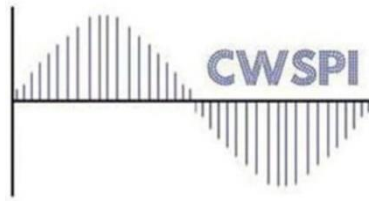


CWSPI'22



<https://cwspi.cs.ucy.ac.cy/>

14th Cyprus Workshop on Signal Processing and Informatics

FINAL PROGRAM AND BOOK OF ABSTRACTS

Venue: University of Cyprus, Library "Stelios Ioannou"

Room: LRC 014, Ground floor

via Zoom at the following link:

<https://ucy.zoom.us/j/99828653934?pwd=Y1FESHQ2eFZ3ZHd6cVhZUjdjNWlrQT09>

Meeting ID: 998 2865 3934

Passcode: 881970

14:00-19:15, July 13th, 2022

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Table of Contents

	Pages
Preface.....	2
Workshop Organising Committee.....	3
Technical Program.....	4
Abstracts.....	7

14th Cyprus Workshop on Signal Processing and Informatics (CWSPI) - 2022

Preface:

Following the successful one-day workshop hosted over the past 13 years, we would like to cordially invite you to participate in the upcoming 14th Cyprus Workshop on Signal Processing and Informatics (CWSPI 2022).

The overall objective of CWSPI 2022 is to disseminate new research findings in the areas of signal processing, image processing, analysis and informatics. Over the years, CWSPI has grown to become the primary forum of Cyprus' graduate students to present their latest research endeavors. Moreover, this one-day workshop hosts presentations by faculty and industry researchers serving a key mission of CWSPI, towards establishing strong industry – academia and multi – university collaborations. The workshop is strongly supported by the CYENS and KIOS Centres of Excellence, constituting an ideal event for sharing new knowledge while building effective research networks.

We would like to express our sincere thanks to IEEE Cyprus Section, the IEEE Engineering in Medicine Biology and Signal Processing Societies (EMBS & SPS) Cyprus Chapters, the IEEE CIS Cyprus Chapter and the IET Cyprus Network for their support and sponsorship.

This year the event will be carried out in hybrid mode, given the current situation with the pandemic.

Wishing you a fruitful and joyful event.

M. Neofytou, A. Panayides
July 2022

Topics:

- Digital signal and image processing
- Interactive Media, Virtual Reality and Augmented Reality Systems and Applications
- Speech, and audio, processing
- Intelligent and Cognitive systems
- Sensor networks and signal analysis
- Biomedical signal, image, and video analysis
- Wireless communications and signal processing
- FPGAS in signal, image and video processing.

Workshop Organizing Committee	
Chair	A. S. Panayides, CYENS Centre of Excellence, Cyprus
Co-Chair	M. Neofytou, 3AeHealth, LTD, Cyprus
Program Chair	C. P. Loizou, Cyprus University of Technology, Cyprus
Program Committee	M.S. Pattichis, University of New Mexico, USA E. Kyriacou, Cyprus University of Technology, Cyprus A. Spanias, Arizona State University, USA C. S. Pattichis, University of Cyprus, Cyprus
Local Arrangements	C. S. Pattichis, University of Cyprus, Cyprus
Publications	C. P. Loizou, Cyprus University of Technology, Cyprus
Liaison/Publicity	T. Kasparis, Cyprus University of Technology, Cyprus
Webmaster	M. Neofytou, 3AeHealth, LTD, Cyprus

Venue

University of Cyprus (New Campus)
Library "Stelios Ioannou"
LRC 014, Ground floor

P.O.Box. 20537, CY-1678 Nicosia,
CYPRUS

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Webpage:	http://cwspi.cs.ucy.ac.cy
	http://www.ehealthlab.cs.ucy.ac.cy/
Facebook	https://www.facebook.com/cwspi.cyprus

Technical Program

TIME	SESSIONS
13:50	Introductions
13:55-14:00	Welcome <i>Andreas Spanias & Marios Neofytou</i> <i>Arizona State University, USA</i> <i>University of Cyprus, Cyprus</i>
	SESSION 1: PLENARY TALKS <i>Andreas Spanias</i> <i>Arizona State University, USA</i>
14:00-14:45	Computer Vision and Machine Learning for the Real World <i>Nikos Papanikolopoulos, McKnight Presidential Endowed Professor, Minnesota Robotics Institute Director, Department of Computer Science and Engineering, University of Minnesota, USA</i>
14:45-15:30	A large-scale mortality risk study using interpretable neural networks <i>Marios S. Pattichis, University of New Mexico, USA</i>
15:30-16:00	COFFEE BREAK
	SESSION 2: IRES SenSIP - DCU and IRES SenSIP KIOS Programs <i>Andreas Spanias, Arizona State University SenSIP, USA</i>
16:00-16:10	Introduction to the IRES SenSIP - DCU and IRES SenSIP KIOS Programs <i>Andreas Spanias, Arizona State University SenSIP, USA</i>
	Session 2.1 NSF IRES –ASU- University of Cyprus KIOS Researchers
16:10-16:20	Quantum and Classical Machine Learning Algorithm Comparisons for Monitoring PV Array Faults with Emphasis to Shading Detection <i>Kaden McGuffie¹, Glen Uehara¹, Andreas Spanias¹, Lenos Hatzidemetriou²</i> <i>¹ASU SenSip, ²UCy KIOS Center</i>
16:20-16:30	IRES Cyprus Experience: A Collaborative Project on Machine Learning and Cyber Security for Energy Applications <i>Trevor Irvin¹, Glen Uehara¹, Andreas Spanias¹, Sameeksha Katoch¹, Theocharis Theocharides², Christos Laoudias², Christos Kyrkou²</i> <i>¹ASU SenSip, ²UCy KIOS Center</i>
16:30-16:40	IRES Cyprus Project: Quantum Machine Learning for Monitoring PV Faults with emphasis on Detecting Soiled Panels <i>S. Naik¹, G. Uehara¹, A. Spanias¹, T. Theoharides², C. Laoudias², C. Kyrkou²</i> <i>¹ASU SenSip, ²UCy KIOS Center</i>
16:40-16:50	An IRES Experience in Cyprus: Solar Array Fault Detection using Classical and Quantum Support Vector Classifiers <i>Niki Kyriacou¹, Glen Uehara¹, Andreas Spanias¹, Lenos Hadjidemetriou²</i> <i>¹ASU SenSip, ²UCy KIOS Center</i>
	Session 2.2 IRES – ASU-Dublin City University Researchers (2 minutes each - elevator pitch - 1 slide)
16:50-16:52	Point of Care Sensors for Iron Detection <i>E. Montoya, E. Forzani, Aoife Morrin, Margaret McCaul</i>
16:52-16:54	Application of a Microfluidics System for Iron Detection in Water <i>A. Nguyen, E. Forzani, G. Raupp, Aoife Morrin, Margaret McCaul</i>
16:54-16:56	Application of Machine Learning for Iron Sensor Color Readout <i>A. Mayers, G. Raupp, E. Forzani, Aoife Morrin, Margaret McCaul</i>
16:56-16:58	Joint Classification and Segmentation of 2D T1-weighted CE-MRI Images using Deep Learning

