Topic Descriptions – PhD in Computer Science

Research Topic 1: Query Temporal Databases Under Temporal Ontologies - an excursus on first-order temporal logics

Supervisor: Prof. Artale Alessandro

Topic Description:

Current data models and database systems are meant to capture snapshots of the world, i.e., the current state of the database, with the next snapshot replacing the previous one. Recording the current, past, and possibly predicted future snapshots is the very first step towards capturing evolution. This functionality is supported by temporal information systems. Data warehousing systems, based on keeping aggregates of past snapshots, have extensively shown that keeping knowledge over time entails the possibility, for example, to analyze evolution trends as a fundamental component of most decision-making processes.

A critical step in capturing the behavior of temporal information systems is enforcing rules that govern the evolution of data. Such constraints play a fundamental role in maintaining data consistency. Temporal conceptual data models have been developed with the aim of expressing such temporal constraints over temporal information systems. They extend standard conceptual schemas with means to visually represent temporal constraints imposed on temporal database instances.

This thesis builds on the ongoing research work conducted at the KRDB center at the Free University of Bozen-Bolzano on temporal databases, temporal conceptual models and temporal knowledge representation languages. The main objective of this thesis is to investigate the problem of querying an underlying temporal database by formulating the query in the alphabet of the temporal conceptual model seen as the schema of the temporal database. The temporal scenario is of a particular interest since it opens the critical issue on whether constants mentioned in the dataset should be interpreted rigidly at different points in time or instead can refer to different domain elements at different time points. The student will study ontology languages extended with temporal operators and equipped with constants possibly interpreted non-rigidly and investigate the computational complexity of such new temporal ontology language together with the complexity of query answering.

Required mandatory skills: PhD topics reside at the intersection of knowledge representation and reasoning, logic, and semantic technologies. The candidate should have undertaken knowledge representation or logic courses with proficiency. The research is more of a theoretical nature but it is also possible to pursue applicative scenarios.

Desirable (optional) skills: Previous experience with temporal or modal logics, knowledge graphs and semantic web languages (OWL or Description Logics) is a strong plus. Ideally, the MSc thesis has led or will lead to a publication.

Research Topic 2: Large Language Models (LLMs) Reasoning abilities

Supervisor: Prof. Bernardi Raffaella

Topic Description: We invite applications for a PhD position in Natural Language Processing. Topics are not sharply defined but might connect to our ongoing research line, run in collaboration with other european research groups. Specifically:

- Evaluation of Large Language Models (LLMs) and Vision Language Models (VLMs) reasoning abilities through mechanistic interpretabilities in diagnostic settings.
- Evaluation of LLMs and VLMs in interactive conversational settings to evaluate their reasoning abilities in problem-solving language-based settings.
- Training LLMs and VLMs through games to enhance their cognitive skills, reasoning abilities and language use.

Furthermore, we also welcome expressions of interest in

- (Long)video grounding requiring temporal reasoning to connect the relevant story-events. The topic can be offered in co-supervision with other faculty, experts in computer vision and temporal reasoning.

Required mandatory skills: PhD topics reside at the intersection of Natural Language Processing and Machine Learning. The candidate has undertaken NLP and Deep Learning courses with proficiency. Solid programming skills and experience with deep learning frameworks such as pytorch are required.

Desirable (optional) skills: Familiarity with evaluation methods; background in cognitive science is desirable.

Research Topic 3: Higher-order complex networks and dynamical systems on top of them

Supervisor: Prof. Bertotti Maria Letizia

Topic Description:

The study of numerous systems composed of a large number of interacting entities cannot disregard the network of links existing between individual entities. Whereas the study of complex networks, graphs composed of numerous nodes and arcs describing binary relationships, has been in recent decades the subject of a myriad of works, only recently has the need for a further paradigm shift been realized, aimed at dealing with networks in which higher-order relationships are considered alongside binary ones. A very interesting research perspective opens up here with obvious possible spin-offs in various fields. Aspects that require attention range from the need for an innovative formalization for the representation of networks to the analysis of statistical quantities that different network topologies may have, to the study of dynamical systems that may relate to the social sciences (spread of epidemics, formation of opinions, ...), ecology (networks with interacting species, ...), economics (networks of economic or financial transitions, ...), and engineering (electrical networks, ...). A fundamental question common to all these contexts concerns understanding how the presence of higher-order interactions affects the dynamics and contributes to the macroscopic emergence of a given outcome. In summary, possible research topics include the creation of codes for the generation of synthetic higher-order complex networks, the development of new mathematical schemes and methods for the study of specific systems on top of these networks, analytical and computational investigation of the dynamics.

