AI for Sustainability: Research at Ud'A Node

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Abstract

This paper summarizes the activities regarding the development of Artificial Intelligence (AI) for Sustainability conducted by the members of the AIIS (Artificial Intelligence and Intelligent Systems) node of the University "G. d'Annunzio" of Chieti-Pescara (Ud'A).

Keywords

Artificial Intelligence, Multi-Agent Systems, Argumentation, Abstraction, Verification, Large Language Models, Machine Learning, Deep Learning, Sustainability

1. Introduction

There is a growing recognition of AI's own environmental footprint and this calls for AI researches being environmentally responsible and aligned with sustainability values. In fact, AI can serve as a powerful instrument for addressing environmental and climate issues, optimising decision-making, improving energy efficiency, and facilitating the transition to a more sustainable future.

2. Projects

We are actively participating in several projects, having AI for sustainability or AI in general as central topic:

Existence, Complexity and efficiency of stable solutions in green-Oriented GAMES (ECOGAMES) funded by PNRR Mission 4, line 1.3, funded by the European Union – NEXTGENERATIONEU, "Future Artificial Intelligence – FAIR" project - PE0000013, Spoke 9, CUP D23C24000210006. The project aims at bridging the fields of game theory and environmental sustainability with a specific focus on integrating energy-efficiency in systems formed by selfish agents.

Smart Knowledge: Enhancing Argumentation and Abstraction for Explanation and Analysis (SMARTK) funded by PNRR Mission 4, line 1.3, funded by the European Union – NEXTGENERATIONEU, "Future Artificial Intelligence – FAIR" project - PE0000013, Spoke 9, CUP D23C24000220006. The project aims at advancing the fields of argumentation, abstraction, and automated reasoning in knowledge representation.

Social Interaction with Argumentation (ASIA) funded by INdAM-GNCS. The ASIA project proposes a novel combination of methodologies, techniques, and tools for argumentation analysis, machine learning, and social network analysis.

Modeling and Formal Verification of Dialog Systems funded by INdAM-GNCS, CUP E53C22001930001. The project aims to explore existing literature and improve upon the methods for validating abstract argumentation frameworks that have been previously suggested, while also potentially introducing new approaches.

Formal Verification of Debates in Argumentation Theory funded by INdAM-GNCS, CUP E55F22000270001. The aim of the project is to extend formal debate verification approaches in argumentation

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theory using new abstraction and probability-based interpretations.

Multi-objective Optimization of Digitally Manufactured Earth Building Components supported by Neural Networks (MUD-MADE) funded by PNRR Mission 4 - Component C2, Investment 1.1, PRIN, CUP D53D23020070001. The project aims to propose a novel artificial intelligence-supported workflow useful for designing raw earth building components produced with digital manufacturing technology (i.e. 3D printing, Robotic arm or Laser cutter).

Fracture Risk evaluation in bone metastatic patients by Artificial InteLligence (FRAIL) funded by PNRR Mission 4 - Component C2, Investment 1.1, PRIN, CUP D53D23013760006. The project investigates whether AI can produce a reliable and explainable decision support system that can assist physicians in complex care decisions regarding patients affected by bone metastases, by making their treatment as accurate as possible.

3. Research Activities

We now describe the scientific work related to AI for Sustainability that is carried out from the researchers of the Ud'A node of AIIS, with particular focus on the projects listed in Section 2.

3.1. On Green Sustainability of Resource Selection Games

In our interconnected world, increasingly dependent on digital platforms and, at the same time, marked by growing concerns about environmental sustainability, a pressing issue demanding timely and efficient solution is the reduction of power consumption of Information Technology (IT) devices (personal computers, data centers, networks). It is highly anticipated, in fact, that their contribution to the annual electricity consumption in 2030 will exceed 10% of the total demand [1]. Motivated by these considerations, we have studied in [2] a multi-agent system in which agents compete for the usage of power-consuming resources and are charged a cost proportional to their fair share of the power consumption, by investigating the (in)efficiency of stable solutions.

3.2. Coalition Formation Games

Teamwork and coalition or group formation is an important and widely investigated issue in computer science research. In many economic, social and political situations, individuals carry out activities in groups rather than by themselves. In these scenarios, it is of crucial importance to consider the satisfaction of the members of the groups. Considering environmental sustainability, teamwork among different stakeholders (individuals, communities, businesses, and governments) is essential for achieving common goals such as reducing pollution and carbon emissions, addressing environmental and climate issues or managing natural resources sustainably.

A notable class of coalition formation games is that of hedonic games, introduced in [3], in which agents have preferences over the set of all possible agent coalitions, and the utility of an agent merely depends on the composition of the coalition she belongs to. Work on hedonic games mainly studies the existence, computation and performance of stable solutions, i.e., solutions where no agent or group of agents has interest in deviating from the outcome, with respect to several notions of stability such as Nash or strong Nash stability, core stability, individual stability and so on (see [4] for a nice survey).

Some members of the AIIS node of Ud'A are actively working on coalition formation games [5, 6, 7, 8].