14th Cyprus Workshop on Signal Processing and Informatics (CWSPI) - 2022

	G. Billingsley, V. Narayanaswami, A. Spanias, N. O'Connor, Julia Dietlmeier
16:58-17:00	Move Well Being Well: Predicting VO2 Max using FMS Testing of 5 to 14-Year-Olds C. McConnell, V. Narayanaswami, A. Spanias, N. O'Connor, Stephen Behan, Michael Scriney, Una Britton
17:00-17:02	Predicting VO2 Max with Machine Learning M. Gunatilaka, V. Narayanaswami, A. Spanias, N. O'Connor, Stephen Behan, Michael Scriney, Una Britton
17:02-17:15	COFFEE BREAK
	SESSION 3: MEDICAL IMAGING Chair: Andreas Panayides CYENS
17:15-17:25	Identification and Classification of Benign and Malignant Masses based on Subtraction of Temporally Sequential Digital Mammograms Kosmia Loizidou ¹ , Galatea Skouroumouni ² , Gabriella Savvidou ³ , Anastasia Constantinidou ³ , Christos Nikolaou ⁴ and Costas Pitris ¹ ¹ <i>Department of Electrical and Computer Engineering, KIOS Research and Innovation Center of Excellence, University of Cyprus, Cyprus</i> ² <i>German Oncology Center, Cyprus</i> ³ <i>Medical School University of Cyprus and the Bank of Cyprus Oncology Centre, Cyprus</i> ⁴ <i>Limassol General Hospital, Cyprus</i>
17:25-17:35	Hessian-Free Optimization for Accelerating the Training of Convolutional Neural Network Classifiers of Brain Magnetic Resonance Images Maria Constantinou, Marios Pafitis, Chris Christodoulou <i>Department of Computer Science University of Cyprus</i>
17:35-17:45	An Automated 2D U-Net for the Segmentation of Cancer Brain Metastases Using MRI Images Vangelis Tzardis ¹ , Efthymoulos Kyriacou ¹ , Christos Loizou ¹ , Anastasia Constantinidou ² ¹ <i>Cyprus University of Technology</i> ² <i>Medical School University of Cyprus and the Bank of Cyprus Oncology Centre, Cyprus</i>
17:45-17:55	Brain Magnetic Resonance Imaging Segmentation System in MS with Deep Neural Networks Giorgos Adamides <i>Department of Computer Science, University of Cyprus</i>
17:55-18:05	Deep learning-based segmentation of the atherosclerotic carotid plaque in ultrasonic images Georgia D. Liapi ¹ , Efthymoulos Kyriacou ¹ , Christos P. Loizou ¹ , Andreas S. Panayides ² , Constantinos S. Pattichis ³ , Andrew N. Nicolaides ⁴ ¹ <i>Cyprus University of Technology</i> ² <i>CYENS Centre of Excellence</i> ³ <i>University of Cyprus</i> ⁴ <i>Vascular Screening and Diagnostic Center</i>
18:05-18:15	Optimizing QoE for Medical Video Streaming Ioanna Valiandi ¹ , Nacim Ramdani ² , Konstantinos Ziliaskopoulos ³ , Stamatia Rizou ³ , Marios S. Pattichis ⁴ , Constantinos S. Pattichis, Andreas S. Panayides ¹ ¹ <i>VIDEOMICS Group, CYENS Centre of Excellence</i> ² <i>PRISME Laboratory, Université d'Orléans, Bourges, France</i> ³ <i>Research and Development, Singular Logic</i> ⁴ <i>Electrical and Computer Engineering, University of New Mexico, U.S.A.</i> ⁵ <i>University of Cyprus & CYENS CoE</i>
18:15-18:25	A Review on Machine Learning Methods on BioVid Heat Pain Database Melpo Pittara ¹ , Nicolai Petkov ¹ , Constantinos S. Pattichis ² ¹ <i>Bernoulli Institute for Mathematics Computer Science and Artificial Intelligent, University of Groningen, Groningen, Netherlands</i>

14th Cyprus Workshop on Signal Processing and Informatics (CWSPI) - 2022

	² <i>Department of Computer Science, University of Cyprus, Nicosia, Cyprus</i>
	SESSION 4: INTELLIGENT SYSTEMS Andreas Lanitis ^{1,2} ¹ CYENS Centre of Excellence ² <i>Cyprus University of Technology</i>
18:25-18:35	An Integrated Approach for Visualizing Student Activity During Distance Education Michalis Kontos ¹ , Eleni Dimitriadou ² , Lefteris Ioannou ² , Andreas Lanitis ^{1,2} ¹ CYENS Centre of Excellence ² <i>Cyprus University of Technology</i>
18:35-18:45	Data-driven Tools for Marine Spatial Planning Marina Polykarpou <i>Cyprus Marine and Maritime Institute Larnaca, Cyprus</i>
18:45-18:55	Data Information Interoperability Model for IoT-enabled Smart Water Networks Mandeep Singh ¹ , Wenyan Wu ² , Stamatia Rizou ³ , Edlira Vakaj ² ¹ <i>Birmingham City University & Singular Logic</i> ² <i>Birmingham City University</i> ³ <i>Singular Logic</i>
18:55-19:05	Competing Mutual Information Constraints with Stochastic Competition-based Activations for Learning Diversified Representations Anastasios Antoniadis, Konstantinos Panousis, Soterios Chatzis <i>Computer Engineering and Informatics Cyprus University of Technology (CUT) Limassol, Cyprus</i>
	Closing Remarks

Abstracts

SESSION 1: PLENARY TALKS

Computer Vision and Machine Learning for the Real World

Nikos Papanikolopoulos, *McKnight Presidential Endowed Professor, Minnesota Robotics Institute Director
Department of Computer Science and Engineering, University of Minnesota, USA*

Abstract

Recent advances in computational hardware, computer vision, and machine learning have created some unique opportunities for real-world data-centric systems. The talk will focus on some projects that use innovative imaging along with active learning and reinforcement learning to perform tasks in mental health assessment, intelligent transportation systems, human-robot interfaces, sports training, and precision agriculture. For example, we will describe a framework that performs the precise detection and characterization of plant deficiencies. This step is often followed by the proper deployment of fertilizers. In particular, the proposed methodology utilizes drone collected images to detect nitrogen (N) deficiencies in maize fields and assess their severity using low-cost RGB sensors. Our proposed methodology is twofold. A low complexity recommendation scheme identifies candidate plants exhibiting (N) deficiency and, with minimal interaction, assists the annotator in the creation of a training dataset which is then used to train an object detection deep neural network. Results on data from experimental fields support the merits of the proposed methodology with the mean average precision for the detection of N-deficient leaves reaching 82.3%.

