LIST OF RESEARCH PROJECTS – CALL 39th CYCLE
PHD PROGRAM IN COMPUTER SCIENCE

A1-Visual Anomaly Classification and Segmentation in Volumetric Data

Advisor: **prof. Oswald Lanz**
Co-advisor: **to be defined**

Project Description:
Anomaly detection aims at identifying anomalous patterns that are different from those seen in regular instances. Diffusion models have recently been proposed for anomaly detection in images [Wyatt et al, CVPR'22], another promising direction is to employ vision-language pretrained models for classification and segmentation of anomalies with descriptive labels and visual prompts [Jeong et al, CVPR'23]. Recent trends include generating synthetic images to complement training datasets [VISION challenge, CVPR'23].
Anomaly detection in three-dimensional data such as computed tomography and magnetic resonance imaging is less explored but has important applications in the medical and industrial domain, among others. Also, video clips can be viewed as space-time volumes of pixel data. When dealing with volumetric data, conventional 2D Convolutional Neural Networks (CNNs) can be applied to volume slices. Resulting architectures are parameter efficient and computationally cheap, but by design they cannot capture three-dimensional features. 3D CNNs are designed to learn three-dimensional features but incur in higher computation costs and have more parameters thus higher risk of overfitting when trained on small datasets. Pseudo-3D CNNs such as [Sudhakaran et.al, TPAMI'23], learn spatial-temporal features more efficiently and with fewer parameters. Others employ similar ideas in a Vision Transformer architecture [Zhang et.al, MM'21]. While these were introduced for video tasks, we have evidence that a reformulation for semantic segmentation of three-dimensional data is promising. In this PhD project, initial studies could be set out to explore similar ideas in diffusion models for classification, segmentation and generation of volumetric data.

Required skills:
The PhD research project resides at the intersection of computer vision, computer graphics and machine learning. The candidate has undertaken computer vision and deep learning courses with proficiency. Ideally the MSc thesis is in the field of deep learning and computer vision. Solid programming skills and experience with deep learning frameworks such as pytorch are requested.

A2-Neural Radiance Fields for Novel-Scene Synthesis

Advisor: **prof. Oswald Lanz**
Co-advisor: **to be defined**

Project Description:
Neural Radiance Fields (NeRFs) provide a modern framework for synthesizing novel views of complex scenes and objects. Given a set of images with known camera poses, an implicit representation of the scene's geometry and appearance gets decoded into the weights of a neural network. The network can then be queried to predict the color of a pixel capturing a light ray through the scene, and a novel view of the scene can be assembled pixel-by-pixel using the network.
While amazing progress has been achieved since the seminal work was published at ECCV 2020, there is still much to explore to unleash the full potential of NeRFs for flexible synthesis. Editing geometry and appearance separately, which is supported by-design in classical 3D reconstruction and rendering, enables creating novel scenes but in NeRF disentangling their representations is non-trivial. Going beyond color to describe a scene objects' appearance is key for photo-realistic relighting and relies on decoding materiality such as metalness, roughness and glossiness, which requires finer modeling in NeRF. Conventional NeRF has no memory, each scene is built from scratch for each object while there are evident advantages if representations of similar scenes can be shared. Insertion of novel objects in existing scenes is trivial in classical rendering, but here requires a compositional design of NeRF. Another under-explored topic is handling time in NeRF to synthesize novel-view videos of deformable objects and dynamic scenes. The

project has access to SOTA technology from the research partner Covision Lab https://www.covisionmedialab.com/.

Required skills:
The PhD research project resides at the intersection of computer vision, computer graphics and machine learning. The candidate has undertaken computer vision and deep learning courses with proficiency. Ideally, the MSc thesis would be in the field of deep learning and computer vision, providing the background on one aspect related to the project. Solid programming skills and experience with deep learning frameworks such as pytorch are requested. Knowledge of the principles of computer graphics is a plus.

A3 -Video Search and Retrieval with Multimodal Prompts

Advisors: **prof. Oswald Lanz**
Co-advisor: **prof. Markus Zanker**

Project Description:
Video Search and Retrieval using natural language queries has attracted increasing interest due to its relevance in real-world applications, from intelligent access in private media galleries to web-scale video search. Learning the cross-similarity of video and text in a joint embedding space is the dominant approach. Large Language Models (LLM) trained on massive scale natural language texts provide powerful query embeddings that can capture context information. Vision Transformers (ViT) are the promising building block to establish similar foundation models for vision. Indeed, the recently released Segment Anything Model (SAM) utilizes ViT embeddings for image encoding. Another remarkable development was Contrastive Language-Image Pretraining (CLIP) to align image and text embeddings. And indeed, SAM utilizes CLIP embeddings for free-text prompt encoding.
Aim of the PhD study could be to explore on the role of time in video search and retrieval with multimodal prompts, and on how temporal modeling can be realized in VSR architectures. A scenario of interest could be instructional videos, where typically a sequence of actions is performed and paired with a narration that can be transcribed into text. Search and retrieval could be prompted with free-text and an image of a tool or object of interest. Related recent works in this context are Zhou et al, CVPR'23 and Zhong et al, CVPR'23. The Visual Computing and Learning group has recently published works on action recognition and anticipation, text-video retrieval and video question answering at TPAMI, CVPR, ACM MM, ICMR, ICPR, ICIP.

