

# AI for Industry at the Computer Science Faculty of the Free University of Bozen-Bolzano

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## Abstract

We provide an overview of some of the main research lines and project activities focused on AI for industry and developed within the Faculty of Computer Science of the Free University of Bozen-Bolzano (unibz). Each section refers to a research line connected to a funded project. In particular, we highlight project details, participants, and a description of the executed and planned research activities connected to the project.

## 1 AI for Data-Aware Processes and Manufacturing

### Project

- Title: *Automated process planning in cyber physical production systems of smart factories (SMART-APP)*;
- Funding scheme: UNIBZ Interdisciplinary Projects 2020;
- Period: 01/10/2020 - 30/09/2022;
- Budget: 130 K€ for unibz.

### Participants

- From unibz - Fac. of Computer Science: D. Calvanese (Faculty PI), P. Felli, M. Montali, S. Winkler;
- From unibz - Fac. of Science and Technology: Erwin Rauch (coordinator), Raphael A. Rojas, Benedikt G. Mark, Renato Vidoni.

**Description.** A central research line within the KRDB Research Centre for Knowledge and Data at unibz focuses on the formal specification, verification, reasoning, and mining of integrated models for processes and data. This is a long-standing problem at the intersection of AI, BPM, and database theory [Baral and De Giacomo, 2015; Dumas, 2011; Calvanese *et al.*, 2013].

One relevant application domain for these models and techniques is *manufacturing as a service* in Industry 4.0. Here, products to be manufactured are not known in advance, batch sizes are small, and a facility may produce items belonging to heterogeneous product families for different customers. A key task in this setting is that of process planning, i.e., assessing whether a given product specification (including both data and control-flow aspects) can be realized in a given factory. The process plan controller, i.e., the control software that delegates the operations in the plan to the appropriate manufacturing resources, must then be synthesized.

Within SMART-APP we are approaching this task by connecting it to previous foundational results achieved within our group [Calvanese *et al.*, 2018; Ghilardi *et al.*, 2020]. In particular, we are studying verification and synthesis problems considering different models for data and processes [De Giacomo *et al.*, 2022; Felli *et al.*, 2022]. From the practical standpoint, the project aims at providing, testing and evaluating a proof-of-concept prototype for the synthesis of manufacturing controllers, ranging from the modelling of the equipment and the product specification to the generation of executable machine code.

## 2 AI for Process Mining

### Project

- Title: *exPlainable kNowledge-aware PrOcess INTelligence (PINPOINT)*;
- Funding scheme: PRIN 2020;
- Duration: starting in the first quarter of 2022;
- Budget: 976 K€ (194 K€ for unibz).

### Participants

- From unibz: M. Montali (coordinator), P. Felli;
- Other members: C. Di Ciccio (Sapienza University of Rome), R. Peñaloza Nyssen (University of Milano-Bicocca), L. Pontieri (CNR), F. Ricca (University of Calabria);
- Additional supporters: C. Ghidini (Fondazione Bruno Kessler), three companies (providing use cases in logistics and customer care).

**Description.** Process mining is a collection of process intelligence techniques combining model-based and data-oriented analysis to obtain insights about the execution of business processes in reality [van der Aalst, 2016]. Several process mining tasks exist to discover processes from event data, check conformance of actual with expected behaviours, provide runtime operational support, and enhance models with insights from data. However, three crucial limitations hamper the process mining pipelines. First, data extraction and preparation often consist of handcrafted operations without documentation nor traceability, thereby making the provenance of process mining results obscure. Second, process mining pipelines do not include background, domain knowledge, and cannot properly contextualise the produced results in a specific organizational setting. Third, process mining techniques incorporate black-box components and handcrafted methods that are opaque and unable to explain the produced results.

The PINPOINT project attacks these limitations by developing a full-fledged set of techniques towards explainable, knowledge-aware process intelligence. It does so by relying on recent advancements in AI and declarative processes, which at unibz have been investigated for more than a decade, foundationally [Montali *et al.*, 2010] and in terms of tool support [Alman *et al.*, 2021]. In particular, within PINPOINT we intend to exploit declarative, multi-perspective formalisms combining time [Maggi and Westergaard, 2014], data [Artale *et al.*, 2019] and uncertainty [Maggi *et al.*, 2020a; Maggi *et al.*, 2020b] to express process knowledge, and targets end-to-end explainable process mining pipelines through integrated learning and inference algorithms.

### 3 Virtual Knowledge Graphs for Data Access and Integration

#### Project

- Title: *Scalable End-user Access to Big Data (Optique)*;
- Funding scheme: EU FP7;
- Duration: 11/2012 - 10/2016 (48 months);
- Budget: 873 K€ for unibz.

#### Involved people

- From unibz: Diego Calvanese (local PI), Elena Botoeva, Benjamin Cogrel, Julien Corman, Elem Güzel Kalayci, Davide Lanti, Guohui Xiao.

