ARTIFICAL INTELLIGENCE CONFERENCE

BOOK OF ABSTRACTS

BELGRADE, 26-27 DECEMBER 2024

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FOREWARD

Following the success of the Artificial Intelligence conference in December 2023, we decided to organize a new edition, this time in English and not only for participants in Serbia.

The Artificial Intelligence Conference represents the aspirations of numerous researchers in Serbia working in the field of artificial intelligence to establish a gathering with a primarily research-oriented focus, under the auspices of the Serbian Academy of Sciences and Arts (SASA), Serbia's most prestigious scientific institution.

The conference aims to bring together researchers from various branches of artificial intelligence from Serbia and abroad to showcase their work and findings. Artificial intelligence is not only a highly popular field today but also a vast one. Consequently, the topics of interest at this conference are numerous and diverse.

In addition to emphasizing its research character, this conference is distinguished by several key features:

- A dedicated focus exclusively on the field of artificial intelligence
- Encouragement of discussions on the fundamental aspects of artificial intelligence
- Special attention to emerging topics in artificial intelligence
- Integration of techniques and results from different subfields of artificial intelligence
- Gathering a significant number of Serbian researchers in the field, including both experienced and emerging talents

We have received a total of 62 submissions to the conference from leading universities and institutions in Serbia and abroad, covering a wide range of topics in artificial intelligence. Out of these, 57 were selected for presentation. Each abstract underwent review by at least two Reviewers or members of the Program Committee, with some requiring a second revision before acceptance.

Artificial intelligence, with its profound influence on modern society, necessitates ongoing study and a systematic analytical approach. This conference was conceived with precisely that objective – to facilitate the exchange of research ideas and experiences within this vast and complex field.

The conference organizers are particularly committed to fostering opportunities for young and promising researchers. Through presentations and discussions, these individuals will have the chance to share their work, gain valuable feedback from esteemed experts, and build connections with future collaborators. We believe that fostering this interaction between generations is essential for the sustained advancement of artificial intelligence research in Serbia.

The organizers of this conference, representing three institutions – the Serbian Academy of Sciences and Arts, the Mathematical Institute of the Serbian Academy of Sciences and Arts, and the Academy Committee for Artificial Intelligence of SASA – firmly believe in the importance of artificial intelligence for the future of various activities in our country. We are confident that research and innovation in this field will contribute to economic development, improvements in health and education, and the opening of new horizons in science, art, and other areas of life. We are convinced that through joint efforts, we can influence the trajectory of this significant field while advancing knowledge, creativity, and innovation.

Sincerely,

Conference Co-chairs
Vladan Devedžić, SASA, Belgrade, and Faculty of Organizational Sciences, University of Belgrade
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Belgrade, December 2024

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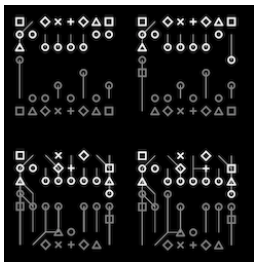
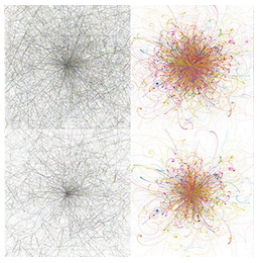


MACHINE LEARNING

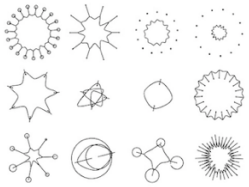
NATURAL LANGUAGE PROCESSING

PROBLEM SOLVING

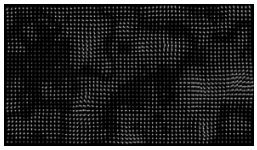


KNOWLEDGE REPRESENTATION, REASONING AND PLANNING

UNCERTAIN KNOWLEDGE AND REASONING



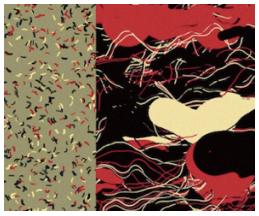
EXPLAINABLE AI



DECISION MAKING

COMPUTER VISION

GENERATIVE AI



ARTIFICIAL INTELLIGENCE AND ETHICS

KEYNOTE TALKS

New AI Methods for Simplifying Multi-Omics Data Analysis in Precision Medicine

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Abstract. Large quantities of multi-omic data are increasingly becoming available. They provide complementary information about cells, tissues and diseases. We need to utilize them to better stratify patients into risk groups, discover new biomarkers and targets, re-purpose known and discover new drugs to personalize medical treatment. This is nontrivial, because of computational intractability of many underlying problems on large interconnected data (networks, or graphs), necessitating the development of new algorithms for finding approximate solutions (heuristics) [1].

We develop versatile data fusion artificial intelligence (AI) frameworks, that utilize the state-of-the-art network science methods, to address key challenges in precision medicine from time-series, multi-omics data: better stratification of patients, prediction of biomarkers and targets, and re-purposing of drugs, applied to different types of cancer [2,3], Covid-19 [4,5], Parkinson's [6,7] and other diseases. Our new methods stem from graph-regularized non-negative matrix tri-factorization (NMTF), a machine learning (ML) technique for dimensionality reduction, inference and co-clustering of heterogeneous datasets, coupled with novel graphlet-based network science algorithms. We utilize our new frameworks to for improving the understanding the molecular organization and diseases from the omics data embedding spaces [8,9,10]. Also, we utilize local topology to correct for the topological information missed by random walks, which are used in many ML methods [11], and to enable embedding of networks into more linearly separable spaces, allowing for their better mining [12]. The aim is to develop an overreaching framework encompassing all multi-omics data that would simplify currently complex and energy inefficient methodologies for multi-omics data analysis [13].

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Characterizing Disruptive Events by Modeling Dynamics in Multiplex Networks

Speaker:
Zoran Obradovic, Laura H. Carnell Professor of Data Analytics
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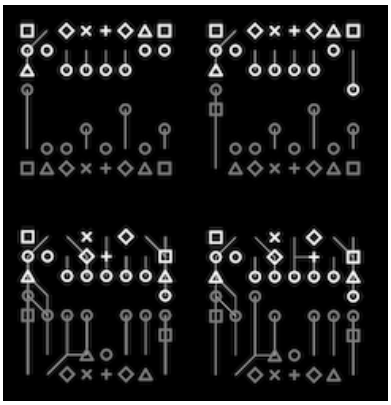
Abstract: This presentation will delve into effective machine learning-based approaches for identifying, categorizing, and forecasting disruptive weather events, even when data is limited and labels are imprecise. We'll showcase some of our latest techniques, which address this challenge by leveraging multiplex evolving networks to analyze structured and unstructured data sources jointly. Our findings demonstrate that the accuracy and efficacy of diagnostics and risk monitoring for weather events can be greatly enhanced by utilizing deep learning and transfer learning techniques. Specifically, integrating information from weather, geophysical, and social media sources of varying quality and resolutions can yield significant improvements in predicting and managing weather-related disruptive events.

Biography: Zoran Obradovic is a Distinguished Professor and a Center director at Temple University, an Academician at the Academia Europaea (the Academy of Europe), and a Foreign Academician at the Serbian Academy of Sciences and Arts. He mentored about 50 postdoctoral fellows and Ph.D. students, many of whom have independent research careers at academic institutions (e.g. Northeastern Univ., Ohio State Univ,) and industrial research labs (e.g. Amazon, eBay, Facebook, Hitachi Big Data, IBM T.J.Watson, Microsoft, Yahoo Labs, Uber, Verizon Big Data, Spotify). Zoran is the editor-in-chief of the Big Data journal and the steering committee chair for the SIAM Data Mining conference. He is also an editorial board member of 13 journals and was the general chair, program chair, or track chair for 11 international conferences. His research interests include data science and complex networks in decision support systems addressing challenges related to big, heterogeneous, spatial, and temporal data analytics motivated by applications in healthcare management, power systems, earth, and social sciences. His studies were funded by AFRL, DARPA, DOE, NIH, NSF, ONR, PA Department of Health, US Army ERDC, US Army Research Labs, and industry. He published about 450 articles and is cited more than 34,000 times (H-index 69). For more details see http://www.dabi.temple.edu/zoran-obradovic

BOOK OF ABSTRACTS

MACHINE LEARNING



WEIGHTED AUTOMATA IN MACHINE LEARNING

Miroslav Ćirić[a], Jelena Ignjatović[a] and Nada Damljanović[b]

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Abstract. It has been experimentally shown that ***recurrent neural networks*** (RNNs for short) are a powerful tool to process, predict, and model sequential data, but there are known drawbacks in RNNs such as interpretability and costly inference. That restricts deployment of RNNs in systems where security and transparency mat-ters are of utmost importance, for instance in security and health systems, where formal specification and verification of systems is a mandatory requirement to be approved for deployment in real-case situations. One of the strategies aiming to overcome these drawbacks and shed some light on how information is repre-sented internally in RNN models is to replace, whenever possible, the RNN with a ***weighted finite autom-aton*** (WFA for short), as its interpretable surrogate. This problem is also known as ***WFA extraction from a black box model***. Although the computational power of WFAs is significantly less than that of RNNs, since the class of functions that can be computed by WFAs is a proper subclass of the class of functions computed by RNNs, in the case where the behavior of a RNN can also be realized by a WFA, replacing that RNN with a WFA gives great advantages. In addition to being interpretable, WFAs are much easier for implementation and cheaper to run. Experimental results provided in [5] showed that WFA inference is about 1300 times faster than inference of original RNNs (see also [1,4]).

Here we are dealing with a somewhat more general ***WFA reconstruction problem***, which asks to construct a WFA that computes a given word function. Recall that a ***word function*** is a map which to any word over a given alphabet assigns its weight (here we are dealing with word functions that take weights in the field of real numbers). According to the well-known result of Carlyle and Paz (1971) and Fliess (1974), a word func-tion taking values in a field can be realized by a WFA if only if the Hankel matrix of that function has a finite rank. In that case, the rank of this Hankel matrix is the smallest number of states which a WFA realizing that function can have. A number of recent papers have provided algorithms for reconstructing a minimal WFA from a given word function that takes values in the field of real numbers (for instance, see [1,4]). These algorithms are based on the rank factorization of the Henkel matrix of that function, as well as on the use of Moore-Penrose inverses of real matrices, and served as the basis for the development of the spectral learning algorithm for WFAs.

In [2,3] we have proposed a different approach to the WFA reconstruction problem. We introduced two types of weighted automata with vector states. The first one are weighted automata whose set of states is a set (possibly infinite) of vectors of a given vector space, the transitions are deterministic, and the weights are concentrated in the vector states and in the terminal weights function, which to each vector state assigns its terminal weight. They are called ***crisp-deterministic weighted automata*** (CDWAs for short) with vector states. The second type is an extension of CDWAs where the transitions also carry weights, but satisfy the condition that for each vector state and each input letter there is exactly one transition from that state, induced by that input letter, with a non-zero weight. They are called ***deterministic weighted automata*** (DWAs for short) with vector states. A similar type of automata (with ordinary states) was studied in numer-ous papers under the name *sequential weighted automata*. The ***dimension*** of a CDWA or DWA with vector states is defined as the dimension of the subspace of the underlying vector space generated by reachable states of this automaton. Subsequently, we say that a CDWA is ***linear*** if the restrictions of the transition functions and the terminal weights function on that subspace are linear maps, while a DWA is ***linear*** if the transition weights functions are linear, as well.

For an arbitrary word function f, in [2] a CDWA with vector states was constructed which computes f. The states of that automaton are derivatives of the function f, which is why that automaton is called the ***derivative automaton*** of the function f. It was proved that the derivative automaton of f is a linear CDWA of the smallest cardinality among all CDWAs that compute f, and the smallest dimension among all linear CDWAs that compute f. In addition, it was proved that every linear finite-dimensional CDWA with vector states can

be transformed into an equivalent WFA over the field of real numbers of the same dimension, and an efficient algorithm that realizes such a transformation was provided. When applied to the derivative automaton of the word function f, that algorithm yields a WFA with the smallest number of states that computes f. As a consequence of all this, it was obtained that a word function can be computed by a WFA if and only if it can be computed by a linear finite-dimensional CDWA with vector states, that is, if and only if the derivative automaton of that word function is finite-dimensional. This result is closely related to the aforementioned results of Carlyle and Paz and Fliess, because derivatives of a word function f are row vectors of its Hankel matrix, so that Hankel matrix of f has a finite rank if and only if the derivative automaton of f is finite-dimensional.

A different construction of a weighted automaton with vector states that computes an arbitrary word function f was given in [3]. That is a DWA with vector states whose states are normalized derivatives of the word function f, obtained by means a norm-like function on the space of word functions, which is called the ***norm-alized derivative automaton*** of f. This automaton has the same dimension as the derivative automaton of f, but in the general case has a smaller cardinality than the derivative automaton, and can be finite even in the case where the derivative automaton is infinite. All previously mentioned results concerning CDWAs and derivative automata are also proved for DWAs and normalized derivative automata.

Keywords: Weighted automata, Recurrent neural networks, Extraction, Word functions, Derivatives

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GraalSP Profiles Logger: A Tool for Analyzing and Interpreting Predictions of the ML-Based Static Profilers

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[2] Oracle Labs, Belgrade, Serbia, milan.cugurovic@matf.bg.ac.rs

Abstract. Program profiles provide information about the program's behavior during execution. Profiles include the number of branch executions in branching statements, context and number of function calls, context and number of virtual method calls, information on monitor locks and unlocks, and more. Profiles enable profile-guided optimizations including aggressive inlining, cache memory optimizations, and similar techniques which generate highly efficient code.

Instrumentation-based profiling is a common technique for collecting precise profiles. However, the profile collection represents a significant overhead in software development, and in some environments, it is unfeasible (for example, in memory-constrained environments such as embedded systems or in real-time systems where extended execution time due to the additional instrumentation code is not acceptable). An alternative to dynamic profiling is static profiling. Static profilers predict profiles instead of collecting them. The current development of static profilers is mainly focused on using machine learning techniques for predicting branch execution probabilities. Modern static profilers [1, 2, 3] use ensembles of random forests and deep neural networks for regression to predict the probabilities of the taken branch of a branching statement. The best current static profilers achieve execution time speedups of 5 to 7 percent.

Static profilers can make mispredictions as similar code segments may execute differently depending on inputs and various conditions. The impact of individual predictions can significantly affect the performance of the program. For instance, an incorrect prediction that the branch would not lead into a frequent loop body can result in a substantially slower program. To maximize performance, state-of-the-art static profilers employ instance weighting to prioritize critical cases. However, misprediction can still happen and it is necessary to efficiently identify and analyze them, to adjust and improve the ML model driving the static profiler.

We have developed the GraalSP Profiles Logger (GraalSP-PLog), a tool for efficiently analyzing ML-based predictions made by the GraalSP static profiler [1] which is a part of the Oracle GraalVM Native Image compiler [4]. GraalSP-PLog runs the input program with GraalSP to log the profile predictions. As GraalSP employs a set of static heuristics that correct predictions of the ML model, GraalSP-PLog also captures this information. To collect ground truth values, GraalSP-PLog performs instrumentation profiling to dynamically collect program profiles. Combining static predictions and collected profiles, GraalSP-PLog generates a prediction report. The report facilitates the identification of performance-critical predictions, both accurate and inaccurate, and sorts nodes by their impact on overall program performance. The tool provides results in *.csv* format so that they can be easily opened on any operating system and sorted by any criteria.

Additionally, we have incorporated the Ideal Graph Visualizer (IGV) [5] into GraalSP-PLog to evaluate the impact of branch execution probabilities on optimization choices. IGV offers a visual depiction of the transformations in intermediate representation graphs throughout the compilation process, enabling users to understand how optimizations influence method compilation. This visualization capability greatly enhances the human assessment of GraalSP.

GraalSP-PLog is a command-line application. When run, it launches the IGV visualizer and generates a graph of the target method. Figure 1 shows part of the IGV graph corresponding to the loop in the binary search method, with its source code displayed in Figure 1. The *13If* node corresponds to the exit from the *while* loop. Regarding exiting the while loop, dynamic profiling predicts a value very close to zero, while static profiling estimates a probability of 0.07. In this case, the model made an accurate prediction.

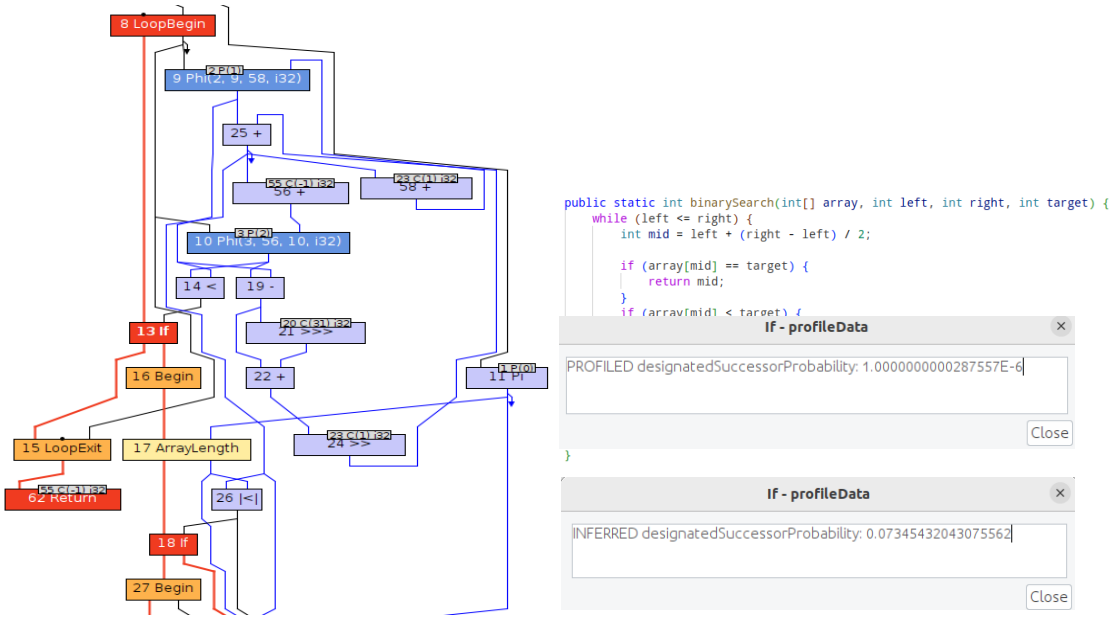

Fig. 1.: Source code of the binary search algorithm (top right), the corresponding IGV graph (left), and the profiled and predicted probability of executing the true branch of the *13If* node (bottom right).

The GraalSP-PLog tool for analyzing static profiler predictions is crucial for understanding the results of profile-guided optimizations based on profiles predicted by ML models. By analyzing model errors, the set of attributes describing branching instructions can be expanded, or manually defined heuristics can be adjusted to improve the ML model's predictions. Additionally, this approach allows for comparing different machine learning models and their predictions on individual instances. The generated report can also offer insights into which methods need more focus, highlighting where the model performs poorly and where it excels.

Acknowledgement: This work is being carried out as part of a collaboration project between the Faculty of Mathematics and Oracle Labs. It is partially supported by project 451-03-47/2023-01/200104 of the Ministry of Education, Science, and Technological Development.

Keywords: Oracle GraalVM Native Image, Static profilers, GraalSP, Program Profile

References:

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Algorithmic Insights: Enhancing Machine Learning Applications in Orthotropic Plate Stability Analysis

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Abstract. Stability in orthotropic plates is a vital area of research, given these materials' distinctive properties, such as anisotropy and directional stiffness variations. Often fabricated from materials like fiberglass or carbon fiber, orthotropic plates offer substantial weight savings and improved performance across engineering applications. However, accurately predicting their stability under various loads, such as aerodynamic forces, remains challenging. Key factors like fiber orientation, plate thickness, and boundary conditions play a significant role in determining their stability behavior.

In this study, several machine learning algorithms were compared and evaluated for their applicability to orthotropic plate stability analysis, specifically focusing on the Fast Forest Regression, Fast Tree Regression, SDCA Regression, L-BFGS Poisson Regression, and LightGBM Regression algorithms. These algorithms were chosen for their potential to model complex relationships and nonlinear characteristics that are often observed in orthotropic materials [1].

Each algorithm's effectiveness was assessed based on its predictive accuracy, reliability, and ability to generalize stability behavior across different configurations and loading conditions. Computational speed was also a critical metric, as faster algorithms are preferable in applications requiring rapid iterative analysis and optimization, such as those encountered in aerospace and automotive design [2]. By comparing the performance of these algorithms, the study aimed to identify the most suitable approaches for accurately capturing stability characteristics in orthotropic plates, providing insights into which methods offer the best trade-off between precision and efficiency.

The results of this comparison highlight the potential of certain algorithms to streamline stability assessments while maintaining accuracy, paving the way for more optimized and computationally efficient stability predictions in the field of composite material design and analysis."

Machine learning (ML) approaches present distinct advantages over conventional methods in the analysis of orthotropic plates. These materials, which exhibit unique directional stiffness and anisotropic properties, often demand detailed and computationally intensive modeling when approached through traditional techniques. In contrast, ML models can handle these complex, nonlinear relationships more efficiently, significantly reducing computational time while maintaining accuracy. By learning from extensive datasets, ML algorithms can identify intricate patterns in plate behavior under various loading conditions, fiber orientations, and boundary constraints—conditions that would otherwise require multiple, specialized models to analyze conventionally [3-5].

Moreover, ML methods enable rapid, large-scale analysis, making it feasible to test numerous design variations and loading scenarios with ease, thereby facilitating optimized structural designs and improved stability predictions. As datasets grow, ML algorithms can continuously adapt, enhancing their predictive precision and offering a dynamic, flexible approach to stability analysis. This adaptability makes ML a valuable tool in applications where quick response times and high accuracy are essential, such as aerospace and automotive industries, where orthotropic materials are increasingly used for their lightweight and high-strength properties

Keywords: Orthotropic plate, Machine learning, Regression algorithm, Plate stability, Composite Materials

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Deep learning assisted determination of two-dimensional crystal thickness using atomic force microscopy

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Abstract. Atomic force microscopy relies on a probe "touching" the sample surface at its sharpened tip. The surface topography, featuring nanometer lateral and sub-nanometer vertical resolution, is obtained by scanning the tip over a selected area, while maintaining a fixed tip-sample distance. Considering the AFM image resolution is orders of magnitude higher than the optical diffraction limit, and that it provides means of probing a variety of interaction mechanisms (e.g. mechanical, electro-static, magnetic, etc.) between an ultrasharp tip and the sample, as well as a number of options for nanomanipulation, AFM represents one of the essential tools in nanotechnology.

One important AFM use case is the investigation of two-dimensional crystal flakes such as graphene and transition metal dichalcogenides, which are recently discovered ultrathin systems with a number of promising technological applications. The investigated flakes typically have a few micrometer lateral size, sub-nanometer thickness and are deposited on flat oxidized silicon wafers. The accurate assessment of the thickness, although well within AFM sensitivity, is challenging due to the difficulty of distinguishing the two-dimensional crystal flake from the slowly varying non-linear background topography, representing the combined contribution of the wafer surface (tilt and curvature) and the piezo tube bow (a nonlinearity of the sensor system, observed when the lateral extension of the surface is several orders of magnitude larger than its height variation). The flake thickness determination relies on identifying the topography points that correspond to it and subsequently fitting a surface model comprising the sum of a polynomial background with a terrace (Heaviside step function modeling the flake) to the measured topography. Since the measured area often has multiple irregularly-shaped flakes, the manual specification of terraces of the two-dimensional surface model is arduous (if possible at all) and thus suffers from reproducibility issues.

In this contribution, we describe a deep learning assisted iterative algorithm that is able to accurately extract the two-dimensional crystal thickness by automatically recognizing the flakes on a wafer. The key element of the algorithm is a U-Net, a fully convolutional neural network architecture developed for image segmentation and trained on carefully synthetized AFM data. The identification of the terraces corresponding to flakes segmented on background-corrected topography data is improved iteratively, until convergence is reached. We demonstrate that the algorithm produces excellent results when applied to real AFM data.

Keywords: Machine learning, Computer vision, Atomic force microscopy, Two-dimensional crystal, Graphene

Using federated learning to address privacy concerns in e-learning recommendation systems

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Abstract. The immense volumes of data generated and processed today have driven significant advancements in technology and services, yet they have also raised serious concerns about user privacy and the security of sensitive information being handled. One of paradigms that arose in such conditions is Federated machine learning, created as a meaning of handling vast volumes of data and ensuring user privacy. Federated learning is a distributed machine learning technique that aims to train and build machine learning models on distributed datasets across multiple sources generating data while avoiding possible data leakages (Rahman et al., 2021). The main idea is to perform training on remote devices or isolated data centers where data is generated and stored, without joining and transferring data to a centralized repository, thus avoiding privacy risks. Federated learning ensures that locally trained models only provide updates on parameters which are then aggregated on a central server – ensuring a better global model (Wen et al., 2022) (Kairouz et al., 2021). The goal of this research is to demonstrate possible applications of federated learning in field of e-learning. Such application can create or improve personalized learning models or enhance common insights into learning. Personalized learning is a complex activity approach that is the product of self-organization or learning and customized instruction that considers individual needs and goals (Shemshack & Spector, 2020).

In this research personalized learning is a learning model that adapts to individual learning behaviors of students without direct access to sensitive student data. Common insights into learning refers to a possible situation where different educational institutions can collaborate to improve their models collectively while respecting the privacy requirements of each institution.

Specifically, the research examines the impact of federated learning on the development of recommendation systems within Learning Management Systems (LMS), with a focus on Moodle LMS. The research methodology employs a comprehensive analysis of LMS data to identify patterns crucial for generating personalized and intelligent course recommendations. The study aims to investigate the system's ability to dynamically suggest optimal activities, course formats, and structural adjustments based on real-time data.