Required skills:
The candidate has undertaken computer vision and natural language processing studies at university courses with proficiency. Ideally, the MSc thesis would be in the field of deep learning and computer vision or natural language processing, providing the background on one aspect related to the project. Solid programming skills and experience with deep learning frameworks such as pytorch are requested.

A4 -Explanations for a Human-centric AI

Advisor: **prof. Markus Zanker**
Co-advisor **prof. Roberto Confalonieri (University of Padova)**

Project Description:
In recent years, we have witnessed the advent of increasingly accurate and powerful algorithms and techniques to personalize the content presented to users. This capability to effectively assess users' tastes and interests in information is primarily based on the collaborative recommendation paradigm (often exploiting machine learning techniques) without taking enormous amounts of knowledge, both structured and unstructured, describing the domain of interest into account. Therefore, this project will focus on the study of the aspects related to the exploitation of external and explicit knowledge sources to feed a recommendation engine and how they can aim at beyond the accuracy objectives in contrast to traditional recommendation algorithms. It will be investigated how knowledge encoded in ontological and logical knowledge bases, knowledge graphs, and/or the semantics arising from the analysis of semi-structured textual sources can lead to more novel and diverse recommendations, as well as enhance them with explanations of the recommended elements. Finally, understanding the impact of explanations on the human users is another important aspect of this PhD project as this is partially overlooked in the literature.

Required skills:
skills in data analytics, recommender systems, machine learning, knowledge graphs.

A5-Building AI Assistants for Startups Using Large Language Models and Prompt Engineering

Advisor: **prof. Xiaofeng Wang**
Co-advisor: **dr. Eduardo Martins Guerra**

Project Description:
Most startups operate with limited resources and experience. AI technologies enable them to accomplish many tasks under these constraints. The recent advance of large language models (LLMs, e.g., ChatGPT of OpenAI, Bing of Microsoft) offers new opportunities to support startup endeavor. Given the nascent nature of LLMs, how they could be utilized to support startups is yet to be investigated.
Prompt engineering is believed to be at the core of the effective use of LLMs. A prompt refers to a set of text instructions crafted to program and customize LLMs for the desired interaction. Prompt engineering is the means by which LLMs are programmed via prompts. Prompt engineering skills are vital for fully leveraging LLMs, but they do not come naturally and need to be learned. This can pose a challenge to startup teams, who often operate on tight resources and have many other critical tasks to attend to.
This research project aims to facilitate startups in utilizing LLMs as AI assistants through prompt engineering. The research will employ a design science research approach. Two main artifacts are envisioned: 1) a ``startup prompt book'', a knowledge base that contains a set of rules that transform intuitively expressed questions and requests from startup teams into prompt-engineered questions as input to LLMs; and 2) a ``prompt engine'' that can automate the prompt engineering process and choreograph conversations with LLMs. These two artifacts are at the core of an AI assistant that can become a valuable resource for a startup team.

Required skills:
- Software engineering general knowledge;
- Understanding of AI-assisted tools and techniques (experience in chatbots and natural language processing is preferred but not mandatory);
- Basic knowledge on business development in startups;
- Conduction of empirical studies using qualitative and quantitative research methods (e.g., interviews, surveys); and
- Good communication and scientific writing skills.

A6-Graph Data Management with Linear Algebra

Advisor: **prof. Werner Nutt**
Co-advisor: **dr. Julien Corman**

Project Description (Max 250 words):
Graphs arise naturally when modeling social or traffic networks, molecules, or general world knowledge. While linear algebra operations over real or complex numbers are central in processing large data sets, specifically in data science and artificial intelligence, it is less known that many data analysis techniques over graphs can be expressed using linear algebra over a wide class of algebraic structures that are known as semirings.
In mathematics and computer science researchers have come up with techniques to efficiently execute linear algebra operations over these structures. It is not clear, however, to which extent and how linear algebra over semirings can be integrated into existing data management techniques.
The goal of this PhD project is to contribute to this goal. The following are examples of research questions that arise in this context:

- What is the scope of questions about graphs that can be formulated in this way?
- How can linear algebra over semirings be embedded in larger declarative languages to satisfy the needs of applications? What is the expressivity of such languages?
- How do properties of the language depend on the properties of the semiring employed?
- What algorithms allow one to execute such queries efficiently? How can query execution be supported by auxiliary structures such as indexes?

