers, including the tasks of writing and reviewing papers and projects.	core
	ICL: Artificial Intelligence	1-knowledge	2-understand	-	-	Research skills, including time management, research effectiveness, personal effectiveness, writing skills, presentation and communication skills, technical presentation and critical reading of literature.	core

	institution	level	bloom	domain	subdomain	name	election
	UMAAS: Business Intelligence and Smart Services	1-knowledge	2-understand	-	-	Communicate in a clear and effective manner	core
	VUA: International Technology Law	1-knowledge	2-understand	-	-	Map a research area, draft research questions appropriate for a master thesis	core
	TUM: Biomedical Computing	1-knowledge	2-understand	-	-	Present their findings	core
	TUM: Biomedical Computing	1-knowledge	2-understand	-	-	Convincingly present their ideas and findings both verbally and in writing.	core
	EPFL: Data Science	1-knowledge	2-understand	-	-	Write a scientific or technical report.	core
	EPFL: Data Science	1-knowledge	2-understand	-	-	Summarise an article or a technical report.	core
	SHEFFIELD: Computer Science with Speech and Language Processing	1-knowledge	2-understand	-	-	Summarise and present coherently an argument	core
	USG: Computational Linguistics	1-knowledge	2-understand	-	-	Know what methodological and practical tool basis to start from if they want to do research or technological development in a particular subarea.	core
	UCAMB: Machine Learning and Machine Intelligence	1-knowledge	2-understand	-	-	Understand how to define and conduct a research project.	core
	UEDIN: Cognitive Science	1-knowledge	2-understand	-	-	Discuss a research topic in detail leading to new hypotheses	core
	UEDIN: Cognitive Science	1-knowledge	2-understand	-	-	Present their work orally and visually, with demonstration of working artifacts where appropriate	core
	ICL: Control Systems	1-knowledge	2-understand	-	-	Understand the literature so personal knowledge and skills can be kept up-to-date,	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	3-apply	-	-	Communicate research-based knowledge and discuss professional and scientific problems with both peers and non-specialists	core
	POLIMI: Computer Science and Engineering	2-skill	3-apply	-	-	Use information technology to plan, design, manage, decide, produce and supervise,	core
	TUM: Biomedical Computing	2-skill	3-apply	-	-	Use document systems in written form	core
	UCARDIFF: Artificial Intelligence	2-skill	3-apply	-	-	Clear and efficient communication of complex ideas, principles and theories by oral, written and practical means, to a range of audiences	core

	institution	level	bloom	domain	subdomain	name	election
	EPFL: Data Science	2-skill	3-apply	-	-	Use both general and domain specific IT resources and tools	core
	SHEFFIELD: Computer Science with Speech and Language Processing	2-skill	3-apply	-	-	Function in a computer-based learning environment, making full use of email, the internet and electronic media,	core
	UB: Artificial Intelligence	2-skill	3-apply	-	-	Solve the analysis of information needs from different organizations, identifying the uncertainty and variability sources	core
	UB: Artificial Intelligence	2-skill	3-apply	-	-	Solve the decision making problems from different organizations, integrating intelligent tools.	core
	UB: Artificial Intelligence	2-skill	3-apply	-	-	Effective use of information resources: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.	core
	UPC: Automatic Control and Robotics	2-skill	3-apply	-	-	Effective use of information resources: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.	core
	UPC: Computer Vision	2-skill	3-apply	-	-	Solve problems in new or little-known situations within broader (or multidisciplinary) contexts related to the field of study.	core
	UPC: Computer Vision	2-skill	3-apply	-	-	Use acquired knowledge as a basis for originality in the application of ideas, often in a research context.	core
	KTH: Machine Learning	2-skill	3-apply	-	-	Do a library search within the subject	core
	KTH: Machine Learning	2-skill	3-apply	-	-	Write a technical report within the subject	core
	VUA: International Technology Law	2-skill	3-apply	-	-	Access relevant academic research resources	core
	VUA: International Technology Law	2-skill	3-apply	-	-	Pursue a functional writing strategy.	core
	TUM: Biomedical Computing	2-skill	3-apply	-	-	Recognise and resolve misunderstandings between different parties involved in the creative process.	core
	UCAMB: Machine Learning and Machine Intelligence	2-skill	3-apply	-	-	Presentation skills through presenting their research in progress,	core
	UCAMB: Machine Learning and Machine Intelligence	2-skill	3-apply	-	-	Methodological and other technical skills necessary for research in their chosen area,	core