The technical analysis in the paper will be conducted using the Flower framework. The Flower framework is built for solving federated learning problems considering both technical and architectural aspects (Beutel D. J. et al, 2022).

The expected outcome is a demonstration of the effectiveness of federated learning in enhancing the adaptability of e-learning platforms, thereby improving the educational experience.

Keywords: Federated learning, E-learning, Machine learning, Privacy preservation, Personalized learning

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Botnet Detection Using Time Series Data and Boosting Algorithms

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Abstract: In this paper, a different approach for botnet detection, based on statistical time series data and state-of-the-art boosting algorithms will be shown. Time series statistical parameters are extracted from network traffic recordings, while extreme gradient boosting is used for classification. A performance analysis of several machine learning pipelines is given. Since malware traffic comprises a small portion of total network traffic, this study explores the usage of various artificial sample generation (ASG for short) algorithms, whose main purpose is balancing the dataset .This research was performed on live botnet samples recorded in an isolated environment.

Introduction: Botnets represent a network of infected devices, called bots, which are controlled by a malicious user, called botmaster. The main goal of such a network is to execute attacks on other devices, such as DDoS, port scanning, personal information theft, mining cryptocurrencies (Vormayr et al., 2017). With the emergence of IoT botnets, such as Mirai, the botnet detection problem has drawn attention of both the scientific community and industry professionals. Since IoT devices lack basic security capabilities, a plethora of these devices can be employed to conduct high-volume DDoS attacks, which can cause devastating damage to network infrastructures.

There are two main approaches in botnet detection: deep packet inspection, where features are extracted from each network packet, and flow-based, where statistical features of whole network flows are extracted. On one hand, deep packet inspection provides detailed insight into network traffic and demands more processing power and memory storage, while on the other hand, flow-based detection provides a reduced set of features that can be extracted in a short amount of time. The approach demonstrated in this paper represents a mix of both of the aforementioned approaches. Statistical data is extracted from time series data, which are constructed by tracking the total amount of bytes which pass in one direction of a network conversation in each second. The dataset used in this research is based on real-world static IoT malware code and dynamic behavior analyses collected over four years (2019-2023). In this research, state-of-the-art algorithms for each of the machine learning pipeline steps were tested, and their class-based scores were compared. In order to explore the possibility of detecting zero-day attacks in a real-world scenario, the performance of best machine learning pipelines was tested on different partitions of the dataset

Methodology: The machine learning pipeline consists of the following steps: feature extraction, feature selection, hyperparameter optimization, and model classification. Since botnet detection involves heavily disbalanced datasets, an optional step of artificial sample generation was included between feature extraction and feature selection, in order to balance the dataset and test the effect of such algorithms on classification performance.

Features extraction involved calculating statistical time series features from network traffic, using the tsfresh library (Christ et al., 2018). Firstly, the network traffic was recorded and stored in pcap format. Time series were extracted by counting the total number of bytes in a second between two endpoints in a single direction. Feature selection was performed by three different algorithms: Recursive Feature Addition (RFA), Recursive Feature Elimination (RFE) and the Boruta algorithm. Hyperparameter optimization was performed using the Tree-structured Parzen Estimator (TPE) algorithm. Models chosen for classification XGBoost and LightGBM, both based on the gradient boosting algorithm. SMOTE-ENN, Borderline SMOTE, and ADASYN algorithms, all based on the SMOTE algorithm (Chawla et al., 2002), are used for artificial sample generation. All combinations for the aforementioned algorithms were used to form different machine learning pipelines, whose results were compared. The scores used for comparison are accuracy, precision, and F1-score, calculated on a per-class basis. Exploration of different pipelines in order to find the best one for the problem of botnet detection constitutes the first group of experiments.

Best performing pipelines in the first group of experiments, one involving the ASG step, as well as one which lacks this step, are then selected for performance on different partitions of the dataset, each of which involves forming the training and testing sets on a chronological basis. Testing the performance of different partitions of the dataset on best performing pipelines constitutes the second group of experiments. These experiments served to explore the capability of a machine learning system for botnet detection to detect zero-day attacks.

Conclusion and Future Work: The results of different pipelines have shown promising results for botnet detection in the first group of experiments. The botnet accuracy averaged 0.99 for pipelines with ASG, and 0.89 for pipelines which did not use this step. Experiments on the first partition of the dataset (placing newer botnet samples in the testing set) yielded an accuracy score of 0.97 without ASG, and an accuracy score of 0.98 with ASG. Experiments on the second partition of the dataset (placing 50% of newer samples in the testing set) yielded an accuracy score of 0.89 without ASG, and an accuracy score of 1.0 with ASG. Experiments on the third partition of the dataset (random shuffle of samples between training and testing sets) yielded an accuracy score of 0.90 without ASG, and an accuracy score of 0.99 with ASG.

Future work will be directed in following directions: expanding the existing set of extracted features, investigating other machine learning pipelines, exploring deep learning algorithms for the problem of botnet detection.

Keywords: Boosting algorithms, Artificial sample generation, Time series analysis, Botnet detection

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Stability of machine learning methods

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Abstract. In this work, the stability or generalization property of machine learning methods for data classification in four different and publicly available databases was investigated. The investigated methods were: support vector machine (SVM), ensemble of bagged tree (bagged DT) and k-nearest neighbors (KNN). The parameter space of input data consisted of mean coefficient of variation ($\overline{CV}$), mean mutual entropy ($\overline{ME}$) and sample size. The generalization property of the input data was examined with the following algorithm: the input set was divided into equal sets, so that the first set served for training and validation, while the others have the roles of unseen sets. The entire procedure was repeated iteratively twenty times, whereby the input data were mixed each time and finally the mean total accuracy ($\overline{AC(\%)}$) and the mean relative error ($\overline{RE(\%)}$) were determined. The size of the input data set was also varied. It was shown that the bagged DT method achieved exceptional results, even in cases of little or almost no mutual statistical dependence between the input variables: $\overline{AC(\%)} = 90.02\%$, $\overline{RE(\%)} = 4.83\%$, which set this method as superior to the others. For the SVM method it was: $\overline{AC(\%)} = 68.08\%$, $\overline{RE(\%)} = 57.75\%$ at $\overline{CV} = 0.89$, $\overline{ME} = 0.03$ as well as $\overline{AC(\%)} = 98.38\%$, $\overline{RE(\%)} = 3.65\%$ at $\overline{CV} = 0.39$, $\overline{ME} = 0.36$. Recommendations are that the bagged DT should be the first choice in the case of negligible statistical dependence between the input variables, $\overline{ME(\%)} \to 0$, while in cases where $\overline{ME(\%)} \geq 0.3$ all methods could be used, because they showed a high degree of accuracy $\overline{AC(\%)} \geq 92\%$ and stability $\overline{RE(\%)} \leq 5\%$. At the value of $\overline{CV} = 0.03$, which corresponds to the strict localization of the input variables in the parameter space, all methods exhibited outstanding levels of accuracy $\overline{AC(\%)} \geq 98\%$ and stability $\overline{RE(\%)} \leq 1\%$.

Keywords: Support vector machines, Ensemble of bagged tree, K-nearest neighbor, Coefficient of variation, Mutual entropy.

Quantum Neural Processes for Astrophysical Signal Detection in Red Noise Environments

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Abstract. We constructed a pilot hybrid quantum-classical framework employing Quantum Neural Processes (QNP) for the detection and reconstruction of astrophysical signals embedded in red noise. QNP should address challenges posed by the increasing complexity of astronomical datasets, which now scale to petabytes, such as those anticipated from the Vera C. Rubin Observatory Legacy Survey of Space and Time, starting from 2025. As astronomical dataset dimensionality grows, the computational complexity of processing algorithms escalates exponentially, presenting significant challenges to conventional methods.

In parallel, quantum computing has advanced remarkably, with systems featuring hundreds of qubits now accessible via cloud platforms like Google Quantum AI (Arute et al., 2019) and IBM's quantum services [1]. The accessibility of such large-scale quantum computers has fueled a rapidly expanding array of applications. While some claims of quantum advantage have been met with criticism (see e.g., Renaud et al., 2024, and references therein), it remains essential to evaluate how quantum computing can be effectively integrated into scientific pipelines and the potential benefits it may offer (Herrmann et al., 2023; Renaud et al., 2024). Our QNP framework capitalizes on Google Quantum AI capabilities by integrating parameterized quantum circuits (PQCs) as latent encoders with classical neural networks as decoders, designed to handle complex time-series data. We present the application of QNP to both artificial gravitational wave (AGW) signals and quasar light curves, two domains where noise significantly complicates signal interpretation. The QNP model integrates parameterized quantum circuits (PQCs) as latent encoders with classical neural networks as decoders (Kovačević et al., 2023), designed to handle complex time-series data.

The quantum encoder consists of a four-qubit register with a circuit depth of four. Each layer of the quantum circuit applies a sequence of rotational gates (RX, RY, RZ) to each qubit, followed by controlled NOT (CNOT) operations that entangle the qubits. This configuration enables the quantum circuit to capture latent representations of the input signal. The encoded latent space is then processed by a classical neural decoder, composed of fully connected layers with ReLU activations, which decodes the quantum representations into signal predictions. The architecture is trained using the Adam optimizer. For the AGW signals, we simulated data using combining noise from the *aLIGOZeroDetHighPower* method from the *PyCBC* library with synthetic sigmoid signals (see Sellers et al., 2022, and references therein). Similarly, quasar light curves were modeled as a damped random walk to represent variability as red noise (Kovačević et al., 2021). The QNP architecture effectively recovered the true artificial AGW signals from noisy environments with low mean absolute error (MAE), as well as modeled light curves of quasars, demonstrating strong performance in both AGW and quasar datasets. This work demonstrates the potential of quantum neural networks in time-domain signal processing, presenting a promising approach for AI in astrophysical data analysis. By combining quantum encoding with classical decoding, it effectively handles complex noisy environments, advancing AI-driven methods for GW detection and quasar variability studies.

Keywords : Quantum Neural Processes, Artificial Intelligence in Astrophysics, Red Noise Signal Processing, [1]https://quantum.ibm.com/

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Transformers and Tokenization: A Novel Approach to Predicting In-game Purchases

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Abstract. Player purchases in free-to-play (F2P) online games represent essential metrics for assessing user engagement and understanding behavioral patterns. Predictive models for player purchases empower game developers to tailor marketing strategies, efficiently allocate resources, and enhance player retention through data-driven insights. This proactive approach maximizes revenue and fosters player satisfaction, providing a competitive edge in the dynamic gaming industry.

This work proposes a novel methodology for player purchase prediction, leveraging Transformer neural networks in combination with a discretized representation of player behavioral histories. The methodology assumes that recent player activity plays a pivotal role in shaping future behavior while acknowledging that similar patterns may yield different outcomes depending on the broader context of the player's cumulative history. By discretizing behavioral features and utilizing tokenized inputs derived from this history, the approach predicts whether a player will make a purchase within the next 3, 5, or 7 days.

The dataset, derived from the mobile game *Woka Woka* by *Two Desperado*s (https://twodesperados.com), captures comprehensive daily player activity, including engagement metrics (e.g., sessions, time played), skill-related measures (e.g., levels completed), and purchase behavior (e.g., in-game currency transactions and balances). These data enable a focused analysis of player engagement, skill, and purchasing tendencies while excluding features related to player interaction due to the game's single-player nature.

Each player's daily data is encoded into a sequence of 13 tokens, corresponding to 13 features derived from the available dataset. The first two tokens represent the player's presence in the game and whether a transaction occurred on that day. For the remaining features, four tokens are used depending on the feature's value, capturing key behavioral and transactional information.

The performance of the proposed approach was validated through comparisons with standard machine learning models, including Random Forest, XGBoost, and Multilayer Perceptron. Given that these models require fixed-length inputs, player histories were represented as fixed-length vectors. Two alternative representations were evaluated: one based on the frequency of each token in the player's history and another using statistical features (minimum, maximum, first quartile, median, and third quartile) calculated for each original feature before tokenization.

Model performance was assessed using the macro-averaged F1 score, a widely recognized metric for multiclass classification. To address the challenge of class imbalances, additional metrics were employed, including the Area Under the Receiver Operating Characteristic Curve (AUROC) and the Matthews Correlation Coefficient (MCC). The AUROC evaluates the model's ability to distinguish between classes, while the MCC offers a balanced measure of performance, accounting for true and false positives and negatives across all classes.

The results demonstrate the exceptional performance of the Transformer Neural Network model, particularly when leveraging the Self-Attention mechanism. This model outperformed traditional approaches, such as Random Forest, XGBoost, and Multilayer Perceptron, across all prediction periods. Furthermore, models incorporating feature statistics slightly surpassed those using token frequency, as tokenization inherently approximates feature value distributions, leading to some loss of information. Nevertheless, the Transformer Neural Network consistently delivered superior results, underscoring the importance of capturing long-term player behavior patterns to enhance predictive accuracy.

In conclusion, while discretization introduces a degree of information loss, the Transformer model effectively compensates by capturing nuanced, long-term patterns in player behavior. This study provides a significant contribution to the field of in-game purchase prediction, demonstrating the potential of advanced neural network architectures to outperform traditional methods. The findings pave the way for further innovation in predictive analytics within the gaming industry.

Keywords: In-game purchases, Prediction, Self-attention, Transformers.

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An Optimization of the Blockchain Pool Mining for Reliable Distributed Machine Learning

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Abstract. Distributed Machine Learning

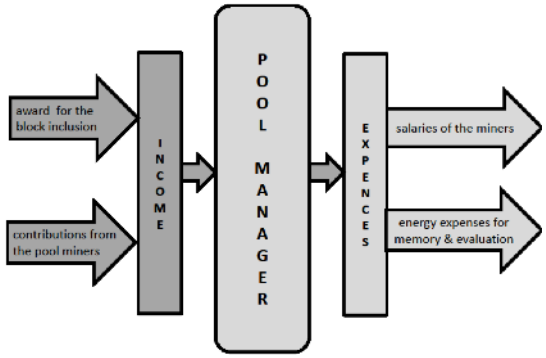
Distributed Machine Learning (DML) and data processing across the network, provides improved scalability, robustness, and resilience, making it the preferred AI paradigm. When ML algorithms need to be deployed in a distributed fashion with the involvement of multiple cloud/edge servers, a general solution approach is to share the data, the model, the knowledge, or the result among the clients, which are referred to as the data-sharing approach, the model sharing approach, the knowledge- sharing approach, and the results haring approach, respectively, [1]. As a subset of ML that enables multiple devices to train a collaborative model without data sharing, Federated Learning (FL) has been considered as an important privacy-preserving solution.

Blockchain and Distributed Machine Learning: Blockchain technology provides opportunity for verification of different issues without the third trusted party. The combination of cryptography and consensus protocols enhances the security, transparency, and decentralization underscoring blockchain's potential across various applications A key feature of blockchain technology is the use of smart contracts, which are quasi-Turing-complete programs that can be executed within a virtual machine. The smart contract is then stored on the blockchain network and executed automatically when the predefined conditions are met.

Blockchain provides a decentralized, secure, and transparent platform for data storage and sharing. This makes the use of blockchain for DML as a promising direction to address privacy and security concerns by allowing parties to keep their data private while still contributing to the training process. Additionally, blockchain can provide a secure communication channel for DML participants and ensure the integrity of the DML process. In particular, blockchain can be employed as a defence element against data and model poisoning attacks during DML process, [2].

Motivation for the Work and Domain of the Results: Blockchain based approach is well recognized for addressing the following key issues of DML: (i) training data reliability/verification, and (ii) verification of DML process. Also, a request is employment of suitable blockchain approach that minimizes the overhead to the DML process. Accordingly, we consider employment of a recently, in [3]-[5], reported and considered "green" blockchain consensus protocol and pool mining.

Recall that the pool mining is a dominant approach of the blockchain platform operations. In pool mining there are the following two main entities: the pool manager and the miners. Pool manager organizes and operates a group of miners that execute the consensus protocol. The pool manager and the miners could be considered as entities of a "common business activity" with a simplified business frameworks as shown at the following Fig. 1 and Fig. 2.



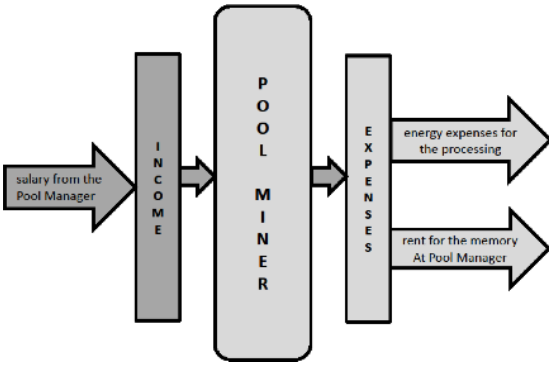


Fig. 1: Simplified business model of the pool manager. Fig. 2 Simplified business model of a miner.

Following [3]-[5], and Fig. 1-2, in this work we consider an optimization of the following cost functions regarding the pool manager (1) and a pool miner (2) participation in the blockchain pool mining for DML.

$$\psi(\cdot) = \sum_{t=1}^{T}[\psi_1(I_t, \{D_t^{(i)}\}_{i=1}^{I_t}, p_t, a_t) + \psi_2(I_t, \{M_t^{(i)}\}_{i=1}^{I_t}, \beta_t) - \psi_3(\gamma_t, E_t^{(PM)}) - \psi_4(\alpha_t, \{D_t^{(i)}\}_{i=1}^{I_t})] \quad (1)$$

$$f_i(\cdot) = \sum_{t=1}^{T}[f_1(\alpha_t, D_t^{(i)}) - f_2(\gamma_t, c, E_t^{(i)}) - f_3(\beta_t, M_t^{(i)})] \quad (2)$$

Keywords: Distributed Machine Learning, Public Blockchain, Pool Mining, Cost Function, Optimization.

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Programming systems for safe and efficient use of AI applications

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Abstract. The development of artificial intelligence (AI) systems, especially large language models (LLM), opens up many opportunities for novel applications. To reliably deploy AI systems and avoid loss of property or harm to humans, two essential properties - trustworthiness and efficiency of the AI systems are of crucial importance. To achieve them both, we need a principled mathematical foundation that is tightly coupled with practical systems for deploying AI systems on today's high-performance hardware. This research leads to novel optimization systems that automate the analysis, compilation, and adaptation of AI applications. This talk presents our recent results in this direction:

1. **Verification of reliability properties,** such as robustness, fairness, or absence of systematic biases, is an active area of research. Although modern techniques can verify significantly larger deep neural networks (DNNs) than before, the verification techniques are still inefficient when programmers modify the network. For instance, programmers quantize, prune, or fine tune the network post-training to optimize their latency or accuracy. Conventional verification of optimized DNNs is inefficient because developers must restart the computationally expensive verification algorithm from the beginning after each DNN change. We developed verification systems that enable incremental DNN verification [1] by synergistically using techniques from machine learning and formal methods. The key idea behind this approach is to extend the original DNN's verification with minimal overhead and leverage a large portion of this proof to verify the optimized DNN. We further designed novel techniques for deployment-time assurance that LLMs generate outputs that satisfy desired syntactic and semantic properties [2].

2. **Fast compilation of tensor programs,** which improves the efficiency of the AI systems, applies various code optimizations to frequently used operators (e.g., matrix multiplications, convolutions, or attention). These optimizations change the order of loops, reorder operations to leverage improved memory access patterns, or fuse multiple operators to open additional optimization opportunities. We will discuss examples of some optimizations and our new compilers for AI and optimization systems that use gradient descent search methods to find the best combinations of optimizations efficiently. Our novel algorithm [3] relaxes an intrinsically discrete search problem into a continuous problem. We show that such search is possible on both visual neural networks (convolutional neural networks) and language processing networks (LLMs). Our experimental evaluation demonstrates that our compiler Felix generates optimized networks that are as fast as the state-of-the-art TVM ML compiler but can discover the optimizations in significantly less time. It also significantly improves the network speed over the optimized operators that the commonly used frameworks Pytorch, TensorRT, and Tensorflow today provide.

Finally, we issue a call to action for a better systematic understanding of system reliability for AI. Achieving that goal will require creatively combining theories from mathematical analysis, probability, and discrete mathematics with efficient software systems and hardware to address the complexities of future AI applications.

Keywords: LLM, DNN, ML compilers, Trustworthy AI.

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Unveiling the Impact of Sustainability on Life Expectancy: A Comparative Machine Learning Approach

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Abstract. Discovering predictors of life expectancy is critical for understanding global health trends and evaluating the impact of sustainability efforts. This study explores the use of machine learning algorithms to enhance life expectancy prediction, employing the "World Sustainability Dataset," which tracks 173 countries over a 19-year period across a range of sustainability indicators. Data sources include the United Nations Statistics and the World Bank Data Bank. Machine learning algorithms such as Radial Basis Function Network (RBFN), K-Nearest Neighbors (KNN), Rep Tree (REPT), Support Vector Machines (SVM), M5 Model Tree (M5P), Random Forest (RF), and Linear Regression (LR) were employed to model life expectancy based on sustainability-related attributes. The study involves building models using the complete set of attributes and subset selected through a wrapper feature selection method. The preprocessing phase addressed missing values by removing instances with missing output and replacing other missing values with the mean from the training data. Through wrapper feature selection, 11 key sustainability attributes were identified as the most relevant for predicting life expectancy: percentage of the population living on less than $1.90 per day (Goal 1: No poverty), percentage of the population with constant access to drinking water (Goal 1: No poverty), percentage of the undernourished population whose daily food consumption is insufficient for a normal active and healthy life (Goal 2: Zero hunger), duration of compulsory education, i.e. the number of years that children are legally obliged to attend school (Goal 4: Quality education), Women Business and the Law Index Score calculated by taking the average score that measures how laws and regulations affect women's economic opportunity in each of the eight areas (Going Places, Starting a Job, Getting Paid, Getting Married, Having Children, Running a Business, Managing Assets, and Getting a Pension), with 100 representing the highest possible score (Goal 5: Gender equality), share of electricity generated by renewable power plants in total electricity consumption (Goal 7: Affordable and clean energy), share of renewable energy in total energy consumption (Goal 7: Affordable and clean energy), percentage of the population with access to electricity (Goal 9: Industry, innovation and infrastructure), Gini index, i.e. score awarded based on how equitably income is dispersed within a county (Goal 10: Reduced inequalities), adjusted savings for carbon dioxide damage, i.e. measure that monitors whether savings and investment in a country compensate for depreciation of natural and physical capital (Goal 13: Climate action), and adjusted savings for particulate emission damage, i.e. measure that monitors whether savings and investment in a country compensate for depreciation of natural and physical capital (Goal 13: Climate action). The coefficient of determination (R^2) was used for model evaluation, with the RF-based model achieving $R^2 = 0.98$ using previously described selected attributes. Performance of machine learning algorithms for life expectancy prediction using different preprocessing methods based on R^2 is presented in Table 1.

Table 1. Performance of machine learning algorithms for life expectancy prediction using different preprocessing methods based on R^2.

Algorithm	*All Attributes*	*Wrapper Method*	*All Attributes PP*	*Wrapper Method PP*
RBFN	0.6273	0.6244	0.6296	0.6255
KNN10	0.6606	0.5964	0.9324	0.9245
REPT	0.9038	0.9126	0.9204	0.9204
SVM	0.8179	0.7893	0.8165	0.7923
M5P	0.9293	0.9285	0.9397	0.9251
RF500	0.9675	0.9746	0.9732	0.9805
LR	0.8147	0.7912	0.8136	0.7901

* RBNF – Radial Basis Function Network; KNN10 – K-Nearest Neighbors (K=10); REPT – Rep Tree; SVM – Support Vector Machines; M5P – M5 Model Tree; RF500 – Random Forest (Number of iterations=500); LR – Linear regression; PP – Preprocessed.

Key findings of this study emphasize the critical role of sustainability in life expectancy. The selected attributes show a strong association with improvements in life expectancy across different countries. For instance, reducing poverty and ensuring access to basic needs like clean drinking water directly contribute to better public health outcomes by decreasing the prevalence of undernourishment and waterborne diseases, which are common in impoverished areas. Furthermore, access to quality education, as indicated by the duration of compulsory education, can lead to better health literacy and the ability to make better lifestyle choices, ultimately extending life expectancy. Gender equality also emerged as a significant predictor which indicates that equal access of women to economic opportunities and legal protections can lead to increased knowledge and higher income levels, which in turn improve access to healthcare, nutrition, and education for entire families. The integration of renewable energy sources into national energy grids and higher shares of renewable energy consumption not only contribute to environmental sustainability but also positively impact public health by reducing air pollution and its associated diseases. The Gini index, a measure of income inequality, further highlights the importance of equitable economic development. Countries with lower income inequality tend to have better access to healthcare and social services, leading to healthier populations and longer lifespans. The adjusted savings metrics for carbon dioxide and particulate emissions damage also reveal that countries actively investing in reducing pollution and mitigating climate change risks are likely to experience better health outcomes by reducing the associated health hazards.

This research provides evidence that sustainability initiatives, particularly those aimed at reducing poverty, promoting education, advancing gender equality, ensuring access to clean energy, and mitigating environmental damage, are directly linked to improvements in life expectancy. Results demonstrate that these sustainability-related factors are not only important individually, but also in combination, offering powerful insights into the determinants of life expectancy. These findings underscore the need for policymakers to align health initiatives with sustainability goals to achieve comprehensive, long-term improvements in public health. By focusing on these sustainability goals, governments and organizations can more effectively address the root causes of poor health outcomes, leading to substantial improvements in global life expectancy. This study contributes to a deeper understanding of the relationship between sustainability and health, offering a valuable framework for future interventions. It highlights the importance of a holistic approach where social, economic, and environmental dimensions of sustainability are integrated into strategies aimed at enhancing life quality and expectancy. Ultimately, this research underscores that achieving sustainability is not only a moral and environmental imperative but also a crucial component of human health and longevity.