Required mandatory skills: Calculus and linear algebra, Basic knowledge of ordinary differential equations, and of complex networks. Experience with software like Mathematica, Python or similar, Computer programming skills, Critical thinking, Collaboration skills.

Desirable (optional) skills: Some knowledge of statistical mechanics and agent-based models.

Research Topic 4: AI-driven Design and Management of Knowledge Graphs

Supervisor: Prof. Calvanese Diego

Topic Description: We invite applications for a fully funded 3-year PhD position in *AI-driven Design and Management of Knowledge Graphs (KGs)*. The project lies at the intersection of Artificial Intelligence, Data Management, and Knowledge Representation, with a particular focus on **Virtual Knowledge Graphs (VKGs)** and their integration with modern AI techniques, including Large Language Models (LLMs) and agentic AI systems.
The successful candidate will have the opportunity to shape their research direction within this broad area, aligning it with their background and interests. Possible research directions include both foundational and applied topics such as:

- **Query rewriting and optimization** in Virtual KGs over heterogeneous data sources, including graph databases, relational systems, Web APIs, temporally annotated data, and geospatial data.
- **Privacy-aware and secure management** of Virtual KGs.
- **Update handling and consistency management** in both virtual and materialized KGs.
- **AI-assisted design, maintenance, and evolution of Virtual KGs**, leveraging LLMs and agentic AI techniques.

From a foundational perspective, the PhD research may focus on developing novel algorithms and formal methods for these challenges, along with a rigorous study of their computational properties and theoretical guarantees.
From an applied and experimental perspective, the developed techniques can be implemented, evaluated, and validated within the state-of-the-art open-source VKG system **Ontop** (https://ontop-vkg.org), developed by the In2Data research group coordinated by Prof. Calvanese. The candidate will contribute to advancing Ontop and experimenting with cutting-edge AI-driven solutions in realistic and large-scale scenarios.
This position offers a stimulating research environment with strong theoretical foundations and impactful real-world applications at the frontier of AI and data management.
Required mandatory skills: Master's degree (or equivalent) in Computer Science, Artificial Intelligence, Data Science, or a closely related field.

- Strong background in at least one of the following areas:
  - Databases and data management
  - Knowledge representation and reasoning
  - Artificial Intelligence
  - Algorithms and computational complexity
- For an applied PhD, solid programming skills (preferably in Java).
- Good knowledge of data management technologies (e.g., SQL, relational databases).
- Strong analytical and mathematical skills.
- Ability to conduct independent research and communicate scientific results effectively in English (both written and oral).

Desirable (optional) skills:

- Knowledge of
  - Knowledge graphs, RDF, OWL, SPARQL.
  - Virtual Knowledge Graphs (a.k.a. Ontology-based data access – OBDA).
  - Query optimization and query rewriting techniques.
  - Description logics or formal methods.
- Experience with:
  - Graph databases (e.g., Neo4j), triple stores, or semantic technologies.
  - LLMs, generative AI, or agentic AI systems.
  - Privacy-preserving data management.
  - Temporal or geospatial data modeling.
- Experience contributing to open-source software projects.
- Prior research experience demonstrated by publications or a strong Master's thesis.

Research Topic 5: Native Support for Time Series Analytics in Database Engines

Supervisor: Prof. Dignös Anton

Topic Description: Time series data are generated at an unprecedented scale across domains such as Industry 4.0, IoT, healthcare, traffic monitoring, and scientific experimentation. Efficiently managing and analyzing this data is essential for data-driven decision-making. However, current database systems provide only partial and often ad hoc support for time series analytics, lacking a principled set of native operators and optimization techniques tailored to time-dependent data.

This PhD project aims to advance the state-of-the-art in in-database time series processing by developing novel models, operators, and execution strategies that enable efficient and scalable analytics directly inside database systems. The research will investigate how core time series operations—such as imputation, anomaly detection, similarity search, clustering, and forecasting—can be integrated into query processing frameworks in a systematic and optimized manner.

Key challenges include defining expressive yet efficient abstractions for time series data, designing cost-based optimization strategies, and enabling high-performance execution on large-scale and heterogeneous datasets. The developed methods will be implemented within a database system prototype and evaluated using synthetic benchmarks and real-world industrial datasets.

The project combines database systems research, algorithm design, and experimental system evaluation, offering strong practical relevance and scientific impact.