This is joint work with a large number of colleagues including T. Morris, V. Morellas, L. Guzman, P. Stanitsas, H. Nelson, C. Conelea, K. Cullen, D. Zermas, C. Smith, and T. Bacharis.

SESSION 2: IRES SenSIP - DCU and IRES SenSIP KIOS Programs

Introduction to the IRES SenSIP - DCU and IRES SenSIP KIOS Programs

Andreas Spanias, ASU, USA

Abstract

The ASU-DCU international research experiences for students (IRES) project is a workforce development program that embeds students in machine learning and sensor research. This collaborative NSF IRES program engages faculty mentors from the ASU SenSIP Center, and the Insight SFI Research Centre for Data Analytics and Biodesign Europe at Dublin City University (DCU), which will train students in sensor design, analytics and machine learning algorithm development. Sensor and machine learning research will address engineering and computing problems in health care and other related applications. IRES participants will be tasked with studying hardware, algorithms and software for various tasks including activity detection, gait modeling, imaging, hemochromatosis prediction, and health care analytics. The program will also likely feature one research project in quantum machine learning. Crosscutting efforts include training in international research presentations, research documentation and building awareness of international policies and standards. Students will present their results to international audiences and receive feedback and mentorship from faculty, industry and program evaluators. The program includes weekly research updates by the students, participation in a workshop and continued engagement after the summer experience. The paper describes various components of IRES sensor and machine learning research through ongoing center projects at ASU and DCU. We will also provide some details on research results and outcomes during the first year of this three year program.

Session 2.1 NSF IRES –ASU- University of Cyprus KIOS Researchers

Quantum and Classical Machine Learning Algorithm Comparisons for Monitoring PV Array Faults with Emphasis to Shading Detection

Kaden McGuffie¹, Glen Uehara¹, Andreas Spanias¹, Lenos Hatzidemetriou²

¹ASU SenSIP Center

²UCy KIOS Center

Abstract

Solar panels are becoming more common for everyday energy production, however there are drawbacks that inhibit them from reaching their optimal potential. One major drawback comes from a variety of faults within utility scale solar panel arrays. Using machine learning algorithms, engineers are able to drastically reduce the time for detecting and repairing solar panels faults.

The focus of this project is to use machine learning to detect shading effects on utility scale PV arrays. The first phase of this SenSIP-KIOS collaborative IRES project included training at ASU on a variety of machine learning algorithms and software. In this phase of the project, it became evident that there are challenges in using the machine learning (ML) models for detecting shading. We began our studies on ML by considering three classical models, namely, used: Logistic Regression (LR), Support Vector Machine (SVM), and Neural Networks (NN). The three methods were compared using solar fault data and results were produced in terms of prediction accuracy. We then began exploring quantum machine learning models and the aim is to training and testing the quantum model, the accuracies will once again be compare them with classical models in terms of performance (accuracy) and computational complexity. Our collaboration with the University of Cyprus started after our arrival in Nicosia. We became involved with research projects at KIOS. The aim of this activity at KIOS was to gain familiarity with the research operations at the University of Cyprus. Our involvement was with the power systems lab at KIOS. At the end of the project, we will report our comparative studies and also describe the overall experience at the KIOS center. Support for the collaborative IRES project was provided by the SenSIP center and NSF grant

IRES Cyprus Experience: A Collaborative Project on Machine Learning and Cyber Security for Energy Applications

Trevor Irvin¹, Glen Uehara¹, Andreas Spanias¹, Sameeksha Katoch¹, Theocharis Theocharides², Christos Laoudias², Christos Kyrkou²

¹ASU SenSIP Center

²UCy KIOS Center

Abstract

In this SenSIP-KIOS collaborative IRES Cyprus Program, the objective is to gain a better understanding of topics related to machine learning and cyber-security for energy-related applications. The project started at ASU with classical machine learning training for solar array fault detection. During that time, we began working with ASU mentors to study the use of machine learning for classifying PV faults using a solar panel array dataset. My work focused on the short circuit fault data using binary classification. After gaining understanding of classical machine learning, we began exploring quantum machine learning using the same dataset. The idea is to compare classical and quantum machine learning in terms of performance and complexity with regard to PV fault detection and classification applications. The second part of our research experience focused on KIOS related projects where the objective was to gain a deeper understanding of current research direction and EU policies governing research operations at UCy. The KIOS project focus was cyber-security for autonomous vehicles with the purpose of developing an anti-hacking device. Smart devices controlling solar systems also suffer cyber-attack vulnerabilities which present a challenge in PV monitoring and control.

Support for this project was provided by the SenSIP center and NSF IRES grant 1854273

IRES Cyprus Project: Quantum Machine Learning for Monitoring PV Faults with emphasis on Detecting Soiled Panels

Sanika Naik¹, Glen Uehara¹, Andreas Spanias¹, Theocharis Theocharides², Christos Laoudias², Christos Kyrkou²

¹ASU SenSIP, ²UCy KIOS Center

Abstract

With the world's growing energy crisis becoming a more prevalent issue, solar energy has risen as the leading sustainable and cost-effective replacement for fossil fuels. As is the case with all emerging industries, progress is accompanied by barriers that must be addressed. In this research, we study the efficiency of solar panels in regards to fault detection. This task requires constant monitoring of the voltage, current, temperature and irradiance. This project aims to classify soiling faults by characterizing relevant features as the inputs of the machine learning (ML) algorithm. More specifically, in the first phase of this project at ASU, we began studying a variety of ML algorithms including: classical artificial neural network, support vector machine and logistic regression models and their application to solar array data. After we gained basic knowledge on classical machine learning methods and software, we then began exploring quantum machine learning methods and their application to PV fault detection. We presented our progress in weekly meetings at ASU and, for the second phase of the project, we traveled to the University of Cyprus-KIOS center where we became involved with local projects. Specifically, we became involved with the CAMEL project - a European project that aims to improve cyberthreat detection and mitigation techniques for intelligent and automotive systems. We note that cybersecurity is also an issue in solar array monitoring, so, knowledge gained in the CAMEL project may help also in developing methods to combat cyber-attacks in solar systems. The second part of University of Cyprus engagement helped us gain a knowledge of current research directions and EU policies governing research operations at KIOS.

Support for the collaborative IRES project was provided by the SenSIP center and NSF grant 1854273.