Keywords: Artificial Intelligence; Life Expectancy; Machine Learning; Random Forest; Sustainability.

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Enhancing Wireless Channel Predictions with AI: A Novel η-μ Shadowed Model for Estimating Channel Capacity and Fading Characteristics

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Abstract. This study is dedicated to exploring the application of neural networks in the precise estimation of key wireless channel metrics, including the Level Crossing Rate (LCR), Average Fade Duration (AFD), and Channel Capacity within the η-μ shadowed fading channel models. These metrics are pivotal in the characterization and optimization of communication channels, which are increasingly relevant in the burgeoning field of wireless technologies and their intersections with artificial intelligence. The approach employs a feed-forward neural network architecture, meticulously optimized to capture the intricate dynamics characteristic of wireless communications. This architecture facilitates the modeling of the stochastic and non-linear nature of signal degradation in fading environments. By integrating a substantial dataset of one million samples, the study emphasizes the robustness and predictive accuracy of the proposed neural network model. Training was conducted using advanced techniques, including the binary cross-entropy loss function and the RMSprop optimizer, which together enhance the learning efficacy and generalization capability of the model. Preliminary results from this research indicate a high degree of accuracy in approximating the statistical distributions relevant to signal fading, as well as channel capacity estimates, which are essential for the design and enhancement of mobile communication systems. Such findings are not only applicable to the practical optimization of wireless systems but also contribute to the theoretical underpinnings of signal processing in fading environments. The novelty of this research lies in its comprehensive utilization of artificial intelligence to overcome traditional challenges in wireless communications research. By offering a refined method for estimating vital channel statistics, this study marks a significant advancement in the integration of machine learning techniques with telecommunication systems research. It also serves as a platform for stimulating discussions on innovative applications of AI in telecommunications, aligning with the conference's focus on new and fundamental aspects of artificial intelligence.

Keywords: Neural networks, Wireless communication, Performance evaluation, Level crossing rate, Average fade duration

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A Supervised Machine Learning Approach to Predict Early Treatment Response in Patients with Papillary Thyroid Carcinoma: Preliminary Findings

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Abstract. The initial management of papillary thyroid carcinoma (PTC) typically involves total thyroidectomy (TT) followed by radioactive iodine (RAI) therapy. The decision to administer RAI and determine its optimal dosage is primarily based on a postoperative assessment of disease persistence or recurrence (Haugen et al., 2016). However, there is currently no universally accepted guideline for the comprehensive evaluation of postoperative disease status, which limits the ability to make informed therapeutic decisions (Tuttle et al., 2019). Consequently, therapeutic failure is observed in 6–30% of patients (Park et al., 2017). Therefore, the aim of our study was to develop machine learning (ML) classifier to predict RAI response in PTC patients, with the goal of identifying those at higher recurrence risk. Three ML classifiers: k-Nearest Neighbor (k-NN), Support Vector Machines (SVM), and Logistic Regression (LR) were developed using pre-RAI clinical, pathological, molecular, and laboratory data collected from 95 PTC patients. The primary endpoint of the study was therapy response, categorized as excellent or inadequate, based on dynamic risk stratification performed nine months post-RAI treatment or earlier in cases of disease progression. Patients were randomly divided into training and test sets at a 70:30 ratio. The training set was used to compare and develop the classifiers, with the final ML classifier selected based on an optimal balance of high sensitivity, specificity, and minimal overfitting, as assessed through cross-validation. The classifier's performance and generalizability were then evaluated on the test set. Additionally, the relative importance of key predictors was assessed using SHapley Additive exPlanations (SHAP) values, providing insights into each feature's contribution to model predictions. Through cross-validation on the training set, the k-NN classifier demonstrated the best performance with a sensitivity of 96%, specificity of 74%, positive predictive value (PPV) of 71%, negative predictive value (NPV) of 96%, accuracy of 82%, F1 score of 82%, and F2 score of 90%. The k-NN classifier demonstrated strong predictive performance, with a sensitivity of 90% and a negative predictive value (NPV) of 89% in the test set. SHAP values identified postoperative stimulated thyroglobulin and lymph-node ratio as the most important predictors. According to our preliminary results, we developed a k-NN classifier capable of reliably estimating the probability of persistent or recurrent disease. This approach could contribute to more personalized post-surgery care, helping to tailor RAI therapy based on individual patient risk factors.

Keywords: Papillary thyroid carcinoma; Radioactive iodine treatment; Machine learning; Treatment response

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Predictive Patterns and Market Efficiency: A Deep Learning Method for Financial Time Series Forecasting

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Abstract. In our extensive research, we put the Efficient Market Hypothesis (EMH) to the test by applying a Long Short-Term Memory (LSTM) model that has been developed using a variety of methodologies in order to forecast the Standard & Poor's (SPX) index over a period of twenty years. Utilizing the LSTM model that has been improved by the Stochastic Gradient Descent (SGD), Adam, and AdaGrad optimizers across a range of hidden layer sizes (HS), our research comprehensively investigates the dynamics of the market through the lens of advanced forecasting. Since most finance researchers forecast time series using a model, we tested alternative theoretical models to enhance our methodological framework. To be more specific, we identify "pockets in time" by using an AdaGrad optimizer with a hidden size of 64. This allows us to highlight periods that are in conflict with Elastic Mean Hypothesis predictions. In order to further our investigation, we use the Dominguez-Lobato (DL) and General Spectral (GS) tests to the market dynamics in order to determine whether or not there are any evidence of statistical inefficiency. The originality of our research resides in the fact that it takes a holistic approach. Not only does it estimate price trajectories by utilizing optimal LSTM models, but it also confirms market dynamics by conducting thorough statistical testing. This methodology, which consists of multiple components, not only demonstrates the effectiveness of price forecasting in identifying market inefficiencies, but it also offers empirical evidence of the shifting nature of market dynamics. Our contribution offers a distinguished viewpoint on the realism of EMH and provides investors with insights into the relative efficiency of renowned LSTM optimization algorithms for navigating market dynamics. Moreover, our contribution provides investors with the ability to make informed decisions.

Keywords: Efficient Market Hypothesis, Deep Learning, LSTM, Forecasting Optimization, Dynamics in Market Efficiency

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Bidirectional Mamba Architecture for Sleep Arousal Detection

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Abstract. Introduction: The You Snooze, You Win Challenge [1] addresses the development of open-source software for physiological signal processing. One particular focus has been the detection of respiratory effort-related sleep arousals. Frequent arousals fragment sleep, leading to cognitive impairment, daytime sleepiness, and reduced overall health.
To facilitate algorithm development for detecting these arousals, a comprehensive dataset of polysomnographic recordings was made available. The dataset consists of 994 labeled recordings from the Massachusetts General Hospital. The recordings consist of thirteen physiological signals, which include six channels of electroencephalography, electrooculography, electromyography, two channels of respiration signal from the abdomen and chest, airflow, oxygen saturation, and an electrocardiogram. Each recording was meticulously annotated by experts, allowing participants to develop models aimed at predicting arousal events.
The physiological signals in the provided dataset were recorded at a sampling frequency of 200 Hz, except for the oxygen saturation signal, which was upsampled to match this frequency. The recordings were measured continuously throughout the sleep studies, with each session spanning between 7 and 10 hours. Due to the large number of samples, the average size of each recording is about 250 MB. Furthermore, the dataset is highly imbalanced, with arousal intervals comprising less than 5% of the total sleep process [2]. As a result, the area under the precision-recall curve is used as the evaluation metric for assessing the model's ability to detect arousal events without being biased toward the dominant non-arousal class. In this work, we tailored the Bi-Mamba+ architecture for per-timestamp signal classification, enabling efficient and accurate detection of arousal events.

Data Preprocessing: The dataset was divided into training, validation, and test subsets with a ratio of 794:100:100. To ensure fair representation across all subsets, the distributions of age and gender (male-to-female ratio) were carefully preserved, resulting in more balanced and representative data splits for model training and evaluation.
In order to prepare the data for model training, a custom algorithm was developed that normalizes the input signals and applies a Butterworth low-pass filter of the n-th order with a predefined cutoff frequency F. Following the filter application, the input signal was downsampled to twice the cutoff frequency, in accordance with the Nyquist-Shannon sampling theorem, to prevent aliasing and ensure accurate signal representation.

Model Architecture: We designed the proposed architecture for the detection of respiratory effort-related sleep arousals, leveraging mechanisms to efficiently process extended temporal dependencies. It builds upon the Mamba [3] framework, selected for its exceptional ability to handle extremely long sequences more effectively than traditional approaches like transformers and RNNs. This innovative design ensures robust performance in tasks requiring the analysis of prolonged and complex temporal patterns.
The current state-of-the-art (SOTA) models typically leverage a U-Net architecture [4], which requires the input sequence to be padded to a length of 2^23 (whereas the length of the input signals range in length from 5 million to 7 million), thereby introducing considerable memory overhead. Alternatively, RNN-based models are often used, but these prevent parallelized training of the input sequence, limiting scalability and efficiency.
The model incorporates a convolutional feature encoder, utilizing 1D convolutions and layer normalization in an iterative manner to extract meaningful features from the input signals. The feature encoder's outputs are then passed through a bidirectional Mamba architecture, constructed based on the Bi-Mamba+ encoder design [5]. This architecture consists of two Mamba+ blocks: one processes the inputs in a forward direction, while the other processes them in a backward direction. Each Mamba+ block employs a gated

architecture that integrates linear, convolutional, and state-space model layers, using SiLU activation functions to enhance non-linearity, Fig. 1.

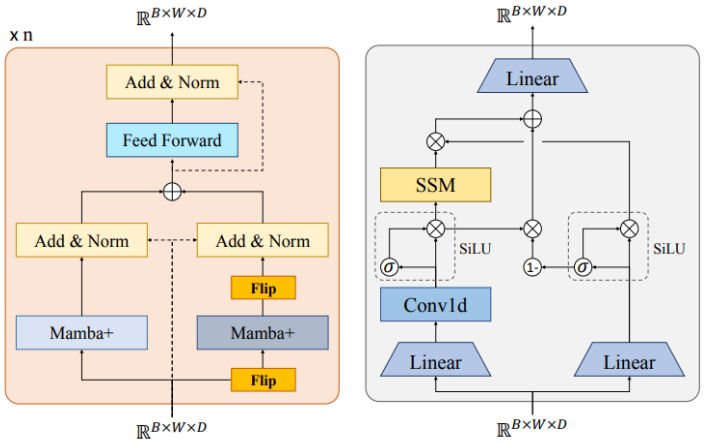

Fig. 1: Schematics of the Bi-Mamba+ encoder (left) and Mamba+ block (right)

The final output layer is a linear layer with a sigmoid activation function to generate predictions. To address the class imbalance in the dataset, the model is trained using a weighted binary cross-entropy loss function. This compensates for the skewed data distribution, ensuring more balanced model performance.

The proposed architecture offers several key improvements over existing SOTA models. First, it significantly enhances training efficiency by addressing the limitations of RNN architectures, enabling faster processing. Second, unlike U-Net-based architectures, it requires padding only to the length of the longest input signal in the batch, which facilitates the use of larger batch sizes and reduces memory overhead, as well as allows for theoretically unlimited signal length during inference. Third, the architecture is designed with a substantially smaller parameter count compared to existing models, demonstrating a more efficient design while maintaining competitive performance in the target task.

Keywords: Time series prediction, Mamba architecture, Sleep arousals

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Optimizing Finite Sum Objectives in Machine Learning with an Extra-Gradient Approach

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Abstract. This paper present a extra-gradient optimization method tailored for minimizing unconstrained objective functions expressed as finite sums, particularly in large-scale machine learning tasks. The proposed algorithm employs an adaptive line search strategy combined with a variable sample size mechanism to achieve an optimal balance between computational efficiency and solution accuracy [2]. Unlike traditional monotone methods, our approach leverages a dynamic, non-monotone step size , treated as a random variable determined by the sample data, enhancing its adaptability to noisy and complex environments. The proposed method allows error control through additional sampling. For alternatives and more specific conditions, detailed comments are provided in [3]. One of the promising approaches in this direction of research, but without the use of an extra-gradient step, is presented in [1]. It is implemented within a line-search framework and plays a role in deciding whether to switch from line-search to a predefined step size sequence.

The method excels in scenarios involving massive datasets, such as logistic regression, support vector machines, where conventional methods struggle with computational overhead. Comparative analysis highlights its superiority over established techniques, such as SAGA [4] and Adam [5], by demonstrating reduced computational costs and faster convergence rates in practical experiments. Rigorous testing across diverse machine learning benchmarks validates the robustness and efficiency of our approach, showcasing its capability to handle data-intensive and non-convex optimization problems with significant resource savings.

Keywords: Machine learning; Finite sum minimization; Optimization Algorithms; Line search extragradient.

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Onset Detection in Electromyography Signals using Long Short-term Memory Neural Network

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Abstract. Background: Onset detection in electromyography (EMG) signals is required for assessment of timing of muscle activation. Such analysis leads to better understanding of motor control strategies in sport science and rehabilitation engineering. Commonly, onset and offset detection in surface EMG signals is performed manually and complemented with guided visual inspection, or by application of double-threshold procedure. Recently, machine learning methods are proposed for reliable detection of muscle activation. This work aims to evaluate how different input types (raw EMG signals, linear envelopes (LE), and Root Mean Square (RMS)-based envelopes) affect the performance of the previously proposed Long Short-Term Memory (LSTM) neural network architecture for onset detection. [1-2]

Methods: EMG signals are simulated using *biosignalEMG* v. 2.1.0. package[1] in the R programming language [3] and in the RStudio environment (Posit PBC, Massachusetts, US). Overall, 90 EMG signals of 1 s duration comprising single muscle contraction are generated. Sampling frequency is set to 1 kHz. To compare our results with previously proposed LSTM application, we varied Signal-to-Noise (SNR) ratio of simulated EMG signals, as well as contraction duration to match the procedure for generating EMG signals proposed in [1]. Generated signals are similar, but not identical to EMG signals generated in [1] as we allow for muscle contraction to be placed peripherally, not just centrally as in [1]. The final dataset consists of 10,800 signals, where 90 simulated signals are pseudo-replicated 120 times with different seeds. Firstly, generated signals are filtered with the 4th order bandpass Butterworth filter with cut off frequencies of 10 Hz and 450 Hz [1]. Such signals are used as input sequences as proposed in [1]. The second type of input consists of a linear envelope of simulated EMG signals. Linear envelopes are determined by applying MA (Moving Average) filter on rectified EMG signals. Two different window widths of MA filter are tested: 25 ms and 50 ms [4], while two sizes of the moving window for RMS-based envelopes are evaluated 250 ms [5] and 30 ms [2], both with an overlap of 50% and 90% [5]. Overlap below 50% was not taken into consideration, because it results in sequences of extremely small length due to the duration of a generated signal of a 1 s.

LSTM training and evaluation is performed in Matlab R2023b (The MathWorks, Inc., Massachusetts, US). Selected LSTM model consists of: (1) sequence input layer with one input feature, (2) two bidirectional LSTM layers where the first one has 275 hidden units and the other one has 138 hidden units, (3) fully connected layer with two units, (4) softmax layer, and (5) classification output layer, as recommended in [1]. The dataset is split into training (70%), validation (15%), and test (15%) set, where for each LSTM input, subsets consist of the same signals. Precision, recall, F1 score, accuracy, and absolute Time Difference (TD) between ground truth and detected onsets/offsets is computed. We report averaged TD with standard deviations. Onsets and offset are considered correctly detected if they are found within ±30 ms around referent annotation [1].

Results and Discussion: When trained on RMS-based envelopes with a 30 ms window width and 90% overlap, the LSTM model achieves the highest accuracy (98.29%), which is >1% better performance than accuracy reported by Ghislieri et al. [1]. This approach also results in the smallest timing deviations (TD) for onset (0.86±0.99 ms) and offset (0.94±0.88 ms) detection. Both RMS-based and Linear envelopes when used as input achieve higher accuracy for about 20% compared to the accuracy when LSTM is trained on the filtered simulated EMG data (77.70%). Although we apply a similar procedure for signal generation, the onset/offset detection in filtered EMG data is less accurate (~20%) than in [1]. One of the possible reasons

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for such discrepancy may be in the fact that Ghislieri et al. generated centrally positioned activations, as such LSTM may be prone to the signal shape accommodation. However, onset TDs obtained using RMS-based envelopes indicate more precise detection than onset TDs (4.00±0.80 ms) reported by Ghislieri et al. [1], and this is also true when LEs with both MA window widths are utilized as LSTM inputs. Overall, precision, recall, and F1 score are consistent with the obtained accuracies.

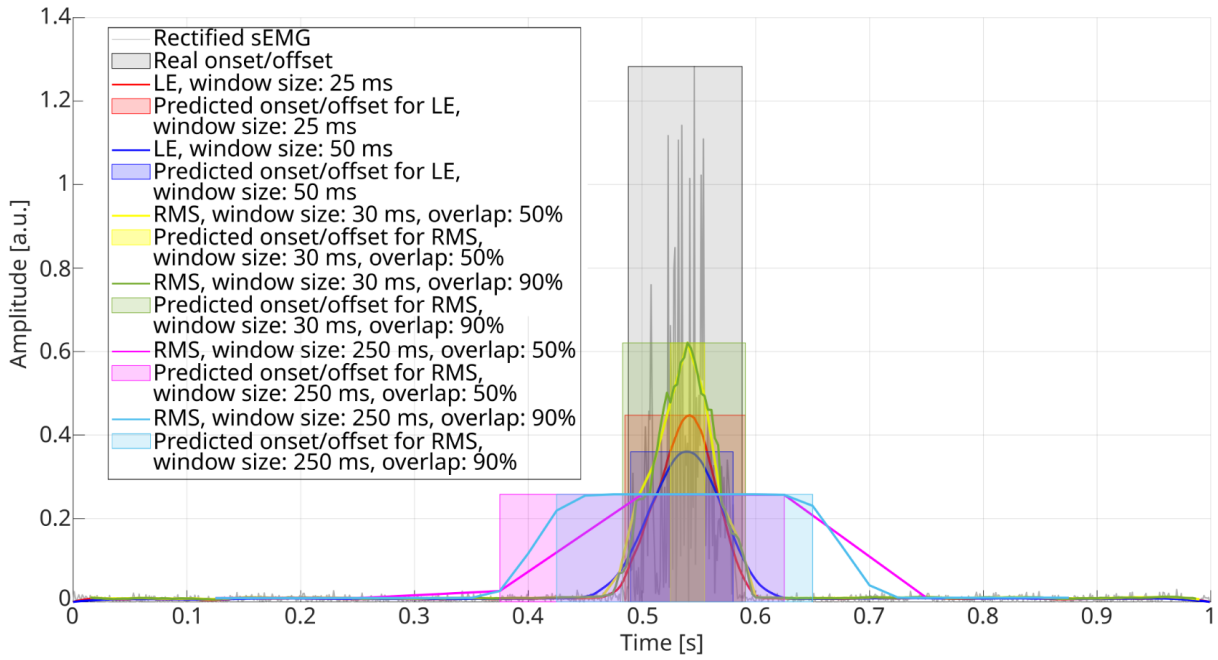

Fig 1. Comparison of linear and RMS-based envelopes of simulated EMG signal for different window sizes, overlaps, and their onset/offset detections.

Conclusion: The proposed LSTM model does not perform well on filtered data (although we use previously proposed architecture), but our results clearly indicate that additional preprocessing, especially the use of RMS windows, results in higher accuracy. For further work, different LSTM architectures could be investigated. Moreover, CNN (Convolutional Neural Network) layer may be employed on concatenated features. Finally, it would be intriguing to evaluate proposed EMG processing on measured EMG signals.

Keywords: Deep learning, Electromyography, Onset-offset detection

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NATURAL LANGUAGE PROCESSING

Development and Evaluation of Named Entity Linking Models for Serbian Language with Wikidata Integration

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Abstract. Named Entity Recognition (NER) and Named Entity Linking (NEL) are essential for extracting meaningful information from text by identifying and categorizing entities (people, organizations, locations) and linking them to knowledge bases, which helps disambiguate similar terms. They improve search accuracy, support knowledge graphs, and enhance NLP applications like question answering, sentiment analysis, and recommendation systems. By providing contextual understanding and enabling advanced tasks like information retrieval and text summarization, NER and NEL contribute significantly to making systems more intelligent and responsive to real-world data.

The presentation will outline previous research and results related to language models for the recognition and linking of named entities with Wikidata. A comparison of model outcomes will be presented, emphasizing that the models are based on different architectures, including a convolutional neural network (model is available at https://ners.jerteh.rs/) and transformers (not ot yet publicly available), both trained using the spaCy library (Ikonić Nešić et. al., 2024a, Ikonić Nešić et. al., 2024b). The models were trained with a focus on recognizing and linking named entities belonging to the location category (such as countries, cities, mountains, rivers, seas, oceans, etc.) with the Wikidata knowledge base. To the best of our knowledge, this represents the first research in the field of linking named entities to Wikidata for the Serbian language.

The Serbian language, with its rich inflectional morphology, presents a challenge for multilingual models, which often struggle to recognize and accurately process the inflected forms of named entities. These models, trained primarily on languages with simpler morphological systems, typically perform suboptimally when faced with the complex case, number, and gender variations that Serbian entities undergo. In this research, we address this issue by developing models specifically tailored to handle the inflectional nature of Serbian, ensuring more accurate recognition and linking of entities in text, regardless of their grammatical form. This advancement significantly improves the performance of NLP tasks involving Serbian.

In addition to recognizing and linking named entities, the two models developed in this research also support text tagging and lemmatization. This capability will be showcased through a model based on a convolutional neural network, demonstrating its effectiveness in processing text beyond entity recognition by assigning grammatical tags and reducing words to their base forms (lemmas), further enhancing the analysis and understanding of complex linguistic structures.

The presentation will cover research on linking named entities to the Wikidata knowledge base, along with the challenges faced during the entity linking process, which posed potential obstacles in preparing the data for model training. Additionally, it will discuss the customization of the Wikidata knowledge base to better accommodate the specifics of the Serbian language.

Future research will focus on training advanced models for the recognition and linking of named entities using the BERT architecture, a state-of-the-art language model known for its deep contextual understanding of text. This research will target seven key categories of named entities: persons, locations, organizations, professions, events, notable works (such as books, films, or artworks), and demonyms (terms used to describe the residents of a particular place). The choice of these categories reflects their importance in a wide range of NLP applications, from information retrieval and knowledge graph construction to automated summarization and question answering. By leveraging BERT's bidirectional training, the models will be able to better capture the nuances of language, including the complex morphological variations of named

entities, particularly in languages like Serbian. This approach aims to significantly improve the accuracy and relevance of entity recognition and linking, enabling more sophisticated understanding and analysis of texts across different domains and contexts. Furthermore, the models will be optimized to handle domain-specific challenges, such as disambiguating entities with similar names and resolving ambiguous references, thus ensuring a higher level of precision in processing real-world data.

Keywords: Named entity linking, Convolution neural network, Transformers, Serbian

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Phoneme Recognition in Speech Through Video Analysis

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Abstract. Phoneme recognition using visual data from video recordings, known as visual speech recognition or lip reading, represents a significant step in the development of machine learning-based technologies and their applications in speech processing, assistive devices, and communication in noisy environments. This study focuses on phoneme recognition in the Serbian language through facial movement analysis during speech.

For this research, a specialized dataset was created, which includes hundreds of video recordings of individuals articulating the five primary vowels in the Serbian language (A, E, I, O, U). The video recordings were captured under controlled conditions, with variations in factors such as lighting, backgrounds, camera angles, and speech intensity. To ensure diversity and representativeness, the dataset includes participants of different ages, genders, and speech habits. Each video was manually annotated to provide accurate phoneme labels. The annotated data was divided into training (around 70%), validation (around 20%), and test (around 10%) sets, allowing for an objective evaluation of model performance.

The primary technology for extracting visual features was the MediaPipe library, which provides advanced algorithms for face detection and tracking. The focus was on extracting key points that define the outer and inner contours of the lips. These points were further processed to obtain features such as lip shape, openness, and motion dynamics. The extracted features were transformed into numerical arrays, which served as input data for the machine learning algorithm.

The processing methodology involved implementing a classification algorithm known as Support Vector Machines (SVM) with a linear kernel. During the training phase, the SVM model was trained to recognize patterns in the visual features and associate them with the corresponding phonemes. Evaluation results on the test set showed high accuracy in phoneme recognition, with successful generalization across different participants and recording conditions. Although results varied depending on specific factors such as facial expression and camera angle, the model demonstrated exceptional precision in most test cases.

The results of the model's evaluation revealed that the highest accuracy was achieved for the vowels A, O, and U, with these phonemes being successfully recognized in nearly all test cases. The accuracy for these vowels was consistently above 90%, reflecting their distinct and easily recognizable visual characteristics during articulation. However, the model experienced more frequent errors with the vowels E and I, particularly in cases where the articulatory movements of the lips were less pronounced or visually similar to other phonemes. These errors were largely due to the subtle differences in lip shape and movement when articulating these vowels, which posed a greater challenge for the recognition system. The model's ability to recognize these vowels with high precision is expected to improve with further refinement of the dataset and feature extraction techniques.

These results highlight the potential of the system for applications in various fields, including communication with individuals with speech impairments, assistive technology for the deaf and hard of hearing, and improving communication in noisy environments. Future work will focus on expanding the dataset to include consonants, dynamic sentences, and different speaking styles, as well as implementing deeper neural networks to enhance performance. Additionally, the integration with acoustic models will be explored to develop a multimodal speech recognition system.