3.3. A Concurrent Language for Interacting Argumentative Agents

Many AI applications aim to mimic human behavior and reasoning to allow machines to emulate human-like thoughts and actions. A significant challenge lies in providing mechanisms to formally articulate specific types of knowledge, allowing machines to use it to reason and infer new insights. Modelling the behaviour of concurrent agents that interact and reason in a dynamic environment is a difficult task. It requires tools that can effectively capture different types of interactions, such as persuasion and deliberation, while helping agents make decisions or reach agreements. Argumentation theory provides formal frameworks for representing and evaluating interacting arguments. It is therefore important to define a language for modeling the interaction of concurrent and argumentative agents in a distributed system. This language should allow the representation of different types of dialogues, describing the reasoning process employed by agents, thus making it a powerful tool for agent interaction.
A member of the AIIS node of Ud'A is actively working on the definition of a Concurrent Language for Interacting Argumentative Agents [9, 10, 11, 12].

3.4. Abstraction and Explanation

In computer science, abstraction is the standard tool used to model and study complex systems. For example, abstraction is used in model checking, analysis and verification of software, neural network analysis or robust learning.

The AIIS node of Ud'A has a strong background in abstraction, in particular on abstract interpretation and its

many applications [13, 14]. In this context, by exploiting the algorithms [15, 16] and the tools [17, 18] developed by the members of the AIIS node of Ud'A we are designing abstractions and tools for the analysis of the concurrent language for interacting argumentative agents discussed in the previous section [9, 10] and for the analysis of power consumption of software and neural networks.

3.5. Automated Reasoning for Verification

Several verification problems for programs written in different programming languages, business processes, networks, and in general software systems, can be modeled as satisfiability problems for Constrained Horn Clauses (CHC) [19].

The AIIS node of Ud'A has worked on the development of methodologies for transforming CHCs and verifying their satisfiability, with applications in:

- verification of reachability properties for imperative programs manipulating arrays [20, 21] and Algebraic Data Types (e.g. lists and trees) [22, 23, 24];
- verification of relational properties among programs [25] (e.g. equivalence, functionality, injectivity, monotonicity, non-interference);
- verification of reachability and controllability properties of business processes defined using BPMN with time extensions [26];
- generation of CHC verification conditions [27] based on the operational semantics of the programming language and the proof rules of the considered class of properties.

Focusing on sustainability, we envision potential applications on the verification of power consumption for programs, gas usage for smart contracts on a blockchain, and on checking relational equivalence of systems, before and after power consumption optimization.

3.6. Machine Learning to Forecast Particulate Matter and Trace Gas Emissions for Air Quality Assessment

This research, focusing on the use of particulate matter (PM) data—particularly PM10 and PM2.5 concentrations, but also nitrogen oxides (NO_x) and ozone (O_3)—to evaluate air quality, employs advanced machine learning techniques including neural network models to analyze and interpret continuous data from regional air quality monitoring stations [28].

Furthermore, the integration of meteorological parameters into the machine learning models enhances the accuracy of predictions about air quality variations under specific environmental conditions, demonstrating the ability of AI to provide deeper insights into environmental health impacts. To this respect, using a Nonlinear Autoregressive Exogenous (NARX) neural network, we provided a time series forecast of NO_2 and CO given four meteorological parameters: (i) air pressure, (ii) relative humidity, (iii) average daily temperature, and (iv) wind speed [29]. We have also recently proposed a novel recurrent neural network-based system for tracking and forecasting the dispersal of air pollutants PM2.5 on building sites based on established environmental parameters [30]. Preliminary findings for predicting pollutants in spatial domains can also be found in [31].

This research is conducted in collaboration with the Mathematical Institute of the Serbian Academy of Sciences and Arts, the University of East Sarajevo, Italferr S.p.a. and the Atmospheric Physics and Chemistry Laboratory (UdAtmo - www.atmo.unich.it).

By exploiting this research, policy-makers and urban planners can develop more effective strategies for pollution control and urban planning: AI helps in reducing the health risks associated with air pollution and also contributes to the broader goal of sustainable urban development.

3.7. Machine Learning Models for Ecological Footprint Prediction

In order to comprehend the effects of human activity on the ecosystem, this research direction studies predictive models for ecological footprint, measuring the speed in consuming resources and generating waste compared to the speed of nature in absorbing human's waste and generating resources.

In the recent time, we constructed and evaluated four hybrid machine learning models (artificial neural network, random forest regression and K-nearest neighbor regression) for predicting the total ecological footprint of consumption from multiple energy inputs and population number. The adopted energy inputs are: (1) natural gas, (2) coal, (3) oil, (4) wind, (5) solar photovoltaic, and (6) hydropower sources that are the main sources of energy consumption [32]. We also generated time series vector autoregression prediction models of the ecological footprint based on energy parameters [33].

The AIIS node of Ud'A is conducting this research with the Mathematical Institute of the Serbian Academy of Sciences and Arts and with the University of Belgrade.

3.8. Social Sustainability and LLMs

According to the European Green Deal and to the Digital Services Act, creating and supporting digital environments that are safe and supportive for all individuals is one the objectives that underlines the broader sustainable development goals. Combating online misogyny, in particular, aligns with Sustainable Development Goal 5 of the United Nations. While recent advances in Generative Pretrained Language Models have raised important

questions about their safety and fairness [34], many researchers are exploring their use to enforce online safety. Generative LLMs are indeed flexible tools to implement data analysis automation task, including hate speech detection [35, 36] and stance/polarity estimation [37].

