UCG
University of Montenegro

Ministry of Science and Technological Development

Scientific Symposium
Days of Diaspora and (Scientific) **Partners** (of Montenegro)
Naučni simpozijum
Dani Dijaspore i (Akademskih) **Prijatelja** (Crne Gore)
Podgorica
October **18-19** Oktobar **2023**

BOOK of ABSTRACTS, BIOSKETCHES & SELECTED FULL ARTICLES

ABOUT THE UNIVERSITY OF MONTENEGRO

The University of Montenegro is the oldest and the only state university in Montenegro that provides comprehensive education in the fields of social, humanistic, technological, natural, and medical sciences.

It was founded in 1974, with the belief that it would educate professionals essential for the dynamic socio-economic and cultural development of Montenegro. At its inception, it consisted of three faculties: Economics, Technical Sciences, and Law.

Today, on the eve of celebrating its 50th anniversary in 2024, the University of Montenegro comprises 19 faculties and three scientific institutes: the Historical Institute, the Institute of Marine Biology, and the Institute for Advanced Studies. The university accommodates around 20,000 students across Montenegro.

The teaching is structured in accordance with curricula from esteemed European higher education institutions, facilitating smooth mobility for students and academic staff through more than 150 signed agreements within the Erasmus+ program, as well as over 80 bilateral agreements.

It strengthens its position in the realm of science through international cooperation and project activities aimed at supporting research capabilities. As a central institution for science, culture, and the arts in Montenegro, it consistently builds connections with the business, social, and international sectors through productive collaboration with the business and public sectors.

The University of Montenegro is a member of prestigious international organizations, such as:

- *The European University Association*
- *Magna Charta Universitatum*
- *The Francophone University Association*
- *The University Network of the Adriatic Ionian Initiative*
- *Network of Universities of Small Countries and Territories*
- *The Balkan University Association*
- *Ulysseus European University*
- *European Security and Defence College*

ABSTRACTS & BIOSKETCHES

Ilija Antović Faculty of Organizational Sciences, UBG, SRB

Advances in Software Engineering: User Interface

Abstract: The design and implementation of user interfaces are two of the most effort and time consuming activities of the software development process. The lecture will address the automation of the process of designing and implementing user interfaces. The automation is based on the identified connections between software requirements, particularly use cases, and the resulting user interface of the application, taking into account the characteristics of the targeted implementation technologies and application types. We will also discuss the principles and characteristics which should be an integral part of the tool for automation of user interfaces development, that are all implemented in SilabUI approach.

Bio: Ilija Antović was born in Kotor, Montenegro, where he completed elementary and high school. He obtained BSc, MSc, and PhD degrees from the Belgrade University, Faculty of the Organizational Sciences, Belgrade (UB-FOS). He was the head of the Software Engineering Laboratory and active member of the Council at UB-FOS. He was author and coauthor of many papers published in scientific journals and international conferences. Today he works as associate professor at UB-FOS Software Engineering Department. His main research interests are the automation of software development process, software architectures, technologies and methods, as well as the development of eGovernment.

Dušica Babović-Vuksanović Mayo, Rochester, USA

Advances in Management of Neurofibromatosis Type 1

Abstract: Neurofibromatosis type 1 (NF1) is an autosomal dominant condition characterized by pigmentary skin changes and a variety of associated complications including tibial dysplasia, optic glioma, scoliosis, developmental difficulties and predisposition for development of tumors. Diagnosis is based on clinical criteria and/or genetic testing. NF1 is caused by deficiency of neurofibromin, a tumor suppressor gene with consequent activation of RAS pathway. Management of NF1 has been mostly symptomatic due to lack of effective therapies. Recent advances have led to approved medical treatments for patients with plexiform neurofibromas, and the progress has been made on development of treatments for other NF1-related complications.

Bio: Dušica Babović-Vuksanović is a Professor of Pediatrics and Medical Genetics. She has been a staff of Mayo Clinic in Rochester, MN since 1999. She carried on multiple leadership positions including a role of Chair of the Department of Clinical Genomics, Residency Program Director, member of the IRB Board, and member of the Executive Committee of the Center for Individualized Medicine at Mayo. Currently, she is serving as a Director Neurofibromatosis Program at Mayo Clinic and Director of the Mayo Clinic Center of Excellence for Rare Disease. She is conducting multiple clinical trials for patients with neurofibromatosis and schwannomatosis. Dr. Babovic-Vuksanovic has more 150 peer reviewed manuscripts and book chapters, many national and international presentations and visiting professorships.

Vesna Bengin BioSense, UNS, SRB

Advanced Sensing for the Agriculture of the Future

Abstract: To optimize agricultural production, a plethora of sensors is needed to accurately measure various parameters related to the plant and its environment. However, no single approach can enable the development of all sensors needed. In this paper, we present an advanced approach to sensing, based on the acoustic artificial materials. We start from the idea of electro-magnetic metamaterials, expand it to the acoustic domain, and finally present a novel GRIN medium which supports the propagation of surface acoustic waves that can be externally manipulated to enable highly accurate temperature mapping, as well as gas sensing.