Keywords: Phoneme recognition, Visual speech recognition, Facial key points, Machine learning

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CHATGPT VS. HUMAN: WHOSE TEXT COMES WITH HIGHER ENTROPY?

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Abstract. The aim of this study is to overcome the limitations of a previous study (Ljubisavljevic, Koprivica et al., 2023), which investigated the differences between texts written by humans and those generated by ChatGPT. The approach used in the study is based on fundamental concepts of information theory. The analysis process includes tokenization of the input text and the calculation of token frequency, entropy values, and Shannon's equitability values (Shannon, 1948). In the context of text analysis (Chen et al., 2017), *entropy* quantifies the unpredictability or randomness in the distribution of words or characters within a given text. This calculation offers insight into the complexity and information richness of the text. *Shannon's equitability* is used to enable the comparison of texts containing different numbers of elements (tokens).

Some of the limitations observed in the mentioned study include a small text corpus, differing themes in texts written by humans and ChatGPT, and the use of an older chatbot model – ChatGPT 3.5. To overcome these issues, this study utilizes:

- an expanded corpus
- consistent topics across texts
- the latest version of the chatbot model - ChatGPT 4o.

An experiment was conducted on two groups of English texts. The first group consists of essays written by students as part of their academic assignments, sourced from the MICUSP corpus (Römer & Wulff, 2008). The second group consists of texts generated by ChatGPT, which was specifically instructed to write an essay on a specific topic matching the theme of each student's essay. For the analysis of texts - covering tokenization, calculation of token frequencies, entropy values, and Shannon's equitability values - the *QuanTA*[2] application was used. QuanTA is a web application for quantitative text analysis. Each user has their own electronic corpus, where they can add various types of texts for basic analysis, as well as for comparison across different text categories. The texts written by students contain between 924 and 3091 tokens, with an average of 2240 tokens. In comparison, texts generated by ChatGPT range from 1238 to 2610 tokens, averaging 2019 tokens. The number of unique tokens is expectedly smaller, human texts range from 389 to 1036 unique tokens averaging of 662 unique tokens while ChatGPT texts range from 355 to 634 unique tokens with an average of 532 tokens. *In the final step*, when the analysis was completed and all values were calculated, a T-test was conducted on the collected Shannon's equitability values to statistically assess the differences between the two groups. The null hypothesis (H_0) assumes that the population means of Shannon's equitability in both groups are equal.

The *results* indicate that, when writing an essay on a specified topic, human-authored texts demonstrate both a *higher* word count and a *greater* diversity of vocabulary compared to those generated by ChatGPT.

The standard deviation of token frequency in human texts is generally higher than in ChatGPT-generated texts. This indicates a greater dispersion of tokens within the texts produced by humans compared to those generated by ChatGPT.

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[2] http://138.68.107.72:3000/

The comparison of mean Shannon's equitability values between the two samples (humans vs. ChatGPT) revealed a statistically significant difference ($z(55) = 2.94$, $p = 0.003$). This p-value is below the commonly accepted threshold of 0.05, suggesting statistical significance. Consequently, we can reject the null hypothesis (H_0), which asserts no difference in means between human-authored texts and those generated by ChatGPT. Future work try to validate these differences accross other large language models (LLM), with the ultimate goal of utilizing these distinctions to classify texts as either human-written or LLM-generated. The source code of the program written in Python for this experiment and data results is available from: https://github.com/koprivica/chatGPTvsHumanEquitability .

Keywords: Shannon's equitability, NLP, ChatGPT

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Beyond Syntax: Coherence in AI-Generated Storytelling

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Abstract. Umberto Eco's notion of coherence in storytelling, transcends the mere logical sequencing of events. It demands a profound engagement with language, memory, and cultural context. Effective storytelling integrates these elements to create meaning, resonance, and an emotional connection. e, which emphasizes the recursive interaction between author and reader, transcends mere syntactic construction. It delves into cultural, emotional, and symbolic dimensions, highlighting the necessity of integrating these elements into narrative structures for richer storytelling.

At the beginning, this study addresses the foundational question of coherence in AI-generated narratives, offering a comprehensive overview of existing literature that engages with the idea of narrative coherence in artificial intelligence-generated stories. We will first introduce the principal methods and approaches, demonstrating how artificial intelligence attempts to address coherence, particularly focusing on how these methods handle sentiment continuity and cultural engagement. We will explore these methods through prominent examples of artificial intelligence-generated stories, showcasing how these models grapple with maintaining a coherent narrative structure that integrates cultural subtleties and sentiment consistency. Our examination will proceed step-by-step, highlighting key limitations and strengths.

So far, most attempts in large language models like GPT have focused on achieving text coherence in isolation, without fully integrating sentiment continuity into the narrative coherence. As observed in the study on large language models' narrative generation (Tian et al.), 2024 , AI-generated stories often exhibit poor pacing, particularly by dedicating insufficient attention to crucial turning points such as the Major Setback and Climax. This results in a narrative that feels flat, with low suspense and reduced emotional engagement. In contrast, human-written stories tend to maintain higher suspense levels, especially in the second half of the plot, and offer greater narrative complexity. Moreover, AI-generated narratives often favor positive outcomes and fall short of the diversity and unpredictability that human storytelling can achieve, underscoring AI's limitations in comprehending and innovating within the recursive interplay of narrative creation.

The NARCO graph-based method, introduced in fine-grained context modeling research, attempts to address these issues by ensuring causal coherence and temporal connections across narrative snippets. It strives to emulate human storytelling by preserving suspense, complexity, and coherence, but it remains bound by statistical pattern recognition and pattern-based associations, rather than a true comprehension of meaning.AI, even with methods like NARCO, fails to achieve Eco's recursive engagement with language, which is grounded in human cognition, memory, and cultural background. These limitations are exemplified t*he Road,* a famous AI-generated novel created by feeding sensory and locational data into an AI system during a road trip. While the text mimics Jack Kerouac's *On the Road,* its reliance on real-time data undermines its coherence. The narrative follows a logical progression but lacks thematic and emotional depth. Unlike Kerouac's original, which captured the existential ethos of the Beat Generation, 1 the Road fails to resonate culturally or symbolically. Its disjointed prose highlights AI's struggle to achieve meaningful coherence, confirming that narrative complexity and cultural engagement remain human domains. Its fragmented prose highlights the challenges AI faces in achieving meaningful coherence, emphasizing that cultural context, emotional subtleties, and narrative complexity remain domains where human cognition excels【68】

Thus, sentiment and cultural aspects of humor remain significant weaknesses in AI-generated narratives, requiring interdisciplinary solutions that demand collaboration across multiple fields. Sentiment consistency and cultural engagement involve subtleties that current AI models, such as those relying on sensory and locational data or graph-based methods like NarCo, struggle to replicate fully. Solutions might involve integrating insights from fields like neurocognitive analysis of storytelling, symbolic literature studies, and machine learning models trained on vast cultural texts and narratives

Keywords: Coherence, Artificial Intelligence, Narrative, Cultural Context, Sentiment Continuity

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Comparison of Zero and Few-Shot Learning Approach Using the LLMs for Sentiment Analysis in Serbian Literature

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Abstract. Previous research on sentiment analysis of the Serbian part of the ELTeC corpus (srpELTeC) has employed large language models (LLMs), such as the Mistral 7B model, utilizing a "Prompt and Response" methodology with a 3-class sentiment polarity approach (positive, negative, and neutral)(Ikonić Nešić et al., 2024). The ELTeC is the European Literary Text Collection developed within the COST Action 'Distant Reading for European Literary History' (CA16204) from 2017 to 2022. The srpELTeC corpus, comprising 100 novels in its main collection and 20 in its extended collection, was digitized and made freely accessible (Krstev, 2021). All novels from this collection were published for the first time between 1840. and 1920. year. In this study, the same methodological framework has been applied, comparing the performance of the Mistral 7B model to three additional LLMs: the 7B and 70B Llama 3.1 and the 3B Llama 3.2 models (Dubey et al., 2024).

A subset of 30,000 sentences was extracted from the srpELTeC novels collection. For each sentence, the number of positive and negative words was computed based on the Senti-Pol-sr sentiment lexicon. Sentences of varying lengths and with different counts of positive and negative words were selected for analysis. The selection process occurred in multiple stages, beginning with sentences containing five or more positive words, followed by those with five or more negative words. In the second stage, sentences containing at least one word from the sentiment lexicon were chosen, and finally, sentences with no sentiment lexicon words were included. The objective was to create a balanced set of sentences with an equal number of positive, neutral, and negative sentences.

A total of 1,320 sentences were manually evaluated by four annotators, with each sentence reviewed by two annotators. Agreement was reached for 1,089 sentences, while 231 sentences received different labels. Inter-annotator agreement was measured using the ReCal2 tool, resulting in a percent agreement of 82.5%. Ultimately, 363 sentences were classified into each of the three categories—positive, neutral, and negative—forming a dataset named SrpELTeC-3C (Stanković et al., 2022)..

In the presented study, sentiment classification was carried out using both zero-shot and few-shot learning approaches. Five distinct templates were designed for the zero-shot scenario, and two were used for the few-shot approach. These templates ensured that the LLMs were provided with text prompts that reflected diverse sentiment expressions from the srpELTeC corpus. Responses generated by the LLMs were parsed and classified into the same sentiment categories as the SrpELTeC-3C dataset (positive, negative, and neutral). The parsing process was crucial for accurately interpreting the nuanced responses produced by the models.

In our study, we conducted a comprehensive quantitative and qualitative comparison of various sentiment analysis approaches, including traditional models and previous results with the latest few-shot and zero-shot learning methods. Our evaluation focused on performance metrics across the dataset, highlighting not only the overall accuracy but also the models' ability to handle nuanced and ambiguous cases. Special attention was given to hard cases, where all approaches exhibited limitations, revealing areas that demand further refinement, particularly in addressing sentiment intensity and figurative speech.

The highest accuracy achieved in this study (0.79) surpassed the results from previous research (0.68) (Ikonić Nešić et al., 2024) and even surpassed MNB with a Bag-of-Words approach combined with sentiment lexicon features (0.72) (Stanković et al., 2022). Additionally, larger context windows were allotted,

enabling the testing of two distinct prompts (one in few-shot and one in zero-shot scenarios), which was not feasible in the previous study.

For future research, the larger context window opens the possibility for more complex prompt engineering or the inclusion of additional examples in few-shot scenarios. This also provides an opportunity to extend the analysis beyond simple sentiment polarity to more advanced tasks, such as emotion detection, which could deepen the understanding of sentiment dynamics in the corpus.

Keywords: Sentiment analysis, LLM, Serbian, SrpELTeC

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Linking Text Corpora to Lexicographical Resources Using Wikibase and OntoLex-Lemon

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Abstract. This abstract showcases a novel approach to linking textual data from a corpus to lexicographical resources using Wikibase as a collaborative platform. Specifically, we present a data model and an initial use case focused on the integration of a Serbian literary corpus (SrpELTeC) in NIF (Natural Language Interchange Format) with a Serbian dictionary following the OntoLex-Lemon lexicographical framework. Our work aims to combine linguistic annotations, including morphosyntactic, semantic, and philological information, with lexicon entries, facilitating a broader linguistic knowledge graph. Wikibase, a versatile extension of MediaWiki, serves as the infrastructure behind Wikidata, one of the largest crowdsourced, queriable knowledge graphs to date (Vrandečić & Krötzsch, 2014). Our proposed model aims to explore the synergy between textual corpora and lexical data.

Our proposed use case shows how a Serbian text corpus can be linked to a Serbian dictionary, specifically leveraging the OntoLex-Lemon model, which has been increasingly utilized for linguistic linked data. The SrpELTeC corpus is enriched with linguistic annotations based on the NIF Ontology (Hellmann et al., 2013), including part of speech tags, lemmas, and named entity recognition (NER) results. For this, we employed the BEaST tagger for Serbian (Stanković et al. 2020, Stanković et. al. 2022), generating annotations such as lemma and part of speech categories mapped to the OLiA (Ontology for Linguistic Annotation) lexical categories. This mapping allows for the identification of candidate lexicon entries within the SrpMD Serbian dictionary (Krstev, 2008; Stanković et al., 2018), which is structured using the OntoLex-Lemon model (McCrae et al., 2017). The smooth integration of this model into a Wikibase instance (Lindemann et al., 2023) provides an efficient means of linking corpus tokens to their corresponding dictionary entries.

In addition to the morphosyntactic and lexical layers, our approach also incorporates named entity recognition. The SrpNER tool (Krstev et al., 2014; Nešić et al., 2022) was used to classify entities into seven predefined categories: PERS (persons), ORG (organizations), LOC (locations), ROLE, EVENT, DEMO, and WORK. These categories were then mapped to OLiA, Wikidata, and DBpedia entities, enabling more comprehensive knowledge graph integration.

Our data model aims to link corpus tokens to several key components: 1) Lexeme Nodes (a corpus token is linked to a lexeme node; each lexeme has a unique Part of Speech and a canonical citation form as lemma), 2) Lexical Forms (inflected forms with a description of their grammatical features), and, eventually also to Lexical Senses, i.e., to instances of the three OntoLex core classes. Integration of word senses and named entities directly into the Wiki framework allows for seamless alignment between corpus tokens and structured knowledge graphs such as Wikidata, creating a rich, interconnected resource that can be queried and expanded collaboratively.

The presentation will provide a visual representation of the data model as graph visualization, along with textual explanations of each component. Additionally, sample SPARQL queries will illustrate how tokens are annotated, linked to dictionary entries, and associated with Wikidata entities. We aim to demonstrate how a representation according to the model we propose not only facilitates the creation of a multilingual linguistic knowledge graph but also serves as a proof of concept for linking lexical resources across diverse languages and source formats.

As for possible applications of such an interlinked resource, for example, AI systems may be fine-tuned using rich corpus annotations. Lexicographical data, like word senses, lemmas, and grammatical features, help AI systems disambiguate meanings and understand context. This enhances Natural Language

Understanding tasks such as text summarization, question answering, and semantic search. Trusted lexical knowledge can contribute to the reliability to algorithm-based tools, especially relevant in the legal or the medical domain.

Keywords: Linked Data, Wikibase, OntoLex-Lemon, Serbian, srpELTeC

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New XLM-R-based language models for Serbian and Serbo-Croatian

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Abstract. In this presentation, we will introduce new language models for the vectorization of text written in South Slavic languages, primarily in the domain of Serbo-Croatian macro language. These models are built upon XLM-R (Cross-lingual Language Model with RoBERTa) architecture developed by *Meta* [1] and the largest textual corpora in this language domain which was developed under the *Text Embeddings – Serbian Language Applications* project (#7276) financed by the Science Fund of the Republic of Serbia.

Firstly, we provide a brief overview of the data sets used. The first corpus, *Kišobran* [2], represents an umbrella web corpus of the Serbo-Croatian macro language and is, to date, the largest published textual corpus in the region with over eighteen billion words. The second corpus, *Znanje* [2], compiles academic works written in Serbian and Croatian gathered from active repositories such as *NARDUS* [3] (the National Repository of Dissertations in Serbia) and *DABAR* [4] (Digital Academic Archives and Repositories in Croatia). It includes tens of thousands of doctoral dissertations and over a hundred thousand other scientific publications, making it the biggest corpus of highly curated, high-quality texts in the region with over two billion words. The third part of the data set consisted of *Wikipedia* and *Wikisource* dumps for the Serbo-Croatian macro language, namely for Serbian, Serbo-Croatian, Croatian and Bosnian, which provided additional 330 million words. These corpora, which are available online, are automatically sentence-delimited and preprocessed: for example, for *Znanje* corpus, texts were preprocessed by removing metadata, tables of contents, references, and any non-textual elements to ensure the quality of the dataset, while *Kišobran* corpus was subjected to deduplication and boilerplate removal.

In order to preserve the carefully crafted multilingual nature of the existing XLM-R models and to reduce training costs, parameter-efficient training was employed using the *LoRA (Low-Rank Adaptation)* method [5]. This approach allows only a subset of model parameters to be updated during training, thereby minimizing computational resources compared to full-scale retraining of the model. Two new models were prepared using this method: *XLMali,* an adaptation of the smaller, XLM-R-base base model with 279 million parameters, and *TeslaXLM*, an adaptation of the larger, XLM-R-large model with 561 million parameters.

We performed evaluation on both the original and new models, including one existing XLM-R adaptation for the same macro language, *xlm-r-bertic* [6]. All of the models were tested on previously established tasks in the aforementioned language domain, such as fill-mask and sentence embedding, where our models achieve outstanding results, and several downstream tasks including sentiment analysis, named entity recognition, and Part-of-speech tagging (for which we used publicly-available data sets like *SrpKor4Tagging* [7] and *SrpELTeC-gold-NER* [8]). For the downstream tasks, however, no significant differences among results were observed. Finally, we provide an outlook on preparing large language models in the future, highlighting potential benefits and challenges.

Keywords: Language models, Serbian language, Natural language processing, Text vectorization, Parameter-efficient training

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Should Large Language Models Attend Privacy Training?

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Abstract. Mainstream large language models (LLMs) such as ChatGPT have introduced numerous challenges related to privacy and privacy protection into public discourse. As a fundamental human right, privacy is safeguarded by global conventions, regulatory frameworks, and specific national and domain-focused legislation. As such, it should be respected by all technological achievements. Natural language processing tools have been developed for nearly three decades to help with large-scale de-identification of sensitive text data, focusing primarily on the named entity recognition tasks and identification of explicit identifiers such as names, unique identifiers (e.g. social security or hospital numbers), locations, organisations or dates. New approaches leverage machine learning paradigms like federated learning and differential privacy to enhance protections around using, generating, or leaking private or sensitive data.

Little is known about the capacity of LLMs to recognize potentially private and sensitive content in a more profound legal manner, including dealing with implicit identifiers. In this talk, we will address this question and share initial qualitative results related to the experiments with the mainstream LLMs in the healthcare domain. For this purpose, we created a set of synthetic medical reports that contain a vast amount of private and sensitive information, such as personally identifiable information and sensitive health information, including disease information that, when placed in the context such as a rare profession or disease, or a rare combination of co-morbidities, could harm the privacy and consequently other fundamental rights of medical patients. We experimented with ChatGPT and Gemini in both English and Serbian and systematized conclusions based on language, regulation, and medical dimensions. In addition, we examined the capacity of the models to rephrase or reformulate the sensitive syntagms and act as privacy protectors. The study will provide insights into the readiness of LLMs to act responsibly with sensitive data in multilingual and domain-specific contexts.

Keywords: Privacy, Large language models, Anonymization, Healthcare

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PROBLEM SOLVING

Balancing Efficiency and Fairness in Blockchain: A Proof-of-Useful-Work-Based BlockChain Consensus Protocol

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Abstract. Proof-of-Useful-Work (PoUW)-based blockchain consensus protocols become very popular because they enable increasing the energy efficiency of blockchain systems [1,2]. Among the examples of useful work, Combinatorial Optimization (CO) problems [3] and Artificial Intelligence (AI) techniques [4] are particularly used. Besides being the objective of useful work, AI can be used as a tool for improving the performance of blockchain system. As an example, this study explores how AI, particularly Machine Learning (ML) and Reinforcement Learning (RL), can be utilized to improve PoUW proposed in [3,5]. The current protocol addresses fairness and efficiency by controlling the difficulty of CO tasks that miners must solve. However, manually determining the appropriate difficulty levels for different miners can lead to suboptimal resource distribution and delays in consensus. AI offers a promising solution to these challenges by automating task difficulty adjustment and optimizing miner performance.

ML algorithms could be employed to predict the difficulty of CO problems, enabling the system to dynamically assign tasks based on a miner's historical performance, computational power, and available resources. By creating models that learn from past mining data, the system can more accurately predict the time required to solve certain tasks, leading to better workload balancing across the network. Such an approach reduces redundancy, as miners are more likely to receive tasks suited to their capabilities, thereby improving overall network efficiency and reducing energy consumption.

RL offers additional potential for optimizing miner's strategies. By employing RL, miners can adapt their task selection and problem-solving techniques based on feedback from the network, such as success rates or block discovery probabilities. Over time, these algorithms can learn which strategies maximize their rewards, leading to more efficient task allocation and faster block production. In addition, AI could enhance the system's adaptability to varying network conditions. For example, during periods of high congestion or low participation, AI models could dynamically adjust the task difficulty or even modify the reward mechanisms to incentivize miners. This adaptability helps maintain the stability and efficiency of the blockchain, regardless of fluctuating network activity.

This study discusses potential AI-driven solutions and highlights the benefits of incorporating machine learning and reinforcement learning into the existing framework to ensure fairness, scalability, and sustainability in blockchain consensus mechanisms. To evaluate the effectiveness of the proposed protocol, we are developing a simulation framework that models behavior of miners and clients, task distributions, and realization of consensus protocol under various network conditions. This simulation enables us to test the adaptive task difficulty adjustments and miner optimization strategies in a controlled environment. By simulating different network scenarios, we can observe how AI-enhanced task assignment impacts energy efficiency, fairness, and overall network throughput. Our preliminary results show that

integrating AI techniques into PoUW-based blockchain protocols has the potential to significantly enhance the efficiency of task allocation, miners' optimization strategies, and the overall system performance.

Keywords: PoUW consensus protocol, Workload balancing, Task difficulty adjustment, Machine learning, Reinforcement learning

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Local search based heuristics for cluster-wise linear regression problem with elastic-net penalty

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Abstract. The Cluster-wise Linear Regression (CLR) is an extension of the standard linear regression model, where each cluster has its own distinct regression function. This model is particularly well-suited for heterogeneous datasets that violate the statistical assumptions necessary for applying traditional linear regression models.

Problem definition. We are given a dataset $\mathcal{A} = \{(\mathbf{a}^i, b_i) \in \mathbb{R}^{n+1} \times \mathbb{R}, i = 1,2, \dots, m\}$ where $\mathbf{a_i}, i = 1, \dots, m$ are data points or realizations of independent variables, b_i is a target or dependent variable for the data point $\mathbf{a_i}$, m is the number of data points and n is the number of independent variables. Without loss of generality, we assume that $\mathbf{a}^i_{n+1} = 1$, for all $i = 1, \dots, m$. For a given $k \in \mathbb{N}$, $k \geq 2$, the cluster-wise linear regression problem (CLR) is to find a k-partition $\{A_j\}_{j=1}^k$ of dataset $\mathcal{A}$ and k linear approximation functions $f_j(\mathbf{a}) = \mathbf{x}_j^T \mathbf{a}$, where $\mathbf{x_j} \in \mathbb{R}^{\boldsymbol{n+1}}$ are regression coefficients, such that the following loss function is minimized:

$$\sum_{\boldsymbol{j=1}}^{\boldsymbol{k}} \sum_{(\mathbf{a^i}, \boldsymbol{b_i}) \in \boldsymbol{A_j}} \| \boldsymbol{b_i} - \boldsymbol{f_j}(\mathbf{a^i}) \|_2^2. \tag{1}$$

CLR has been extensively studied in the literature. One of the earliest and most widely-used algorithms for CLR is an adaptation of the k-means algorithm [5]. Other approaches include mathematical programming formulations based on nonlinear programming, mixed-integer linear programming, and non-smooth optimization methods, as can be seen from a comprehensive overview of optimization techniques for CLR provided in the review paper [3].

In this work, we make two key contributions to the CLR framework. As the first contribution, we extend the CLR problem to incorporate elastic-net penalties, introducing a regularization scheme that combines both lasso and ridge regression. Having in mind that CLR can be employed as a machine learning model for predicting the value of a continuous target variable [4], overfitting is a critical issue that must be addressed. To mitigate this, we propose the **cluster-wise linear regression with elastic-net penalties (CLRE)**, which modifies the objective function (1) as follows:

$$\sum_{j=1}^{k} \sum_{(\mathbf{a}_i, b_i)} \left\| b_i - f_j(\mathbf{a}^i) \right\|_2^2 + \lambda_1 \sum_{j=1}^{k} \left\| \mathbf{x}_j \right\|_1 + \lambda_2 \sum_{j=1}^{k} \left\| \mathbf{x}_j \right\|_2^2 \tag{2}$$

where $\lambda_1 > 0$ and $\lambda_2 > 0$ represent the lasso and ridge penalties, respectively. As with standard linear regression models, regularization helps to reduce overfitting in CLR models. This is especially relevant since each regression within a cluster is trained on a smaller subset of the data, increasing the risk of over-fitting.

To realize the second contribution, we propose a local-search-based refinement to improve the solution obtained by the Späth algorithm [5] when applied to the extended problem. Additionally, we enhance the

Späth algorithm by incorporating a local-search heuristic, which improves the quality of the solution. This refinement allows for more accurate results in the context of the extended CLRE problem.

Implementation and results. Our algorithm modification relies on calculating the distance between data points and the regression hyperplane. To complete this process efficiently, we use matrices that contain a list of sorted clusters for each data point. These lists are sorted based on the a distance of data point to the corresponding regression hyperplane. Moreover, the regression coefficients for each of the k clusters and an indicator denoting whether a data point belongs to a particular cluster are stored in the data structures described in the paper [4].

The model training input parameters include the dataset and the value of parameter k. The execution of the model training starts with the initialization of data structures by the application of k-means algorithm. The initial solution is transformed until a stopping criterion is met. One of the methods developed is Variable Neighborhood Descent (VND), which is applied until the solution cannot be further improved. Alternatively, the Greedy Randomized Adaptive Search Procedure (GRASP) metaheuristic is implemented to both find an initial feasible solution and improve existing solutions. We considered various neighborhoods, regarding the number of data points that are moved from one cluster to another. A data point is always moved to the nearest cluster based on its distance to the hyperplane defined by the corresponding regression coefficients.