	institution	level	bloom	domain	subdomain	name	election
	UEDIN: Cognitive Science	2-skill	3-apply	-	-	Search and use appropriately databases of scientific literature	core
	UEDIN: Cognitive Science	2-skill	3-apply	-	-	Use existing research literature or other prior work to justify choices in experimental design, theoretical goals, and and or implementation	core
	UEDIN: Cognitive Science	2-skill	3-apply	-	-	Discuss and solve conceptual problems which arise during the investigation	core
	ICL: Control Systems	2-skill	3-apply	-	-	Write effective technical reports	core
	ICL: Control Systems	2-skill	3-apply	-	-	Communicate effectively, as a result of clear and precise thinking, using presentations, web-pages and written reports,	core
	ICL: Control Systems	2-skill	3-apply	-	-	Use Information and Communications Technology,	core
	UTRECHT: Human Computer Interaction	2-skill	3-apply	-	-	Clearly communicate research findings in both written and oral form to an audience of specialists as well as people otherthan professional experts within an international context,	core
	UPC: Computer Vision	2-skill	4-analyse	-	-	Analyse advanced knowledge in the area, and put forward innovative ideas.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	4-analyse	-	-	Analyse results and draw conclusions on a scientific basis	core
	KTH: Machine Learning	2-skill	4-analyse	-	-	Integrate tools to design computer programs that show different properties that are expected by an intelligent system	core
	KTH: Machine Learning	2-skill	4-analyse	-	-	Integrate knowledge critically and systematically and identify the need of additional knowledge	core
	UB: Artificial Intelligence	2-skill	4-analyse	-	-	Analyse and solve complex technical problems	core
	UPF: Intelligent Interactive Systems	2-skill	4-analyse	-	-	Search and distinguish the types of information sources and their impact,	core
	UPF: Intelligent Interactive Systems	2-skill	4-analyse	-	-	Selection of the techniques and methods that can be applied to different types of research work,	core
	ICL: Artificial Intelligence	2-skill	4-analyse	-	-	Conduct detailed literature searches,	core
	TUM: Biomedical Computing	2-skill	4-analyse	-	-	Argue with specific objectives in mind and to deal open-mindedly with criticism.	core
	UBATH: Robotics and Autonomous Systems	2-skill	4-analyse	-	-	Effectively analyse and communicate within a technical team structure.	core
	VUA: International Technology Law	2-skill	4-analyse	-	-	Analyse legal academic texts from a methodical perspective, and identify methodical problems.	core

	institution	level	bloom	domain	subdomain	name	election
	UEDIN: Cognitive Science	2-skill	4-analyse	-	-	Outline project and research management issues and potential legal, social, ethical or professional issues	core
	TUM: Biomedical Computing	2-skill	5-evaluate	-	-	Perform self-guided literature research and critical reading of scientific publications, define and evaluate experiments and prepare documents according to scientific standards.	core
	KTH: Machine Learning	2-skill	5-evaluate	-	-	With a holistic approach, critically, independently and creatively identify, formulate, analyse, assess and deal with complex phenomena and issues, even with limited information,	core
	KTH: Machine Learning	2-skill	5-evaluate	-	-	In speech and writing clearly report and discuss their conclusions and the knowledge and arguments on which they are based,	core
	KTH: Machine Learning	2-skill	5-evaluate	-	-	Within the frames of the degree project assess and show awareness of ethical aspects of research and development work, with respect to methods, working methods and results of the degree project	core
	SHEFFIELD: Computer Science with Speech and Language Processing	2-skill	5-evaluate	-	-	Present and defend a substantial piece of work, to engage with enquirers and respond effectively to questions.	core
	UB: Artificial Intelligence	2-skill	5-evaluate	-	-	Evaluate and analyse on a reasoned and critical way about situations, projects, proposals, reports and scientific-technical surveys	core
	UMAAS: Business Intelligence and Smart Services	2-skill	5-evaluate	-	-	Demonstrate academic reasoning and critical thinking based on evidence and theory	core
	ICL: Artificial Intelligence	2-skill	5-evaluate	-	-	Integrate and evaluate information from multiple and diverse sources,	core
	UCARDIFF: Artificial Intelligence	2-skill	5-evaluate	-	-	Critical appraisal of your own and other's work through written and verbal means	core
	VUA: International Technology Law	2-skill	5-evaluate	-	-	Understand and critically evaluate the traditional legal approaches in the areas covered by these disruptive technologies.	optional
	UEDIN: Cognitive Science	2-skill	5-evaluate	-	-	Select literature appropriate for the review subject , and critically evaluate research literature in the chosen area	core
	UEDIN: Cognitive Science	2-skill	5-evaluate	-	-	Evaluate and search traditional library resources	core
	UEDIN: Cognitive Science	2-skill	5-evaluate	-	-	Critically evaluate research literature or other prior work appropriate for their project subject	core
	UEDIN: Cognitive Science	2-skill	5-evaluate	-	-	Critically evaluate the investigation, including design choices made	core