An IRES Experience in Cyprus: Solar Array Fault Detection using Classical and Quantum Support Vector Classifiers

Niki Kyriacou¹, Glen Uehara¹, Andreas Spanias¹, Lenos Hadjidemetriou²

¹Arizona State University SenSIP

²University of Cyprus KIOS Center

Abstract

PV arrays require real-time monitoring and maintenance for effective performance. Detection and identification of faults are critical to this maintenance. The first objective of this research experience is to use both classical and quantum machine learning to detect and classify faults in photovoltaic (PV) arrays. In this SenSIP-KIOS collaborative project, we compare the use of classical support vector classifiers (SVCs) to simulated quantum SVCs (QSVCs) to determine whether there is an empirical quantum computing advantage. The two methods are compared in terms of performance and computational complexity. The second objective of this international experience is to become familiar with the research operations of the KIOS center at the University of Cyprus (UCy). This will be accomplished by becoming embedded in a KIOS project to gain a deeper understanding of current research directions and EU policies governing research operations at UCy. The project at KIOS involves the use of classical machine learning to predict wind power generation based on meteorological features.

Support for this project was provided by the SenSIP center and NSF IRES grant 1854273.

Session 2.2 IRES – ASU-Dublin City University Researchers

Point of Care Sensors for Iron Detection

Emily Montoya¹, Erica Forzani², Aoife Morrin³, Margaret McCaul³

¹Arizona State University Fulton School of Engineering

²School for Engineering, Matter, Transport, and Energy at Arizona State University

³Insight and School of Chemical Sciences at Dublin City University

Abstract

Iron deficiency and iron overload can be major contributors to health issues. Being aware of the concentration of iron in one's blood is essential to maintaining good health. We intend to use a sensor created during previous research to further develop a point-of-care device. Our goal is to develop a method of getting consistent RGB values over the sensor area despite lighting and camera resolutions. By doing this, users will be able to use any photo of their sensor to retrieve accurate iron concentration results. This project is sponsored by NSF IRES Award 2107439. Additional Support and Logistics by ASU SenSIP, DCU Insight Centre, and Biodesign Europe.

Application of a Microfluidic System for Iron Detection in Water

Ngan Anh Nguyen¹, Gregory Raupp², Erica Forzani^{1,2}, Aoife Morrin³, Margaret McCaul³

¹School of Engineering for Matter, Transport, and Energy, Arizona State University

²Center for Bioelectronics and Biosensors, Biodesign Institute, Arizona State University

³Insight Centre and School of Chemical Sciences, Dublin City University

Abstract

Abnormal blood iron levels are affecting millions of people worldwide. There has been a previous work developed for iron detection using a colorimetric sensor. We build on this work and introduce an improved method in combination with machine learning detect color changes from sensor images regardless of the lighting conditions. Besides, another platform based on microfluidics was studied for potential monitoring

of iron in natural waters. This project is sponsored by NSF IRES Award 2107439. Additional Support and Logistics by ASU SenSIP, DCU Insight Centre, and Biodesign Europe.

Joint Classification and Segmentation of 2D T1-weighted CE-MRI Images Using Deep Learning

Grace Billingsley, Julia Dietlmeier, Noel E. O'Connor, Vivek Narayanaswamy, Andreas Spanias

Abstract

Improvements in digital imaging technology in the medical field have resulted in the use of imaging for diagnosis in place of traditionally invasive procedures. In this study, a machine learning approach for processing MRI scans is presented, using convolutional neural networks (CNN) to perform classification and segmentation of 2D T1-weighted MRI images. This project is sponsored by NSF IRES Award 2107439. Additional Support and Logistics by ASU SenSIP, DCU Insight Centre, and Biodesign Europe.

Move Well Being Well: Predicting VO2 Max Using FMS Testing of 5 to 14 Year Olds

Cameron McConnell¹, Dr. Michael Scriney², Dr. Stephan Behan², Dr. Úna Britton², Dr. Andreas Spanias³, Vivek Narayanaswamy³

¹SCAI at Arizona State University

²Insight Centre at Dublin City University

³School of ECEE at Arizona State University

Abstract

Moving Well Being Well is a large-scale project assessing fundamental movement skills (FMS) with young children. Under the guidance of mentors at DCU, a dataset of categorical and continuous variables from over 2377 participants were analyzed using machine learning and the Python programming language to assist in testing and proving hypotheses. These include finding another way to predict VO2 max aside from a twenty-meter shuttle run test, body images influence on physical activity, and finding associations between failure rate of FMS tests and other variables i.e., body mass index (BMI) or VO2 max. This project is sponsored by NSF IRES Award 2107439. Additional Support and Logistics by ASU SenSIP, DCU Insight Centre, and Biodesign Europe.

Predicting Children's VO2 Max with Machine Learning

Movinya Gunatilaka¹, Dr. Michael Scriney², Dr. Stephan Behan², Dr. Úna Britton², Dr. Andreas Spanias³, Vivek Narayanaswamy³

¹SCAI at Arizona State University

²Insight Centre at Dublin City University

³School of ECEE at Arizona State University

Abstract

VO2 max is an important measure of cardiorespiratory fitness that describes your body's maximal oxygen uptake. Having higher VO2 max levels correlates with lower risk of obesity, cardiovascular disease, and Type 2 Diabetes. "Moving Well-Being Well" (MWBW) was a national physical literacy study done in 2017 on primary school children across Ireland. Data ranged from personal survey results to measurements of physical activity (such as VO2 max) and mastery of Fundamental Movement Skills (FMS). It is proven that a strong foundation in FMS during the ages of 5 to 12 leads to sustained active lifestyles into adulthood. The goal of this study is to be able to predict VO2max classifications based on FMS performance and other

health measures by discretizing the VO2 max values, then training the MWBW dataset using various machine learning models like logistic regression, neural networks, and support vector machines. This project is sponsored by NSF IRES Award 2107439. Additional Support and Logistics by ASU SenSIP, DCU Insight Centre, and Biodesign Europe.

Application of Machine Learning for Iron Sensor Color Readout

Amber Mayers¹, Gregory Raupp¹, Erica Forzani^{1,2}, Aoife Morrin³, Margaret McCaul³

¹School of Engineering for Matter, Transport, and Energy, Arizona State University

²Center for Bioelectronics and Biosensors, Biodesign Institute, Arizona State University

³Insight Centre and School of Chemical Sciences, Dublin City University

Easy access to simple sensors will provide straightforward accessibility for people to take greater control over their health. Machine learning can be applied to ensure that people can be provided with consistent accurate results without the need for a healthcare provider. The purpose of this project is to create an user-friendly image processing code that can read out RGB values on sensors to detect iron concentrations in blood. This tool can also be used in environmental science applications such as determining iron concentration in water. This project is sponsored by NSF IRES Award 2107439. Additional Support and Logistical by ASU SenSIP, DCU Insight Centre, and Biodesign Europe.