Bio: Prof. Bengin is the co-founder of the BioSense Institute and the coordinator of a €30-million H2020 project ANTARES, evolving BioSense into European Centre of scientific excellence. She is a scientific advisor at BioSense, a full professor at the University of Novi Sad and an *Extraordinary Professor* at Stellenbosch University in South Africa. Among other duties, Prof. Bengin serves as a member of UNICEF Business Advisory Board in Serbia, a consultant for UN FAO, and a consultant for UNDP. She is the recipient of the special award granted by the European Commission *Marie Curie Actions for an Innovative Europe: Excellence, mobility and skills for researchers,* the award *She's Mercedes* for outstanding women in science and technology awarded by the Mercedes-Benz company, and many more.

ABSTRACTS & BIOSKETCHES

Nikola Bešić IGN, Nansy, FRA

Remote Sensing: An Experience of Atmospheric and Forest Observations in the Context of the Changing Climate

Abstract: Remote Sensing is the science of acquiring information about the Earth's surface without being in contact with it, by sensing and recording scattered or emitted electromagnetic energy and processing, analysing and applying that information. This talk aims at presenting a typical remote sensing challenge of reconciling electromagnetism, data sciences and Earth's sciences, illustrated through an experience of using remote sensing for atmospheric and forest observations. The intervention as well seeks to emphasize the importance of meticulous Earth observations in the context of the changing climate and the indispensable role of remote sensing in the climate change adaptation and mitigation strategies.

Bio: Nikola Bešić received a BSc degree in electrical engineering from the UoM (2009) and an MSc degree in optics and RF engineering from Grenoble INP (2011). In 2014, after staying with the GIPSA-lab (Grenoble), he obtained a PhD in remote sensing from L'université Grenoble-Alpes, and simultaneously a PhD from the UoM. He was a postdoctoral researcher at the Environmental Remote Sensing Laboratory (EPFL, Lausanne), staying as well with the Radar, Satellites and Nowcasting group (MeteoSwiss, Locarno). He was also a researcher at the Centre for Radar Meteorology (Météo-France, Toulouse), and at AgroParisTech (Nancy), before joining the French National Mapping Agency (IGN).

Ivan Božović BNL & Yale, USA

CANCELLED

Reporting from the Frontiers of Superconductivity Research

Abstract: The discovery of high-temperature superconductivity in copper oxides in the late eighties was a turning point in the history of Condensed Matter Physics. It spurred momentous advances in theory and experimental techniques and brought in new applications. However, understanding of this phenomenon is still lacking and remains one of the most important open problems in physics. More recently, some metal hydrides were found to superconduct up to room temperature, although only under enormous pressure of several million atmospheres. If we can find a way to achieve the same at ambient pressure, that may change the way Earth looks from space.

Bio: Ivan Božović is Distinguished Scientist and MBE Group Leader at Brookhaven National Laboratory and Adjunct Professor at Yale University. He is Member of European Academy of Sciences, Foreign Member of Serbian Academy of Science and Arts, Fellow of APS, Fellow of SPIE, Professor honoris causa of University of Montenegro, and Moore Foundation Principal Investigator. He received McGroddy Prize, Bernd Matthias Prize, SPIE Science Award, Max Planck and Van Der Waals Lectureships, etc. Ivan's research interests include unconventional superconductivity, film synthesis and characterization, and nano-scale physics. He published well over 300 research papers, including over 30 in Science and Nature journals.

Ilir Çapuni Barleti University, ALB

A Mechanistic Model for Cancer: Exploring the Automata Rules that Cause Uncontrolled Cell Proliferation

Abstract: A mechanistic approach to cancer involves studying and understanding cancer at a cellular and molecular level, focusing on the mechanisms and processes involved in its development, progression, and response to treatment. In this talk, we will present an asynchronous parallel model of computation that accurately models core features of the structure and functioning of living cells. Instead of considering specific genes, proteins, and molecules involved in cancer, our focus will be on fundamental cellular interactions and a basic regulatory mechanism that ensures the longevity of tissue structure, specifically repair-healing mechanisms. We will observe how certain self-organizing healing rules or strategies, under specific conditions, can cause programmatically guided but uncontrolled proliferation of cells.

Bio: Ilir Çapuni obtained his PhD in computer science from Boston University in 2012. He is one of the founders and a Steering Committee member of the Balkan Communications conference. His research interests include reliable computation and algorithm aspects of computer networks. He constructed a Turing machine that can compute reliably even in the presence of noise with moderate slowdown and increase in space. He also devised a method to synchronize computer clocks by analyzing time information embedded in HLS video packets. He is a technical scuba instructor and a father of three kids.

