AI for Industry at FBK

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Abstract

This paper describes the vision, the organization and the activities of the Center for Digital Industry at Fondazione Bruno Kessler (FBK). We detail the objectives pursued by the Center, the competencies in Artificial Intelligence, Machine Learning, Robotics, and the achievements in transferring the research results into applications.

Keywords

Artificial Intelligence, Vision, Automated deduction, Metrology, Edge AI

1. Introduction

The Bruno Kessler Foundation (FBK) is a non-profit private research foundation located in Trento, Italy. Recognized nationally and internationally for its contribution to scientific and technological innovation, it is organized in several research centers. Among these, the Center for Digital Industry (DI Center) is committed to advancing cutting-edge Artificial Intelligence and digital research and technologies to tackle the complex challenges of the industrial landscape today. The Center's core strength lies in its interdisciplinary approach, integrating a wide spectrum of Computer Science and Artificial Intelligence methodologies. A key feature is its balanced focus on symbolic AI, encompassing knowledge representation and reasoning, along with data-driven AI, using machine learning (ML) and advanced analytics.
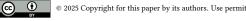
The DI Center pursues three strategic objectives. The primary goal is to conduct *top-level research* that expands the frontiers of knowledge and technological capabilities within the digital industry. The second is to achieve a demonstrable *impact* at the societal level, bringing research toward practical solutions and applications. The third is *economical sustainability*, competing on the research market and demonstrating at the same time the quality of the research and solutions developed.

Strategy The Center operates by combining three key ingredients: research, assets, and technology transfer. Research is carried out in several vertical areas and is experimentally supported by assets that, once matured in terms of technology readiness, are then deployed in applied settings for technology transfer. This model - which we refer to as TT-driven research - is circular in the sense that feedback and empirical data gathered from collaborative engagements with industrial partners are subsequently utilized to suggest future research directions. This ensures continuous relevance and maximized impact. Furthermore, the assets are developed to be domain-independent, in order to support their application in different sectors with limited effort invested in customization.

From research to applications The research pillars underpinning the Center's activities are oriented to the development and validation of systems operating autonomously in complex and unpredictable environments to carry out critical functions. The basic components of such systems include Advanced

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Perception, Prediction and Learning, Deliberation and Control, while the Model-Based Design paradigm supports their validation. These pillars facilitate the development of interdisciplinary solutions in areas such as: Flexible Process Management, Autonomous Robotics, Quality Control, Predictive Maintenance, and Critical System Certification. These solutions are applied in a variety of sectors, including industrial production, industrial automation, logistics, railways, avionics, space, oil and gas, energy production, biomedical, agrifood, and cultural heritage.

2. Research Units

The Center is structured around eight collaborative research units, which are presented below.

Software Engineering. This unit specialises in the development of robust and reliable software systems. Research areas include Requirements Engineering and Software Testing, for complex parametric systems, using automated reasoning based on search-based, AI-based, and formal techniques. The unit developed and maintains a custom library for automated test case generation (EvoMBT) based on metaheuristics, and machine learning techniques [1]. Applications focus on the railway domain and manufacturing sectors [2, 3], with projects focusing on the definition of automated test generation methodologies and tools to be applied to railway systems, the design and verification of autonomous railway vehicles, and the testing and validation of extended reality applications via multi-agent systems.

Open Platforms and Enabling Technologies for the Internet of Things The unit focuses on the development of intelligent, autonomous IoT infrastructures and platforms for highly distributed applications, with a strong emphasis on digital agriculture. Activities include adapting AI techniques for edge devices, integrating advanced robotics, and developing predictive models for irrigation [4] and farm management. The team also explores data governance through decentralized blockchain architectures and European data spaces. Key applications involve smart irrigation, food traceability [5], and robust localization for autonomous agricultural robots [6]. OpenIoT aims to enhance efficiency, sustainability, and data sovereignty through cutting-edge IoT and AI solutions.

Formal Methods for System and Software Design The unit develops advanced formal methods to ensure the correctness, safety, and reliability of complex systems and software. A wide range of formal verification techniques are explored and applied, including automated reasoning, contract-based design, and runtime verification, with a focus on the rigorous verification and validation of cyber-physical systems and AI-based systems.

A core strength lies in symbolic model checking, an efficient technique for the automatic generation of mathematical proofs of system and software correctness. In addition, the unit has established a strong expertise in fault injection and model-based safety analysis, which are essential to evaluate the reliability of the system and to analyze the effectiveness of safety mechanisms such as fault detection, isolation, and recovery mechanisms.

The unit develops and maintains a suite of formal verification tools, including MathSAT, nuXmv, OCRA, and xSAP, widely adopted in safety-critical domains such as space systems, railway infrastructure, automotive and avionics systems, energy systems, and industrial manufacturing. The unit collaborates closely with industrial partners to apply formal methods to concrete real world problems and has a strong track record of successfully applications in safety-critical domains (see, e.g., [7, 8, 9]).