SESSION 3: MEDICAL IMAGING

Identification and Classification of Benign and Malignant Masses based on Subtraction of Temporally Sequential Digital Mammograms

Kosmia Loizidou¹, Galateia Skouroumouni², Gabriella Savvidou³, Anastasia Constantinidou³, Christos Nikolaou⁴ and Costas Pitris¹

¹Department of Electrical and Computer Engineering, KIOS Research and Innovation Center of Excellence, University of Cyprus, Cyprus

²German Oncology Center, Cyprus

³Medical School University of Cyprus and the Bank of Cyprus Oncology Centre, Cyprus

⁴Limassol General Hospital, Cyprus

Identification and Classification of Benign and Malignant Masses based on Subtraction of Temporally Sequential Digital Mammograms

Kosmia Loizidou¹, Galatea Skouroumouni², Gabriella Savvidou³, Anastasia Constantinidou³, Christos Nikolaou⁴ and Costas Pitris¹

Abstract—Breast cancer remains the leading cause of cancer deaths and the second highest cause of death, in general, among women worldwide. In this study, classification of benign and malignant masses, based on the subtraction of temporally sequential digital mammograms and machine learning, is proposed. In total, 196 images from 49 patients, with precisely annotated mass locations and biopsy confirmed malignant cases, were included. Various features were extracted and five feature selection algorithms were employed to identify the most important features. Ten classifiers were tested using leave-one-patient-out and 7-fold cross-validation. Neural Networks, achieved the highest classification performance with 90.85% accuracy.

I. INTRODUCTION

Breast cancer is the most frequently diagnosed cancer and mammography is extensively used as a screening and diagnostic tool. Accurate classification of benign vs. malignant masses is one of the most challenging tasks for radiologists, thus, Computer-Aided Diagnosis (CAD) systems are being developed. Various algorithms have been proposed for the classification of breast masses [1]. However, most use only the most recent mammogram for the diagnosis, which does not allow comparison with available prior images of the same patient. In this study, an algorithm for the classification of benign and malignant masses is proposed, based on the subtraction of temporally sequential digital mammograms and machine learning.

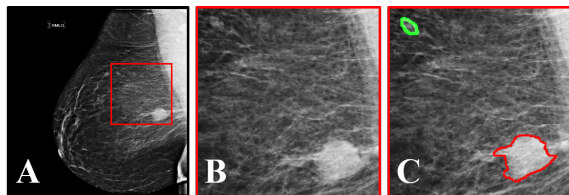


Fig. 1. Dataset example. (A) Mammogram of a woman with benign and malignant masses. (B) Zoomed regions marked by the red square in A, including the masses. (C) The regions in B with precise marking of mass locations (green for benign, red for malignant), as annotated by two expert radiologists.

This research was funded by the European Union’s Horizon 2020 research and innovation program under grant agreement No. 739551 (KIOS CoE) and from the Republic of Cyprus through the Directorate General for European Programs, Coordination and Development.

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³Medical School University of Cyprus and the Bank of Cyprus Oncology Centre, Cyprus

⁴Limassol General Hospital, Cyprus

II. MATERIALS AND METHODS

This study required a custom dataset, which included precise annotation of each individual mass, served as the ground truth (Fig. 1). Fifteen cases exhibited only benign masses in the most recent mammograms. The remaining 34 patients had at least one biopsy confirmed malignant mass in the most recent screening. The prior mammogram was registered to the most recent one, using Demons, and then subtraction took place (Fig. 2). Following, machine learning was implemented to classify the true masses as benign or malignant. In total, 96 features were extracted and five feature selection techniques were tested. The complete dataset was used in a Leave-One-Patient-Out (LOPO) and 7-fold cross-validation.

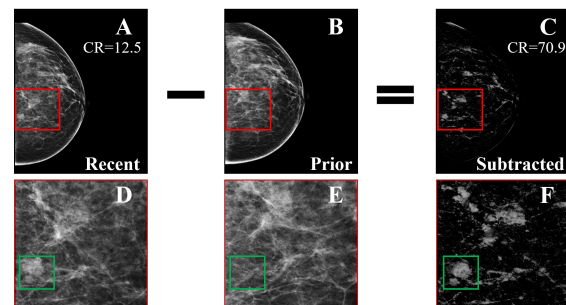


Fig. 2. Example of temporal subtraction. (A) Most recent mammogram. (B) Prior mammogram. (C) The result of subtracting the registered version of B from A. (D)-(F) Zoomed regions marked by the red squares in A-C, where the green squares enclose a new malignant mass that was not subtracted. The Contrast Ratio (CR) has increased 5 times after subtraction.

III. EXPERIMENTAL RESULTS

Feature selection revealed the most significant features for the classification of breast masses as benign vs. malignant. Neural Networks achieved the highest classification performance, with 90.85% accuracy and 0.91 AUC.

IV. DISCUSSION

Neural Networks had an average of 0.06 false positives and 0.07 false negatives per image. Out of 58 benign masses, 6 were wrongly detected as malignant affecting 3 patients. Similarly, out of 84 malignant masses, 7 were misclassified as benign in 3 patients. With further expansion and improvement, the proposed algorithm has the potential to substantially contribute to the development of automated CAD systems with significant impact on patient prognosis.

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Hessian-Free Optimization for Accelerating the Training of Convolutional Neural Network Classifiers of Brain Magnetic Resonance Images

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Hessian-Free Optimization for Accelerating the Training of Convolutional Neural Network Classifiers of Brain Magnetic Resonance Images

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Abstract—Convolutional neural network (CNN) models are increasingly being proposed for computer-aided diagnosis of neurological diseases from brain magnetic resonance images (MRI). One of the main challenges of CNN models is the long time required for training. Here, we investigated using Hessian-free optimization, a second-order algorithm to accelerate the training of CNN models for brain MRI classification.

Keywords—convolutional neural networks, Hessian-free optimization, magnetic resonance imaging, Alzheimer’s disease

I. BACKGROUND

Brain magnetic resonance imaging (MRI) is routinely used to diagnose and monitor neurological disorders, including Alzheimer’s disease. To automate this process, a number of machine learning algorithms have been proposed, with convolutional neural network (CNN) classifiers being very promising because they are effective for extracting patterns from large image datasets and solve the commonly-encountered problems of natural images (e.g. shifting, scaling, differences in resolution) [1,2]. However, a main challenge of CNN models is the long time required for training.

II. ALGORITHMS

Most applications of CNN models for MRI classification use first-order algorithms for optimization, such as stochastic gradient descent (SGD) and adaptive momentum (Adam), and to accelerate training, they use transfer learning, i.e., pre-trained convolutional layers. First-order algorithms minimize the objective function using the gradient, and thus are susceptible to pathological curvature of the objective function. Second-order algorithms use the Hessian matrix to advance towards the global minimum of the objective function; and can thus overcome this problem. Hence, second-order algorithms are expected to converge faster than first-order algorithms. The calculation of the Hessian matrix is, however, too computationally demanding for large network models. Hessian-free optimization (HFO) algorithms [3] compute an approximation of the Hessian matrix and thus are much more computationally efficient. Nevertheless, to the best of our knowledge, it has not been shown whether HFO can increase the training speed of CNN models for the classification of brain MRI.