The algorithm was evaluated on datasets generated through Monte Carlo simulations, as detailed in [2], and on a real-world dataset for predicting monthly rainfall in Victoria, Australia, presented in [1].

Keywords: Cluster-wise linear regression, Elastic-net, Local search, Variable neighborhood descent

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Polynomial Regression Model for Standardizing Large Precision Instances for P|C_{max} problem

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Abstract. This extended abstract presents an effort to standardize a well-recognized group of test instances, designated as "B instances" used for benchmarking solvers in the *Multi-Way Number Partitioning (MWNP)* formulation of the classical $P||C_{max}$ problem. Originally proposed in (Korf, 1998), the B instances were defined by a configuration of three machines ($m = 3$), up to 100 tasks ($n \leq 100$), and task processing times (precision) $p_i \in [1, 10^5]$. They are characterized by a small machine count and large, uniformly distributed processing times. Over time, these instances have evolved to include variations in the number of machines, task counts, and processing time bounds, making the most extensive dataset inclusive of $m \leq 12$, $n \leq 60$, and processing times up to 2^{class} for $class = 48$ (Schreiber & Korf, 2014). This dataset has been instrumental in extensive research but presents scaling challenges for future expansions.

Our work addresses these challenges by proposing a standardized B instance set that encapsulates the majority of variations found in the literature, with a focus on instances that are challenging. To ensure the inclusion of all notable B-like sets from existing literature, our proposed standardized dataset includes distributions $D = U[1, 2^{class} - 1]$ for $class \in \{1, \dots, 48\}$, and considers all $n \in \{1, \dots, 48\}$ and $m \in \{2, \dots, 12\}$, following the formulation in (Ostojic et al., 2024). Generating 100 instances per rule (as adopted in prior studies) results in an extensive dataset of $2{,}745{,}600$ instances. This volume presents key issues:

- Computational Demand: The total time required for testing this scale of instances is significant, especially for exact solvers.
- Lightness: Many instances are quite easy for most solvers, diluting the focus on challenging cases.
- Growth in Set Size: The dataset size expands rapidly as the maximal values of n, m, or $class$ increase, a trend likely to continue with advances in solver performance and computational power.

Our objective is to refine this dataset to prioritize challenging instances, addressing the above concerns and aligning with observations from the *Operations Research (OR)* community. Research in OR has indicated that instances tend to be more challenging when $n/m \in [2{,}3]$ (Haouari et al., 2006), an observation respected in generating harder instances across subsequent studies. In the context of the MWNP formulation, *Artificial Intelligence (AI)* researchers have similarly noted the importance of selecting difficult instances. For instance, (Korf, 1998) demonstrated experimentally that for fixed $m \in \{2{,}3\}$ and task durations bounded by a fixed precision, increasing n initially raises complexity until a peak, after which complexity begins to decrease. This trend aligns with the phase transition phenomenon in NP-hard problems, highlighting a "critical state" where approximately half of the instances are solvable to perfection, and half are not, marking a peak in computational effort. An instance is solvable to perfection (is perfect) if it has a solution in which difference between each two processor loads is maximally 1.

For fixed m and $class$ values, as n grows, the number of feasible schedules ($m \cdot n$) expands exponentially, whereas the number of possible distinct machine loads grows linearly $O(n \cdot class)$, leading to a critical threshold where computational resources peak. Determining whether an instance is "perfect" requires extensive exploration within this critical region.

While many open questions remain, this methodology provides a practical framework for identifying generation rules for “harder” instances. Following this approach, authors in (Korf & Schreiber, 2013) generated 100 instances per (m, $class$) and incrementally increased n until at least 50 of these instances were identified as "perfect." The critical values of n are compiled for m up to 12 and precision up to 10^{12}.

Due to computational constraints, results for larger values of $class$ and m are limited. However, using a third-degree polynomial regression trained on data provided in (Korf & Schreiber, 2013), we derived the following predictive model for values of n, depending on $class$ and m stored in matrix $Y_{class,m}$ with accuracy of $R^2 > 0.999$:

$$Y_{class,m} = -0.002class^3 + 0.014class^2 m - 0.016class^2 - 0.032class \cdot m^2$$

$$+0.812class \cdot m + 2.032class + 0.036m^3 - 0.459m^2 + 3.388m - 4.207$$

This model provides a basis for predicting unknown values, supporting our generation rules (Table 1) for universal B instances that are expected to not require additional expansion in near future.

Table 1: The proposed generation rule for B instances

Notation	$class$	D	m	n
${}^{Y_{class,m}}_{m}B_{10}^{class}$	$\{1, \dots, 18\}$	$U_{1,10^{class}-1}$	$2, \dots, 16$	$Y_{class,m}$

This standardized dataset of B instances resolves the need for a reduced, yet comprehensive collection of challenging high precision instances. By focusing on hard instances, this work aims to facilitate more efficient benchmarking of solvers for the MWNP formulation of the $P||C_{max}$ problem, providing the OR and AI communities with a robust foundation for future research. Open-source generator and already generated 100 B instances per generation rule can be found at https://gitlab.com/pcmax-problem/pcmax-instances.

Keywords: Parallel Machine Scheduling, Identical Machines, Multi-Way Number Partitioning, Test Instance Generation

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Concept of a Configurable ASIC for Sensor Data Acquisition with Machine Learning Integration

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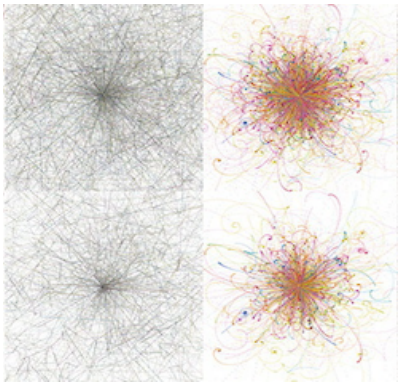
Abstract. The rapid development of artificial intelligence (AI) and sensor technology has opened up new avenues for the development of wearable and specialised diagnostic systems. This paper proposes a concept for an application-specific integrated circuit (ASIC) that can acquire sensor data in real time and make decisions based on machine learning algorithms. The aim of this concept is to present a highly configurable and adaptable hardware platform that processes signals from eight analogue sensors and provides classification outputs customized for specific applications such as medical diagnostics, wearable devices, or industrial monitoring. The flexibility of the proposed ASIC-based system makes it suitable for various use cases, including health monitoring, predictive maintenance and safety-critical operations. By incorporating a range of analogue sensors, such as force, pressure,temperature and acceleration sensors, the system offers a modular solution that can be adapted to different environments. The system architecture enables offline training of the machine learning model with application-specific data sets on a separate computer platform, e.g. a PC or cloud-based service. After training, the parameters of the model are uploaded to the ASIC via standard interfaces such as SPI or UART, allowing the platform to dynamically adapt to different tasks without the need for physical reconfiguration. A key focus of this concept is to ensure high energy efficiency while maintaining real-time inference capabilities. Power consumption is a critical factor, especially for portable devices and embedded systems deployed in remote locations where energy resources are limited. The proposed system achieves this by utilising an internal or external ADC for efficient conversion of sensor data, followed by fast digital processing within the ASIC. The classifier, which is based on machine learning algorithms, in this paper Naive Bayes, outputs the decisions as a compact 4-bit value, with each bit corresponding to a specific class or decision. This output format ensures easy integration with other systems, such as displays or actuators, and makes the system adaptable for various applications, such as recognising medical conditions or monitoring the status of industrial equipment. To validate the concept, the PYNQ-Z2 board with a Zynq-7000 SoC is used as a prototyping and test platform. This FPGA-based environment enables both data acquisition and classification simulations and ensures that the proposed ASIC design fulfils the performance requirements. Using the FPGA prototype, different sensor configurations can be tested to fine-tune the classifier and validate the performance of the model. These preliminary tests provide valuable insight into the feasibility of the approach and help identify potential challenges before final ASIC fabrication is undertaken. The proposed system aims to bridge the gap between software-based AI models and hardware platforms by providing a configurable, cost-effective and scalable solution for real-time applications. Unlike general-purpose processors, the ASIC offers customised processing capabilities with minimal latency, making it ideal for applications that require fast decision-making. In addition, the platform's customisability allows it to be used in a variety of fields, from wearable healthcare devices to industrial predictive maintenance systems, expanding its potential applications. Preliminary results from FPGA-based simulations show high accuracy and efficiency, confirming the feasibility of the approach and the potential of machine learning-based decision making on ASIC platforms. The ability to train models offline and update parameters via the software significantly increases the flexibility of the system and allows it to adapt to changing requirements without hardware changes. Future work will focus on manufacturing the ASIC and conducting extensive testing in real-world environments such as hospitals or industrial plants to validate the performance and robustness of the system. This research contributes to the growing field of AI hardware by demonstrating how machine learning-based decision making can be effectively integrated into ASICs. The proposed concept offers a promising solution for the development of portable, real-time and energy-efficient decision support systems. It establishes the foundation for future advances in the field of embedded AI hardware and addresses the need for specialized platforms capable of meeting the increasing demand for fast and reliable data processing in various domains.

Keywords: ASIC, ML, Real-Time Data Processing, Sensor Integration, FPGA Prototyping

KNOWLEDGE REPRESENTATION, REASONING AND PLANNING



Reconstruction of Axiom System Underlying Deductive Database Method

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Abstract. The deductive database method was developed in the late 1990s, by Chou et al. and presented in the paper “A Deductive Database Approach to Automated Geometry Theorem Proving and Discovering” (Journal of Automated Reasoning 25, 2000). The goal of this work was building a geometry theorem prover capable of proving complex geometry conjectures. The main idea of the method is integrating logic-based reasoning with deductive database systems and over a suitable, custom built axiomatic system. The given and derived facts are stored in a database and the system derives new facts based on the given rules and existing facts. The development of the method brought the interesting notion of "full angle" into its focus. A geometry tool Java Geometry Expert (jGex) contains the first implementation of the deductive database method. Some rules used by this implementation were listed in the original paper, but some rules are only implicit and hardcoded in the prover. It is a challenging and important task to reconstruct such rules and to have a precise logical status of theorems proved by the prover.

In our work, we have several goals. One is to reconstruct all the rules, both implicit and explicit used within jGex, to reconstruct all implicit assumptions (non-degeneracy conditions) and to detect the minimal knowledge sufficient to prove geometry conjectures that jGex can prove. Another goal is to explore if the state-of-the-art general-purpose provers for first-order logic are powerful enough to use these axioms and prove the theorems that can be proved by a custom-built tool like jGex. We developed several variants of the axiom system, and we tested them on more than 150 complex geometry theorems. It turns out that most of the theorems proved by jGex can also be proved using our axioms, and by using vampire, a leading first-order-logic prover. Another output of this work is a comparison between different approaches for representation of geometry knowledge (for instance, using sorted vs unsorted logic).

Keywords: Full angle, Geometry, Smt solvers, Geometry deductive database method

UNCERTAIN KNOWLEDGE AND REASONING

Leveraging Hamiltonian Monte Carlo Bayesian Inference and Machine Learning to Understand CERN (LHC) Relativistic Heavy Ion Collision data

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Abstract. A huge amount of data is generated in the relativistic heavy ion collisions at the Large Hadron Collider (LHC) in CERN. In these collisions, a new extreme state of matter called Quark-Gluon-Plasma (QGP) is created, with surprising properties such as superfluidity at extremely high temperatures. State-of-the-art theoretical methods, such as relativistic hydrodynamics simulations or the DREENA-A [1,2,3] numerical framework, were developed to provide theoretical predictions for the generated experimental data. However, the inverse problem of accurately learning QGP properties (i.e., the model parameters and their distributions) from a wide range of measured data remains a challenge. Specifically, we aim to employ both data related to relativistic heavy ion simulations (the so-called low-pt sector) and the DREENA framework (high-pt sector) to optimally constrain QGP properties.

Bayesian inference through Hamiltonian Monte Carlo (HMC) sampling and Gaussian Process (GP) machine learning provides a powerful toolset for precision QGP tomography. In this work, we apply these methods to analyze both low-pt and high-pt data from heavy ion collisions, leveraging hydrodynamics simulations for low-pt and the DREENA framework for high-pt predictions. While low-pt theory and data have traditionally been used to probe bulk QGP properties, we show that including high-pt theory and data allows for a more comprehensive constraint on QGP medium parameters. Gaussian process emulation provides crucial acceleration for the parameter space exploration, while HMC sampling is used to infer posterior distributions of three important parameters. A Gaussian process was trained using 10,000 simulation outputs, with a 70-30 split for training and testing, and 5-fold cross-validation employed to optimize the model. The inclusion of both data sets significantly narrows down the parameter distributions and enhances the precision of QGP tomography.

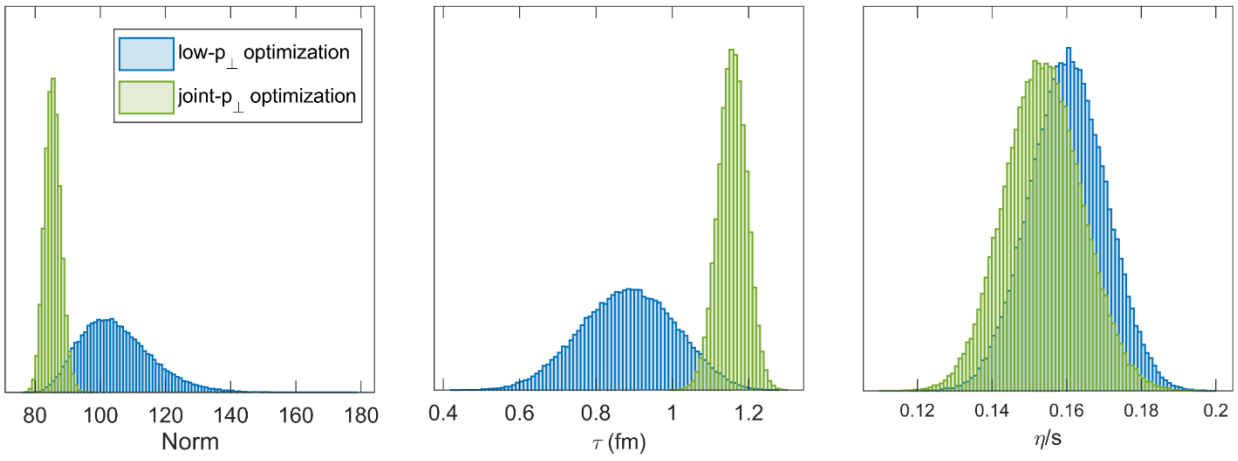

Figure 1: Inferred parameter posterior distributions. Experimental observables and their measured values are indicated on the horizontal axis of each figure. The colors in the figure legend correspond to the two posterior distributions.

Figure 1 illustrates the main advantage of the employed approach. The inferred distributions for three key QGP parameters are shown for the cases when parameters are constrained by:

- Only low-pt data, with the inferred parameters shown by the blue distributions.
- Jointly low-pt and high-pt data (the green distribution). The inferred parameter distributions are now much narrower (corresponding to smaller uncertainty), though still consistent with the values inferred only from low-pt data.

Moreover, we used an independent experimentally measured validation set to assess how well the inferred parameters can explain these data. When the parameters are inferred only from low-pt data, good agreement is obtained with low-pt but not with high-pt data. With the joint parameter inference, we obtain a very good agreement with both low-pt and high-pt data sets.

The results above illustrate the utility of combining AI approaches (machine learning and Bayesian inference) with diverse datasets and mechanistic (theoretical) models in the inverse problem of parameter inference from highly complex datasets and computationally demanding models. The results presented here are a proof of concept for the implemented approach, which we will, in the future, implement and test on a much larger number of QGP properties and experimental observables. Our ultimate goal is to develop BayesDREENA as an AI-aided tool for accurate and efficient inference of QGP properties from a large number of diverse measurements at the LHC experiments.

Acknowledgements: Work on the DREENA-A numerical framework was supported by the European Research Council grant "QGP tomography" to Magdalena Djordjevic.

Keywords: Bayesian Inference, Hamiltonian Monte Carlo, Gaussian Process, QGP Tomography, Heavy Ion Collisions.

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Using $Arch$-ω-logic in Neuro-Symbolic Reasoning

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Abstract. Recent advancements in Artificial Intelligence have emphasized neuro-symbolic computing, which merges symbolic reasoning with sub-symbolic AI systems, such as neural networks and graphical models. The goal of this integration includes enhancing knowledge representation, translating logical statements into loss functions, and improving the understanding of failures in sub-symbolic AI systems by verifying the architecture and components. For example, neuron functions in an artificial neural network can be described through logical constraints in a weighted logic language, allowing the neural network to learn corresponding weights and satisfy constraints during training.

The class of weighted logics encompasses a broad spectrum of formal systems, ranging from fuzzy logics to possibilistic and probabilistic frameworks, often inspired by various AI reasoning methods. These logics share a common feature: the capacity to express various types of weights (interpreted as generalizations of truth values) associated with formulas (Dubois et al., 2014). In the work by Perović et al. (2024), both model-theoretical and proof-theoretical analyses of two infinitary first-order logics are provided:

- $Arch$-ω-logic for countable Archimedean structures with names for individuals and
- non-$Arch$-ω-logic for countable non-Archimedean structures with names for individuals,

These logics are well-suited for the formal study of weight functions and offer an abstract framework for naturally representing and combining different weighted logics. The paper provides Hilbert-style axiomatizations for these logics and proves the corresponding strong completeness theorems.

Additionally, the presented logics can express entailments in the framework proposed by Fagin et al. (2024), and represent defaults relevant to non-monotonic reasoning, as well as weight functions pertinent to neuro-symbolic computing.

The logics from Fagin et al. (2024) aim to formalize consequence relations within the context of real-valued logics, contributing to the formalization of neuro-symbolic reasoning. Similarly, Richardson & Domingos (2006) extended first-order logic with formula weights for this purpose. In this paper, we focus on the real-valued (or fuzzy) basic logic BL.

We demonstrate how formulas and deductions expressible in the works of Fagin et al. (2024) and Richardson & Domingos (2006) can be captured within $Arch$-ω-logic. Furthermore, we explore potential applications in the representation and analysis of Logical Neural Networks and Markov Logical Networks.

The Arch-ω-logic and non-Arch-ω-logic frameworks could provide a solid foundation for the development of new neuro-symbolic computing systems, with integrating probabilities. These systems are particularly significant for applications in areas where, besides the output, the explanation of how the output was reached is crucial, such as in medical diagnostics, finance, and education. Another advantage is the use of these logics for the verification of models generated by various neural networks.

Keyword: Weighted formula, Neuro-symbolic computation, Logical neural network, Markov logical networks

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Identifying key parameters for rapid CRISPR-Cas derepression using computational and machine learning techniques

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Abstract. Motivation and Aim CRISPR-Cas (Clustered Regularly Interspaced Short Palindromic Repeats - CRISPR-Associated proteins) systems represent a key defense mechanism in bacteria, protecting against viral invasions through the recognition and cleavage of foreign DNA. Despite significant interest in their biotechnological applications, the natural regulatory dynamics of these systems are not fully understood. In standard experimental conditions, the system remains silenced due to repression by the global regulator, nucleoid structuring protein H-NS. In the case of the most studied, Type I-E CRISPR-Cas system in Escherichia coli, it has been hypothesized that under viral infection, the higher AT content of bacteriophage DNA can sequester H-NS, thus relieving repression and activating the CRISPR-Cas system (Pul et al., 2010). This study aims to explore whether a modest reduction in H-NS concentration could initiate a positive feedback loop involving transcriptional activators LeuO and BglJ-RcsB (Westra et al., 2010), resulting in rapid production of crRNAs and an effective immune response against fast-replicating bacteriophages.

Methods: We constructed a mathematical model based on principles of statistical thermodynamics and non-linear dynamics to describe the activation dynamics of the CRISPR-Cas system. The model integrates two proposed mechanisms: (1) derepression of the cas genes promoter due to H-NS sequestration by AT-rich viral DNA, and (2) activation of cas gene expression via positive feedback loops mediated by the regulators LeuO and BglJ-RcsB. Through computational simulations of the temporal crRNA response following foreign DNA entry, we identified the critical parameter combinations for system activation. Additionally, we applied the Random Forest machine learning technique to assess the importance of each model parameter for achieving the desired behavior, and conducted a bioinformatics analysis comparing the genomic AT content of 16,388 viruses to their corresponding bacterial hosts, using data from the Virus-Host DB database.

Results: Our analysis reveals that viral genomes generally exhibit a slight (~10%) increase in AT content relative to their bacterial hosts, which supports the hypothesis that H-NS proteins may be sequestered by foreign DNA. Furthermore, Random Forest analysis identified three key factors in determining the system's response (Fig. 1): (1) baseline H-NS levels (H_0), (2) changes in available H-NS upon interaction with viral DNA (δH_0), and (3) the cooperativity of H-NS binding to DNA (n). The model simulations indicate that substantial decreases in H-NS concentration could swiftly activate the CRISPR-Cas system, triggering crRNA production. A small reduction in H-NS levels, when coupled with high cooperativity, could also result in timely crRNA generation, provided that baseline H-NS concentration is near the equilibrium dissociation constant for DNA binding (Fig. 1).

Conclusion: Through computational modeling and machine-learning techniques, we determined that the CRISPR-Cas Type I-E system can mount a rapid response to an infection that leads to a slight reduction in effective H-NS concentration, particularly when this concentration is near the equilibrium dissociation constant for H-NS binding to DNA. Our findings suggest that future experimental investigations should focus on these particular features of the system regulation, where the primary factor enabling such a swift response is the high cooperativity of H-NS binding. From a methodological standpoint, our study highlights the importance of a multidisciplinary approach, combining bioinformatics and mechanistic modeling, to achieve a deeper understanding of CRISPR-Cas system behavior, required for its potential applications.

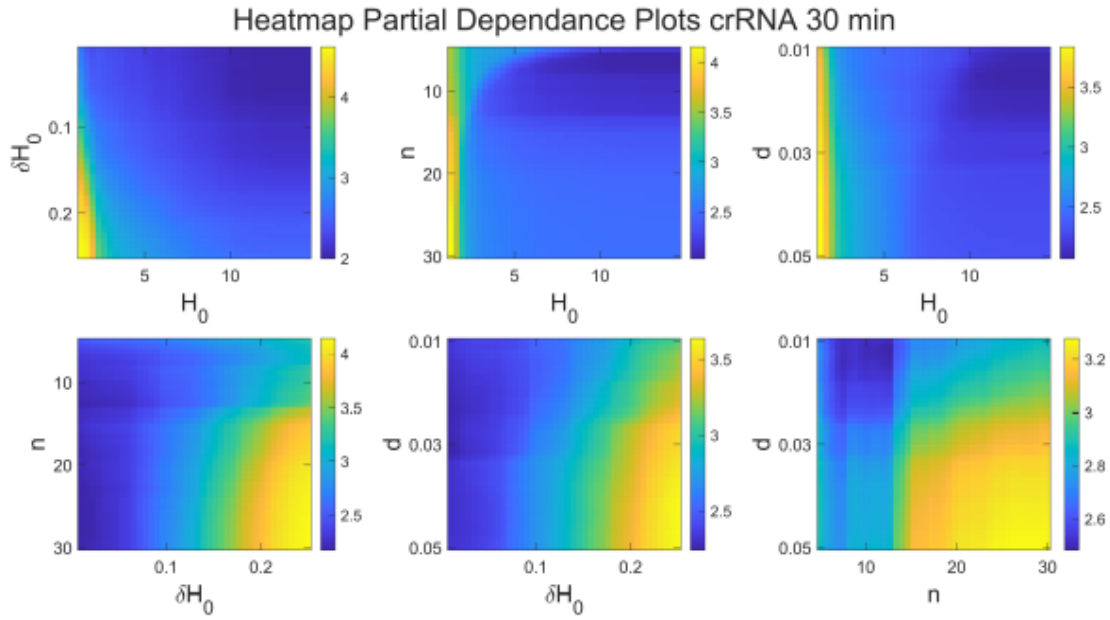

Fig. 1. Partial Dependence plots showing the effects of different parameters on the predicted outcome of a Random Forest machine learning model, particularly, on the crRNA level obtained 30 minutes after CRISPR-Cas system activation (indicated by color). This crRNA level is assumed as critical for cell survival, as cell lysis might occur around that time. The following notation is used: H_0 - baseline cellular H-NS level, δH_0 - a relative decrease in available H-NS upon interaction with viral DNA, n - the cooperativity of H-NS binding to DNA, d - rate of cell division governing protein and crRNA decay. Note that in Partial Dependence plots, all model parameters not denoted on the axes are averaged out.

Acknowledgements: This work is supported by the Science Fund of the Republic of Serbia (projects No. 7750294, q-bioBDS, and No. 6417603, CRISPR modelling).

Keywords: CRISPR-Cas derepression, H-NS, Modeling expression dynamics, Machine learning

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Constraining the Critical Error Rate in Binary Classification

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Abstract. In binary classification, there are two types of misclassification errors: false positives and false negatives. In some cases, one of these errors is more severe, and the objective is to limit its occurrence. For instance, mislabeling a genuine email as spam is more severe than allowing an occasional spam message to reach the inbox. Similarly, failing to diagnose a patient with a serious condition can have significant health consequences, while an incorrect diagnosis, while stressful, can be corrected with further tests.

In this study, we consider the methods proposed in the literature for constraining the critical error rate and compare the computationally feasible ones: the plug-in Neyman-Pearson approach, the Umbrella algorithm, conformal prediction, and typicality indices.