Required skills:
In general, applicants for this project are expected to have some acquaintance with logic and algebra. They should feel at ease with abstract mathematical thinking and mathematical proofs. Furthermore, good knowledge of data structures and algorithms is expected.

A7-Process Mining on Object Networks

Advisor: **prof. Marco Montali**
Co-advisor: **prof. Diego Calvanese**

Project Description:
Business process management (BPM) is a well-assessed discipline at the intersection between operations management, computer science, and software and systems engineering. By combining model-driven engineering and data science, process mining techniques are nowadays being used by a plethora of organisations to improve processes based on the factual event data recorded within the organisation.
Traditionally, processes are modelled, executed, and mined by focusing on a single notion of "case", describing the main process subject. This is completely inadequate in widespread, real-life scenarios where multiple, interrelated objects co-evolve through the execution of one or more processes. Such object-centric processes present a number of key, foundational open challenges that we want to investigate in this PhD project. Specifically, we want to attack three interconnected, open problems:
1) The logs generated by case-centric processes are flat, sets of traces. Object-centric processes instead call for representing networks of objects and events, which need to be extracted from data sources that only represent them implicitly (think, e.g., at ERP/CRM systems and their underlying databases). Novel techniques are needed to extract and represent such object/event networks and their corresponding domain knowledge.
2) Novel formalisms and techniques from artificial intelligence (in particular knowledge representation and reasoning) must be developed to model and reason upon objectcentric processes, considering at once data, actions, control-flow, and their mutual interconnections.
3) Algorithms to efficiently analyse object/event networks and semi-automatically discover object-centric process models able to properly reconstruct the generated logs are missing, and need to be investigated, implemented, and validated on real life data.

Required skills:
The student is expected to have a general background in computer science, and in particular in the object-oriented paradigm, relational databases, and artificial intelligence. The ideal candidate should have also a good background in formal methods, and good programming abilities. The PhD project can be developed along different directions, deciding with the student which of the three illustrated problems to attack, and whether to do so in a foundational or applied way (or, even better, a mixture thereof).

A8 - Ontology-driven Belief Propagation for Cybersecurity

Advisor: **prof. Diego Calvanese**
Co-advisor: **dr. Mattia Fumagalli**

Project Description:
Many complex application scenarios, such as risk propagation and more in general cybersecurity, require combining and reasoning upon different forms of knowledge, specifically structural knowledge about a domain of interest and probabilistic knowledge about the relations that exists between objects and events, such as causality, correlation, participation, or parthood. Different formalisms have been developed over the years to represent the different forms of knowledge, such as ontology languages (relying on variants of Description Logics) to represent structural knowledge, and Bayesian networks to represent probabilistic knowledge. However, it is still open how to properly integrate such formalism in a coherent setting that allows one to represent, reason upon, and query the integrated forms of knowledge in a uniform and coherent manner. In this PhD project, we aim at developing such a general framework that combines an ontology language with a Bayesian network, and that is based on a logic to reason upon and query a

Bayesian network. The framework will be applied and evaluated on the cybersecurity domain, and specifically on the problem of risk propagation.

Required skills:
The student is expected to have a general background in computer science, and in particular in discrete mathematics and artificial intelligence. The ideal candidate should have also agood background in logic, and good programming skills. The PhD project can be developedalong different directions, deciding with the student on which of the challenges to focus,and whether to do so in a foundational or applied way (or, even better, a mixture thereof).

A9 - Learning Mappings in Virtual Knowledge Graphs

Advisor: **prof. Diego Calvanese**
Co-advisor: **dr. Davide Lanti**

Project Description:
Virtual Knowledge Graphs (VKGs, also known as Ontology-based Data Access), which provide a framework for flexible and efficient management of large amounts of richly structured data. In VKGs, the knowledge about a domain of interest is encoded in an ontology, and declarative mappings relate the classes and properties of the ontology to actual data sources. Through the ontology and the mappings, the data at the sources is exposed as a (virtual) knowledge graph, which can be queried by users. A key issue in the adoption of VKG-based solutions is the design of the mapping layer, which is a highly complex task that requires a good understanding of the domain of interest and deep knowledge of the VKG based approach. Such activity is still carried out with substantial manual effort. The aim of the PhD research project is to develop different machine learning techniques (e.g., clustering, pattern mining, but also techniques leveraging Large Language Models) to discover/learn mappings in an automatic or semi-automatic ways. The developed techniques will have to rely both on schema-level information (schema-driven mapping discovery) and on the actual data stored in data sources (data-driven mapping discovery), and may require phases of interaction with users. The developed techniques will be implemented and tested on state-of-the-art VKG systems and deployed in the context of real-world use cases.