Planning, Scheduling and Optimization This unit is focused on the research field of automated planning and scheduling. This core problem is relevant in many diverse application sectors such as manufacturing, logistics and robotics. In this area, the unit is active along the following three main research directions. 1. State-of-the-art techniques for efficient optimal [10] and "satisficing" automated temporal planning, also in combination with motion planning. 2. The combination of automated temporal planning and reinforcement learning (RL) [11]. This research line is the core component of

the running STEP-RL ERC Starting Grant project. 3. The connection between formal methods and planning, including some seminal works on the theoretical foundations of planning [12]. In addition to these core research competences, the PSO unit is active in the technology transfer of solutions based on finite-horizon scheduling and constraint optimization. Over the years, the unit developed a set of software assets including the Unified Planning library, the TAMER planner, and the PySMT library.

Data Science for Industry and Physics   This unit focuses on applying Data Science methodologies and approaches for developing predictive models based on machine learning from heterogeneous data. DSIP is actively collaborating with industrial partners and research organizations. DSIP is involved in developing Deep Learning solutions for time series analysis and forecasting in the context of condition monitoring and predictive maintenance for industrial processes. In the earth and climate sector, DSIP is involved in projects ranging from machine learning applied to spatiotemporal data for weather nowcasting and forecasting, Earth System Modeling, statistical downscaling, data quality, and anomaly detection of observations. As for applications in physics, DSIP is developing Deep Learning solutions for the data analysis of High Energy Physics experiments in the ATLAS collaboration at CERN and Space Physics within the CSES-LIMADOU mission [13, 14, 15].

3D Optical Metrology   This unit focuses on the science and engineering of precise 3D measurement and modeling. Research areas include geomatics, metrology, 3D mapping, photogrammetry, and geospatial data analytics. The unit's R&D outcomes support applications in territorial mapping, cultural heritage documentation, industrial quality control, and digital twin creation. Key instrumentation includes stereo-vision systems, portable laser scanners, and photometric stereo systems. Current projects include FEROX (robotics and AI for automating wild berry harvesting), TRACENET (virtual reality-based training for civil protection teams), USAGE (use of geospatial data to support the implementation of various Green Dead priorities in different European cities) and 3D-4CH (a Competence Centre in 3D Cultural Heritage).

Technologies of Vision   This unit focuses on advancing computer vision technologies in several research directions. Specifically, with a group of several research scientists and PhD students, TeV works at the intersection of machine perception, artificial intelligence, and robotics, developing vision systems that interpret, reconstruct, and understand complex visual environments. Their research spans a wide range of topics including 2D and 3D scene understanding, image and video analysis, object detection, segmentation, tracking, and robotic perception [16]. Leveraging state-of-the-art technologies such as deep learning, multimodal fusion, and large vision-language models, the unit focuses on enabling machines to understand the world in ways that mirror human perception. An important feature of TeV's work is its comprehensive coverage of vision tasks across different domains and modalities. The unit develops algorithms for zero-shot learning, neural rendering, Gaussian splatting [17], optical flow estimation, visual odometry, and anomaly detection. Their expertise extends to point cloud representation, scene reconstruction, Simultaneous Localization and Mapping, and 3D semantic segmentation, enablers for spatial awareness in autonomous systems. They also contribute to real-world applications including smart retail, food quality analysis, aerial imaging, microscopy, and sports analytics. TeV's contributions are frequently validated through impactful datasets, such as those capturing drone imagery in natural environments or industrial scenarios, and through open research on vision benchmarks. The unit has established a strong presence in the evolving field of vision-language integration. Their recent work includes the development of systems capable of vocabulary-free 3D segmentation and natural language interaction with scenes, supporting advanced applications in robotics [16], embodied AI [18], and assistive technologies. The group also explores emerging methods in neural radiance fields and fast pose estimation models [17], facilitating more photorealistic and computationally efficient spatial modeling. TeV maintains a dynamic approach to bridging theoretical research with industrial relevance. By building generalizable and adaptive computer vision solutions, TeV continues to drive progress in making machines see and understand the world with increasing

depth and nuance.

Machine Translation   The MT unit is dedicated to advancing automatic translation technologies for both text and speech, enabling seamless multilingual communication and access to large-scale spoken and written content. Its core activities focus on developing deep learning architectures and methods adaptable to diverse contexts, domains, and applications that can serve the translation industry, such as simultaneous speech translation [19] and subtitling [20]. These solutions leverage cutting-edge technologies, including large language models and foundation models. The unit also conducts research on the ethical and societal implications of translation technology, by designing evaluation methods, resources, and studies involving human participants, with a focus on gender-inclusive [21] and human-centered translation [22]. In addition, the research is dedicated to developing sustainable and trustworthy approaches to automatic translation, including resource-efficient solutions and methods for explainable AI. All models, code, and datasets developed by the unit are publicly released.