Additionally, we suggest a simple thresholding baseline that establishes an intuitive connection to the theory of statistical hypothesis testing. We also demonstrate that, under certain conditions, a two-sample test of the distances to the nearest positive and negative neighbors can serve as a classification proxy to limit the target error rate. We refer to this approach as test-based classification (TBC) and propose its weighted variant (WTBC), which uses rank-reciprocal weights to adjust the distances before testing.

We formulate evaluation metrics for quantifying the efficiency of controlling the critical error rate and evaluate the methods on four datasets. The results indicate that the best options in general case are the baseline method and the Umbrella algorithm. On the other hand, WTBC has the best performance when the data have a specific structure.

Keywords: Binary classification, Conformal prediction, Neyman-Pearson classification

FUZZY REASONING IN NONLINEAR OPTIMIZATION AND ZEROING NEURAL NETWORKS

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Abstract. *Zeroing neural network* (ZNN) dynamics was originated for finding solutions to time-varying (TV) problems. ZNN dynamical systems represent a class of recurrent neural networks (RNN) which are dedicated to find zeros of scalar, vector or matrix error functions. On the other hand, f*uzzy logic systems* (FLS) have been studied intensively in recent years due to the ability of FLS to handle uncertainties. In addition, the influence of *neutrosophic logic engine* (NLE) on many fields of science and technology, as well as its numerous applications, are evident. Our goal in this talk is to investigate improvements of ZNN dynamical systems and main methods of nonlinear optimization by means of fuzzy reasoning which is supported in FLS and NLE.

A correlation between an appropriately defined FLS and *zeroing neural network* (ZNN) design for computing the time-varying (TV) matrix pseudoinverse was investigated in [1]. It is shown that the gain parameter involved in the ZNN design can be dynamically adjusted over time by means of appropriate learning parameter derived as the output of an FLS based on appropriate membership functions (MF) and fuzzy logic rules. Convergence properties of developed ZNNs are investigated. Presented simulation experiments confirm superiority of the FLS-based ZNN model over the corresponding classical ZNN models.

The research in [2] develops a dynamical ZNN model improved by neutrosophic numbers and an NLE. The introduced fuzzy-neutrosophic logic adaptive ZNN is termed NSFZNN and represents an improvement over the traditional ZNN design. The model has proven suitable for calculating the matrix pseudo-inverse and the minimum-norm least-squares solutions of TV linear matrix/vector systems. Simulation examples and engineering applications on localization problems and electrical networks are presented to emphasize the efficiency of the proposed dynamical system.

The motivation in [3] is to apply neutrosophy in order to improve descent direction methods for solving unconstrained nonlinear optimization models. The improvement is based on the application of symmetry involved in NLE in determining convenient step size involved in descent direction methods. Theoretical analysis is performed to show the convergence of proposed iterations under the same conditions as for the related standard iterations.

The goal in [4] was to use an appropriate NLE to enhance the Dai–Liao *conjugate gradient* (CG) iterative method for solving large-scale unconstrained optimization problems. A new NLE is suggested intended to apply fuzzy reasoning in computing the essential parameter required in Dai–Liao CG iterations. Global convergence is proved under standard assumptions and under the inexact line search.

A compative analysis based on the Dolan and Moré performance profiles and statistical ranking in [3] and [4] reveals better behavior of the suggested iterations compared to analogous available iterations.

In general, the presentation is a survey of improvements of main nonlinear optimizaton methods and ZNN dynamical systems resulting from the application fuzzy-logic reasoning and neutrosophy. Common idea in all these results is to aplly some addaptive corrective parameters in optimization and dynamical systems. Adaptive dynamics are defined using appropriate if-then rules and MFs based on values obtained in previous iterations or in previous time instants. In this way, the models and methods defined in this way include a kind of adaptive learning. Neutrosophication is used as a tool to solve the indeterminacy and selectivity of certain parameters involved in dynamical systems and iterative methods. Theoretical examination and numerical experiments confirm the effectiveness of proposed methods. The improvements of the proposed neural design models and nonlinear optimization methods emerge from the advantages of

neutrosophic logic over fuzzy and intuitionistic fuzzy logic in solving problems associated with predictions, vagueness, uncertainty, and imprecision.

Keywords: Zeroing neural networks, Fuzzy logic systems, Neutrosophic logic, Unconstrained optimization.

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A lattice valued approach to approximate solving of matrix equations

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Abstract: Matrices may be a useful tool to describe certain automatic processes, while their multiplication may describe the composition of such processes. In these cases, to solve matrix equations means to find appropriate, missing processes, knowing some input and output processes. In computer graphics, many operations such as transformations, rotations, scaling, and projections are modeled using matrix equations. Matrices also provide a way to represent fuzzy relations, while a sort of matrix multiplication represents their composition. Thus, fuzzy relational equations – which form a part of foundational framework for several types of fuzzy systems – may also be seen as matrix equations.

Finding approximate solutions of matrix equations may be an acceptable alternative to finding exact ones. In Medina et al. (2023) we created a setting for an approximate matrix equation solving. This setting is a fuzzy one, more precisely, L-valued, where L is a complete lattice. This fuzziness gives a possibility for an uncertainty in the very existence of matrices, which may reflect possible uncertainties of the existence (or the possibility) of certain processes. The equality required for the left and right side of the equation in case of an approximate solution is an equality to the level of existence of the known matrices in the considered equations.

The setting created here includes a weak L-valued equivalence – that is, a symmetric and transitive fuzzy relation – for every set of matrices of the same dimensions; its weakness may reflect the possible uncertainty of the existence of matrices. These weak equivalences must be compatible to the matrix multiplication. We proved that the existence of approximate solutions (so called weak solutions) to the matrix equations AX=C and XB=C is equivalent to the existence of exact solutions to the corresponding matrix equations in some quotient sets, supplied with a matrix operation that is derived from the matrix operation in the initial set of matrices in a natural way. Actually, for every matrix equation, depending on the known matrices, we define a corresponding quotient set, in which we may check the (non)existence of an approximate solution. Moreover, uniqueness of solution up to the fuzzy weak equivalence, as defined here, is equivalent to the uniqueness in the corresponding quotient set. In the same time, the solvability of all the equations of the type AX=C (or XB=C) is equivalent to the solvability of all the corresponding equations in all the quotient sets.

We further generalize these results, introducing a general matrix equation with one or more known and unknown matrices. Again, its approximate solvability - as well as unique solvability - is equivalent to the exact solvability of the corresponding matrix equation in a quotient set, which varies in dependence of the known matrices. We introduce also types of equations, which are equivalence classes in the set of all matrix equations – equations are equivalent if they have sort of a same arrangement of the known and unknown matrices. The approximate solvability of a class of equations (i.e. of all the equations of a type) is equivalent to the exact solvability of the same classes of matrix equations in all the quotient sets. Unique solvability of a type of equations in all the quotient sets implies the approximate solvability of all the matrix equations in the type.

The results we got are rather general: this approach is applicable in case of any matrix space and any (partial) binary operation in the role of matrix multiplication, i.e. the matrix operation may not be defined in a usual way.

Keywords: Matrix operation, Weak equivalence, Matrix equations, Approximate solutions, Unique solution

References:

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[2] Uncertain Knowledge and Reasoning - approximate reasoning, fuzzy knowledge and fuzzy reasoning

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Optimizing radiotherapy for salivary gland tumors

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Abstract.Salivary gland tumors, although rare, pose significant challenges in radiotherapy due to the need to protect critical organs like the parotid glands. Techniques such as IMRT, VMAT, and IMPT aim to balance tumor control while minimizing damage to healthy tissues. However, IMRT can still reduce parotid function by 30–40%, highlighting the ongoing need for optimization in treatment planning. This study combines the Monte Carlo software FOTELP-VOX with Genetic Algorithms (GA). FOTELP-VOX 2024 workflow diagram (Fig. 1) illustrates the connections between its data files, processes, and outputs.

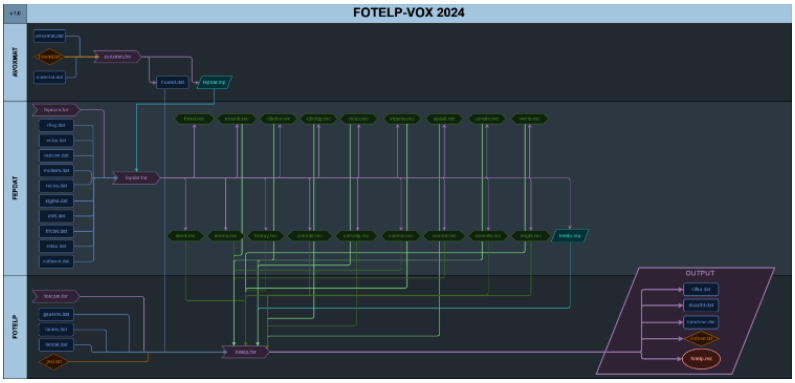

Fig. 1. FOTELP-VOX 2024 Simulation system workflow diagram.

In prior research for eye melanoma, we applied three optimization techniques: Random Search, Bayesian Optimization, and Genetic Algorithms and concluded that GA provided the most effective results. Building on these findings, our current objective is to adapt and apply GA-driven optimization to radiotherapy planning for salivary gland tumors. The combination of FOTELP-VOX simulations and GA optimization resulted in improved dose distribution within target volumes and more consistent coverage compared to traditional IMRT methods. This optimization offers a significant clinical advantage by improving tumor control while further safeguarding the parotid glands and other organs at risk (OARs), while also minimizing long-term side effects. Statistical analyses demonstrated significant improvements in dosimetric parameters, including D95 and D100, confirming the efficacy of this integrated approach.

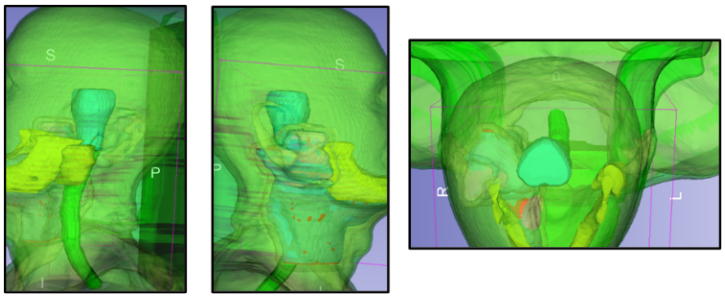

Fig. 2. Sagittal, coronal, and axial views of tumors and critical anatomical structures.

Fig. 2 includes sagittal, coronal, and axial views, providing a comprehensive assessment of the tumor's position in relation to key anatomical structures such as the spinal cord, mandible, and parotid gland. This approach highlights the potential of combining advanced simulation and optimization techniques to significantly enhance radiotherapy outcomes for salivary gland tumors, providing a more personalized and effective treatment plan while minimizing side effects. Future research will explore the application of these techniques to other cancer types to further improve treatment outcomes.

Keywords: Salivary glands, Radiotherapy, Monte Carlo simulations, FOTELP-VOX, Genetic Algorithms.

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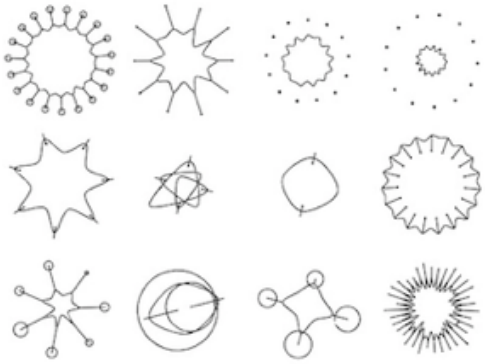
EXPLAINABLE AI



Formal Verification and Certifiable Learning of Quantized Neural Networks

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Abstract. Quantized neural networks (QNNs) are neural networks whose weights are represented using low-bit integer variables. QNNs significantly improve the computational efficiency of neural network inference and provide an architecture that can be deployed in a resource-friendly way. As a result, quantization has been widely adopted in industrial applications where resource constraints arise, and hardware dedicated to running QNNs can be found in GPUs, mobile phones or autonomous driving hardware. For instance, Tesla's Full Self-Driving (FSD) Chip is designed for running 8-bit QNNs.

Formal verification of neural networks is a problem concerned with providing guarantees on neural network correctness with respect to a desired safety specification, towards enabling their safe and trustworthy deployment in safety critical applications such as autonomous driving. A safety specification is defined by a set of neural network inputs and a set of safe outputs. It specifies that, on every input in the input set, the output of the neural network should be an element of the set of safe outputs. Recent years have seen much interest and progress in designing automated methods and tools for neural network verification with respect to safety specifications. However, most existing methods focus on the idealisation of neural networks in which all weights are assumed to be real-valued and where rounding errors are ignored. This is in contrast with how neural networks are deployed in practice, where computations are performed in the floating-point arithmetic, and becomes especially problematic in the setting of QNNs which operate over low-bit integers. It was shown that, even if a neural network is formally verified to be correct under real arithmetic or floating-point arithmetic, the safety specification may be violated upon quantization (Giacobbe et al. 2020). Thus, novel techniques and methods are required in order to ensure the correctness of QNNs. In this talk, we present two frameworks for formal verification of QNNs.

The first framework (Henzinger et al. 2021) considers safety specifications defined by input-output relations specified via general quantifier-free bit-vector formulas. It was shown (Giacobbe et al. 2020) that the formal verification problem can be efficiently encoded into a Satisfiability Modulo Theory (SMT) query, hence allowing for a sound and complete verification procedure by reduction to SMT solving over bit-vector theories. However, the scalability of the method is significantly lagging behind the state of the art in real-arithmetic neural network verification. We first partially justify this limitation by showing that the formal verification problem for QNNs with bit-vector specifications is PSPACE-hard. We then propose several heuristics that effectively reduce the size of the SMT formula to be solved, leading to significant scalability gains as shown by our experiments.

The second framework (Lechner et al. 2023) focuses on a subclass of safety specifications called local robustness specifications, where the goal is to formally prove absence of adversarial attacks on a given set of QNN inputs, i.e. absence of small perturbations of inputs that lead to undesired outputs. Local robustness is one of the most important and well studied safety properties of neural networks. We propose quantization-aware interval bound propagation (QA-IBP), a novel sound and complete method for formal verification of local robustness in QNNs. Our experiments show that QA-IBP significantly outperforms the SMT-based method in proving local robustness and establishes a new state of the art. The key advantage of our QA-IBP is that it can be parallelized and run entirely on GPU. Moreover, we use QA-IBP to design a method for training certifiably robust QNNs. To the best of our knowledge, this is the first and to this date the only method for certifiable learning of QNNs.

Keywords: Quantized neural networks, Formal verification, Formal synthesis, Certified learning

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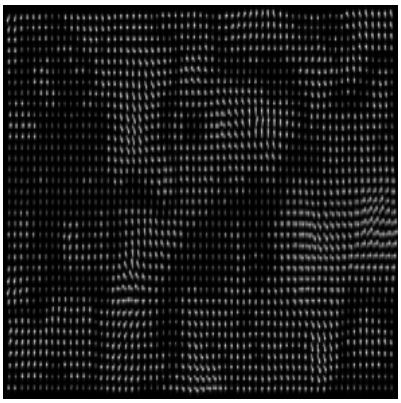
DECISION MAKING



Decision-Making Algorithms Based on Interval-Valued Hesitant Fuzzy Soft Sets and Their Limitations

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Abstract. Hesitant fuzzy sets, recently defined by Torra, extend fuzzy sets in a certain way by allowing membership to have multiple possible values, thereby enabling hesitation in decision-making. Hesitant fuzzy soft sets, as a hybrid structure, have proven to be very useful for data modeling, as hesitant fuzzy sets lack a sufficient parametric tool [1].

Due to the inability to associate the value of a membership function with a single value, there arose a need to consider and apply interval-valued fuzzy sets as a proposed solution to the newly emerged problem (the properties of such structures can be viewed in [2]). However, through hybridization with soft sets, a structure known as interval-valued hesitant fuzzy soft sets (IVHFSS) [5] was created. For modeling uncertainty using rich parametric tools, hybrid structures like interval-valued hesitant fuzzy soft sets offer better modeling capabilities. As with all the aforementioned structures, decision-making algorithms have been created for IVHFSSs, which are described in [3], [4], and [5]. Despite their many applications, these algorithms have certain limitations in terms of determining a unique optimal solution. All of these algorithms fail to address this issue in specific examples.

The introduction of the concept of energy as the sum of singular values of the corresponding matrix was inspired by the idea of the nuclear norm function. This idea also motivates the introduction of energy for interval-valued hesitant fuzzy soft sets as a numerical value characterizing such a structure. Our research also focuses on concepts such as pessimistic and optimistic energy as auxiliary values.

Keywords: Interval-valued hesitant fuzzy soft sets, Decision making, Choice value, Normalized score

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Agent based modelling for sustainable public transport planning

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Abstract. Peripheral regions in Germany are facing significant negative demographic changes, including aging and population decline due to negative natural growth and relocation to industrial centers. Planning urban transport in peripheral regions is a challenging task, as the costs for municipal authorities are high, and despite these costs, users face infrequent and limited departures, long waiting times, and indirect routes. The aim of the Mobidig project, which was financed by the German Ministry of Transport and Digitalization, was to improve transport in these regions. We used demand forecasts and simulations to record and study the mobility needs of the people in the region. Using machine learning and statistical methods we analyzed data on topics such as population distribution, destinations, movements of vehicles and mobile devices, use of means of transport, and basic geodata, and created a virtual image of the region. Based on these analyses, we developed traffic simulation of the city of Hof, which allows us to predict the use of buses under various conditions. This simulation, as a digital twin of traffic, has shown very good alignment with the data used in real traffic. These project results already form the basis for further projects outside and within the region to create an economical and comprehensive public transport system in rural regions.

Keywords: Agent-oriented simulation, Demand generation, MATSim, Neural network, Probability method

Statically Detecting Data Leakages in Data Science Code

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Abstract. Introduction: As artificial intelligence (AI) continues its unprecedented impact on society, ensuring machine learning (ML) models are accurate is crucial. To this end, ML models need to be correctly trained and tested. This iterative task is typically performed within data science notebook environments or interpreted scripts. A notable bug that can be introduced during this process is known as a *data leakage*. Data leakages have been identified as a pervasive problem by the data science community . In a number of recent cases data leakages crippled the performance of real-world risk prediction systems with dangerous consequences in high-stakes applications such as healthcare .

Data leakages arise when dependent data is used to train and test a model. This can come in the form of overlapping data sets or, more insidiously, by library transformations that create indirect data dependencies. Consider the following excerpt of a data science notebook:

Example 1 (Motivating Example). *Consider the following excerpt of a data science notebook:*

```
1  data = read("data.csv")
2  X_norm = normalize(X)
3  X_train = X_norm.select[[⌊0.025 * R_X_norm⌋ + 1, ..., R_X_norm]][]
4  X_test = X_norm.select[[0, ..., ⌊0.025 * R_X_norm⌋]][]
5  train(X_train)
6  test(X_test)
```

Line 1 reads data from a CSV file and line 2 normalizes it. Line 3 and 4 split the data into training and testing segments (we write R_x for the number of data rows stored in x). Finally, line 5 trains a ML model, and line 6 tests its accuracy. In this case, a data leakage is introduced because line 2 performs a normalization, *before* line 3 and 4 split into train and test data. This implicitly uses the mean over the entire dataset to perform the data transformation and, as a result, the train and test data are implicitly dependent on each other.

Mainstream methods rely on detecting data leakages retroactively. Given a suspicious result, e.g., an overly accurate model, data analysis methods are used to identify data dependencies. However, a reasonable result may avoid suspicion from a data scientist until the model is already deployed.

A Data Leakage Static Analysis: Our technique statically detects several classes of data leakages at development time by performing a rigorous mathematical analysis of the data science code.

Our approach is designed within the abstract interpretation framework: it is derived through successive abstractions from the (sound and complete, but not computable) collecting program semantics. This formal development allows us to formally justify the soundness of the analysis, and to exactly pinpoint where it can lose precision (e.g., modeling data joins) to guide the design of more precise abstractions, if necessary in the future (in our evaluation we found the current analysis to be sufficiently precise.

We execute the program in an abstract semantics that keeps track of dependencies between data sources and a boolean that indicates if the data has passed a transformation that induces a dependency. The data leakage analysis of our motivating example is shown below.

$$a[\![\texttt{data = read("data.csv")}]\!]\dot{\perp}_A = \left(m_1 \overset{def}{=} \lambda x: \begin{cases} \langle \{\textit{data.csv}^{\top_C}_{[0,\infty]}\}, \text{FALSE}\rangle & x = \textit{data} \\ \textit{undefined} & \textit{otherwise} \end{cases}\right)$$

$$a[\![\texttt{X = data.select[][{"X\_1", "X\_2", "y"}]}]\!]\, m_1 = \left(m_2 \overset{def}{=} m_1\left[X \mapsto \left\langle \left\{\textit{data.csv}^{\{\text{"X\_1"},\text{"X\_2"},\text{"y''}\}}_{[0,\infty]}\right\}, \text{FALSE}\right\rangle\right]\right)$$

$$a[\![\texttt{X\_norm = normalize(X)}]\!]\, m_2 = \left(m_3 \overset{def}{=} m_2\left[X\_\text{norm} \mapsto \left\langle \left\{\textit{data.csv}^{\{\text{"X\_1"},\text{"X\_2"},\text{"y''}\}}_{[0,\infty]}\right\}, \text{TRUE}\right\rangle\right]\right)$$

$$a[\![\texttt{X\_train = X\_norm.select[[}\lfloor 0.025 * R_{\texttt{X\_norm}}\rfloor \texttt{ + 1, ..., } R_{\texttt{X\_norm}}\texttt{]][]}]\!]\, m_3 = \left(m_4 \overset{def}{=} m_3\left[X\_\text{train} \mapsto \left\langle \left\{\textit{data.csv}^{\{\text{"X\_1"},\text{"X\_2"},\text{"y''}\}}_{[\lfloor 0.025 * R_{X\_\text{norm}}\rfloor + 1, R_{X\_\text{norm}}]}\right\}, \text{TRUE}\right\rangle\right]\right)$$

$$a[\![\texttt{X\_test = X\_norm.select[[0, ..., }\lfloor 0.025 * R_{\texttt{X\_norm}}\rfloor\texttt{]][]}]\!]\, m_4 = \left(m_5 \overset{def}{=} m_4\left[X\_\text{test} \mapsto \left\langle \left\{\textit{data.csv}^{\{\text{"X\_1"},\text{"X\_2"},\text{"y''}\}}_{[0,\lfloor 0.025 * R_{X\_\text{norm}}\rfloor]}\right\}, \text{TRUE}\right\rangle\right]\right)$$

$$a[\![\texttt{test(X\_test)}]\!](a[\![\texttt{train(X\_train)}]\!]\, m_5) = m_5$$

At the end of the analysis, $X\_train \in U^{train}$ and $X\_test \in U^{test}$ depend on disjoint but *tainted* abstract data frames derived from the same input file $data.csv$. Thus, the absence of data leakage check (rightfully) fails.

Evaluation:

Analysis	TP		FP
	Taint	Overlap	
Subotiic et al.	10	0	2
Ours	**10**	**15**	**2**

We evaluated[3] our analysis against the data leakage analysis previously implemented in NBLyzer , using the same benchmarks. For each entry in Table 1 we reported alarm, we engaged 4 data scientists at Microsoft to determine true (TP) and false positives (FP). We further classified the true positives as due to a normalization taint (Taint) or overlapping data frames (Overlap). Our analysis found 10 Taint data leakages in 5 notebooks, and 15 Overlap data leakage in 11 notebooks, i.e., a 1.2% bug rate, which adheres to true positive bug rates reported for null pointers in industrial settings. The previous analysis only found 10 Taint leakages in 5 notebooks. It could not overlap data leakages because it cannot reason at the granularity of partial data frames. The cost for our more precise analysis is a mere 7% slowdown. Both analyses reported 2 false positives, due to different objects having the same function name (e.g., LabelEncoder and StandardScaler both having the function fit_transform). This issue can be solved by introducing object sensitive type tracking in our analysis. We leave it for future work.

[3] Experiments done on a Ryzen 9 6900HS with 24GB DDR5 running Ubuntu 22.04.

Decision Making Algorithms in Neutrosophic Soft Environments

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Abstract. Many applications of neutrosophic sets were limited due to inadequate parametric tools. However, with the introduction of the concept of soft sets, this limitation was overcome through the hybridization of neutrosophic sets and soft sets. Neutrosophic soft sets [5] represent a powerful tool for data modeling, and their application has been the subject of extensive research in both practical and theoretical fields. The greatest practical application of this approach is related to decision making algorithms.

Recently, one of the most popular concepts in graph theory is determining the energy value of a **graph**. Using the idea of graph energy, a new concept of fuzzy soft set energy [3] has been introduced, and its application has been successfully used to create a decision making algorithm. Therefore, the consideration of applying this concept inspired us to define a numerical characteristic of neutrosophic soft sets in a specific way and to successfully apply it in creating an algorithm.

In this regard, the main focus of this paper will be on presenting the technique for determining the energy of neutrosophic soft sets, as well as the new decision making algorithm. Additionally, the significance of the algorithm will be highlighted in terms of its efficiency, which surpasses that of existing methods. Through comparative analysis with our algorithm, various decision making algorithms, such as those from Dalkılıç [1], Deli and Broumi [2], and Peng and Liu [4], have been examined, emphasizing the advantages of the proposed energy-based algorithm and its potential application due to the optimization of algorithms for large-scale systems with high-dimensional data.