Required skills:
The student is expected to have a general background in computer science, and in particular in databases, discrete mathematics, and artificial intelligence. The ideal candidate should have also a good background in logic, and good programming skills. The PhD project can be developed along different directions, deciding with the student on which of the challenges to focus, and whether to do so in a more foundational or more applied way (or, even better, a mixture thereof).

A10 - Deep Learning for the Analysis of 3D Medical Images

Advisor: **prof. Giuseppe Di Fatta**
Co-advisor: **to be defined**

Project Description:
This project intends to study, develop and apply advanced Deep Learning methods, such as 3D Convolutional Neural Networks (CNN), for the analysis of volumetric medical images, including magnetic resonance images of the brain and 3D images of other human organs.
Accurate segmentation of 3D medical image is a critical step towards disease diagnosis. For example, in neurodegenerative diseases the morphological changes in the brain caused by the disease can be used to support more accurate and earlier diagnosis. A stroke can cause lasting brain damage that can be detected and used for a diagnosis. A database of several thousand human brain images of dementia patients as well of healthy subjects is already available. More data sources and applications will be considered during the project.

Required skills:
This project requires a strong interest in Machine Learning, Deep Learning and image processing. General programming skills in any language (preferably Python) are essential, as well as a good understanding of

the fundamental programming paradigms (imperative, procedural, object-oriented and functional). Good communication kills and good knowledge of the English language for technical report writing and verbal communication are also required.

A11 - Multi-task Learning in Deep Neural Networks

Advisor: **prof. Giuseppe Di Fatta**
Co-advisor: **prof. Giuseppe Nicosia**

Project Description:
In most Machine Learning (ML) approaches, the trained model is specialised on a single task and cannot be adopted to solve any other problem. In contrast, Multi-task Learning (MTL) is an ML approach in which a model is trained to solve multiple tasks simultaneously. This is similar to the learning process in humans, who learn general skills useful to multiple tasks: e.g., hand dexterity is useful to solve many tasks and is improved by learning many tasks at the same time. In recent years, MTL has been shown to be particularly effective in generating better generalised models that take advantage of the similarities and differences across tasks. In this PhD project MTL methods will be investigated to identify and apply novel approaches for Deep Neural Networks. The overarching aim of this project is to contribute to the theory as well as applications with an effective use of MTL in combination with other methods such as Deep Learning, Deep Neuroevolution, non-linear optimization, sensitivity analysis for explainable AI. Multi-task Deep Learning will be applied to some classic and to more recent testbeds for Deep Learning (e.g., CIFAR-100, Atari games, XTREME, StarCraftII) as well as real-world problems, such as the prediction of neurodegenerative diseases (dementia) from brain images or synthetic motor control for modelling rich and diverse motor behaviour across multiple tasks at humanoid scale.

Required skills:
This project requires a strong interest in Machine Learning, and, in particular, in Deep Learning. A good understanding of the basic Mathematics for engineering and computer science, including Linear Algebra, Probability and Calculus, is required. General programming skills in any language (preferably Python) are essential, as well as a good understanding of the fundamental programming paradigms (imperative, procedural, object-oriented and functional). Good communication kills and good knowledge of the English language for technical report writing and verbal communication are also required.

A12 - Analyzing time series with contextual data

Advisor: **dr. Anton Dignös**
Co-advisor: **prof. Johann Gamper**

Project Description:
This project is in the area of time series and sensor data, which nowadays occur in huge amounts in almost all application domains, e.g., scientific experiments, Industry 4.0, IoT, traffic monitoring, health care or precision agriculture to name a few. Hence, advanced solutions to support the processing and analysis of such data are of utmost importance to take full advantage of the available data for decision making.
While most of the existing solutions for processing time series data assume clean data and focus on specific analysis tasks over the data alone, the investigation of storing and processing time series data together with contextual data has been largely neglected. Contextual data is often essential to describe, characterize and understand many behavioral patterns in the time series, hence can significantly boost the analysis process. For instance, in the manufacturing domain time series data are collected from sensors. The type and properties (e.g., sensitivity or precision) of a sensor is contextual information of the produced signal and may have an impact on the shape of a signal. Moreover, properties of sensors might change over time, which makes accurate data analysis very challenging.
In this context, this PhD project focuses on the design, modelling, and implementation of techniques and algorithms that allow to link heterogeneous contextual data with the time series and process them.

