AI's many roads to a more sustainable future: Sustainable AI at unibz

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1 Introduction

The Faculty of Computer Science at **unibz** is doing research in *AI for Sustainability* with ongoing projects about, currently, climate risk assessment and climate change adaptation, smart disposal of refuse, energy efficiency monitoring, forests data management, as well as tourism. This broad research line is brought to fruition through a wide range of AI techniques, including knowledge representation and reasoning, deep learning for computer vision, recommender systems, or game theory.

Sustainable development is one of the core strategic goals in the **unibz** 3-year plan 2020-2022. Similarly, the Autonomous Province of Bozen-Bolzano puts sustainability as a central strategic objective on its political agenda. Sustainability is evaluated following the 17 Sustainable Development Goals adopted by the United Nations. Accordingly, the **unibz** internal funding of research projects in 2022 will be exclusively dedicated to the topic of sustainability.

Currently, several ongoing research and development projects have a focus on sustainability. They are funded by the European Social Fund, European Regional Development Fund, Programma Operativo Nazionale, **unibz**, and local partners, for a total budget of over 750,000 EUR.

2 The Faculty of Computer Science at unibz

The Faculty of Computer Science carries out its research in four research centres with the following foci: Information and Database Systems Engineering (IDSE), Knowledge and Data (KRDB), Software and Systems Engineering (SwSE), and the Smart Data Factory (SDF).

People involved. Alessandro Artale (KRDB), Diego Calvanese (KRDB, SDF), Roberto Confalonieri (IDSE), Francesco Corcoglioniti (KRDB), Julien Corman (KRDB), Johann Gamper (IDSE), Oliver Kutz (KRDB), Davide Lanti (KRDB), Antonio Liotta (IDSE), David Massimo (IDSE), Alessandro Mosca (SDF), Youssouf Oualhadj (KRDB), Francesco Ricci (IDSE), Nicolas Troquard (KRDB), Markus Zanker (IDSE).

3 Themes of research

The approaches to *AI for Sustainability* at **unibz** may be divided into four categories according to the main AI technologies lying at the centre of research: (1) knowledge representation and reasoning, (2) deep learning for computer vision, (3) recommender systems, and (4) multiagent systems.

We briefly describe the activities in each of these research directions.

3.1 Knowledge representation and reasoning

Effective policies and initiatives for environmental sustainability are data-driven. For example, in a greener society favoring the use of renewable electricity, knowing where, when, and how energy is consumed, produced, and stored is crucial for an optimal planning, and requires integrating heterogeneous data from multiple sources (energy plants and providers, homes, industries, smart vehicles, etc). Data abstraction and integration technologies are thus instrumental and **unibz** contributes with the research, development, and exploitation in many sustainability-related applications of the Virtual Knowledge Graph (VKG) technology (see Figure 1). Also known as "virtual" Ontology Based Data Access (OBDA), VKGs enable a "knowledge graph" view of data that is consistent, easily queryable using the language and terms of the domain itself, and virtual as data is efficiently kept in its source systems, this way facilitating more complex analyses and applications in data-complex domains like the sustainability one.

3.2 Deep learning for computer vision

Hyperspectral images allow one to inspect the composition of objects in a scene in a non-destructive way. Hyperspectral images are used in remote sensing applications, astronomy, and recently also in the wood and food processing industry, and in agriculture. **unibz** uses deep learning and hyperspectral image classification in research directed at contributing to improving the smart disposal of wood.

The ultimate aim is to optimise the least amount of waste that reaches the end user, thus avoiding waste. Taking the case of fruit as an example, as soon as we have the technology to avoid putting apples with defects into the sales network, we will be able to reduce the amount of waste, there will be less waste production by the final consumer, less transport of non-prime quality material, and less processing and packaging of fruits for providers. This concept can be applied to the wood industry as well as to other sectors. All these processes, as well as predictive tools for smart crops starting from the fruit