ABSTRACTS & BIOSKETCHES

Mensur Dlakić Montana State University, USA

How to Maintain Life in Boiling Acid

Abstract: Microorganisms from hot springs of Yellowstone National Park represent some of the earliest life forms on Earth. For many of these organisms the placement in the Tree of Life is not yet established. We have sequenced several microbial communities that prefer high temperature (thermophiles). By analyzing organisms that do not require sunlight, we begin to understand how some of the first life forms may have used energy from chemical compounds such as sulfide, hydrogen and methane. Our approach integrates experiments and bioinformatic analyses to develop comprehensive and transformative understanding of the evolutionary history and metabolic capabilities of deeply rooted thermophiles.

Bio: Mensur Dlakić was born in Bijelo Polje, where he attended elementary and high school. He was granted a college degree in Molecular Biology and Physiology from the University of Belgrade. He obtained a PhD in Biochemistry for studies of DNA structure at the University of Nevada, Reno. After postdoctoral training in Cell Biology and Bioinformatics, Professor Dlakic moved to his current faculty position in Microbiology & Cell Biology department at Montana State University, Bozeman. Mensur authored >50 publications, has received NSF and NIH funding, and is on editorial boards of Frontiers in Genetics, Protein Bioinformatics and Cellular & Infection Microbiology.

Dražen Drašković School of Electrical Engineering, UBG, SRB

AI – Apocalypse or Revolution

Abstract: Since the fifties of the last century, when the mathematician A. Turing posed an experiment, and question Can machines think?, Artificial Intelligence (AI) has been developing some years faster and some intervals slower. Today we mainly talk about three types of AI: narrow, strong and super. In this lecture, the most important AI products in the last 20 years will be highlighted: human-computer games, intelligent virtual assistants, and large language models that are actively used in the field of natural language processing, then image generation, recognition, processing, and AI application in the field of autonomous driving and robotics. Will the fate of these AI products be determined by our actions, leading to either a new world revolution or an apocalypse?

Bio: Dr Dražen Drašković is an Assistant Professor at the University of Belgrade, School of Electrical Engineering (UB-ETF). He received a BSc degree in Software Engineering, an MSc degree, and a Ph.D. degree in Electrical and Computer Engineering from the UB-ETF. His current research interests include the application of AI algorithms, machine learning, natural language processing, and big data analysis. He published more than 80 scientific papers. He is a member of international professional organisations IEEE and ACM. He worked as a professional associate, software architect, engineer and consultant, for UNOPS, UNDP, WHO, and other institutions. He was involved in more than 10 international R&D projects (FP7, Horizon2020, Erasmus+, WUS, COST).

Vladan Đokić Rector, UBG, SRB

Advances in Urbanism: Praxis of Urban Morphology

Abstract: In its jubilee year of 215 years, the University of Belgrade and the Faculty of Architecture as its constituent member have an opportunity to host the 30th International Seminar on Urban Form Conference (ISUF2023) titled Praxis of Urban Morphology. The ISUF 2023 aims to build on the previous experience and ideas, and to direct activities toward systematization and synthesis of intellectual heritage at an international level, aiming to embody these ideas into operational knowledge. Accordingly, the presentation would cover the main issues raised by scholars and practitioners both in Serbian Architectural Journal speciall issue and during conferences with the overall goal to contribute to the advancement of knowledge in this field, moreover, to reconsider and critically examine advancements and perspectives on urban morphology.

Bio: Vladan Djokić studied at the University of Belgrade, Faculty of Architecture, finished his master's at the University of Southern California, School of Architecture in Los Angeles, and PhD at the University of Belgrade, Faculty of Architecture. Editor-In-Chief of the international scientific journal of architecture and urbanism – Serbian Architectural Journal since 2009. President of the Serbian Network of Urban Morphology, since 2017. Rector of the University of Belgrade from 2021. In the teaching activity, he lectures a number of courses at AFUB which relate to the field of urban planning and design, and urban morphology. In scientific and research activity he works in the field related to urban planning and design and urban morphology.

ABSTRACTS & BIOSKETCHES

Courtney Jungers & **Sergej Đuranović** WUSTL, St. Louis, USA

New Therapies for Haploinsufficiency-related Genetic Diseases

Abstract: Genetic haploinsufficiency, in which partial or complete loss of one normal allele, is the basis of numerous human diseases. In such disorders, increasing protein levels by intervening therapeutically might potentially slow or cure the disease. Current strategies use deliverables of protein, mRNA transcripts or adenoviruses with gene replacement strategy to increase reduced amounts of haploinsufficent genes. However these strategies cause immune responses, reduced efficiency during long periods of treatment and can not be used for all organs and tissues. Here we discuss new antisense oligonucleotides therapies for the gene specific increase in protein synthesis to ameliorate consequences of genetic haploinsufficiencies.