Required mandatory skills:

- Strong background in database systems or data management
- Solid understanding of algorithms and data structures
- Programming experience (e.g., C++, Java, Rust, or similar)
- Interest in systems research and experimental evaluation
- Excellent written and spoken English

Desirable (optional) skills:

- Background in time series data
- Experience in empirical evaluations

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Research Topic 6: Knowledge-based Artificial Intelligence for Data Science

Supervisor: Prof. Franconi Enrico

Topic Description: Join Prof. Franconi and the renowned KRDB Research Centre to redefine the future of Knowledge-based AI for Data Science. In an era of "black box" models, we are building the semantic foundations that make Machine Learning interpretable, robust, and truly intelligent.

KRDB is a Powerhouse Environment: join a thriving community of 10 professors, 10 postdocs, and 11 PhD students. We provide Elite Mentorship: benefit from the combined expertise of Prof. Franconi, with potential co-supervision from world-class researchers like Prof. D. Calvanese and Prof. A. Artale. Make data meaningful by applying now to join the KRDB team.

Knowledge-based Artificial Intelligence for Data Science enables more advanced and interpretable data analytics and machine learning: by integrating knowledge and semantic layers into data analysis pipelines, data scientists can develop more robust models and interpret predictions more effectively. This ensures data quality, accessibility, integrity, meaning, and interoperability.

Our mantra is Research Freedom: whether your passion lies in Knowledge Graphs, Semantic Data Management, or Data and Knowledge Modelling, we give you the platform to propose and lead your own research agenda. The focus of a PhD research activity can be on any of the following topics (interested candidates are free to revise/adjust/extend the research, and to propose their own topic in the area):

- **Knowledge-based data management** enhances data quality, scalability, and interoperability in complex data-intensive environments, by embedding domain knowledge directly into data operations.
- **Ontologies and knowledge graphs** integrated with data sources support more expressive, semantic-rich querying, and semantic interoperability, with applications to unify and abstract over heterogeneous data, enabling users to interact with data in a more intuitive and meaningful way.
- **Data and knowledge modelling** involves creating high-level, abstract representations of domains to facilitate system design, analysis, and communication among stakeholders, by enabling richer and more precise representations of domain semantics, including temporal aspects.

Required mandatory skills: the PhD topic resides at the intersection of database research, semantic technologies, and knowledge representation. Critical thinking and curiosity are essential, together with a good ability to deal with rigorous and formal approaches. The PhD research could have a more theoretical or more applicative flavor, depending on the interests of the candidate. Contact prof. Enrico Franconi at franconi@inf.unibz.it before applying for the PhD scholarship, so to have more details and clarifications.

Desirable (optional) skills: MSc thesis or working skills in the area form a valuable background experience to start PhD research. Ideally, the candidate has or is going to have some research publication.

Research Topic 7: Computing Education

Supervisor: Prof. Fronza Ilenia

Topic Description: We invite applications for a PhD position in Computing Education. The project aims to design, develop, and rigorously evaluate innovative solutions to enhance online and hybrid learning experiences, including immersive formats such as coding camps and other practice-oriented programs. The research will investigate cutting-edge technologies and pedagogical strategies—potentially leveraging Extended Reality (XR/VR) and Artificial Intellingence—to foster learner engagement, while supporting skill acquisition. The ideal candidate should be prepared to empirically evaluate these solutions by directly engaging with diverse audiences, including school students and teachers of varying ages and backgrounds. Strong communication skills are essential, and the candidate should be interested in participating in communication and dissemination activities and events. The PhD candidate will join a dynamic, multidisciplinary team at the Hands-On LAboratory (HOLA: https://noi.bz.it/en/labs/hola), a state-of-the-art research lab dedicated to advancing Computing Education.

Required mandatory skills:

- Ability to design and create research prototypes
- Understanding of qualitative and quantitative research methods
- Ability to collaborate effectively within a multidisciplinary research team
- Programming skills

Desirable (optional) skills:

- Experience in developing innovative teaching and learning solutions
- Experience organizing or facilitating software/IT-related events (e.g., coding camps, workshops, hackathons)
- Familiarity with learning analytics and data visualization
- Strong communication skills

Research Topic 8: Constructive Methods in Ontology Engineering

Supervisor: Prof. Kutz Oliver

Topic Description: We invite applications for a PhD position in Constructive Methods in Ontology Engineering. The project lies at the intersection of formal and applied ontology and non-classical logic. Its aim is to investigate both the theoretical foundations and practical applications of one or more of the following research directions:

- structural analysis of concept construction under resource constraints,
- constructive semantics for ontology languages, and
- constructive and structural approaches to mereology.

The successful candidate will be expected to engage in interdisciplinary research, combining technical rigor with attention to practical applicability of the selected research problems.