Our experiments in misogynistic content classification [38] show that a zero-shot GPT 3.5-based classifier outperforms traditional Deep Learning methods like BERT, without the need for large annotated training sets. Results indicate that majority voting among multiple AI annotators, each prompted differently, is effective, yet highlights potential for further improvement. Specifically, we are investigating CoT and Planning-like patterns to improve recognition of more specific classes, as misogynistic derogation, treatment, or counter-speech.

In a related line of research, the AIIS node of Ud'A is collaborating in the RightNets PRIN project, leaded by University of Macerata and University of Sapienza, with the goal of enhancing Social Media monitoring dashboards [39] with AI tools in order to more effectively monitoring political and electoral debate on social media.

Another research line focuses on utilizing textual data from social media, particularly during crises and natural disasters, to aid disaster responders. However, these studies face challenges such as dealing with unstructured, noisy, and ambiguous data, varying user credibility, expertise, and bias, and the overwhelming volume of data generated during disasters. Leveraging state-of-the-art machine learning and AI techniques, we have proposed a methodological framework for damage assessment on tweets related to Hurricane Ida that integrates textual classification of social media data, spatial analysis, and visual analytics to provide rapid responses during natural disasters [40].

3.9. Machine Learning Models for Classification of Energy Consumption

Total energy consumption can be heavily conditioned by global demographic and economic changes. Accordingly, this research direction investigates on prediction models of energy consumption.

In the recent time, we considered the application of demographic and economic features as predictor variables for energy consumption. In order to categorize energy consumption levels from (i) gross domestic product, (ii) CO_2 emissions, and (iii) total population, we investigated the usage of multiclass ensembles of support vector machines and linear discriminant analysis [41].

Also, we applied multiple linear regression and multilayer perceptron to forecast energy usage [42]. Energy consumption was the dependent variable, whereas the gross domestic product, population as a whole, and CO_2 emissions were considered the predictor factors.

In this research direction, the AIIS node of Ud'A is collaborating with the Mathematical Institute of the Serbian Academy of Sciences and Arts.

3.10. Forecasting Models for Climate Variables and Renewable Energy

Accurately estimating energy production from renewable energy sources is crucial for ensuring a reliable and consistent supply, aiding in the planning and managing of the power grid. Predicting their power generation is notably challenging due to their dynamic behaviour, influenced by factors like time, weather parameters and location. Beyond the inherent complexity of these phenomena, the difficulties are further compounded by the limited availability of local real-time data, particularly for short-term forecasts. Therefore, the use of forecasting models is essential to achieve this goal. In the case of missing measured data, Regional Climate Models (RCMs) represent a practical and valuable tool for describing the climatology of places. The Fifth-Generation Mesoscale Model (MM5) is one of the most adopted among them. However, various works point out its tendency to under-/overestimate weather parameters. We proposed DL^2F [43], a powerful deep learning model that combines experimental data with MM5 information to address these challenges and enhance the accuracy of forecasting procedures. Our system forecasts four essential weather variables that influence solar power potential: Global Horizontal Irradiance (GHI), temperature, atmospheric pressure, and relative humidity. The model uses a time series for each variable as input and the forecast provided by the MM5 system. Then, it generates new predictions for each variable in the next 3 days. The model's architecture is based on a set of GRU (Gated Recurrent Unit) neural networks. The new more precise predictions are then adopted for calculating the electrical energy production of a photovoltaic cell [44].

3.11. Energy-Efficient Deep Learning

Deep learning models, particularly those at the cutting edge, can require significant computational resources which translate into high energy consumption. This not only increases the cost of training and deploying these models but also has a substantial environmental impact due to the carbon footprint associated with energy production. In this research direction, we developed GloNet [45], an efficient network architecture that can self-regulate its depth, and thus its computational needs, according to the specific requirements of the task. This enhances both sustainability and efficiency by reducing energy consumption and minimizing environmental impact. Furthermore, GloNet improves the accessibility of advanced models for users with limited computational

resources, thereby contributing to the democratization of deep learning. This is particularly impactful in resource-intensive fields such as reinforcement learning [46, 47], making them more attainable and broadly usable.

3.12. Health Sustainability

Some members of the Ud'A AIIS node also work in the field of health sustainability where we have studied the role of AI and the impact of machine learning methodologies to analyze the Long COVID syndrome, from clinical presentation through diagnosis [48].

A multi-omics approach integrating MRI-based radiomics and metabolomics in rectal cancer treatment predicts patient responses, potentially reducing unnecessary surgeries. A novel machine learning model using pre-treatment MRI in locally advanced rectal cancer optimizes neoadjuvant treatments for better organ preservation. A radiomics-based model distinguishes COVID-19 from other acute lung diseases using HRCT, aiding early and accurate management decisions. These methods improve personalized medicine by enhancing predictive accuracy and treatment sustainability [49, 50, 51].

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