Bio: Dr. Sergej Djuranovic is a Professor of Cell Biology and Physiology at Washington University School of Medicine in St. Louis, USA. He earned his MSc in Biochemistry at University of Belgrade, Serbia and his PhD degree at Max-Planck Institute for Developmental Biology in Tubingen, Germany. His postdoctoral training was at Howard Hughes Medical Institute and Johns Hopkins University School of Medicine, Baltimore USA. His group studies mechanisms of gene expression regulation at the level of mRNA and protein synthesis. He is an author on numerous scientific papers, member of science associations as well as boards for pharmaceutical companies, science and diversity groups.

Ivana Đuričić Faculty of Pharmacy, UBG, SRB

Nutraceuticals and Dietary Supplements in Health Promotion

Abstract: Nutraceuticals are foods or part of foods that can provide medical or health benefits. Dietary supplements are defined as concentrated sources of bioactive compounds (e.g., vitamins, minerals, amino acids, essential fatty acids, fibres, probiotics, plants and plant extracts, etc.) in dose forms such as tablets, pills, capsules, and liquids in measured doses. Supplements are intended to support specific physiological functions but not to prevent or treat diseases in humans. Harmonized legislation regulates these products establishing rules to protect consumers against potential health risks and updating the list of substances that are known or suspected to have adverse effects on health.

Bio: Dr sc. Ivana Djuricic is an associate professor at the Department of bromatology within Faculty of Pharmacy, University of Belgrade. Since joining the University of Belgrade, Ivana has been involved in studies related to nutrition science and engaged in interdisciplinary research throughout national projects. As of 2017 she has participated in international COST and ERASMUS projects. Under the authorization of the Ministry of Health, Ivana works on the categorization and certification of dietary products for Serbian market. Ivana Djuricic is a member of Pharmaceutical Associations of Serbia, Serbian Nutrition Society and Association for Personalized-Holistic Approach in the Treatment of Patients.

Siniša Đurović University of Manchester, GBR

Advances in Power Engineering

Abstract: The talk will look at some of the key technical challenges to the electrification of automotive and other transportation in the electro-mechanical power conversion area. The aspects and trends related to electrical machine, power electronic and energy storage device functionality and performance required for delivering the desired electrical transportation systems' ability will be reviewed. Forecasts and future directions for automotive powertrain systems development will also be overviewed and the technical barriers to commercialising this technology discussed.

Bio: Dr Siniša Djurović is a Reader in the Department of Electrical and Electronic Engineering at University of Manchester, UK. His research interests are in condition monitoring, operation and modelling of electric machines and drives in renewables, automotive and industrial applications. He has been an investigator on a number of flagship UK research council projects, most recently leading the Monitoring theme across 5 universities in the EPSRC HOME Offshore consortium. He also works on industrially engaged research, e.g., condition monitoring of electric drives (Airbus, UK), sensing techniques for rotating machinery (QPS Photronics, Canada), FBG monitoring systems application (Dyson, UK) and others.

ABSTRACTS & BIOSKETCHES

Nenad Filipović Rector, UKG & Harvard University, Boston, USA

Digital Patients, Myth or Reality?

Abstract: Digital patients are a new paradigm for development of a new drug and medical device and test them in computer generated patients. SILICOFCM project is multiscale modeling of heart disease which considers a comprehensive list of patient specific features as genetic, biological, pharmacologic, clinical, imaging and cellular aspects. Computational platform for multiscale modelling and AI in biomedical engineering is results of SGABU project that is served as an educational tool for students and researchers. Digital patients concept will connect basic experimental research with clinical study and big data with bioinformatics, data mining and image processing tools in order to reduce animal experiments and clinical studies on real patients. **Acknowledgement:** This study is supported by the projects that have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952603 (SGABU project). This paper reflects only the author's view. The Commission is not responsible for any use that may be made of the information it contains.

Bio: Nenad D. Filipovic is Rector of University of Kragujevac, Serbia, full Professor at Faculty of Engineering and Head of Center for Bioengineering at University of Kragujevac, Serbia. He was Research Associate at Harvard School of Public Health in Boston, US. His research interests are in the area of computational mechanics, biomedical engineering, cardiovascular disease, fluid-structure interaction, biomechanics, bioinformatics, biomedical image processing, machine learning, medical informatics, multi-scale modeling, software engineering, big data, parallel computing, computational chemistry and bioprocess modeling. He also leads a number of national and international projects in EU and US in area of bioengineering, artificial intelligence and software development.

Antonija Krstačić Faculty of Medicine, University of Osijek, CRO

Biomarkers for Acute Traumatic Brain Injury

Abstract: Traumatic Brain Injury (TBI) is the the very important cause of death and disability in children and adults from ages 1 to 44. TBI is defined as an brain injury that temporariliy or permanently impairs brain function, and is most often result of a blow to the head. The leading causes of TBI are falls, motor vehicle crashes, sports injuries, and assaults, respectively. Sometimes it is not easy to make a diagnosis, especially in people with a mild brain injury, because the symptoms are often non-specific. Neurological examination and various imaging techniques such us computed tomography and magnetic resonance are used in the diagnosis of TBI. Recently, it has been proposed to use different biochemical markers whose concentration changes may indicate brain injury in the early stage of the disease. The advantage of determining these markers in relation to imaging techniques lies in this that people do not have to be exposed to radiation, which is especially important in pediatric population.