Required skills:
The required skills for this PhD position are:
- motivation for scientific work
- basic knowledge in databases

- interest in algorithmic thinking and problem solving
- good programming skills
- proficiency in English

A13 - Transforming and explaining data and knowledge, via ontological unpacking and data science methods for data preparation and reverse engineering.

Advisor: **prof. Enrico Franconi**
Co-advisor: **prof. Giancarlo Guizzardi**

Project Description:
This PhD project will explore the use of formal ontology methods for transforming and explaining complex conceptual models, and it will try to combine it with the semantic based data science methods for data preparation and reverse engineering in order to get their conceptual models. The formal ontology technique of ontological unpacking, which involves breaking down a complex concept into smaller, more understandable parts, can help researchers and practitioners better understand the underlying assumptions and mechanisms of a conceptual model. Ontological unpacking is a useful tool for explaining complex conceptual models and improving their clarity and transparency. By using this method, data scientists can gain a deeper understanding of a model's assumptions and mechanisms, leading to more accurate and effective applications in practice. From a different perspective, semantic data science methods use knowledge graphs or conceptual models to represent data meaningfully. This enables better data preparation and a precise and faithful reverse engineering. By restructuring data sources and using semantic annotations, analysts can create a shared understanding of data that's easily communicated and reused. This improves data analysis accuracy and consistency, speeds up model development, and simplifies analysis by providing a more human-readable representation of data. The PhD project will prove the importance of clear and transparent transformation and explanations of complex models and will work on finding solid grounds to the hypothesis that the combination of both ontological unpacking and semantic based data science methods can be a useful tool for achieving this goal.

Required skills:
A successful candidate should have a good background on the data modelling area of computer science and an appreciation of some foundational aspects of computer science, such as semantic technologies or ontologies or knowledge graphs or conceptual modelling or knowledge representation or data science or computational logic.

A14 - Strategy and Explainability for Knowledge Bases

Advisor: **prof. Oliver Kutz**
Co-advisor: **dr. Nicolas Troquard**

Project Description:
This research project aims at advancing the reasoning with conflicting knowledge, both in the strong sense of inconsistency, and in weaker varieties that involve conceptual clashes, empty concepts, or over-commitments. It focuses on bringing together three recent strands of research, namely 1) methods to weight information, 2) methods to weaken axioms, and 3) methods to negotiate or play games with information.
The general application area is knowledge engineering, in particular providing solutions to the problem of resolving inconsistent information when an agent adds new knowledge to a knowledge base. But additionally, this entails the problem of explaining why a certain combination of knowledge is inconsistent, and it requires to explain or justify the proposed changes.
Weighted logic focuses on the idea that different pieces of information have different value, or weight, reflecting a very natural idea from common sense reasoning. Axiom weakening allows for a fine-grained repair of inconsistent knowledge bases. Its main advantage is that it repairs them by making axioms less restrictive rather than by deleting them.
Typical research questions are:

- Strategic reasoning: How can the techniques from multiagent systems and game theory be applied to problems of collaborative ontology engineering and to concept combination? E.g., how can different agents agree on the weight of a particular piece of information?
- Explainability: How can we best combine the ideas of weighted logic, where different pieces of information have different weight, and refinement, where we specialize or generalize our information? How can we explain and justify the weakening of information?

Required skills:

In general, applicants for this project are expected to have some good acquaintance with classical logic and its syntax and semantics. More advanced knowledge of proof methods, meta-theory, and non-classical logic will be a plus. The ideal candidate will already have some background in agents or game theory as well as KR languages such as description logics.

Programming skills: experience with programming would be valuable, particularly for the purpose of carrying out evaluation studies and improving research prototypes.

A15 - Innovative Algorithms for Large Scale Scientific Computation

Advisor: **prof. Bruno Carpentieri**
Co-advisor: **to be defined**

Project Description:

Numerical analysis is the field of mathematics that designs and analyzes algorithms for solving the problems of computational science, which is the scientific study of physical processes through computer modelling and simulation. Recent advances in computer technology are creating unprecedented opportunities for research in computational science, demanding the development of novel algorithms with reduced computational and memory requirements. These problems arise so often in engineering and scientific practice that they occupied the minds of many mathematicians of the last century, from von Neumann to Turing. In this doctoral project, the candidate will develop innovative algorithms to address at least one of the following problems:

- compression methods to enable fast simulations in fusion energy research, and/or high-frequency electromagnetic scattering, and/or computational fluid dynamics applications;
- acceleration algorithms for computing Google's PageRank, with application to the analysis of the transcriptomic gene expression landscape of chronic myeloid leukemia;
- machine-learning-assisted physics-based simulation, e.g., to identify regions of abnormal glucose metabolism in the brain of cancer patients;
- fast numerical solution of partial and time-space fractional differential equations.