3. Applications of AI

The Digital Industry Center actively fosters collaborations with a diverse range of funding agencies, strategic alliances, and industrial partners. These collaborations occur at the local, national, and international levels and serve to accelerate innovation and amplify the Center's impact. The projected funding horizon currently extends to 2027, with support from a diverse portfolio of sources. These include national programs such as PNRR, EDIH-SoE, European initiatives such as H2020-HEurope RIA and IA, and Digital Europe initiatives such as EIT, KDT and TEF. An important part is directly funded by industrial contracts, also under the sponsorship of the PAT LP VI.

Railways   The railway domain is in a profound transition stimulated by the introduction of digital technologies. On the one hand, electromechanical interlocking systems should be replaced by their digital counterpart; on the other hand, trains are increasingly reliant on automated digital control systems and becoming autonomous. FBK is involved in studying research solutions to support this transition by proposing novel software engineering methodologies and supporting tools that have been applied in a series of research projects. Specifically, regarding interlocking systems, a methodology has been developed in ACC, ACC-toolset, ACC-testing projects, whose objective has been to allow railway experts to design and test interlocking systems using model-based software engineering approaches and AI-based and formal reasoning techniques [23, 24]. The ATO projects aim at the design and testing of the control system of an autonomous train for the inspections of the high-speed lines.

Aerospace   The Center boasts a strong history of collaboration in the aerospace domain, with numerous projects undertaken with the European Space Agency (ESA) through ESTEC and ESOC, as well as the Italian Space Agency (ASI). Additionally, the Center has established a productive partnership with Boeing. Current projects demonstrate a focus on integrative AI solutions for aerospace applications. These include EXPLODTWIN, which integrates digital twins, AI, planning, and monitoring; VAIPOSA, dedicated to verifiable AI-based Position, Navigation, and Timing (PNT); AIFDIR, focusing on integrated symbolic and AI-based Fault Detection, Isolation, and Recovery (FDIR); and AISHGO, which explores the application of AI for health monitoring.

Manufacturing   There are numerous applications of AI to manufacturing. First, product quality control is based on vision and metrology techniques in sectors including the production of hollow glass, tires, car components, electronic boards, and assembly of complex subsystems. Condition monitoring and predictive maintenance are tackled in multiple projects, following an approach that integrates symbolic models of the behavior of the equipment and its faults, data-driven techniques for time-series analysis, and Edge AI. The application sectors include marine engines, off-highway vehicles, industrial ovens, and drainage pumps. Adaptive process control and automated planning and optimization are

applied to sectors including electroplating, production of pharmaceutical principles and detergents, recipe scheduling, energy production and storage.

Weather   AI for Weather and Climate at FBK focuses on developing AI models for accurate, timely weather and climate information, addressing climate change challenges. The research focuses on three key areas: nowcasting, downscaling, and seasonal forecasting. Nowcasting utilizes generative AI to produce 0-6 hour precipitation forecasts from radar and observational data, enabling the prediction of extreme events. Downscaling involves creating high-resolution data from low-resolution inputs, making it suitable for seasonal and climate projections. Seasonal forecasting uses AI to identify temperature and precipitation anomalies, starting with European patterns. These projects involve stakeholders such as civil protection agencies for alerts, insurance firms assessing risk, and energy companies managing resources and demand across various timeframes.

Cultural Heritage   In the cultural heritage sector the focus is on developing (i) advanced 3D documentation solutions, (ii) 2D / 3D semantic enrichment processes, and (iii) speech and text translation solutions to improve accessibility and broaden the reach of cultural heritage content. Within the ongoing EU projects 3D-4CH, 3DBigDataSpace and XRCulture, FBK is contributing with large scale 3D semantic reconstruction and machine translation technologies to widespread digital heritage usage and accessibility.

Digital Agriculture   Digital technologies for agriculture represent an application domain of primary interest for Italy and for research at FBK. Italy is facing the challenge of a more efficient agriculture, able to improve the quality and value of products by improving environmental sustainability and enhancing local identities to the maximum extent. The application of Artificial Intelligence to environmental and climatic data, collected automatically in the field by machines, together with the company's process data, allows the development of solutions capable of promoting efficiency and productivity, improving the yield and sustainability of agricultural practices. The Digital Industry Center applies artificial intelligence using advanced expertise in IoT, Edge AI, computer vision, robotics, climate modeling, and digital twins. The strategic initiative is structured around three core pillars: agricultural digital twins for data-driven decision-making, contextual AI for real-time agronomic recommendations, and digital infrastructures for data management and sharing. Various active projects (e.g., IRRITRE, AGRICLIMA, AgrifoodTEF, and AgRimate) enable concrete applications in smart irrigation, climate resilience, and agricultural robotics, strengthening sustainability, productivity, and food quality in the agrifood sector.

Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT-4 in order to paraphrase and reword. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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