Bio: I was born in 1974 in Kotor. Since 2002. I have been working at the Traumatology Clinic, KBC "Sisters of Mercy" in Zagreb. Since 2008. I have been working as a specialist neurologist in the Laboratory for electromyoneurographic diagnostics and treatment of the Traumatology Clinic, KBC "Sisters of Mercy". Since 2018. I have been working as a subspecialist in neuromuscular diseases. I was recognized with the title of primarius in April 2018 by the Ministry of Health. Since 2020. I have been working as the head of the Department of Neurology, Clinic for Traumatology, KBC "Sisters of Mercy". 2022. I was elected to the scientific-teaching title of associate, at the Department of neurology and psychiatry, Faculty of Dental Medicine and Health Osijek, University of J.J. Strossmayer in Osijek. As an author and co-author, I have published about fifty scientific and professional publications.

ABSTRACTS & BIOSKETCHES

Goran Krstačić & Antonija Krstačić Institute for Cardiovascular Prevention and Rehabilitation, Zagreb & University of Osijek, CRO

New Screening Program for Cardiovascular Risk in Asymptomatic People

Abstract: Traumatic Brain Injury (TBI) is the the very important cause of death and disability in children and adults from ages 1 to 44. TBI is defined as an brain injury that temporariliy or permanently impairs brain function, and is most often result of a blow to the head. The leading causes of TBI are falls, motor vehicle crashes, sports injuries, and assaults, respectively. Sometimes it is not easy to make a diagnosis, especially in people with a mild brain injury, because the symptoms are often non-specific. Neurological examination and various imaging techniques such us computed tomography and magnetic resonance are used in the diagnosis of TBI. Recently, it has been proposed to use different biochemical markers whose concentration changes may indicate brain injury in the early stage of the disease. The advantage of determining these markers in relation to imaging techniques lies in this that people do not have to be exposed to radiation, which is especially important in pediatric population.

Bio: He is a Director of the Institute for Cardiovascular Prevention and Rehabilitation in Zagreb, Croatia, last 10 years. He is a full professor of internal medicine and cardiology at the Faculty for Dental Medicine and Health and School of Medicine J. J. Strossmayer University in Osijek. He is senior scientific advisor in a permanent position at the Faculty of Medicine in Zagreb, and college professor at the University of Applied Health Studies. He graduated from business school for a health manager in Zagreb and Vienna. He is associate member of the International Academy of Sciences and Arts in Bosnia and Herzegovina. He served as a chair of the Working group on e-Cardiology ESC and Coordinator of e-Technology, and the board member of EHRA and the board member of Word Association "Computing in Cardiology". He is author more than 150 publications. He is the editor-in-chief of the University textbooks "Neurocardiology", and "Cardioneurology". His area of professional interest and publications is in the field of non-invasive cardiology, digital health, cardioneurology, and cardiovascular rehabilitation.

Elma Kurtagić Johnson & Johnson Innovative Medicines, Boston, USA

Unraveling Disease Complexity and Novel Target Discovery in Systemic Sclerosis (SSc)

Abstract: SSc is a devastating autoimmune disease with chronic progressive course, with high patient heterogeneity for which no disease modifying therapies exist. It is characterized by inflammation, vascular dysfunction, and fibrosis. Our target discovery approach is focused on studying human patient samples using multiomic approach to bridge the gap in understanding disease pathogenesis that is insufficiently represented in preclinical models. Novel computational approach of well-associated proteins (WAPs) was developed that lead to the discovery of new targets. Moreover, the integration of matched patient skin and blood data revealed that patient serum protein profile might serve as a reflection of disease severity at the end-organ level.

Bio: Elma joined Janssen in October 2020 as Associate Scientific Director within the Immunology Discovery. She is leading a team focused on discovering novel targets to treat autoimmune diseases. Prior to Janssen, Elma worked in positions of increasing responsibility at Momenta Pharmaceuticals for 9 years, where she worked on preclinical and clinical assets in oncology and rare autoimmune diseases. Prior to Momenta, Elma conducted postdoctoral research in Biological Engineering department at MIT, studying bivalent EGF receptor ligands and their application in turning-off cancer growth signals. Elma received a bachelor's in Cell Biology from Jacobs University in Germany (2004) and Ph.D. in Cell and Molecular Biology from Boston University School of Medicine (BUSM) in 2010.