	institution	level	bloom	domain	subdomain	name	election
	UTRECHT: Human Computer Interaction	2-skill	5-evaluate	-	-	Evaluate their own learning and development process, and to motivate and correct themselves during their studies where necessary,	core
	UPC: Computer Vision	2-skill	6-create	-	-	Synthesise advanced knowledge in the area, and put forward innovative ideas.	core
	AAU: Vision, Graphics and Interactive Systems	2-skill	6-create	-	-	Formulate and explain scientific hypotheses and results achieved through scientific work	core
	KTH: Machine Learning	2-skill	6-create	-	-	Plan and with adequate methods carry out qualified assignments within given frames, and evaluate this work,	core
	UPF: Intelligent Interactive Systems	2-skill	6-create	-	-	Formulate research questions,	core
	KUL: Artificial Intelligence	2-skill	6-create	-	-	Formulate research goals, determine trajectories that achieve these goals, collect and select information relevant to achieve the research goals and interpret collected information on the basis of a critical research attitude.	core
	ICL: Control Systems	2-skill	6-create	-	-	Management and communication skills, including problem definition, project design, decision processes, written reports, scientific publications.	core
	ICL: Artificial Intelligence	2-skill	6-create	-	-	Work within and contribute to a team, apply management skills such as coordination, project design and evaluation and decision processes as applied in software engineering,	core
	ICL: Artificial Intelligence	2-skill	6-create	-	-	Manage resources and time,	core
	VUA: International Technology Law	2-skill	6-create	-	-	Develop a functional analytical structure	core
	UB: Artificial Intelligence	2-skill	6-create	-	-	Lead, plan and supervise multidisciplinary teams.	core
	ICL: Control Systems	2-skill	6-create	-	-	Plan, conduct and report on a programme of original research.	core
	ICL: Control Systems	2-skill	6-create	-	-	Formulate problem definitions, design and evaluate projects using objective criteria,	core
	UEDIN: Cognitive Science	2-skill	6-create	-	-	Deliver a detailed and balanced report on a research topic	core
	UEDIN: Cognitive Science	2-skill	6-create	-	-	Develop a structured project proposal	core
	UEDIN: Cognitive Science	2-skill	6-create	-	-	Conduct a programme of work in further investigation of issues related to the topic	core
	ICL: Control Systems	2-skill	6-create	-	-	Define problems and design and manage associated projects,	core

	institution	level	bloom	domain	subdomain	name	election
	ICL: Control Systems	2-skill	6-create	-	-	Manage resources and time,	core
	AAU: Vision, Graphics and Interactive Systems	3-disposition	-	-	-	Manage work and development situations that are complex, unpredictable and require new solutions.	core
	AAU: Vision, Graphics and Interactive Systems	3-disposition	-	-	-	Independently initiate and implement discipline-specific and interdisciplinary cooperation and assume professional responsibility.	core
	AAU: Vision, Graphics and Interactive Systems	3-disposition	-	-	-	Independently take responsibility for own professional development and specialization	core
	AAU: Vision, Graphics and Interactive Systems	3-disposition	-	-	-	Take responsibility for own professional development and specialization.	core
	AAU: Vision, Graphics and Interactive Systems	3-disposition	-	-	-	Work according to a scientific method and present results in the form of a scientific article and at a seminar or scientific conference	core
	SHEFFIELD: Computer Science with Speech and Language Processing	3-disposition	-	-	-	Individual initiative, self-motivation and problem-solving skills, fostered through the selection and taking through to completion of a practical, problem-solving project, leading to a dissertation and poster session.	core
	UB: Artificial Intelligence	3-disposition	-	-	-	Respect the legal rules and deontology in professional practice.	core
	VUA: International Technology Law	3-disposition	-	-	-	Identify and avoid plagiarism	core
	TUM: Biomedical Computing	3-disposition	-	-	-	Work in multi-national and multi-cultural teams	core
	UCARDIFF: Artificial Intelligence	3-disposition	-	-	-	Undertake independent study and critical reflection	core
	UPC: Automatic Control and Robotics	3-disposition	-	-	-	Work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and responsibly and making commitments in view of the resources that are available.	core
	ICL: Artificial Intelligence	3-disposition	-	-	-	Transfer techniques and solutions from one area to another,	core
	ICL: Artificial Intelligence	3-disposition	-	-	-	Learn independently with open mindedness and critical enquiry,	core
	ICL: Artificial Intelligence	3-disposition	-	-	-	Learn effectively for the purpose of continuing professional development.	core
	UPC: Computer Vision	3-disposition	-	-	-	Accept responsibilities for information and knowledge management.	core
	UB: Artificial Intelligence	3-disposition	-	-	-	Work in an interdisciplinary team, whether as a member or as a leader, with the aim of contributing to projects pragmatically and	core