III. METHODS

We trained CNN models to classify brain MRI with either SGD or Adam, two commonly used first-order optimizers, or HFO, a second-order optimizer. For HFO, we used the

implementation by Wang et al. [4], which applied the subsampled Gauss-Newton method on CNN models. T1-weighted brain MRI labeled as normal cognitive or Alzheimer’s disease were obtained from the Alzheimer’s Disease Neuroimaging Initiative database (adni.loni.usc.edu). From each brain MRI volume, the middle coronal slice was used as the input to the CNN models.

IV. RESULTS

Our results show that HFO accelerated the training of CNN classifiers receiving MRI data [5]. Overall, HFO converged at least two to four times faster than Adam and SGD. The performance of the models optimized with HFO was comparable or better than those optimized with SGD or Adam. In addition, HFO was more robust to hyperparameter changes than SGD and Adam.

V. CONCLUSION

The results are according to theory and act as a proof of concept that second-order algorithms have an advantage in terms of training speed over first-order methods in training CNN models for MRI data classification.

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An Automated 2D U-Net for the Segmentation of Cancer Brain Metastases Using MRI Images

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An Automated 2D U-Net for the Segmentation of Cancer Brain Metastases Using MRI Images

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Abstract— In this study, we propose an automated system for the segmentation of cancer brain metastases (CBM) using MRI images. The goal is the correlation with regards to the primary cancer site. The segmentation of CBM is a challenging task due to their wide range in terms of number, shape, size and location in the brain. We experimented with the training of a modified U-Net convolutional neural network (CNN) using $N = 3474$ brain image slices for training, $N_V = 579$ for validation and $N_T = 579$ for testing from the public dataset “BrainMetShare”. The proposed model was evaluated on the testing data (N_T), on a lesion-cross section basis with areas from 2.8 to 1225.7 mm² and yielded a mean Dice similarity coefficient (DSC) of 0.73 ± 0.29 across the entire dataset. The present results show the good agreement of the proposed method with the ground truth.

I. INTRODUCTION

Cancer brain metastasis (CBM) is the most common intracranial malignant cancer in the adult population, by far outnumbering the primary brain tumors. CBM patients’ future survival prognosis is often at one year [1]. Currently, the diagnosis of CBM is performed based on clinical information, magnetic resonance imaging (MRI) modalities and histopathological examination (biopsy). MRI assessment of CBM is a time-consuming and tedious procedure with significant inter- and intra-reader variability. Also, biopsy is inherently risky. To cope with these issues, computer-aided decision systems have been developed to automate the initial process of segmentation mainly with state-of-the-art convolutional neural networks [2].

II. METHODOLOGY

The publicly available CBM image dataset “BrainMetShare” was used [2], which includes MRI scans of in total 156 patients, 105 females and 51 males. More specifically, 99 of the patients have CBM originating in lung, 33 in breast, 7 in genitourinary, 5 in gastrointestinal and 5 in miscellaneous cancers. The CBM sizes lie in the range 2–40 mm and were scattered in every region of the brain parenchyma. The used MRI sequence in the training of the segmentation network was T1-weighted spin-echo pre-contrast images. Upon this modality, the ground truth CBM masks were manually generated by different radiologists. All images were resampled to 256×256 pixels in the transverse plane, with a resolution of 0.94 mm, and were skull-stripped. The resolution in between planes was 1.0 mm. Each 3D image scan contains slices varying in the range of 118 to 286.

We kept only the 2D image slices that contained CBM. We then randomly separated the dataset in training/validation and /testing in a ratio 70/15/15 respectively, thus ending up with 3474/579/579 slices respectively. Moreover, for each slice we subtracted its mean and divided by its standard deviation.

The segmentation network was a modified 2D U-Net, consisting of six levels, with each level containing two convolution blocks of filter size 3×3 , a Rectified Linear Unit as an activation function, and a dropout layer. The downsizing operation was performed with 2×2 max pooling, while the upsampling with 2×2 transpose convolutions. Starting from the input 256×256 image, the spatial dimensions got halved in each level until size 8×8 , while the filters increased from 16 up to 512. For the training, the binary cross entropy loss, with the Adam optimizer and learning rate 10^{-4} were used. The batch size was set to 10, due to GPU memory limitations. The optimal number of epochs was experimentally chosen to be 90. Furthermore, the probability threshold to discern between CBM and non-CBM pixels was experimentally determined, by evaluating the model on the training data (each slice) with different threshold values, using the Dice similarity coefficient (DSC) metric. The mean of the best DSCs corresponded to a threshold equal to 0.54 which was chosen.

III. RESULTS

The segmentation results, as evaluated on a CBM cross-section basis, yielded a mean DSC equal to 0.73 ± 0.29 for the testing dataset, with an interquartile range of [0.70, 0.84, 0.91]. Fig. 1 shows two automated segmentations with multiple small CBM and a large one respectively.

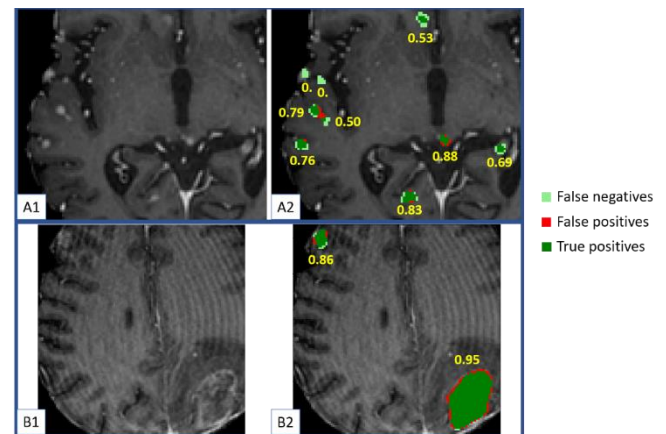


Fig. 1. Two representative segmentation results.

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Brain Magnetic Resonance Imaging Segmentation System in MS with Deep Neural Networks

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Abstract

Multiple Sclerosis is a chronic, auto-immune disease, which refers to the central nervous system. All nerves are covered by a layer called myelin, which is responsible to protect those nerves and preserve their functionality. In case of Multiple Sclerosis, myelin seems to be damaged in way so, that nerves start to function in an unpredictable way. Multiple Sclerosis is a disease characterized by outbreaks. Each outbreak, may cause permanent and non-reversible damage in regard to patient's movement ability, vision and sensations, unless the appropriate medicine treatment is given in time. Here comes the significance of instant detection of presence or differentiation of Multiple Sclerosis, with an automatic Segmentation System using Deep Neural Networks. The dataset which was used, consists of 1838 MRI type T2 images, of 38 patients, with 2 timepoints each. For every MRI image, a corresponding mask exists that marks the appropriate lesions. By making use of the U-Net architecture and after applying a series of processing on training data, a Dice Similarity Coefficient of 0.60 was achieved.