Our goal is to develop numerical tools and open-source software that can enable fast simulation for use in industry or medical research, filling a gap in existing software designed to solve such problems.

Required skills:

Basic knowledge of computational methods in Applied Mathematics. Computer skills. Knowledge of MATLAB or one high-level programming language (C/Fortran/Python). Analysis and problem solving. Critical thinking. Collaboration.

A16 - Neuro-Symbolic Artificial Intelligence for Business Process Analysis

Advisor: **Prof. Fabrizio Maria Maggi**
Co-advisor: **dr. Ivan Donadello**

Project Description:

Deep Neural Networks have revolutionized several areas of computer science, such as image and face recognition, event detection, machine translation, board games and the analysis of business processes. However, these techniques require large amounts of labelled data, have poor generalization performance from few examples and still lack of reasoning capabilities on complex data. By contrast, symbolic Artificial Intelligence is based on rich, high-level representations of the world that use human-readable symbols, that is, logical knowledge such as First Order Logic, Modal Logic, Temporal Logic. In this context, Neuro-Symbolic Artificial Intelligence, which stems from Neural Networks and symbolic Artificial

Intelligence, tries to combine the strength of both paradigms, that is, reasoning with complex representations of knowledge (knowledge-bases, graphs, ontologies) with learning from complex data. Such complex data can be temporal data with a rich semantics such as the logs of a business process. In this Ph.D. project, novel Neuro-Symbolic frameworks (Deep learning with Linear Temporal Logics) will be investigated for solving tasks of business process analysis, such as, the prediction of the next activities to perform that maximize the performance of a business process or the discovery of logical temporal knowledge from data.

Required skills:

- a Master in computer science, mathematics or physics;
- passed a Machine Learning university course;
- some experience with Machine Learning projects;
- knowledge of logical languages (at least First Order Logic);
- proficiency in Python and the main packages for scientific computation: Numpy, Sklearn, Matplotlib, Pandas;
- knowledge of a Deep Learning Framework, Pytorch or Tensorflow;
- good English writing and speaking skills.

A17 - Smart wearable computing for cooperative e-health applications

Advisor: **prof. Antonio Liotta**
Co-advisor: **to be defined**

Project Description:
Smart wearable computing systems (WCS) are gaining significant importance thanks to the miniaturization of artificial intelligence processes, which are enabling a wealth of new applications. Wearables include both devices and body sensors, which are internetworked, can cooperate as cyber-physical objects, and have sufficient compute power to support local computation, sensing, and actuation. The particular application domain of this project is smart health. By embedding machine learning models and processes in wearables, we aim to provide the smart-health system with advanced capabilities such as cooperative sensing, multi-sensor fusion, and activity/situation recognition/awareness, beyond what is currently possible. The lightweight machine learning concepts developed in this project will be tested in a pilot e-health system.

Required skills:
This project requires a strong motivation to study fundamental theory of Machine Learning and is best suited to someone who has already started building a portfolio of data science projects. A good math background is required, including linear algebra and calculus. General programming skills in any language are essential, including the fundamental paradigms of procedural, object-oriented and functional programming. There is a preference for Python, which is the language of choice for this project. Knowledge of e-health or other smart systems would be an advantage.

A18 - Sparse Artificial Neural Networks for Intelligent Internet of Things

Advisor: **prof. Antonio Liotta**
Co-advisor: **to be defined**

Project Description:
Artificial Neural Networks (ANN) are enabling new applications in artificial intelligence, data science and, generally, intelligent systems. ANNs are at the heart of machine learning (ML), which essentially involves training complex prediction models starting form big data. ML is typically relegated to high performance computers that have the compute power to both build and execute the models. In this project, we aim to streamline ML so that it can be performed in commodity hardware. This is particularly relevant in the context of intelligent Internet of Things (IoT), whereby we want to interconnect intelligent objects (at the network edge), thus embedding ML processes into the edge nodes (i.e., beyond the Cloud). In this way, these digital objects will be able to use a range of ML techniques to make sense of their context, make inference on their input data, or act upon their environment. To this end, we study ´sparse´ (rather than

´dense´) ANNs and use ingenuous network science techniques to train lightweight models. The project aims to demonstrate this new concept of edge intelligence in the context of practical case studies such as smart sensing, smart city and intelligent IoT.

Required skills:
This project requires a strong motivation to study fundamental theory of Machine Learning and is best suited to someone who has already started building a portfolio of data science projects. A good math background is required, including linear algebra and calculus. General programming skills in any language are essential, including the fundamental paradigms of procedural, object-oriented and functional programming. There is a preference for Python, which is the language of choice for this project. Knowledge of graph theory and network science would be an advantage.