	institution	level	bloom	domain	subdomain	name	election
						responsibly and making commitments in view of the resources that are available.	
	UB: Artificial Intelligence	3-disposition	-	-	-	Be motivated for professional development	core
	UB: Artificial Intelligence	3-disposition	-	-	-	Meet new challenges and for continuous improvement	core
	UB: Artificial Intelligence	3-disposition	-	-	-	Work in situations with lack of information.	core
	UPC: Automatic Control and Robotics	3-disposition	-	-	-	Sustainability and social commitment: Being aware of and understanding the complexity of the economic and social phenomena typical of a welfare society, and being able to relate social welfare to globalisation and sustainability and to use technique, technology, economics and sustainability in a balanced and compatible manner.	core
	UPC: Computer Vision	3-disposition	-	-	-	Continue the learning process, to a large extent autonomously	core
	UPC: Automatic Control and Robotics	3-disposition	-	-	-	Reason and act based on the so-called culture of safety and sustainability	core
	ICL: Control Systems	3-disposition	-	-	-	Learn independently with open-mindedness and critical enquiry,	core
	ICL: Control Systems	3-disposition	-	-	-	Learn effectively for the purpose of continuing professional development	core
	UTRECHT: Human Computer Interaction	3-disposition	-	-	-	Function effectively and creatively as part of possibly multidisciplinary teams, lead such teams, and communicate effectively with clients, end-users and other stakeholders (e.g.,engineers),	core
	UTRECHT: Human Computer Interaction	3-disposition	-	-	-	Have a realistic idea of the career opportunities after graduating, and of the skills that they need to successfully start a career.	core
	UBATH: Robotics and Autonomous Systems	3-disposition	-	-	-	Show originality in tackling and solving problems and dealing with inter-disciplinary issues.	core
	UMAAS: Business Intelligence and Smart Services	3-disposition	-	-	-	Be more aware of the expectations of the labor market and have identified ways to improve their own employability.	core
	VUA: International Technology Law	3-disposition	-	-	-	Be aware of the contextual demands (not to stifle technological development by enacting restrictive legislation, while at the same time protecting fundamental rights and freedoms of a democratic society) law has to deal with,	optional
	TUM: Biomedical Computing	3-disposition	-	-	-	Understand decision-making processes within a corporate context and make valuable contributions to them.	core
	UBATH: Robotics and Autonomous Systems	3-disposition	-	-	-	Understand the interaction of different skills when analysing unfamiliar multi-disciplinary engineering problems	core

	institution	level	bloom	domain	subdomain	name	election
	VUA: International Technology Law	3-disposition	-	-	-	Explain their own well-founded opinion on the tasks and challenges for the law.	optional
	UB: Artificial Intelligence	3-disposition	-	-	-	Assimilate and integrate the changing economic, social and technological environment to the objectives and procedures of informatic work in intelligent systems.	core
	EPFL: Data Science	3-disposition	-	-	-	Evaluate one's own performance in the team, receive and respond appropriately to feedback.	core
	EPFL: Data Science	3-disposition	-	-	-	Give feedback (critique) in an appropriate fashion.	core
	EPFL: Data Science	3-disposition	-	-	-	Demonstrate critical thinking	core
	TUM: Biomedical Computing	3-disposition	-	-	-	Appraise the social, economic, organisational, psychological and legal effects of informatics on its environment.	core
	VUA: International Technology Law	3-disposition	-	-	-	Assess the legal and societal aspects of a problem in an integrated way and critically reflect on possible approaches and solutions,	optional
	UMAAS: Business Intelligence and Smart Services	3-disposition	-	-	-	Successfully work together and manage tasks in interdisciplinary innovation teams	core
	ICL: Control Systems	3-disposition	-	-	-	Transfer techniques and solutions from one discipline to another,	core

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:
- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696, or
- by electronic mail via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

KJ-09-21-148-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/773615
ISBN 978-92-76-37417-6