Required mandatory skills: PhD topics reside at the intersection of knowledge representation and reasoning, logic, and semantic technologies. The candidate should have undertaken knowledge representation or logic courses with proficiency. Ideally, the MSc thesis is in the field of non-classical logic, KR, or neurosymbolic reasoning.

Desirable (optional) skills: Previous experience with knowledge graphs and ontology engineering methods is a strong plus. Previous experience with software engineering is a plus. Ideally, the MSc thesis has led or will lead to a publication.

Research Topic 9: Computer Vision and Multimodal Learning

Supervisor: Prof. Lanz Oswald

Topic Description: We invite applications for a PhD position in Computer Vision and Multimodal Learning. Please visit the website of the Visual Computing Lab (VCL, https://vision.projects.unibz.it/) for information about the research group. You will join a dynamic team in a vibrant environment. Topics are not sharply defined but might connect to relevant background and existing research of the group in

- Egocentric Perception (action recognition/anticipation/mistake detection, 3D reconstruction and scene graphs),
- Multimodal GenAI (retrieval-augmented generation, video search and retrieval),
- AutoML for Video Understanding (neural architecture search).

Furthermore, we also welcome expressions of interest in

- Foundational research on Neuro-Symbolic Integration in the context of multimodal procedural activity recognition and human-robot collaboration. Can be offered in co-supervision with other faculty, experts in process mining.

VCL is connected to Covision Lab https://covisionlab.com/ and its spinoff company ALLSIDES https://www.allsides.tech/ with which specific topics of interest can be offered.

Required mandatory skills: PhD topics reside 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 required.

Desirable (optional) skills: MSc thesis as valuable background experience to start PhD research. Ideally the MSc thesis has led or will lead to publication.

Research Topic 10: Embedded Machine Learning for Medical AI

Supervisor: Prof. Liotta Antonio

Topic Description: We invite applications for a PhD position in Embedded Machine Learning, hosted at the Data-Driven AI group (www.unibz.it/en/faculties/engineering/research/data-driven-artificial-intelligence). At D2AI, we address a variety of grand challenges in both theoretical AI and its deployment in mission-critical domains such as medicine, biology, climate, energy, finance, industry, and smart living.

This PhD scholarship focuses on the design of efficient, trustworthy, and deployable AI systems for healthcare, at the intersection of Machine Learning and the medical domain. A central theme is Embedded Machine Learning: developing models that are not only accurate, but also compact, energy-efficient, robust, and suitable for real-world medical devices and edge platforms. Particular emphasis is placed on portable, personalized, and precision medicine applications.

Applicants are encouraged to propose their own research project within this vision. The following strands illustrate exemplary directions of interest:

- **Automatic speech recognition in pathological contexts.** Despite major advances in ASR, state-of-the-art systems degrade significantly in the presence of voice distortions. External factors (e.g., noise, reverberation) and internal factors (e.g., speech impairments or voice pathologies) lead to high error rates and unreliable outputs. This project explores personalized and robust ASR systems designed specifically for pathological speech, with a strong focus on compact architectures and efficient inference suitable for real-time, embedded medical applications.
- **Temporal Foundation Models for Clinical Prediction.** Current AI systems face important limitations: Large Language Models cannot natively process high-frequency biosignals (e.g., ECG, PPG), while traditional time-series models often lack clinical semantic understanding. A key challenge is to unify multimodal physiological time series with clinical language models. Possible research directions include hierarchical or multimodal architectures that align time-series representations with LLM latent spaces, enabling joint reasoning over waveforms and clinical narratives. Applications include early warning systems, chronic disease progression modelling, and treatment response prediction. Emphasis will be placed on scalable, efficient inference and deployment in clinical environments.
- **Super-resolution in medical imaging.** Medical images are often acquired under hardware, time, and dose constraints, leading to limited resolution and loss of clinically relevant detail. While deep learning has improved super-resolution, major challenges remain in preserving anatomical fidelity and ensuring robustness—especially when models must operate efficiently on embedded or portable systems. This project will develop trustworthy and lightweight super-resolution methods, focusing on efficient architectures, model compression, uncertainty awareness, and personalization. The goal is to enable reliable deployment on next-generation medical devices and edge platforms.

Applicants are encouraged to contact Prof. Liotta at antonio.liotta@unibz.it before applying formally, in order to discuss potential project ideas.

Required mandatory skills: fundamentals of machine learning; data science methods for data curation; Python programming; MSc thesis involving machine learning.

Desirable (optional) skills: advanced machine learning; deep learning; automatic speech recognition; large language models; time-series analysis and modeling.