**Description.** Most medium-sized and large organizations face the problem of dealing with large and complex collections of data that need to be managed and queried in an integrated way. The Virtual Knowledge Graph (VKG) approach [Xiao *et al.*, 2019], also known as Ontology-based Data Access and Integration (OBDA/OBDI) [Xiao *et al.*, 2018a], provides a solution to the data integration challenge us semantic technologies and the associated standards, specifically (i) RDF as a language to represent knowledge graphs, (ii) a lightweight ontology languages (OWL 2 QL) to encode domain knowledge, (iii) a language to define mappings between the ontology and the data sources (R2RML), and (iv) a language (SPARQL) to query through the ontology the underlying data sources exposed a virtual knowledge graph.

The Optique project [Kharlamov *et al.*, 2015] has developed an extensible platform providing a complete and generic solution to data access and integration through the VKG approach. The development of the platform has been evaluated within two large EU companies in two industrial use cases: (i) At Equinor (formerly Statoil), a Norwegian multinational oil and gas company, VKGs have been used by geologists in Data Exploration, to integrate and uniformly query multiple complex and large data sources. (ii) Siemens Energy runs several service centers that remotely monitor several thousand appliances, such as gas and steam turbines, and the aim of Optique has been to access and integrate sensor data from these devices to perform reactive and predictive diagnostics.

Both use cases rely (among other technologies for query formulation and distributed query evaluation developed in Optique) on the VKG system Ontop [Calvanese *et al.*, 2017; Xiao *et al.*, 2020], conceived and developed at unibz. Ontop is a state-of-the-art query reformulation engine that allows one to efficiently process queries posed over a (domain) ontology, by rewriting such a query with respect to the ontology axioms, and unfolding the rewritten query with respect to the data source mappings. A key challenge in Ontop has been

to make such query reformulation process highly efficient, generating small queries that can also be executed efficiently by the underlying data source. For this purpose, Ontop relies on advanced query optimization techniques, which make extensive usage both of domain knowledge encoded in the ontology, and of constraints on the data sources to which the ontology is mapped [Xiao *et al.*, 2018b].

We observe that the VKG approach, and specifically Ontop, has also been used in other industrial settings. We mention here the project *OBDA Extensions for Bosch*, carried out in cooperation between Robert Bosch GmbH in Stuttgart (Germany) and unibz from 01/05/2019 to 30/11/2019, with a budget of 40,000 EUR. The aim of the project has been to study how to model within VKGs time-based manufacturing data so as to handle both concrete time (timestamps) as well as implicit time (based on sequences). The approach has been evaluated at Bosch on the Surface-mount Technology (SMT) process [Kalayci *et al.*, 2020].

Finally, while Optique has mainly been concerned with relational data sources. However, in any data integration scenario, it is crucial to be able to deal with the heterogeneity coming from multiple types of data sources, such as csv tables, excel files, json documents, (RDF) graphs, or annotated text, and moreover to deal with different forms of data, such as geospatial data and notably temporal data. We are investigating these aspects in our current research.

### 4 AI for Semantic Interoperability

#### Project

- Title: *Semantic modelling and semantic interoperability / Smart Data Integration 4.0*;
- Funding scheme: industry funded applied research project;
- Period: 2018 - 2021;
- Budget: 180 K€ for unibz.

#### Participants

- From unibz: E. Franconi (coordinator), N. Ndefo, F. Sportelli, N. Pedot.

**Description.** An activity which has been always at the core of the KRDB Research Centre for Knowledge and Data at unibz has been semantic interoperability and data integration. In this context, several applied research projects have been funded by industries in recent years. Here we mention the research activity funded by the European Space Agency (ESA) and the Datatellers startup company [Franconi, 2019].

The development and management of complex systems, such as those used by ESA, imply activities involving many parties among all the actors involved, both at global (i.e. company/customer) and local level (i.e. product/supplier), typically under-specified, in conflict with each other, distributed in space and time. Efficient and effective interoperability is required throughout the system development (e.g., satellites) and operations (e.g., missions) lifecycle.

The European Cooperation for Space Standardisation committee addressed these difficulties mandating to address interoperability at the semantic level: it imposes a methodology and tools associated with the conceptual model at global and local levels. A workshop in 2019 aimed to coordinate the efforts to create an Overall System Modelling for System Engineering (OSMoSE) in the context of a Space System Ontology. The projects' activities focused on the support in modelling the "Space System Reference Database" of ESA, to capture, verify and validate all data required to operate the

spacecraft in-flight, and on the design and development of a conceptual modelling tool based on Microsoft Visual Studio to support semantic integration in space systems engineering.