B1 - Process mining: representation, prediction and explanation of temporal data

Academic Advisor: **dr. Chiara Ghidini**
Co-advisors: **dr. Massimiliano Ronzani**

Project Description:
Thanks to the increasing digitalisation of contemporary organizations, event data about the execution of processes are continuously collected. Process intelligence aims at transforming these data into insights into how processes are executed in reality.
In spite of the reported effectiveness of state of the art approaches for process intelligence, an effective intelligent usage of execution data is still reported to be one of the key challenges of today's strategic management. Indeed, AI is becoming increasingly central to realise a view that shifts from descriptive and reactive predictive analytics to proactive prescriptive analytics, able to improve the impact, sustainability, and relevance of data-enabled decisions. Realising this vision requires addressing several foundational challenges: (i) the representational descriptive challenge, which arises from the multiperspective representation of knowledge for the specific domain containing time, resources, data objects, costs ...; and (ii) the predictive and proactive challenge, which demands the usage of data in an explainable manner and to realise recommender systems able to deal with the temporal dimension of data so as to support decision making. It also calls for an integrative approach that leverages the power and flexibility of Machine Learning techniques, combines the (implicit) knowledge contained in the data with the explicit (and often de facto or legally binding) rules governing the process behaviour, and resorts to different reasoning techniques. The PhD project will focus on the development of new AI based techniques able to deal with some of the challenges above and their application in several domains, e.g., the healthcare one.

Required skills:
- Good mathematical background
- Good programming skills
- Good Knowledge of Machine Learning techniques
- Good communication skills and ability to work in team
- Knowledge of Process Mining Techniques (optional)
- Knowledge of Conceptual and/or Logic formalisms (optional)

B2 - Ethical and Sustainable Dialogue Management Systems

Academic Advisor: **dr. Mauro Dragoni**
Co-advisors: **dr. Chiara Ghidini**

Project Description:
One of the pillars of healthcare digital transformation focuses on the integration of AI-based dialogue solutions within the clinician-patient relationships with the aim of monitoring and/or supporting them toward the achievement of healthy functional status.
The advent of large language models (LLMs) changed the research paradigm in natural language processing (NLP) and it put the basis for new challenges.

Two of the most main issues of such LLMs are identified by the analysis of how they are ethical and sustainable.
By "ethical", we mean their capability of both building models that are not biased (in a broader sense) and generating content that is controlled with respect to the task they are used for and the environment in which they are deployed.
Instead, as "sustainable", we mean the possibility of training and fine-tuning LLMs with costs that may be afforded by any academic entity.
In this Ph.D., the candidate will investigate (i) how to design dialogue systems in a sustainable way by performing fine-tuning operations on existing LLMs; and, (ii) how to inject grounded knowledge into LLMs to enable ethical and bounded conversations between the AI-based system and the target users.

Required skills:
- Natural Language Processing
- Computational Linguistics
- Knowledge Management
- Basic knowledge of the Digital Health domain.
- Good knowledge of the English language.
- Team working.

C1- Developing future digital workspaces to support sustainable remote work

Academic Advisor: **prof. Xiaofeng Wang**
Co-advisor: **dr. to be defined**

Project Description:
Developing future digital workspaces to support sustainable remote work:
Remote work became a noteworthy and disputable topic due to the COVID-19 pandemic. Many organizations are pondering about the transition to remote work, including public administrations. However, with the various benefits of remote work also come a number of challenges because brainstorming, knowledge sharing and team building, etc. are more difficult in the digital space. Meanwhile, the lack of social contacts and interactions that happen typically in physical workspace may lead to the decrease of well-being and work-life balance of remote workers. Various digital tools exist to support remote work, e.g., video conferencing, chatting, online task management. However, there is no clear understanding in the existing literature on what future digital workplaces would be beyond a collection of digital tools, and how they address remote work challenges effectively. To fill these knowledge gaps, this project aspires to develop a comprehensive understanding of the challenges and characteristics of remote work, and build a digital workspace that supports sustainable remote work. To achieve these objectives, the project will first empirically investigate the current state-of-the-art and practice of remote work. Based on this understand, then a digital workspace will be developed that leverages cutting-edge concepts (such as metaverse), AI-enabled technologies (which will greatly change the way we work, remote or not), as well as good practices identified from the contexts where online collaboration is perceived effective and natural (such as open-source software development, online collaborative gaming). A novel kind of collaboration and synergy between remote workers will be enabled by such digital workspaces. The overall research paradigm employed in the project will be Design Science Research that incorporates various empirical research methods (e.g., case studies and interviews). The research is interdisciplinary in nature, covering relevant areas of software engineering and organization science. The project will result in cutting-edge scientific publications on the practices and
challenges of remote work and on innovative novel online tools that can support it. The project will yield an economic and social impact that can be linked to several sustainable development goals designated by UN, e.g., Target 8.3 (Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-small- and medium-sized enterprises, including through access to financial services