Vladan Kuzmanović Dean, Faculty of Civil Engineering, UBG, SRB

Power Plants and Diversification of Energy Sources

Abstract: The intensive progress of energy sector began at the end of the 19th century, when the first power plants were built, but the turning point was the Kyoto agreement, which changed even the philosophy of energy producing. Today, all countries face immense challenges in the energy sector. The need to reduce carbon footprint, but to meet the energy demand, requires new technological solutions and the modernization of the energy sector. The appropriate market mechanisms need to be introduced to accommodate diversification of energy sources. This complex and costly transition will have to take place in time when the available public and private capital is limited.

Bio: Vladan Kuzmanović was born in 1966. He is full professor at the Faculty of Civil Engineering, University of Belgrade. Prof. Kuzmanović deals with design and analysis of hydraulic structures. He published four books, more than sixty scientific and professional papers and three national level patents. He participated in more than three hundred projects and technical reviews of more than eighty structures. Prof. Kuzmanović is the vice president of Serbian Chamber of Engineers Management board, member of the Association of Structural Engineers of Serbia and International Commission on Large Dams. Since 2018, he has been the Dean of the Faculty of Civil Engineering.

ABSTRACTS & BIOSKETCHES

Slobodan B. Marković UNS, SRB

Paleoclimate and Humans

Abstract: Nowadays, interaction between paleoclimate and paleoenvironmental changes and human cultures dynamics covers a wide scientific field at the frontier between the geosciences and archaeology. Despite the already published records of the specific evolution of the Pleistocene environment during the last two decades, the integration of these results within the field of archaeology in our part of Europe is scarce. Here we present recent advances in paleoclimatic and archeological research in our region with focus on parts of the record of the Pleistocene and Holocene age, corresponding to the presence of ancient ancestors, with the aim of better understanding their adaptation to sudden and drastic climate changes.

Bio: Slobodan B. Marković was born in Zrenjanin, 1970, Serbia. He obtained BSc, MSc, and PhD degrees from the University of Novi Sad, Faculty of Sciences, Belgrade (UNS-PMF). Since 2009 he is a full professor at UNS-PMF. He was a fellow of Humboldt foundation and fellow of the Award of the President of the Chinese Academy of Sciences. According to Google Scholar base he is the most cited researcher of University of Novi Sad. For 2020 and 2021 he is listed in Stanford list of top 2 % world scientists. In 2023 received the Milutin Milanković award for contribution to research development in Autonomous Province Vojvodina.

Miodrag Mateljević SANU, SRB

Hyperbolic, Euclidean, Minkowski Geometry and Theory of Special Relativity

Abstract: We give a brief overview of the geometries mentioned in the title. In particular we outline short proof of The Pythagorean (or Pythagoras') Theorem based on the statement which are equivalent to The Parallel Postulate and as an application we derive Lorentz transformation.

Bio: Dean at Faculty of Mathematics, University of Belgrade, 2007-2014. Corresponding member of Serbian Academy of Sciences & Arts from 2012-2018. Academician of Serbian Academy of Sciences & Arts from 2018 (Nov 8). Winter semester 1988 as associate professor at University of Pittsburgh. Associate Professorship during 1988/89. at Wayne State University, Detroit. The winner of the City of Belgrade Science Award for 2006. He published about 130 scientific papers in well internationally known journals, which are quoted about 2082 times, and notable books Topics in Conformal, Quasiconformal and Harmonic maps 2012 and Kompleksne funkcije 1 & 2, 2006.

Fedor Mesinger SANU, SRB

Cut-cell Eta Model in Weather and Climate: Challenges Overcome

Abstract: Incentive for writing a weather prediction model stemmed from the author's being exposed to the approach of Akio Arakawa at UCLA. The code Mesinger wrote in Belgrade in 1973, following enhancements by him and the collaborator he acquired, Zaviša Janjić, when installed in 1984 at the U.S. National Meteorological Center, attracted attention. As the "Eta model" it was implemented in 1993 as the U.S. regional weather forecasting model. Now it is extensively used also as a regional climate model over the South American domain, and in near-real time for the North American Regional Reanalysis of the U.S. Climate Prediction Center. Challenges it faced are recalled and results shown of its skill compared to that of the highly acclaimed European Centre for Medium-Range Weather Forecasts model.

Bio: Fedor Mesinger received his Sc.D. degree from the University of Belgrade in 1960. He later spent extended periods at several leading modeling centers. The code Mesinger wrote in Belgrade in 1973, subsequently developed by him and by Zaviša Janjić, he brought in 1984 to the then U.S. National Meteorological Center. As the "Eta model" in 1993 it became the primary U.S. operational regional weather prediction model. Mesinger is a member of the Serbian Academy of Sciences and Arts, of the Academia Europaea, and of the International Eurasian Academy of Sciences. He is the recipient of the 2001 Vilhelm Bjerknes medal of the European Geophysical Society.