## 5 Predictive Maintenance

### Project

- Title: *Predictive Maintenance for Industrial Equipment (PREMISE)*;
- Funding scheme: EFRE/FESR 2014-2020;
- Duration: 01/02/2021 - 30/09/2022;
- Budget: 466 K€ (130 K€ for unibz);
- Web: <https://dbs.inf.unibz.it/projects/premise/>

### Participants

- From unibz: J. Gamper (PI), A. Dignös (Co-PI), M. Ceccarello;
- Other members: M. Deflorian (company Durst), M. Pfeifer (company TechnoAlpin).

**Description.** Today's availability of huge amounts of sensor data allows predictive maintenance, which is scheduled as-needed based on real-time conditions of industrial assets. Predictive maintenance tracks the performance of equipments during normal operation and detects possible defects before a failure occurs. Such a maintenance strategy brings significant cost savings due to a reduction of downtime, as maintenance steps can be better scheduled, and a reduction of resources, as parts are only changed if their performance degrades.

PREMISE aims at developing and implementing a framework for predictive maintenance for industrial devices and is composed of three main components: data pre-processing, data analysis, and prediction. The project is a collaboration between UNIBZ and the companies Durst and TechnoAlpin.

## 6 Wearable Computing

### Project

- Title: *COMMunity-OrieNted WEARrable Computing Systems (COMMON-WEARS)*
- Funding scheme: PRIN 2020.
- Duration: starting in the first quarter of 2022.
- Budget: 944 K€ (186 K€ for unibz).

### Participants

- From unibz: A. Liotta (local PI), M. Segata, G. Di Fatta, L. Cavallaro;
- Other members: G. Fortino (coordinator, University of Calabria), M. Viroli (University of Bologna), E. Schena (Campus Bio-Medico University of Rome), F. Damiani (University of Turin).

**Description.** The project is about smart wearables and body sensor networks (BSN), with applications, e.g., in domestic, urban, manufacturing, emergency, and working environments. This will be achieved by combining recent research conducted by the proposers in aggregate computing, collective opportunistic IoT, machine learning, and WCS/BSN architectures. The project will demonstrate results on use cases in healthcare, emergency response and pandemic management that are strongly impacted by smart wearables.

## 7 Hyperspectral Imaging

### Project

- Title: *Hyperspectral Images for Inspection Applications (H2I)*
- Funding scheme: EFRE/FESR 2014-2020.
- Duration: 17/01/2019 - 16/03/2022.
- Budget: 503 K€ (202 K€ for unibz).
- Web: <https://h2i.inf.unibz.it/>

### Participants

- From unibz: R. Confalonieri (coordinator), B. Attaullah, M. Zanker, Y. Pii (Fac. of Science and Technology);
- Other members: T. Tillo (technical coordinator, IIT-Delhi), M. Caffini, S. Faccini, M. Boschetti, P. Bock (Microtec), S. Malek (Fondazione Bruno Kessler).

**Description.** Hyperspectral images support inspecting the composition of objects in a scene in a non-destructive way. They are used in remote sensing applications, astronomy, and recently also in the wood and food processing industry, and in agriculture. The aim of the H2I project is to develop an end-to-end framework for the classification of hyperspectral images. The proposed hyperspectral framework can be used in online decision support systems in a variety of industrial applications, for instance to detect wood defects and fruit diseases, and to predict the status of agriculture fields for precision agriculture. Results on wood hyperspectral images classification are provided in [Htun *et al.*, 2021].

## 8 Temporal Databases

### Project

- Title: *Enabling Industrial-Strength, Open-Source Temporal Query Processing (ISTEP)*
- Funding scheme: Research Südtirol/Alto Adige 2019, Province of Bozen-Bolzano
- Duration: 01/10/2020 - 30/09/2023
- Budget: 260 K€ for unibz
- Web: <https://dbs.inf.unibz.it/projects/istep/>

### Participants

- From unibz: J. Gamper (PI), A. Dignös (Co-PI);
- External supporters: M. Böhlen (University of Zurich), C. Jensen (Aalborg University).

**Description.** Temporal data is ubiquitous, and its importance has been witnessed by the recent introduction of temporal features in the SQL standard and commercial DBMSs. Despite such efforts, current DBMSs offer little support for query formulation and processing. This makes application code and SQL queries complex and inefficient. Temporal alignment is the first and only framework that provides comprehensive temporal query support over interval-timestamped data, with tight integration into existing DBMSs.<sup>1</sup>

ISTEP aims at boosting the temporal alignment framework as follows: (1) Instead of using two primitives to transform temporal queries into non-temporal queries, which might produce redundancy in the intermediate relations, we are exploring new alignment primitives that are customized for specific temporal operators. Results on built-in computation for temporal joins have been obtained [Dignös *et al.*, 2021]. (2) Since current cost estimates for intermediate relations are very conservative, we are developing more realistic cost estimates. (3)

<sup>1</sup><http://tpg.inf.unibz.it>

We are studying new algebraic equivalence rules for query optimization. If successful, the project will provide the foundation for the first industrial-strength, open-source RDBMS with comprehensive temporal query support.

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