Required skills:
The PhD candidate should have good knowledge and a broad view on the field of software engineering, and a keen interest in the topics related to the proposal. A good knowledge and experience in developing web-based applications using modern frameworks and/or tools are preferred. Some knowledge or

experience of conducting empirical studies using qualitative and quantitative research methods (e.g., interviews, surveys) are also preferred. The candidate should have good communication and scientific writing skills, or willingness to develop such skills.

C2 - Art with and for AI: Towards Increased Trust

Advisor: **prof. Antonella De Angeli**
Co-advisor: **to be defined**

Project Description:
This project proposes interdisciplinary research at the frontiers between human creativity and machine learning. The objective is twofold. Firstly, we aim to synergize new possibilities for artistic expressions driven by human imagination and machine learning. Secondly, we want to design critical artefacts to increase public awareness and build trust in Artificial Intelligence (AI).
Awareness refers to the perception and knowledge of the possibilities and limitations of machine learning. It is a fundamental predecessor of informed trust and a key component of public digital literacy and adoption. The project brings forward several contributions to the PNRR with respect to the topic, the application field, and the educational format. The requirement of increasing the digital literacy of Italian citizens is at the core of the plan. (AI) is identified as a key enabler of recovery and resilience across different missions and the horizontal reformation of the Public Administration. Current research, however, has demonstrated the complexity of explaining how AI works does not only apply to possible users, but also to computer scientists. Foundational concerns have been raised with respect to low public acceptance, a generalized mistrust on machine learning that make decisions and predictions on the human's behalf while relying on biased data.
Source credibility alongside advice personalization and predictability are fundamental determinants of trust in machines. The key research question, therefore, is "how can we enhance AI credibility?" making it transparent for all citizens, independent of their digital skills, cultural background, and idiosyncratic interests. The project addresses this question by combining the scientific method of experimental research in human-computer interaction, the reflexive approach of science and technology studies, and creative practices of critical design. Main project outcomes will be critical design artefacts and academic research and public exhibition that contribute to public awareness of AI.
The project will be run in collaboration with the Municipality of Bozen-Bolzano and in particular with the Councillor of Social Policies who will help the student to select a concrete case study reflecting a concrete concern of the administration and the city. The student is expected to alternate between attendance at the University and at the Municipality The academic team will be supplemented by a cultural association, which is currently working with the University in several projects including Food Data Digestion

Required skills:
The project is open to candidates of different profiles, including the social sciences, design, and computer science. Knowledge of Human-Computer Interaction is an advantage alongside musical knowledge

C3 - Human Computer Interaction & Education

Advisor: **prof. Rosella Gennari**
Co-advisor: **to be defined**

Project Description:
It is important to increase the attractiveness of science and technology (ST) in the general education system and expand its reach to include diverse learners, as recommended by the Sustainability Goals 4 and 5. The traditional education and academic systems have generally attempted to attract young generations into the same ST culture and way of learning, thereby leaving many behind. For instance, a recent 2021 study revealed that learners, starting from primary school, tend to believe that girls are less interested than boys in science and engineering, beliefs which affect girls' engagement in them and their future academic choices (https://www.pnas.org/doi/10.1073/pnas.2100030118).
Overall, an increasing body of work on promoting inclusive ST education and research points to the need of infusing it with novel Human-Centred perspectives. The PhD topic is related to the overall area of Human-Computer Interaction & Education, and he/she will be working with schools and related education stakeholders from the PA and academia. The ideal PhD candidate has a strong interest in HCI & ST Education, good communication and organization capabilities, and he/she can relate easily with people

from different backgrounds and with diverse needs. The precise topic will depend on the PhD candidate and his/her skills in HCI or ST Education. The topic is relevant for Mission 4C1 of PNRR related to the education system, in relation to the digital transition for tackling the S&T and digital divide, besides M1C3, for culture.

Required skills:
The PhD topic is related to the overall area of Human-Computer Interaction & Education, and the PhD candidate will be working with schools and related education stakeholders from the PA and academia. The ideal PhD candidate has a strong interest in HCI & ST Education, good communication and organization capabilities, and he/she can relate easily with people from different backgrounds and with diverse needs. The precise topic will depend on the PhD candidate and his/her skills in HCI or ST Education.