ABSTRACTS & BIOSKETCHES

Miodrag J. Mihaljević SANU, SRB

Artificial Intelligence, ChatGPT and Blockchain Issues

Abstract: Artificial intelligence (AI) and blockchain technology (BC) are among hottest topic within information technologies and provide background for many new applications. Also, these two topics appear as mutually supportive. ChatGPT is AI generated chatting robot that is an integration of multiple technologies such as unsupervised learning, instruction fine-tuning, multi-task learning, in-context learning and reinforcement learning. This talk yields certain illustrations of BC employment for developing trustful AI based big data applications and inparticular an application regarding the training data for ChatGPT that supports reliability/validity of its answers.

Bio: Miodrag J. Mihaljević is a Research Professor and the Deputy Director with the Mathematical Institute, Serbian Academy of Sciences and Arts, Belgrade. His main research interests include cryptology, information security and blockchain technology. Since 1997, he has been holding long-term visiting positions at the universities and research institutes in Japan, including The University of Tokyo, Sony Research Labs, the National Institute AIST, and Chuo University, Tokyo. In 2013, he received the National Award of the Serbian Academy of Sciences and Arts for ten years achievements. Since 2014, he has been an Elected Member of the Academia Europaea. In the years 2020, 2021 and 2022. Dr. Mihaljević is included in the ranked list colloquially known as "World's Top 2% Scientists" (by Elsevier and Stanford University) regarding his career achievements. He is an Elected Member of the Serbian Academy of Sciences and Arts from 2021.

Veljko Milutinović Indiana University, USA

DataFlow SuperComputing for BigData DeepAnalytics

Abstract: This presentation, possibly followed by an on-line mini-course or a full-blown course on DataFlow Programming, analyses the essence of DataFlow SuperComputing, defines its advantages and sheds light on the related programming model that corresponds to the recent Intel patent about the possible future Intel's dataflow processor. The stress is on issues of interest for General Science and Engineering. Presented are the results of the scientific research and industrial developments of the author in the period of 1995 to 2020, with the following potentials: Speedup 10x to 1000x, Power 10x to 100x, Size 10x, and Precision 1x to 10x (variable in the algorithmic level, as needed by applications).

Bio: Professor Veljko Milutinović is an Adjunct Professor, University of Indiana in Bloomington, Indiana, USA and a Former Professor, Purdue University, West Lafayette, Indiana, USA, co-responsible for the DARPA's first GaAs microprocessor and DARPA's first GaAs Systolic Array (4096 CPUs). He is an Adjunct Professor for Life, TU Graz, Austria, a former Professor and a current Visiting Professor, University of Belgrade, Serbia. He is a Life Fellow of the IEEE, Washington, D.C., USA, a Member and a Former Trustee and Treasurer, Academia Europaea, London, GBR, a Founding Member, Serbian National Academy of Engineering, Belgrade, SRB; a Foreign Member, Montenegrin National Academy of Sciences and Arts, MNE (GSC=5800,i10=120,h=40,i100=12).

Branislav Mitrović SANU, CANU & Faculty of Architecture, UBG, SRB

Advances in the Protection of Traditional Architectural Heritage

Abstract: Presenting selected projects located in the coastal and mountainous area of Montenegro, the author interprets the methods, techniques and effects of fitting the modern form into the spatial conditions of the historical architectural heritage. Current solutions are based on the possibilities of transposing the original architectural themes which, varying from the analysis of the meaning of sinkholes and borders to the metamorphosis of the shape of walls and terraced plateaus, define the morphological context of new architectural buildings. In addition to the responsibility according to the programmatic requirements of the new content, the presented role of the designer is aimed at preserving the inherited spatial values. The study aims to show how the articulation of these values, which gives new forms a deeper meaning and shows their true potential, can become an individual task and a challenge for an architectural investment in space that represents much more than a consistent response to utilitarian aspects.

Bio: Graduated on Faculty of Architecture in Belgrade (1974). Employed in the design institute WO Srbijaprojekt (1977-1986), and then in CIP (1986-1990). In addition to his exceptional creative work, he makes his contribution through engagement in teaching at the Faculty of Architecture in Belgrade (1990-2014). He founded the design bureau MITarch studio (since 2006). In the same year, he became a member of SASA (corresponding in 2006, regular in 2012) and a regular member of AESS. He has completed over 200 architectural competitions and won more than 100 awards. Professor Mitrović is the author of about 40 completed buildings. He is the recipient of 40 professional and social awards. He was elected the first professor emeritus of the Faculty of Architecture in Belgrade (2015).

ABSTRACTS & BIOSKETCHES

Petraq Papajorgji Tirana, ALB & University of Florida, USA

Why is it Important to Use Quantitative Methods in Social Studies

Abstract: Social sciences have been historically approached using qualitative approaches. Advances in technology, especially the approach "technology as a service", create a favorable environment for using more easily quantitative methods in social sciences. They facilitate objectivity and replicability for the study, the ability to generalize findings to a larger population, and identify patterns, relationships, and trends within the data. It provides evidence-based insights that inform policy decisionsand social interventions. These models can help forecast future trends, behaviors, or outcomes, aiding decision-making processes. Quantitative research involves developing predictive models based on historical data and helps forecast future trends or outcomes.