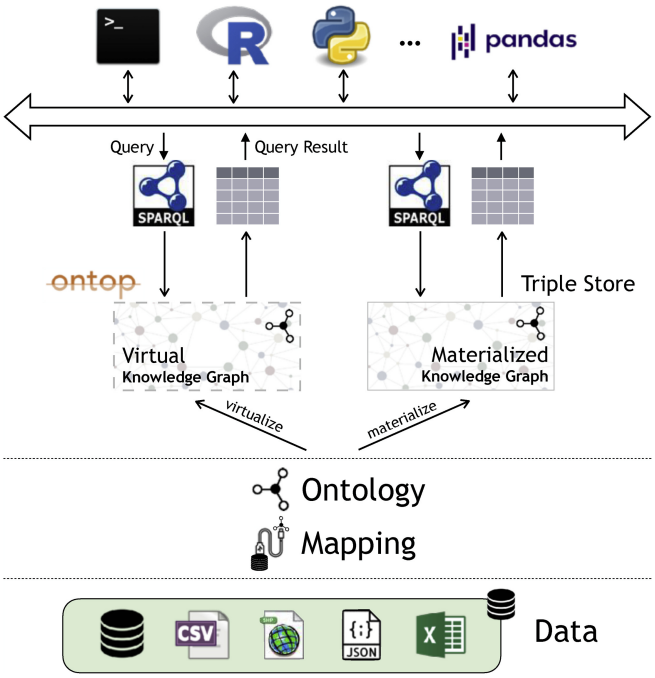

Figure 1: Knowledge graph conceptual framework.

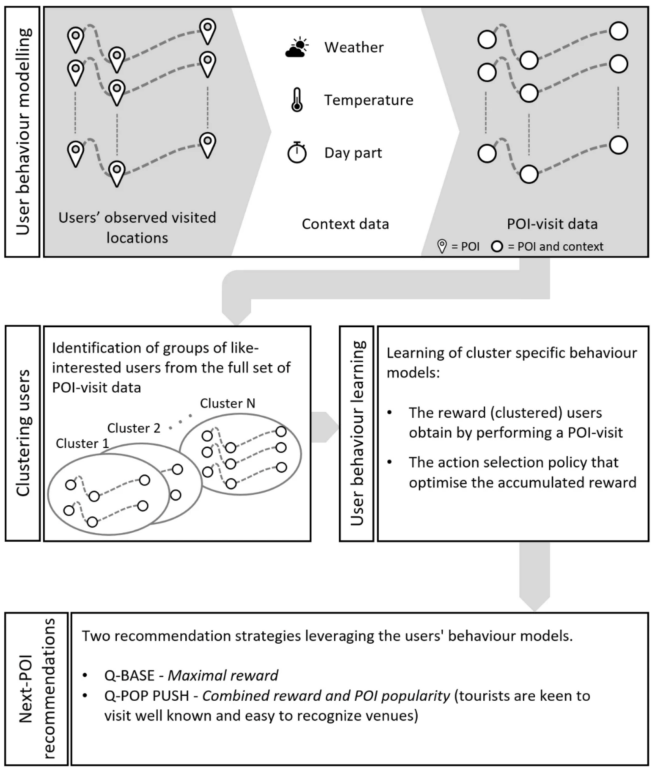

Figure 2: Approach for next-POI recommendation.

produced, could in the future also have a higher level impact in terms of lower CO2 production and lower usage of pesticides and other pollutants.

3.3 Recommender systems

Sustainable tourism is being addressed by **unibz** using recommender systems' technologies aimed at taming various biases of such systems (e.g., concentration bias) and favouring the balanced development of a touristic destination. One of the principal goals here is to help tourists to make choices that are compatible with the available territorial resources and especially to limit overtourism (see Figure 2).

3.4 Multiagent systems and game theory

Resource management in modern societies is a central theme for sustainability. Our actions, and also, and especially, those of our machines, consume, transform, and produce resources. In multiagent systems, resource-conscious agents may be subject to resource constraints to obtain their qualitative objectives, or they may directly seek certain resource objectives. They typically must compete for those resources, and when they are unable to attain a resource alone, they might have to form coalitions to cooperate. Game theory is the study of the strategic interactions among rational agents. The fields of theoretical computer science and computational game theory explore the algorithmic aspects of it. **unibz** has been investigating computational models of games with resource-conscious rational agents (see Fig. 3). Some recent applications have concerned the sustainable management of a common-pool resource in presence of selfish agents.