Deep learning-based segmentation of the atherosclerotic carotid plaque in ultrasonic images

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Deep learning-based segmentation of the atherosclerotic carotid plaque in ultrasonic images

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Abstract— Early stroke risk stratification in individuals with carotid atherosclerosis is of great importance, especially in high-risk asymptomatic (AS) cases. In this study, we present a new computer-aided diagnostic (CAD) system for the automated segmentation of the atherosclerotic plaque in carotid ultrasound (US) images and the extraction of a refined set of ultrasonic features to robustly characterize plaques in carotid US images and videos (AS vs symptomatic (SY)). So far, we trained a UNet model (16 to 256 neurons in the contracting path; the reverse, for the expanding path), starting from a dataset of 201 (AS=109 and SY=92) carotid US videos of atherosclerotic plaques, from which their first frames were extracted to prepare three subsets, a training, an internal validation, and final evaluation set, with 150, 30 and 15 images, respectively. The automated segmentations were evaluated based on manual segmentations, performed by a vascular surgeon. To assess our model's capacity to segment plaques in previously unseen images, we calculated 4 evaluation metrics (mean±std). The evaluation of the proposed model yielded a 0.736 ± 0.10 Dice similarity score (DSC), a 0.583 ± 0.12 intersection of union (IoU), a 0.728 ± 0.10 Cohen's Kappa coefficient (KI) and a 0.65 ± 0.19 Hausdorff distance. The proposed segmentation workflow will be further optimized and evaluated, using a larger dataset and more neurons in each UNet layer, as in the original model architecture. Our results are close to others published in relevant studies.

Keywords— Carotid ultrasound video, atherosclerotic carotid plaques, automated segmentation, deep learning-based segmentation, computer-aided diagnosis.

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Optimizing QoE for Medical Video Streaming

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Abstract

The present study proposes an adaptive video delivery methodology that enhances quality of experience (QoE) and aids towards the wider adoption of wireless medical video communication systems in standard clinical practice.

A Review on Machine Learning Methods on BioVid Heat Pain Database

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Abstract

For millions of people worldwide, pain is an unpleasant physical and mental experience that lowers their quality of life. To provide patients appropriate medical care, studies focused on intelligent pain assessment and management systems development based on physiological signals, and facial expressions analysis through Machine Learning (ML) technology. In this review, we explore different ML methods applied on the BioVid Heat Pain Database for pain intensity estimation, and classification.

SESSION 4: INTELLIGENT SYSTEMS

An Integrated Approach for Visualizing Student Activity During Distance Education

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An Integrated Approach for Visualizing Student Activity During Distance Education

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Abstract—Distance learning became extremely popular during the COVID-19 pandemic, with many people working and attending classes from home. Due to privacy issues, in many countries the use of webcams is forbidden during tele-education. However, when the educator has no optical contact with his/her class, students tend to lose their concentration, and the overall teaching process is jeopardised. The aim of our work is to provide a system that will allow teachers to get informed about student activities during tele-education but without having access to video input from students. In the proposed system, images of students captured by webcams are processed locally at a students' personal machine, in order to identify the student actions. The relevant information is sent to a server at the teacher's side. The server side contains a 3D visualization of the class where each student is represented by an avatar, animated to reflect student actions. This method will keep the teacher informed of the students actions without violating privacy barriers. Figure 1 shows a block diagram of the proposed system that includes the client (student side), and the server (teacher side). The work presented in this paper is influenced by previous work in student action recognition [1], [2], [3], and extends our previous work in the area [4].

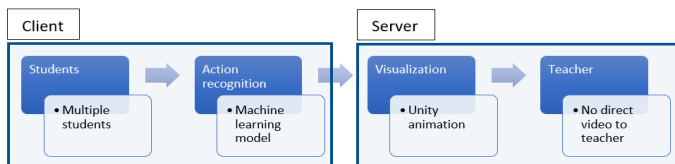


Fig. 1. System Overview

The client side of the proposed system (see Figure 1) incorporates a machine learning model trained to classify the following seven student actions: absent, attending, hand raising, looking elsewhere, telephone call, using phone and writing. The machine learning model used is based on the GoogleNet architecture [5], and during an experimental investigation it managed to classify correctly 94.32% image frames of previously unseen students [4]. The use of the GoogleNet model ensures that the computational requirements for the classification process are minimal, allowing the real-time operation on almost any personal machine used by students during tele-education.

Both the student and the teacher side use a python script for sending and receiving information about student actions. This is done using python socket [6] which provides a way for two nodes to communicate on a network. On the client side, classifications are performed constantly, sending information to the server side about the student action in each image frame captured. This is done at a rate of approximately 90 frames per 10 seconds. On the server side, the classifications are saved and on every iteration (10 seconds) a majority voting strategy within the selected time

interval, is used to determine the exact student action to be written in a log file for each student.

At the server (teacher) side a Unity3D program reads the log file for each student, and activates the corresponding animation of each student avatar that matches the recognized student action. This process is done simultaneously for all students in class, so that the teacher visualizes the actions of all students taking place in a class in a similar way that he/she visualizes students in a real class. Figure 2 shows a screenshot of animated students in the virtual 3D class, where the actions of the student avatars correspond to the actions of each student at the client sides.



Fig. 2. Screenshot of animated students in virtual 3D class

Our work concerns the design of an integrated system where the teacher can visualize student actions, without affecting the privacy of students. Early results and feedback received by stakeholders, prove the promise of this approach. In the future, we aim to perform a comprehensive evaluation of the system, add in the recognition model the ability to recognize additional student actions and emotions, and also provide the ability for the teacher and students to view the class on an online multi-user virtual space, using appropriate Virtual Reality equipment.

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Data-driven Tools for Marine Spatial Planning

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Data-driven Tools for Marine Spatial Planning

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EXTENDED ABSTRACT

The process of allocation of marine areas for various human activities including, among others, aquaculture, renewable energy, tourism, and shipping, requires marine data, expertise on the activity sector, and the identification of the various interactions between activities and the marine environment. The multitude of human activities and marine processes and their complex interactions result to a complex problem of Maritime Spatial Planning (MSP). The solution to this problem requires novel tools for data acquisition, management, processing, and human interaction.

Additionally to well established activities such as shipping and tourism, there are new and rapidly expanding activities. For example, offshore wind farm (OWF) projects with floating structures are part of a rapidly expanding blue energy sector, and the identification and evaluation of the optimal sites for such development is crucial due to the variety of planning and environmental restrictions. Similarly, the establishment of suitable locations for offshore aquaculture projects is important for the sustainability of the mariculture development that has the potential to address the need for providing food to a growing population. Examples of interactions between activities that involve constraints are aquaculture and renewable energy installations that cannot be collocated within shipping routes, and marine protected areas that cannot be collocated with motorized water sports. Favorable conditions include suitable depths and weather conditions for aquaculture, wind energy, marine sports and tourism activities.