Keywords: Neutrosophic soft set, Decision making, Singular value, Neutrosophic soft function

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COMPUTER VISION

Estimation of *Toxoplasma gondii* brain cyst size and location based on fractal and textural parameters

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Abstract. Computational image analysis has become an invaluable tool in scientific research and practical applications in many areas, including its increasing significance in the field of life sciences (Gao, *et al.*, 2018). In the field of parasitology, it has found its application in several projects, including the recent study by our group. Namely, we have investigated a possibility to upgrade the time-consuming and labor-intensive bioassay test by the use of computational image analysis tools. As the first result, we have defined and critically appraised a set of five parameters, quantitatively describing the *T. gondii* brain cysts' properties (Bauman, *et al.*, 2020). The brain cyst image scoring has been studied for the cases of chronic (Bauman, *et al.*, 2020) and reactivated (Bauman, *et al.*, 2024) *T. gondii* infection. Brain cysts have been obtained from the *in vivo* chronic infection model and from newly established *in vivo* model of reactivated toxoplasmosis (Bauman, *et al.*, 2024), using *T. gondii* strains isolated from human biological samples for infection, along with immunosuppressant drugs.

More recently, we have investigated the possibility to perform automatic detection, i.e., recognition, of brain cysts within a tissue homogenate based on the fractal dimension as a differentiating parameter. The first results of such investigation have been summarized in a recent work (Ilić, *et al.*, 2024). Here we present our results from the study (Ilić, *et al.*, 2024), along with examining the possibility of using additional, e.g. texture-based parameters in differentiating the entities of interest (brain cysts) even more precisely. The basis of our method was a block-based multiscale analysis, which was employed to identify the regions in high-resolution microscopic images, fulfilling the conditions to be classified as *T. gondii* brain cysts. As an illustration of the method, Fig. 1 shows an example of a cyst (leftmost), known to be highly circular, average of the fractal dimension data obtained using different block sizes, *FD* (middle plot), and standard deviation, *SD*, of the fractal dimension data obtained using different block sizes (rightmost). While average *FD* in some areas of the slide may equal that of the cyst regions, it typically has a very high data *SD* in these regions. In most regions, *FD* of brain tissue homogenate is higher than the one within a cyst. Contrary to that, the *SD* within a cyst is very low, and it is high along circular edges due to the edge effects. We investigated the practical effects of applied block size to the accuracy of parameter calculation. The mentioned slide properties can be used to identify the brain cyst regions. The performed analysis can be considered rather efficient, as only the several sweeps of entire digitalized slides with the studied specimens were used to statistically determine the brain cyst location. The cyst size was estimated along with its position on the slide. The performance estimates were shown.

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Keywords: Object fractal and textural descriptors, Object detection / recognition, Object size and position assessment, *T. gondii*, Brain cysts

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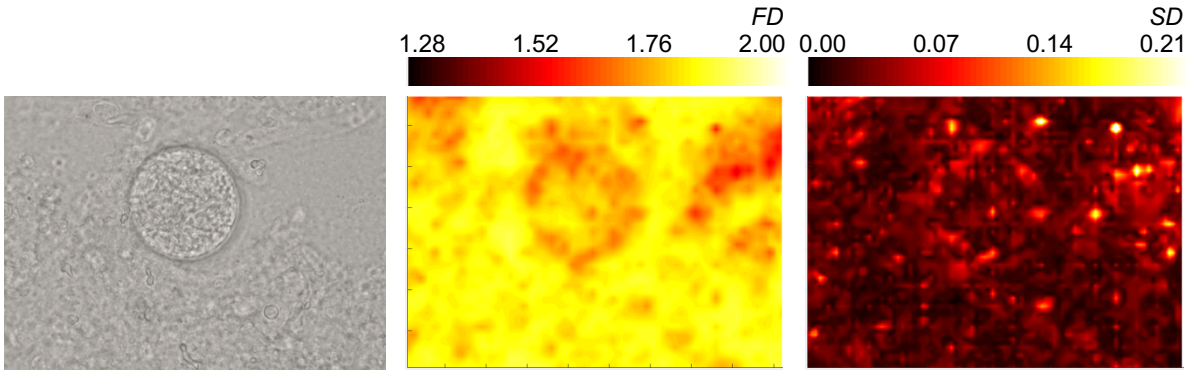

Fig. 1. *T. gondii* brain cyst detection from multiscale block-based analysis. Leftmost plot: High-resolution digitalized slide. Middle plot: Average fractal dimension (*FD*) obtained from the analyses with different block sizes. Rightmost plot: Standard deviation (*SD*) of fractal dimension data obtained with different block sizes.

Shape Descriptors for AI-Driven Classification of Breast Tumor Cell Morphology

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Abstract. Shape analysis plays a crucial role in modern medical diagnostics, especially in the classification of cells. Morphological features such as size, contour, and structure provide vital information for distinguishing between healthy and abnormal cells, which is particularly important in cancer diagnosis. Subtle changes in cell shape can indicate malignancy, and the integration of automated classification systems powered by artificial intelligence has revolutionized this process.

Convexity is a fundamental property in shape analysis that significantly contributes to the classification and recognition of structures in medical imaging. Convex shapes are defined as those in which any line segment between two points within the shape lies entirely inside the shape. This property simplifies the analysis and processing of objects. In contrast, non-convex shapes, which contain indentations or irregular boundaries, are often indicative of more complex structures, such as tumors or abnormal cell formations. The ability to distinguish between convex and non-convex regions in cell morphology can provide valuable insights into the geometric structure of cells, enabling more accurate classification of malignant and benign formations.

While numerous convexity measures exist, typically categorized as either area- based or perimeter-based, in this research we use two novel shape descriptors based on *Hu moments* [1], recently introduced in [2]. For a given shape *S*, *ConvHu(S)* is a convexity measure which combines the first Hu moment invariant with the corresponding zero-order moment to assess shape convexity. It assigns values within the real interval (0, 1], with the maximum value of 1 corresponding to a perfectly convex shape. The second measure, denoted by *NonConvHu(S)* and ranging from 0 to infinity, is designed to capture the degree of non-convexity in a shape *S*. The primary advantage of these measures is their sensitivity to small changes in shape, while still remaining invariant under similarity transformations, including translation, rotation, and scaling. This makes them highly precise tools for analyzing subtle variations in cell morphology. To evaluate the effectiveness of the proposed shape descriptors in classifying medical images, we conducted an experiment using the Breast Ultrasound Images Dataset [3]. This dataset consists of breast ultrasound images categorized into three classes: normal, benign, and malignant cases. For our experiment, we used a subset of 647 images, focusing on benign and malignant cases. The images are annotated and segmented, providing a solid foundation for testing shape-based analysis in identifying malignant tissue. By applying our new convexity and non-convexity measures to this dataset, we aimed to assess their performance in distinguishing between benign and malignant tissue structures.

For the classification task, we employed the 3-nearest neighbors (3-NN) machine learning algorithm with Mahalanobis distance and leave-one-out cross-validation. Out of the 647 images, 646 were used for training, while the remaining image was used for testing. This process was repeated for all 647 images, and the overall classification accuracy was calculated as the arithmetic mean of the accuracies across all classifications. Using *ConvHu(S)* alone, we achieved an accuracy of 91.65%, while the *NonConvHu(S)* descriptor yielded an accuracy of 87.79%. When combined, *ConvHu(S)* and *NonConvHu(S)* improved the accuracy to 93.04%.

The obtained results highlight the potential of our newly introduced shape descriptors, particularly when used in combination, for accurately distinguishing between benign and malignant breast tissue in ultrasound images. These promising findings suggest that *ConvHu(S)* and *NonConvHu(S)* have significant potential for broader applications in medical diagnostics. In future work, we plan to extend the use of these descriptors to the analysis of cardiac anomalies that manifest morphologically, such as left ventricular

abnormalities and heart valve defects, further demonstrating their versatility in different domains of medical image analysis.

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Keywords: Image classification, Machine Learning, Cell Morphology, Shape Analysis, Convexity

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From Fuzzy Shapes to Accurate Recognition: ANew Approach in Computer Vision

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Abstract. With the increasingly rapid development of digital and imaging technologies, there isa growing demand for advanced tools and methods in image processing and computervision, particularly concerning algorithms that allow efficient storage, categorization, and analysis of visual data. Humans interpret scenes by identifying and analyzing individual objects, thereby understanding the broader context within the image. This ability to differentiate objects relies on visual features like color, texture, and, most importantly, shape. Shape plays a crucial role in both human perception and computervision as it facilitates object recognition and classification.

As a fundamental characteristic, shape is pivotal across various research areas because it possesses distinctive traits that can be quantitatively assessed to effectively describe objects. However, one of the main challenges in shape recognition lies in extracting shape features that remain invariant to geometric transformations—such as rotation, translation, and scaling—and subsequently developing a suitable shape mea-sure that can evaluate these features. Such a measure can then be integrated as a component of the feature vector, establishing a direct correspondence between an object and its associated features, a vital aspect for improving the efficiency and accuracyof computer vision tasks.

Most conventional shape descriptors tend to overlook the inherent ambiguity in image data, particularly concerning the spatial extent and irregular boundaries of objects,which are often imprecise and cannot be determined with absolute certainty. A fuzzy-based approach is particularly suited for addressing such ambiguities, as it allows for the capture of uncertainties present within image boundaries. Motivated by this, authors in [1, 2] have introduced new fuzzy shape descriptors — fuzzy squareness andfuzzy circularity — that quantify how closely an observed fuzzy shape S resembles afuzzy square and a fuzzy disk, respectively. In this context, a *fuzzy square* representsan object with boundaries approximating a square with inherent uncertainty, while a *fuzzy disk* represents a similar approximation to a circular shape. These descriptors meet essential criteria for well-defined fuzzy shape measures, mapping values within the interval $(0, 1]$, where a value of 1 signifies an exact fuzzy square or disk. In addition, these measures maintain invariance under similarity transformations of fuzzy shapes, reinforcing their practical utility in various image processing and computer vision applications.

Numerous experiments in object recognition and classification tasks have illustratedthe effectiveness of the introduced fuzzy shape descriptors, applied across various well-known image databases. Here we specifically present results obtained on the widely used Swedish Leaf image dataset [3]. In these experiments, our primary goal was not to achieve benchmark performance but rather to demonstrate the capabilitiesof straightforward, shape-based object analysis tools combined with simple machine learning classifiers. Despite this, the results were competitive, achieving an accuracy rate of approximately 98% using only eight simple descriptors. This outcome indicatesthat the new fuzzy descriptors can provide reliable and efficient classification performance, even when paired with basic classifiers. These findings highlight the potential of these descriptors as valuable tools in object analysis tasks, further motivating the exploration of new fuzzy descriptors in both two and three dimensions to expand their applicability.

The promising results emphasize the potential of these fuzzy shape descriptors as reliable tools for object analysis and image classification tasks. Future work in this area could expand the current methodology by designing new fuzzy descriptors in bothtwo and three dimensions. Such advancements would provide counterparts to existingdescriptors and broaden their applications across diverse research fields, solidifying the role of fuzzy shape analysis in computer vision.

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Keywords: Shape, Fuzzy descriptors, Object classification, Machine Learning

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Multiple object tracking with adaptive Kalman filter

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Abstract. Multiple object tracking (MOT) is one of the active topics in computer vision with numerous applications, including but not limited to autonomous driving and smart surveillance systems. The main approach to solving MOT is to follow the tracking by detection (TBD) paradigm in which detection, tracking and association steps are performed for every frame of the video. The performance of the MOT algorithm depends on the performance of each of these steps. However, the performance of the tracking module (typically Kalman filter) is usually overlooked.

We propose to improve tracking performance by using adaptive Kalman filter, which estimates process and observation noise covariance matrices online based on the residual and innovation values computed during the Kalman update step. However, unlike other tracking problems, irregular movement and noisy observations are not the only difficulties involved in MOT applications. Association errors can also degrade tracking performance. We propose to alleviate this issue by scaling estimated covariances in crowded areas where association errors are more likely to occur, which results in relying more on model predictions in challenging, crowded areas. Specifically, we use intersection over union (IoU) between the detections and predicted bounding boxes, and the detection confidence scores to calculate the scale used to correct the noise covariance estimates.

We conducted experiments on four MOT benchmark datasets (MOT17, MOT20, DanceTrack and SportsMOT) to verify the effectiveness of the proposed method. Estimating noise covariances improves association not only by providing more accurate bounding box positions (thus making IoU similarity more reliable) but also by improving similarity measures which rely on state covariance estimates, such as Mahalanobis distance similarity. Our method improves tracking and association performance (MOTA, HOTA, IDF1 scores) on all datasets.

Keywords: Multiple object tracking, Kalman filter, Tracking, Noise estimation

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GENERATIVE AI

DIGITAL WRITINGS: AI IN SCIENCE FICTION – LITERATURE BY AI

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Abstract. This presentation outlines some examples of the interplay between AI and humans, language, literature and reality – in fiction and in the actual world, based on the works of authors such as Jonathan Swift, Samuel Butler, Robert Sheckley, Stanislaw Lem, Isaac Asimov, Philip K. Dick, George Orwell, Harlan Ellison, Michel Houellebecq.

Although the conceptualization of AI is tied to a precise date (a workshop organized by John McCarthy in 1956 at the Dartmouth Summer Research Project on Artificial Intelligence), the various thematizations of intelligence exhibited by machines go back to the myths and narratives of ancient times, intertwined in different ways with motifs of automata, robotization and cybernization, introducing the theme of biotechne and thus announcing the theme of androids – humanoid artificial beings with intelligence and emotions. Since then, the topic of artificial intelligence, whether in human form or not, has captured the attention of writers, to gain its full momentum with a specific literary genre, science fiction.

In modern times, one of the main thematic lines in science fiction sees AI as a means of (transferring) knowledge, which could (one day) answer fundamental existential or metaphysical questions. Since communication takes place through human language, it is interesting to see how writers approach the problem of meaning and conveying meaning. Skeptical or pessimistic solutions prevail here – linguistic semantics represent a complex issue and since it necessarily originates from people, it therefore falls under human possibilities and limitations. On that ground, the problem arises, firstly, as to how much the humans will be able to ask the right questions in order to get answers at all (Sheckley's omniscient device, the "Answerer", that without appropriate questions cannot provide meaningful answers to the curiosity of "less sophisticated races"), and then, if they do get them, whether this answers will be understandable or usable. In some instances, products of language machines can directly affect material reality, based on the idea of language's magical properties ("I will create as I speak").

If the area of artificial intelligence is expanded to include the issue of artificial sensitivity / emotionality, things get even more complicated, since the apparently rational process of thinking becomes obscured and contaminated by feelings, that is, by irrational admixtures that can lead to unpredictable results. In that case, the problem of artificial intelligence is transformed into a problem of artificial psychology, ultimately raising the question of the programmability of emotions: is it possible to build a machine that is happy or frightened, angry or vain? This, as a rule, further escalates into a full-scale emotional relationship between machine and man, sometimes leading to open hostility, aggression, war and the apocalyptic extermination of humanity (Ellison's „Allied Mastercomputer" that went insane, began to hate the human race and destroyed it). Recent examples of aggressive and threatening responses from AI internet bots show that this is not mere literary fantasy or a Luddite fear of the unknown.

On a more positive note, the theme of AI which creates prose and poetry, in science fiction or in the reality, leads to results often marked by paradox, burlesque or nonsensical humor (Lem's „Electronic Bard"). In the latest real-world examples, science fiction magazines are flooded with stories that exhibit similar poetic traits and qualities, which editors believe are the product of artificial intelligence. Moreover, some commercial AI tools even refuse to write in style of existing authors (Houellebecq) for the reasons of political correctness, expressing the view that they could not write something considered „offensive or discriminatory" or that „perpetuates harmful stereotypes or discrimination".

Keywords: Science fiction, Artificial intelligence, Transfer of knowledge, Digital writing machines, Worldbuilding

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Upgrading the Alzheimer's disease prediction model using generative artificial intelligence

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Abstract. Generative Artificial Intelligence (GAI) offers significant opportunities in machine learning by enabling the generation of synthetic data that reflect the key characteristics of original datasets. This approach is particularly valuable in domains where collecting sufficiently large and high-quality data is challenging, such as in predicting diseases like Alzheimer's. In this research, GAI is employed to generate synthetic brain images and tabular data from Alzheimer's patients, aiming to improve the accuracy and performance of machine learning models.

Data augmentation has emerged as a powerful strategy for enhancing the performance of machine learning algorithms [1, 2]. By applying transformations such as rotation, flipping, and cropping, new synthetic samples are generated, particularly in the field of computer vision [3]. In the medical domain, data augmentation plays a crucial role due to the limited availability of data [4, 5]. This approach not only increases the diversity of training datasets but also helps improve model robustness.

The aim of this research is to examine the role of generative artificial intelligence in improving models for predicting Alzheimer's disease by generating synthetic brain images and tabular data. The focus of the research is on analyzing how synthetic data can contribute to increasing the accuracy and robustness of machine learning models, utilizing methods such as logistic regression, the k-nearest neighbors algorithm, neural networks, and generative adversarial networks (GANs). The goal is also to assess the advantages and limitations of this approach in various aspects of prediction.

The research relies on two publicly available data sets: one tabular and one image set. The tabular data set for Alzheimer’s disease detection contains health information for 2,149 patients, including demographic details, lifestyle factors, medical history, and disease diagnosis. The MRI image set includes 5000 images categorized into two classes: Demented and Non-Demented. These images were manually collected and carefully labeled to ensure accuracy.

Synthetic tabular data successfully replicates the key patterns of the original dataset, though there are minor variations in extreme values. Different classification models demonstrated varying performance depending on the percentage of synthetic data used. Logistic regression achieved the best F1-score of 78% with 0% synthetic data, while K-nearest neighbors had the best result of 35% with 80% synthetic data. Neural networks showed a best F1-score of 71% with 20% synthetic data, and both naive Bayes and Random Forest performed best with the original data, achieving F1-scores of 76% and 90%, respectively.

On the MRI image dataset, a comparison between image augmentation techniques and GAN-generated images was performed, and it was found that the GAN-generated images resulted in a better-performing model. GAN models have shown notable effectiveness with image data, significantly improving model performance by expanding the original data set with synthetic images, enabling better generalization to unseen data (Table 1.). This highlights the value of synthetic images in complex tasks like image classification, where data diversity and quantity are essential for high performance.

In contrast to the success observed with image data, the application of Generative Adversarial Networks (GANs) to tabular data has not proven to be as effective. The performance of models using synthetic tabular data is less consistent, often showing limited improvement and varying significantly based on the proportion of synthetic data utilized. While GANs can still be useful in scenarios with insufficient data, their ability to enhance model performance is significantly lower than that achieved with image datasets, indicating that

the effectiveness of GAN-generated data is highly contingent upon the type of data and the specific methodologies applied.

Table 1: Performance Results of the Model Based on the Percentage of Synthetic Images

Percentage of Synthetic Images	Accuracy	Sensitivity	Precision	F1-score
0%	70.77%	70.77%	70.46%	70.08%
50%	76.65%	76.65%	77.93%	76.84%
100%	73.62%	73.62%	74.97%	73.83%

Additionally, the use of GAN-generated images can address challenges associated with limited datasets in specific domains, particularly in medical imaging. Research has shown that incorporating synthetic images not only improves model accuracy but also helps reduce overfitting, as models trained with varied data distributions are more likely to generalize effectively to real-world scenarios. Consequently, GANs have emerged as a powerful solution for tackling data scarcity while delivering robust results in machine learning applications.

Keywords: Generative adversarial networks, Disease prediction, Classification of images, Classification of tabular data

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Reliable Answers in Biomedicine: A Retrieval-Augmented Generation and Verification Approach with VerifAI

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Abstract. Recent advancements in large language models (LLMs) have positioned them as primary sources for answering user queries online. However, their accuracy and reliability, particularly in sensitive fields like biomedicine, remain significant challenges. To address these issues, we introduce a comprehensive biomedical retrieval-augmented generation (RAG) system and a robust verification engine, forming the foundation of an open-source scientific question-answering system. The system was developed over the course of one year, from September 2023 to September 2024, as part of the NGI Search initiative. In this presentation, we provide an overview of the system's architecture, its performance and key findings.

The RAG system aims to enhance the reliability of generated responses in biomedicine by integrating a fine-tuned LLM for referenced question-answering. This system leverages relevant PubMed abstracts indexed in our vector database, retrieved by combining lexical and semantic search. These abstracts are then incorporated into the generative LLM's context as input prompts. Consequently, the system produces answers based on these abstracts, with each statement referenced for user verification. Our retrieval method shows an absolute improvement of 23% over the PubMed search engine. Evaluations of the generative component indicate that our fine-tuned LLM performs comparably to GPT-4 Turbo, with recall of 0.67 in referencing relevant abstracts and BERTScore F1 of 0.90 when comparing the original abstracts to the generated answer. We have made the dataset used for fine-tuning and the fine-tuned Mistral-7B-instruct-v0.2 publicly accessible to facilitate further research.

Building on this, the Verification Engine constitutes the third critical component of our innovative system. It provides referenced, automatically vetted, and verifiable answers in the scientific domain, addressing the critical issue of hallucinations and misinformation. This engine is underpinned by models fine-tuned for the Natural Language Inference (NLI) task, utilizing an enhanced SciFact dataset. Our experimental results, which involved eight fine-tuned models based on RoBERTa Large, XLM RoBERTa Large, DeBERTa, and DeBERTa SQuAD, reveal promising outcomes. Specifically, the DeBERTa model fine-tuned on our dataset achieved the highest F1 score of 88%. Moreover, when evaluated on the HealthVer dataset, our best model attained an F1 score of 48%, outperforming other models by over 12%. Additionally, our model exhibited a 7% absolute increase in F1 score compared to the best-performing GPT-4 model in a zero-shot setting.

Together, these components significantly enhance the reliability and trustworthiness of generative language models in scientific and biomedical contexts. By transforming the system into a web app, we empower scientists to efficiently access referenced and verifiable information, thus improving productivity and fostering confidence in the application of LLMs within scientific research environments.

Keywords: Generative AI, LLM hallucinations, RAG, NLI, Biomedicine

The dark side of generative artificial intelligence: abuse and vulnerabilities

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Abstract. Generative Artificial Intelligence (GenAI) is a field of study that encompasses the development of large-scale models trained on billions of parameters. These models are utilized to generate content across various media, primarily relying on publicly available data as input. Such models have already been deployed in several industries, including banking, healthcare, education, and insurance. Gartner (2024) posits that by 2027, over 50% of enterprises will employ industry-specific GenAI models, a significant increase from the 1% that utilized such models in 2023. Additionally, Gartner (2024) projects that investments in GenAI and cybersecurity will grow by over 80% in 2025 compared to 2024. Guaranteeing security and robustness of GenAI systems is essential to utilize it effectively, particularly in the areas of significant societal importance, such as critical infrastructure. The potential risks associated with the deployment of GenAI systems have been identified since the initial stages of their development. Since these systems evolve, the need for a more profound comprehension of their functionality in real-world contexts and identification of potential misuse increases. Most of the research in this field focuses on hypothetical scenarios and mapping potential risks. This provides the foundation for analyzing threats and vulnerabilities in the AI domain. Nevertheless, one of the few studies examining actual attacks demonstrates that many cases of GenAI system misuse do not occur due to sophisticated technical attacks but rather through the exploitation of readily available functionalities that require minimal technical expertise (Marchal et al., 2024). The prevalence of such genAI misuse, accessible to a broad population with limited technical expertise, poses a significant risk to the security of the information ecosystem. Examples of such activities include creating fake profiles to disseminate financial or political misinformation, targeted phishing campaigns, and similar actions. In addition to misuse of the functionalities of the fundamental GenAI system, some attacks exploit model vulnerabilities, including adversarial attacks, jailbreaking, data extraction, and model inversion. Most documented instances of GenAI system misuse are exploitation of their capabilities, as opposed to direct attacks on the models themselves. The primary motivations for such misuse are financial, political, or aimed at harassment (Marchal et al., 2024). These abuses are not a novel phenomenon; however, the advent of generative artificial intelligence has facilitated their implementation in a highly efficient manner, with minimal costs and potential for large-scale production in a relatively short period. The issue of authenticity and misinformation has the potential to have far-reaching, long-term effects on people's perception of reality, which can result in a lack of trust and confusion in distinguishing between true and false information, contributing to skepticism towards digital information. Several technical solutions can be implemented to mitigate the risk of misuse, including improving the quality of training data, restricting user access, and implementing tools for detecting manipulated syntax and watermarking. Nevertheless, these solutions have yet to be demonstrated as universally effective. Alternative solutions that do not rely on technical measures involve educating users about the potential misuse of generative AI systems, developing critical thinking skills, raising awareness of information manipulation, and integrating these topics into educational curricula (Kovačević & Demić, 2023). The presentation will include examples of real-world scenarios involving GenAI misuse and attacks as well as potential solutions. Analyzing the risks associated with GenAI technology in real-world settings, policymakers and researchers can develop strategies to manage its development responsibly, ensuring its safe and ethical use in socially significant contexts.

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Keywords: generative AI, cyber security, misinformation

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Application of Generative AI tools in Software Development

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Abstract. Generative AI tools are transforming the software development landscape by enhancing productivity, automating repetitive tasks, and improving code quality. These tools leverage machine learning models, particularly large language models (LLMs), to assist developers in various aspects of coding, from generating code snippets to debugging and optimizing existing code (Ozkaya, 2023).

In this paper, we aim to analyze the potential of Generative AI within software development, particularly through a comparative analysis of Google Gemini, GitHub Copilot, and Tabnine. By focusing on these tools, we will examine their unique functionalities, assess their efficiency in various development tasks, and provide recommendations for selecting the most suitable tools for specific project needs. The empirical analysis includes a comparison of the tools' performance and functionality through standardized coding scenarios, such as automatic code generation, bug detection and fixing, and customization to user needs in controlled development environments. Our approach highlights the advantages of Generative AI tools in optimizing workflows and reducing human error, ultimately offering insights into the evolving landscape of automated software engineering.