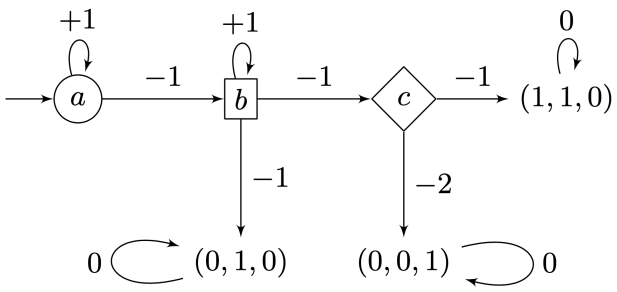

Figure 3: A game arena with three agents and one common-pool resource.

4 Projects related to AI for Sustainability

- **HIVE: Heterogeneous Data Integration into Virtual Knowledge Graphs** Start: 15/04/2021; End: 14/04/2022; Budget: 52,400 EUR; Funding: "Fusion Grant" project sponsored by Fondazione Cassa di Risparmio di Bolzano and Ontopic s.r.l. In coordination with NOI Techpark, Südtiroler Wirtschaftsring and Rete Economia Alto Adige
- **OntoCRM: Climate Risk Management** Start: 01/01/2022; End: 31/12/2023; Budget: 2 years RTDa; Funding: PON Ricerca e Innovazione 2014-2020 / FSE REACT-EU
- **IDEE: Integrazione dati per l'efficientamento energetico** Start: 01/10/2018; End: 30/05/2022; Budget:

226,393 EUR; Funding: ERDF 2014-2020

- **TREE4TREE: Fast Algorithms for Temporal Ontologies Applied to the Modelling of the Sustainable Forest** Start: 01/07/2021; End: 31/10/2023; Budget: 58,561 EUR; Funding: **unibz** CRC 2021
- **CRISP: Climate Risk Planning & Managing Tool for Development Programmes in the Agriculture & Food Sector** Start: 27/10/2021; End: 30/06/2022; Budget: 15,000.00 EUR; Funding: Contract for research project paid by Institute for Earth Observation (EURAC European Academy of Bozen/Bolzano)
- **CompRAS: Computations in Resource Aware Systems** Start: 01/08/2019; End: 31/01/2023; Budget: 72,208 EUR; Funding: **unibz** CRC 2019
- **H2I: Hyperspectral Images for Inspection Applications** Start: 17/01/2019; End: 16/03/2022; Budget: 201,879.00 EUR; Funding: ERDF 2014-2020
- **RESST: Recommender System for Sustainable Tourism** Start: 1/2/2022; End: 7/2/2022; Budget: 35,000 EUR; Funding: Research Contract - Suggesto s.r.l.

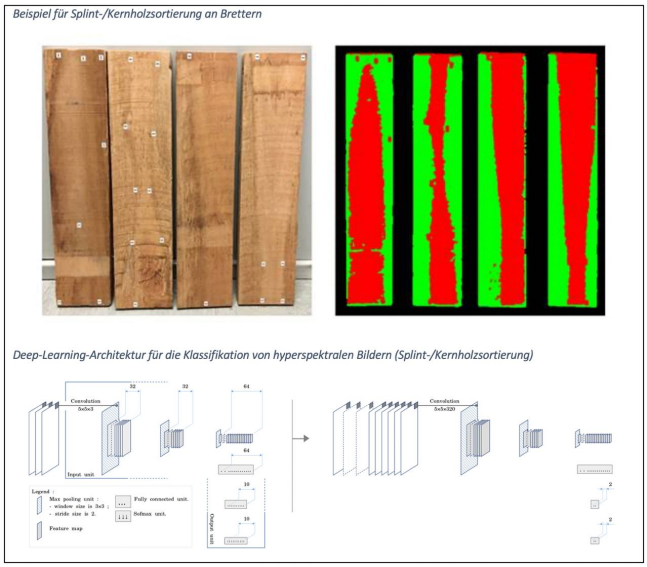

Figure 4: Semantic segmentation of hyperspectral images for wood recognition.