In this work, we define an objective function that is constructed based on criteria that define the operation of each marine activity and its interactions with the marine environment and other activities. The objective function, made of heterogeneous criteria and possibly multiple objectives, forms a multimodal surface. Therefore, the objective function indicates many and possibly non-exclusive solutions to the problem of identification of suitable conditions for marine activities, which is formed as an optimization problem. We solve the optimization problem using a method that combines gradient descent and sequential Monte Carlo methods. We assess the effectiveness of the method in consistently identifying the desired conditions in terms of efficiency and computational expense.

Two use-cases have been so far developed. The first is a method for OWF installation and is implemented in the central Aegean Sea to pre-evaluate candidate regions as regards potential floating OWF development. The second is a method for open sea aquaculture placement that has as a research area the Eastern Mediterranean Sea.

Currently the tool includes data based on mean values, multiple criteria, and a single objective. Further in-depth assessment is necessary in a local spatial scale combined with site-specific technical, environmental, and socio-economic data for a more reliable conclusion. Additionally, the extension of our work will include data with values that vary in time and multiple objectives. We plan to cover more use cases such as the simultaneous identification of aquaculture and offshore energy installations and marine sports and tourism activities.

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Data Information Interoperability Model for IoT-enabled Smart Water Networks

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Data Information Interoperability Model for IoT-enabled Smart Water Networks

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The deployment of data-enabled Internet of Things (IoT)/Web of Things (WoT) at the physical layer of a Smart Water Network (SWN), e.g. smart sensors, valve controllers, and cooling units by water utilities have offered an opportunity to build a cohesive *overlay network* in Smart Water Networks (SWNs). Networked Internet of Things (IoT) offer utilisation of the IoT/WoT data (as numbers, symbols, text, images, sound recordings, unit values, etc.) and information (contextualized data) to enable smart sensing beyond the initial coverage areas of a SWN. However, the SWN applications, e.g. leakage detection, water distribution, water quality management, and customer metering, must interoperate with the IoT/WoT before they can run data-driven information analysis and make decisions or operate appropriately in real-time at the top layer of a SWN.

Syntactic and semantic interoperability is a fundamental requirement for the success of the IoT-enabled SWNs. Still, whilst consuming publicly accessible IoT data, the syntactic and semantic representation of the collected data poses challenges for the success of pervasive and ubiquitous sensing in the water domain. Challenges include the heterogeneity of data representation formats, semantic models, and the adoption of domain-specific standards and ontologies. These challenges emphasise the requirement for enhanced interoperability in SWNs. To address this, we propose a Data and Information Interoperability Model (DIIM) by combining the Semantic Web technologies, widely known for overcoming interoperability issues, and Model-driven architecture (MDA) approach. DIIM facilitates syntactic interoperability by serialization conversion and adoption of domain-specific standards as well as semantic interoperability of metadata by aligning the semantic models of IoT and SWN applications. Furthermore, it automatically creates an ontology as a semantic model if it is missing and adds references to existing domain-specific ontologies as annotation in their models. We evaluate DIIM methodology by applying it to a real-world use case of IoT-enabled applications for water quality monitoring.

This work presents a novel method to address the syntactic and semantic interoperability challenges of IoT-enabled SWNs. *DIIM's syntactic interoperability approach* overcomes the serialization format issues during the parsing of the IoT data by data-consuming applications by applying MDA methods for data format translation. Additionally, DIIM adopts domain-specific standards, e.g. WaterML2, to represent water-related data in time-series before delivering it to the consumer application.

Competing Mutual Information Constraints with Stochastic Competition-based Activations for Learning Diversified Representations

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Competing Mutual Information Constraints with Stochastic Competition-based Activations for Learning Diversified Representations

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Abstract—This work aims to address the long-established problem of learning diversified representations. To this end, we combine information-theoretic arguments with stochastic competition-based activations, namely Stochastic Local Winner-Takes-All (LWTA) units. In this context, we ditch the conventional deep architectures commonly used in Representation Learning, that rely on non-linear activations; instead, we replace them with sets of locally and stochastically competing linear units. In this setting, each network layer yields sparse outputs, determined by the outcome of the competition between units that are organized into blocks of competitors. We adopt stochastic arguments for the competition mechanism, which perform posterior sampling to determine the winner of each block. We further endow the considered networks with the ability to infer the sub-part of the network that is essential for modeling the data at hand; we impose appropriate stick-breaking priors to this end. To further enrich the information of the emerging representations, we resort to information-theoretic principles, namely the Information Competing Process (ICP). Then, all the components are tied together under the stochastic Variational Bayes framework for inference. We perform a thorough experimental investigation for our approach using benchmark datasets on image classification. As we experimentally show, the resulting networks yield significant discriminative representation learning abilities. In addition, the introduced paradigm allows for a principled investigation mechanism of the emerging intermediate network representations.

I. INTRODUCTION

The ability to extract diversified representations is the main focal point of Representation Learning (RL). Despite the immense amount of research effort, though, learning representations with such qualities remains an open research question.

Our ultimate goal is to yield deep networks with considerably diversified resulting representations. We evaluate our approach using well-known benchmark datasets and architectures for image classification.

II. FOUNDATIONAL PRINCIPLES

The output \mathbf{y} of a stochastic LWTA layer’s $(b, u)^{\text{th}}$ unit, $y_{b,u}$, that is, the output of the u^{th} unit in the b^{th} block, as:

$$y_{b,u} = \xi_{b,u} \sum_{j=1}^J (z_{j,b} \cdot w_{j,b,u}) \cdot x_j \in \mathbb{R} \quad (1)$$

where $\xi_{b,u}$ denotes the u^{th} component of ξ_b , and $\xi_b \in \text{one_hot}(U)$ holds the b^{th} subvector of ξ .

We postulate that the winner unit latent indicators $\xi_b, \forall b$ in Eq. (1) are obtained via a *competitive* random sampling procedure; this, translates to drawing samples from a Categorical distribution, where the probabilities are proportional to the intermediate linear computation that each unit performs. Accordingly, the higher the linear response of a particular unit in a particular block, the higher its probability of being the winner in said block; this yields:

$$q(\xi_b) = \text{Categorical} \left(\xi_b \mid \text{softmax} \left(\sum_{j=1}^J z_{j,b} \cdot [w_{j,b,u}]_{u=1}^U \cdot x_j \right) \right) \quad (2)$$

where $[w_{j,b,u}]_{u=1}^U$ denotes the vector concatenation of the set $\{w_{j,b,u}\}_{u=1}^U$. On the other hand, we postulate that the binary latent indicators \mathbf{Z} are drawn from a Bernoulli distribution, operating in an “on”-“off” fashion, such that:

$$q(z_{j,b}) = \text{Bernoulli}(z_{j,b} \mid \tilde{\pi}_{j,b}) \quad (3)$$

where $\tilde{\pi}_{j,b}, \forall j, b$ are trainable parameters. Each stochastic LWTA layer comprises multiple such LWTA blocks. At this point, it is important to note a key aspect of the proposed approach; that is, *stochasticity*. In each layer, different stochastic representations arise due to the sampling procedure for both latent indicators ξ and \mathbf{Z} .

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