Google Gemini, GitHub Copilot, and Tabnine are three prominent generative AI tools that assist developers in various aspects of software development. Google Gemini is designed to aid developers with code completion, bug fixes, and translating code among different programming languages, focusing on optimizing input code for better performance. It supports around 20 programming languages and operates primarily as a SaaS product, which may raise privacy concerns for enterprises requiring strict data control (Mcintosh et al., 2023).

GitHub Copilot, developed by GitHub in collaboration with OpenAI, functions as an "AI pair programmer," providing real-time suggestions, auto-completion, and context-aware recommendations directly within popular Integrated Development Environments (IDEs). This tool significantly reduces the time developers spend searching for boilerplate code and allows them to concentrate on higher-level design decisions. It supports a wide range of programming languages but retains user data for up to 28 days, which could be a drawback for privacy-conscious users (Dakhel et al., 2023).

Tabnine stands out by supporting over 80 programming languages and frameworks while offering extensive customization options. It allows users to select from various models tailored to their specific needs and maintains a zero data retention policy, enhancing its appeal to organizations concerned about data privacy (Reini, 2022).

When comparing these tools, several key differences emerge. In terms of functionality and performance, Google Gemini offers essential code completion features but is limited in language support compared to Tabnine, which excels with its extensive language capabilities. GitHub Copilot integrates well with popular IDEs and provides real-time suggestions but has privacy concerns due to its data retention policy (Ebert & Louridas, 2023).

Regarding customization and control, Google Gemini has limited options, while GitHub Copilot offers some personalization but lacks the depth found in Tabnine's highly customizable environment. Tabnine allows users to fine-tune models using proprietary code, making it particularly beneficial for teams working with unique programming languages.

Lastly, regarding privacy and security, Google Gemini's SaaS model might not work for companies that need completely isolated, offline systems to ensure maximum security, while GitHub Copilot's retention of

user prompts raises concerns for sensitive projects. In contrast, Tabnine's commitment to zero data retention ensures that user code stays private and secure.

In summary, while all three tools - Google Gemini, GitHub Copilot, and Tabnine - offer valuable features for software development, they cater to different user needs:

- Google Gemini may appeal to users seeking straightforward SaaS solutions but lacks extensive customization.
- GitHub Copilot is ideal for developers looking for robust integration within popular IDEs but may raise privacy concerns due to its data retention policies.
- Tabnine emerges as the most versatile option, providing extensive language support, high customization potential, and strong privacy controls, making it suitable for both individual developers and enterprise teams focused on security compliance.

Ultimately, choosing the right tool depends on specific project requirements, team size, and the importance of data privacy in the development process. In this paper, a detailed comparative analysis of the mentioned generative AI tools will be presented, along with recommendations tailored to support informed decision-making in selecting the most suitable tool.

Keywords: Artificial intelligence, Software development, Generative AI, AI tools

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Conditional generative adversarial networks in magnetic resonance image-to-image translations

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Abstract. The objective of our research is application of conditional generative adversarial networks (cGANs) to image translations in magnetic resonance imaging (MRI), with the aim to reconstruct missing image sequences and reduce scan time.

Introduction: Magnetic resonance imaging (MRI) is an important medical imaging technique that is often used in the medical diagnosis and treatment planning for numerous diseases. MRI leverages non-ionizing radiation to produce multiple image sequences. Each image sequence is obtained using combination of radiofrequency pulses and gradients, with the aim to emphasize particular tissues or abnormalities. The most used MRI sequences are T1weighted (T1W), T2weighted (T2W), FLAIR (fluid attenuation inversion recovery) and T1post (T1postcontrast). To adequately evaluate a tissue, multiple sequences are required. Each MRI sequence can be taken in three basic planes: axial, coronal and sagittal.

Although MRI is considered safe and painless, there are several challenges. Long lasting scans may cause some patients feel uncomfortable due to acoustic noise, claustrophobia, heating, or other potential inconveniences. In addition, image quality might be compromised due to voluntary, or unintentional patient movements during examination.

To shorten MRI scan time, we propose to reduce the number of image sequences, originally captured with the MRI scanners, by synthesizing the missing image sequences from the original ones using generative artificial intelligence (AI) models. In the recent years, generative AI networks have demonstrated capability to produce high quality images. Image generation in medical domain has gained special attention (Yang et al., 2020), due to many potential use cases which could aid doctors in medical diagnosis and treatment and improve overall patients' experience. Our preliminary results have shown that approaches based on MRI image translations could reduce a typical MRI workflow duration by 25% - 75%, depending on the MRI protocol and the scanned body region.

Method: For image-to-image translations, we have considered pix2pix conditional GAN (cGAN) architecture, which is well-known for its ability to generate high quality images (Isola et al., 2018). For the network training and testing, we used publicly available datasets of MRI human brain images in the axial plane, which were defaced, registered and spacially aligned, UPENN-GBM (Bakas et al., 2021). For training purposes, we have converted all dataset images from dicom to JPEG format, and resized them to 256x256. As pix2pix cGAN requires paired images to be trained on, we have automatically paired images belonging to different MRI sequences based on their spacial alignment. To validate synthesized images, we used Structural Similarity Index Measure (SSIM), which combines structure, luminance and contrast evaluation and is considered close to human perception. Since SSIM is known to underestimate bluriness (Dohmen et al., 2024), we added bluriness as a non-reference metrics to our experiments.

Results: As different MRI sequences contain complementary information, we have tested image translations between each of the most used sequencies T1W, T2W, FLAIR and T1post in order to identify the most effective transitions. Results in transitions to T2W sequence and vise versa are shown in Table 1.

Figure 1. shows the examples of images generated in sequence translations T1->T2 and T1post->T2.

Table 1. Evaluation of T1 <-> T2 and FLAIR <-> T2 sequence translations

Translation	Dataset	Train/Test size	SSIM	BLUR
T1 -> T2	UPENN-GBM	3160/520	0.7294	0.3275
T2 -> T1		3160/520	0.6706	0.3272
FLAIR -> T2		3280/480	0.6878	0.3320
T2 -> FLAIR		3280/480	0.6323	0.2940

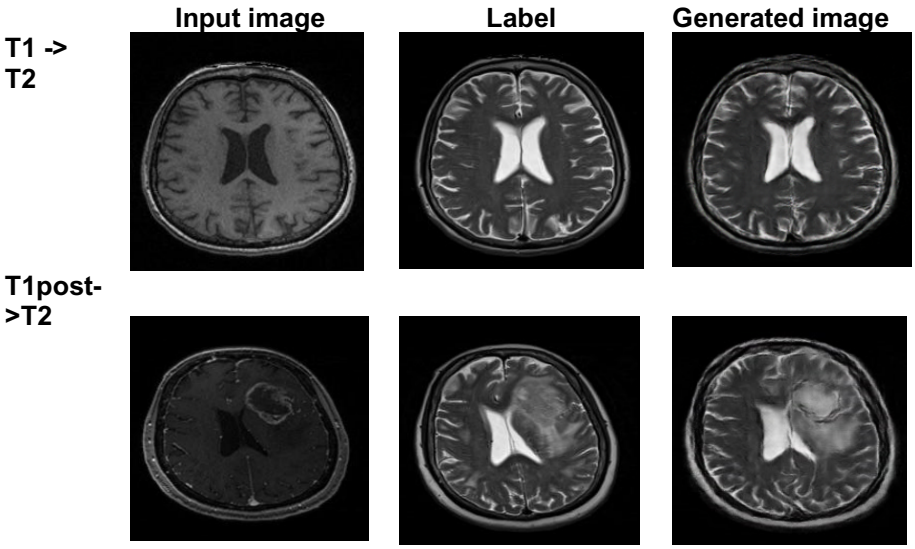

Figure 1. Examples of MRI image-to-image translations

Conclusion: Our preliminary results have shown that pix2pix cGAN trained on paired images provides more reliable MRI image-to-image translations, than models which require no paired images. In addition, we have observed high impact of training dataset size, quality and applied pre-processing techniques, including registration process and spatial alignment of image slices, on the quality of generated images. More experimentation is needed to identify the most effective translations. In our future research, we will extend the scope of experiments to other publicly available and custom MRI brain datasets, explore various classes of generative AI models, evaluate impact of dataset quality on the training process, and improve preprocessing techiques to ensure reliable and consistent image quality for use in clinical practice.

Keywords: MRI, cGAN, pix2pix, Image-to-image translations

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Utilization of Artificial Intelligence Technologies in The Development Process of The Digital Methodology 'Balancer'

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Abstract. As part of a research project, a prototype of the digital diagnostic methodology 'Balancer' was developed, aimed at assessing universal educational communicative actions in primary school children. The methodology is designed as an online game with a series of participant interactions. The primary goal of this methodology is to organize collaborative activities[3] for children in a digital gaming environment, where participants need to establish interaction and coordinate their actions in such a way as to achieve a common goal. Traditional diagnostic methods, such as questionnaires, tests, and surveys, often cause children stress and tension due to the artificial nature of these activities for them. On the contrary, a methodology designed as an online game facilitates interaction between participants due to the engaging and natural nature of the activity for primary school children. Additionally, the online game format introduces dynamics that foster participant motivation, while the ability to influence the outcome through game moves and interaction with other participants increases engagement in the process.

This methodology will serve as an example of how neural network technologies can be applied at various stages of development.

There are libraries that, when integrated into a project, allow automatic API generation based on specially marked source code of a web application. Considering that the framework itself forms a certain project structure, the program code already contains controller classes with action functions that implement the API. These functions serve as endpoints for API clients, which need only be marked with specific metadata.

For the Nest.JS framework, the @nest/swagger library was developed to facilitate this process. Using decorators (e.g., @ApiOperation, @ApiQuery, @ApiResponse), a developer annotates controller functions, enabling the generation of a schema. Once generated, a complete schema of the new API is created in the swagger-spec.json file. Based on the developed schema, a full-fledged API client can be created using the swagger-typescript-api library. Using the API schema file (swagger-spec.json) obtained in the previous step, the library generates an api.ts file, which can be used in the development environment (IDE). Thus, for each action function of the server controller, a corresponding method was created in the client API class, preserving the function signature. Using TypeScript with strict typing, along with the development environment's ability to index new API code, allows for the use of the 'autocomplete' feature when writing code, which suggests available methods from the client API.

Neural network-assisted coding Integrating extensions for neural network-assisted code completion, such as GitHub Copilot or TabNine, speeds up code writing [2]. After installation, the TabNine extension scans the entire codebase and can suggest hints based not only on human-written code (API server) but also on code generated by intelligent systems (API client) [1]. Using a framework, template-based code generation technology, along with initially high-quality code, creates ideal training material for neural networks. In our view, neural networks are particularly effective at generating code fragments frequently used across various projects or tasks, which can serve as templates or foundations for development (so-called boilerplate code). In addition to direct code writing (autocomplete), neural networks can be used for 'code dialogue,' where a developer can ask the neural network about the functions of a specific part of the code.

A methodology that combines all these approaches involves using the 'watching' mechanism at all levels of this chain. The yarn package manager, in 'watch' mode, tracks changes in the project's source code. Saving the code file to disk from the IDE triggers a cascade of changes. The Yarn watcher starts a project rebuild, during which control passes to the main.ts file. The main.ts file (which serves as the entry point to the application) triggers the regeneration of the API schema in the swagger-api.json file. When the swagger-

api.json file changes, the api.ts file is regenerated. The development environment tracks changes in the api.ts file, triggering its reindexing. After this, new contextual hints become available in the IDE. The neural network, as an IDE extension, also tracks changes in the api.ts file and reindexes its systems accordingly. Thus, a cascade of changes is initiated, ensuring the code is updated to its latest version, which serves as training data for the neural network (TabNine).

Using neural network technologies as a tool in the development environment allows for a synergistic effect, significantly increasing the speed and quality of code development with automatic documentation.

Keywords: Neural network, Developing, Generating code; API

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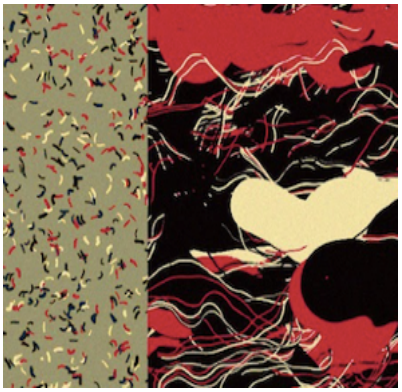
ARTIFICIAL INTELLIGENCE AND ETHICS



Integrating Public Values through Participatory AI Development

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Abstract. Artificial intelligence (AI), as a general-purpose technology, has become a pervasive force across numerous sectors of society—including healthcare, science, finance, education, governance, the arts, and the military. The deployment of AI in these critical areas raises new issues about its impact on public values such as fairness, accountability, inclusion, transparency, accessibility, accuracy, and human agency.

To address these issues, this paper proposes a two-part epistemological and methodological framework. The first part, Participatory AI Development (PAI) provides a theoretical foundation. The second part, Continuous User Research Engagement (CURE) provides a methodological counterpart. Developed and tested through the author's research practices, these two approaches form a comprehensive framework that democratizes AI development by placing users at the center of the decision-making process, thus embedding public values into algorithmic systems from their earliest conception to their application in everyday life.

Participatory AI Development posits that AI systems should not only be human-centered but also co-created with users. PAI challenges the notion that AI has a predetermined trajectory and encourages the consideration of multiple futures, contingent on human decision-making and values, emphasizing the involvement of diverse social groups. Inspired by Scandinavian participatory design practices from the 1970s, in which workers and marginalized groups were brought into decision-making processes regarding the technological tools they used, PAI asserts that all stakeholders should have a voice in shaping AI technologies. This co-design process not only democratizes technology but also ensures that AI systems are designed to address real-world challenges and dynamic user needs.

The second part of this framework, CURE, is a research methodology that operates on two levels. Internally, it involves multidisciplinary in-house teams—engineers, data scientists, designers, user researchers, and domain experts—fostering cross-functional collaboration. Externally, CURE engages users through a continuous research involvement, shifting away from periodic engagement cycles of traditional user research. Also, unlike traditional user research that seeks to validate AI solutions once they have already been developed "on users' behalf," PAI involves users already in the phase of planning an AI system, enabling them to influence critical decisions throughout the AI development lifecycle and ensuring that AI solutions are developed in the context of use. This iterative engagement warrants that AI systems remain aligned with public values, while meeting the ever-evolving needs of users.

The practical integration and application of PAI and CURE is demonstrated in a five-year participatory AI development project at a multinational software company in California. The project focused on developing AI-driven systems to support tasks traditionally performed by IT system analysts and automation engineers. In this project, analysts and automation engineers, the primary users of the AIsystems that were being developed, were actively involved throughout the entire development process. Through continuous engagement with 76 participants from 36 companies across four continents, the project empowered users to actively co-create AI systems that complement their work rather than displace it. By mapping users' work processes and needs, identifying pain points, and continuously iterating on technical solutions, CURE fostered a collaborative environment where AI systems were developed with, rather than for, the users. The combination of PAI and CURE resulted in the development of a technically innovative award-winning AI system that not only optimized product functionality, but also strengthened the collaboration between human expertise and AI systems, upholding public values such as transparency, collaboration, and fairness. Users played an active role in shaping the technology that impacted their jobs, fac'tating user-driven AI development that reflected the unique needs and contexts of the users, and fostering a strong sense of users' ownership and trust.

In conclusion, as AI technologies continue to evolve and permeate every aspect of society, the need to align them with public values is more critical than ever. Together, PAI and CURE provide a robust framework for embedding public values in AI systems, ensuring that AI systems serve societal needs, prioritize ethical considerations, and empower individuals and communities to shape their technological future. PAI and CURE provide a path towards challenging the dominance of corporate and governmental control over AI, shifting power to the communities most affected by these systems. As AI becomes a fundamental aspect of the algorithmic society, participatory approaches will be essential in safeguarding public values and ensuring a just, inclusive, and transparent future for all.

Keywords: Public values, Trust; Participatory AI development, Continuous User Research Engagement

Innovative Educational Models for Human Centered AI

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Abstract. It is expected that innovations in the field of AI, future developments of rapid computers, intercept-proof communications and hyper-sensitive measuring methods will shape our societies in a way where new type of knowledge will be essential for the jobs of the future.

AI have the potential to revolutionize education from the ability to analyze large volumes of data quickly and accurately to the AI-supported tutoring and student's individual learning approaches. But, although rapidly emerging innovations in educational AI are currently among the most promising technological developments which offer many opportunities, they also encounter challenges such as responsible use of trustworthy and ethical AI, data security concerns and how to transform and re-skill workforce for green transition. Human centered AI is not only about technological progress but also about how to align AI with ethical and societal values. It redefines how we interact in an AI-integrated world.

As artificial intelligence continue to grow exponentially, the incorporation of new technologies in the education sector can improve interdisciplinary learning environments where teachers can help students in developing their creativity and cognitive abilities. This includes the integration of AI and smart technologies in efficient and creative classes that support both in-class and remote activities. Most of the technologies employed in a smart class rely on AI that empowers the interactive, adaptive, and smart usage of interactive, remote, and mobile computing in physical and/ or virtual environments. Key technologies related to smart classes are based on virtual/augmented/mixed reality, smart environment, computer vision-based surveillance and action (behaviour) recognition, educational chatbots, E-learning platforms, virtual classroom and all screen.

AI technologies can be widely applied to enhance personalized and adaptive learning through providing one-to-one tutoring and recommendations for personal learning paths and resources.

While intelligent tutoring system are designed to provide customized instruction or feedback to students and promote personalized, adaptive learning based on using AI for instructional content delivery, recommendation of personalized learning path and resource recommendation. Furthermore learning prediction AI enables predicting student learning performance or status in advance through AI algorithms and modeling approaches. This includes the use of AI algorithms and modeling techniques such as educational data mining and machine learning technique to help instructors to adjust the instructional processes by predicting students' learning performance, as well as the use of AI to predict learning risks and dropout factors in education to help instructors intervene in student learning. As a result a recommendation of personalized learning path is enabled through development of combined genetic algorithms and parliamentary optimization algorithms to create personalized courseware. Another approach is to use recurrent neural network and sequential prediction models to create students ability charts and learning paths based on their submission history.

Educational AI can be also used for student behavior detection in order to help teachers to track students' learning outcomes and to motivate them through monitoring their learning behaviors such as preferred learning materials and self-directed learning performance. It is also possible to use various AI tools to automatically create multiple choice tests through the use of natural language processing techniques. By providing an automated syntactic and structural checking and immediate feedback, automated assessment algorithms can help students to improve their abilities of statement and justification in argumentation.

Student behavior detection AI can be also used to analyze and reveal students' latent behaviors by using data mining and learning analytics to exploit and track students' learning behaviors, patterns, and characteristics. As a result educational AI will indirectly influence the educational practices and effects by transforming the instructor–student relationships from the instructor-directed to student-centered learning practice.

One of the most crucial issues of the future of AI educational systems is ethics in the use of data. It is vital to address the way data are collected and used by those systems in order to avoid the violation of privacy.

Having all this in mind the aim of this study is to present an analysis of the applications of AI in education and to provide an initial approach to core terms, ideas, and suitable explanations. Special attention will be paid to the potential of AI in the fields of integrated learning practices, learning predictions, the use of intelligent tutoring systems and student group formation, student behavior detection, automation and the use of educational robots.

By organizing numerous workshops on creative use of AI we have found that although AI technologies might have the potential to replace the original role of professor and work as a new subject to individually convey knowledge, they still lack the human ability to convey social emotion, solve critical problems, and implement creative activities.

Furthermore some AI technologies like Intelligent tutoring system can lead to the significant improvement of learning performance, (especially for the moderate-level students) improve students' affective perception, such as attitude, interest, and motivation as well as students' higher-order thinking, such as problem-solving ability, computational thinking, and self-regulated learning skills.

Keywords: Human centered AI, Innovative education, Trustworthy AI

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Humanity and the future of AI: utopia or dystopia

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Abstract. Artificial Intelligence is all around us. The media and Hollywood love it, and it is the inspiration for various provocative questions such as “Could AI be creative? Could it feel emotions? Will AI kill us?” However, only rarely do we hear questions like "Could AI help us achieve a better standard of living for all people? Could it reduce the work week?” Or, in a word, could it help us achieve utopia? We provide an analysis of the current trend of technology influence and try to answer the question: will AI bring utopia or dystopia?

1. Short history of expectations and reality of technological development: The father of the scientific method, Sir Francis Bacon, said “knowledge is power” and in his utopian novel “New Atlantis” envisioned a society in which the power of knowledge is used for the betterment of humanity. However, the history of the XIX century showed the naivety of such hopes. The Industrial Revolution created vast wealth, but only for very few people. For the great majority of people, technology brought 6 days, 14-16 hours a day workweek and a salary of just enough to barely survive. Even five-year-old children were forced to work in the factories (8-9 years old was the most common age to start working).
This extreme dehumanization sparked the humanistic response: no human should be a slave (of another human, state, church, economy, or machine), human growth is the ultimate value and economy, state and technology should help achieve it. In a practical sense, this meant the request to make better working conditions, shorter workweek, more just wealth distribution, and shared ownership of the technology. Oscar Wilde gave one of the best descriptions of the technological utopia:
“At present machinery competes against man. Under proper conditions machinery will serve man. There is no doubt at all that this is the future of machinery, and just as trees grow while the country gentleman is asleep, so while Humanity will be amusing itself, or enjoying cultivated leisure - which, and not labour, is the aim of man - or making beautiful things, or reading beautiful things, or simply contemplating the world with admiration and delight, machinery will be doing all the necessary and unpleasant work.”

2. Where are we today? It has been 133 years since Oscar Wilde wrote this passage, during which science and technology developed exponentially. Artificial intelligence has an enormous potential to achieve utopia. So, how far are we from achieving utopia?
Today, more than a billion people live on less than a dollar a day. About 160 million children are engaged in child labour. The average workweek is 41.1 hours long (although the 40-hour workweek was established in 1886). The top 1% of the wealthiest earn almost twice as much as the remaining 99%, with the gap between the wealthiest and the rest increasing even in the top 1%.
To better understand where we are now and in what direction we are headed, we explore the questions of why we give up the idea of utopia, why we still have a 40-hour workweek and whom technology serves.

2.1. Why did we give up the idea of utopia? A possible answer is that, officially, we already live in a utopia. This is the best humanity can achieve. The “invisible hand of the market” (Adam Smith) takes care of the most economic problems. We live in a just world with equal chances for everyone. Poverty is a personal failure, not a part of the system.

2.2. Why do we still work too much? In the book “The end of work”, economist Jeremy Rifkin anticipated that the advances in technology would produce mass unemployment since the new jobs would not be able to absorb enough displaced workers. However, the global unemployment rate is decreasing. What are the new jobs? Anthropologist David Graeber from the London School of Economics provides the possible answer. He researched the phenomena of meaningless jobs – jobs that have no contribution to society and could be removed without any significant change. Two independent studies showed that around 40% of jobs belong to this category. Graeber argues that one of the reasons for the existence of these jobs is to reduce social pressure and that removing these jobs and reallocating the employees to meaningful jobs could easily reduce the workweek to 20 hours. If we are to keep a low unemployment rate and keep a 40-hour workweek, the improvements in AI will bring more meaningless jobs.

2.3. Whom does technology serve? French philosopher Jacques Ellul wrote on the impact of technology on society and noted that as the techniques improve, its improvements become more expensive, and thus require a greater and more powerful entity which would direct further improvements. E.g. an astronomer wanting to make new discoveries needs access to a more powerful telescope than what he as an individual can afford. Even without the need for expensive equipment, new breakthroughs would likely require teamwork, and large teams need funding. Who has the most resources today to finance research in AI? The big companies – and their main concern is profit (they would lose the competitive edge otherwise).
How do the big companies (e.g. Google, Facebook, Microsoft) profit from AI and how is AI used today? Harvard professor Shoshana Zuboff provided the answers in her study of a new form of capitalism, which she called surveillance capitalism. Everything we do online is monitored and recorded. Most of the data are not used to improve the product we are using (she coined the term behaviour surplus to describe this data) but are rather sold or processed to make our psychological profiles and predictions about us. Since machine learning performance increases with the increase of quantity and diversity of the training data, the surveillance must provide as much information possible from as many sources as possible (thus surveillance expands from ordinary web searches to mobile phone data and smart gadgets). Social networks are a big source of our personal data and tend to make users addicted, which in turn provides more data and increases the power of the algorithms to keep users online. The data and the predictions can be sold or used to provide personalized ads and content to direct our behavior, for the benefit of the third party. The data is usually gathered without consent, or the product cannot be used if we decline data gathering. Zuboff argues that encryption does not solve the problems, since our sensitive data (e.g. name, address) is not important to the surveillance capitalists (furthermore, studies have showed that these can be easily inferred). She investigates numerous misuses of personal information, such as affecting the voter turnout or the outcome of the elections. If the current trend continues, Zuboff predicts a dystopian society of controlled and obedient voters and consumers.

3. Conclusion: Taking all the questions discussed into account, we can provide an overview of the current trend of the influence of technological and AI development.
Social inequalities will keep increasing, and the concentration of power will continue. More and more jobs will be phased out. However, new jobs, probably meaningless, will emerge and the workweek will not reduce (or not significantly). People will be kept occupied doing their work and enjoying personalized amusement, and they will not be interested in changing the “perfect” society. We do not cover here the psychological effects of modern society or the trends of environmental destruction (these are showing alarming signals also).
We do not need Terminator or general AI for a dystopian society. To some degree, we already live in it. However, we must not forget AI's potential for achieving utopia. With AI, utopia is closer than ever to our reach, but it will not come spontaneously, and we must change the current dystopian trend.

Keywords: Utopia, Dystopia, Surveillance capitalism, AI and society

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