5 Resources and applications

- Ontop is a Virtual Knowledge Graph system. It exposes the content of arbitrary relational databases as knowledge graphs. These graphs are virtual, which means that data remains in the data sources instead of being moved to another database. Taking advantages of lightweight ontologies, Ontop translates SPARQL queries expressed over the knowledge graphs into SQL queries executed by the relational data sources. See Ontop open source VKG engine co-developed by **unibz** https://ontop-vkg.org/.
- In partnership with local energy providers and municipalities, the IDEE project is developing a domain ontology of energy consumption, and a VKG (powered by Ontop) of energy consumption data in South Tyrol. The VKG portal https://idee.projects.unibz.it/ (restricted access), will be queried by visualization tools to assist municipalities, especially those signatories of the Covenant of Mayors.
- In partnership with Microtec Gmbh, the H2I project is developing a set of deep learning techniques to deal with spatial and spectral information, specifically suited for hyperspectral data. https://h2i.inf.unibz.it/.

6 Challenges and perspectives

All approaches to *AI for Sustainability* envision solutions to technological challenges for a more sustainable future. We outline some of the roads followed in our various projects.

6.1 Knowledge representation and reasoning

Sustainable planning requires integrating heterogeneous data from multiple sources.

The HIVE project aims at extending the VKG paradigm beyond relational data sources. The OntoCRM project aims at extending current VKG technology to dynamically computed data. This is to make possible new analyses and applications in data intensive domains like environmental sustainability.

The aim of the IDEE project is to develop a technological infrastructure based on VKGs for the integration of data concerning buildings, with an emphasis on the energy related data, and to provide techniques and tools for the visualisation and analysis of such data.

The aim of the CRISP project is to develop the prototype of a back-end semantic engine, based on the VKG approach, for climate risk analysis and generation of customised adaptation measures and reports. One central objective is a climate risk-oriented domain ontology to represent impact chains related to climate risks, and in particular their relation to agricultural practices.

The TREE4TREE project investigates the feasibility of automated reasoning over temporal knowledge bases, and the applicability of the developed solutions in a real-world use case in the area of the sustainable forest.

6.2 Deep learning for computer vision

The aim of the H2I project is to develop an end-to-end framework for the classification of hyperspectral images (see Fig. 4), in a variety of applications, for instance to detect wood defects, and to check the status of agriculture fields for precision and sustainable agriculture. There are difficulties related with Hyperspectral Images, in particular with extracting useful information from them. It is challenging because the spectral dimension is present in addition to the spatial dimension. The project aims at developing an end-to-end framework for the classification of hyperspectral data, suitable for wood detection, wood fungi recognition, and the maturation of fruits.

6.3 Recommender systems

The aim of the RESST project is to study, design and implement a set of methodologies and software components that can offer to the user of tourist websites and portals personalised suggestions calculated by adopting machine learning and information retrieval techniques. Standard recommendation technologies often produce visits to the destination that are against the interest of the local administration, as they tend to suggest points of interest that are well known, contributing to further crowding certain locations and limiting the development of other, less popular, locations. The proposed techniques enable the optimization of multiple criteria, hence balancing the user satisfaction with a sustainable flow of visits to the destination.

6.4 Multiagent systems and game theory

The focus of the CompRAS project is on the algorithmic solutions for problems of management of common-pool resources, viz. resources like water, air, coal, pastures, or fish stocks. A typical problem is to automatically synthesise a regulation within a commons such that selfish but rational agents will never deplete the system's common resources. For a long time, it was believed that common-pool resources were bound to collapse due to the actions of self-interested players. The great contribution of E. Ostrom was to evidence wide-ranging instances where this is not in fact the case, and to identify design principles of successful common-pool resource management. The models and algorithmic solutions discovered by CompRAS are aimed to be theoretical contributions towards intelligent engineering methods for the commons. We can hope that pursued efforts in this direction may yield useful engineering solutions for future commons management.

7 Publications

Some relevant publications for the above projects include the following:

: RESST [Massimo e Ricci, 2021; Hazrati e Ricci, 2022]

: CompRAS [Condurache *et al.*, 2021]

: H2I [Htun *et al.*, 2021]

: HIVE, OntoCRM, IDEE, CRISP [Xiao *et al.*, 2020; Calvanese *et al.*, 2021]

: TREE4TREE [Artale *et al.*, 2021]

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