Bio: Prof. Dr. Petraq Papajorgji is Emeritus Professor at the European University of Tirana, Tirana, Albania. His area of expertise is modeling complex information systems. Prof. Papajorgji was, for 10 years, editor-in-chief of the International Journal of Agricultural and Environmental Information Systems (IJAEIS), Associate Editor of the Journal of Biomedical Data Mining, Iberoamerican Journal of Applied Computing, Member of the Center for Applied Optimization University of Florida, Gainesville, Florida, USA, Honorary Citizen of Berat, Albania. Prof. Papajorgji is a member of the group awarded the Prize of the Republic for the study "On the Conditions of the Olive Tree in Albania", 1986.

Dušanka Savić-Pavićević Faculty of Biology, UBG, SRB

Repeat Expansion Disorders in the Genomic Era

Abstract: Short tandem repeat expansions in the human genome cause >50 rare neurological diseases. After the initial success in the 1990s, when the genetic basis of clinically well-known diseases such as myotonic dystrophy, Huntington's disease, and Fragile X syndrome was finally solved, the main barrier in studying long, repeated DNA sequences was a technological limitation. The development of novel long-read sequencing technologies, including nanopore sequencing, is rapidly transforming the analysis of repeat expansions and has a huge potential to speed up gene discovery and clinical diagnosis. Besides, long-read sequencing is expected to improve understanding of pronounced individual variability among patients which is crucial for the design of clinical trials testing novel therapeutics for these incurable diseases.

Bio: Dušanka Savić-Pavićević is a Professor of Molecular Biology. She was born in Kotor and completed elementary and high school in Bar. She earned BSc, MSc and PhD degrees from the University of Belgrade-Faculty of Biology. She is a principal investigator with expertise in human molecular genetics and its application in biomedical research (>80 papers, GS citation >1500, h index 22). She is an expert witness for forensic genetics and the Head of the Center for Human Molecular Genetics supervising rare disease genetic testing, paternity testing and newborn screening for spinal muscular atrophy. She serves as the President of the Serbian Society for Molecular Biology.

Petar Seferović SANU, SRB

Advances in Cardiology

Abstract: This presentation sheds light on the ongoing research in the domain of cardiollogy with the stress on the emerging approaches of the world's leading institutions. Both prevention and treatment are covered through a description of the state-of-the-art procedures. The presentation concludes with a summary of the most important trends in the field.

Bio: Petar M. Seferović, MD, PhD, FESC, FACC; Co-Editor for Eastern Europe, European Heart Journal; Vice-president, European Society of Cardiology (2020-2022); President, Heart Failure Association of the ESC (2018-2020); Academician, Serbian Academy of Sciences and Arts; Professor of Cardiology, University of Belgrade Faculty of Medicine and Heart Failure Center, Belgrade University Medical Center; President, Heart Failure Society of Serbia.

ABSTRACTS & BIOSKETCHES

Bratislav E. Stipanić Project Biro Utiber, SRB / HUN

Modern Cable-Stayed Bridges

Abstract: Modern cable-stayed bridges, with multi-stayed cables, are constructed for spans 200-1200m as 2-spans, 3-spans and multi-spans structures; having one, two or several pylons. Also they are applicable for modest spans having limited bridge deck depths and for footway/cycle bridges. The wide variety of cable-stayed bridges has been built all over the world; having steel, concrete or composite deck and steel or concrete pylons. Modern cable-stayed bridges have the effective architecture appearances, because of layout combinations related to: configuration of cable stays (harp, modified harp, fan or star) in single or double "planes" (with back-stays or without); type of steel or concrete pylon (single, double, portal, A-shaped, H-shaped, Y-inverted, M-shaped) – vertical, inclined or spaced; and type of steel, concrete or composite deck (box beam with/without struts, 2 or multi beams). Paper author's designs of cable-stayed bridges are analyzed as well.

Bio: Born in 1949 in Kotor. He got BSCE, MSCE & PhD degree on Belgrade University – Faculty of Civil Engineering – where he was employed until 2014 giving lectures on Metal Structures and Bridges; afterwards professor on State University in Novi Pazar until 2018. From 2019 he has been employed in Project Biro Utiber Novi Sad. His scientific research has been dedicated to the analysis of bridge structures (133 published papers). His professional work has been related to design of bridges (Solidarity Bridge in Plock across Vistula River spanning 375m & other bridges) and supervision of construction works (Ada Bridge in Belgrade, Bridge at Ostružnica, Bridge at Sremska Rača – all across Sava River). He is chairman of IABSE National Group Serbia.

Petar Šćepanović Roche, Basel, CHE

Interplay Between Human Genetics and the Microbiome in Patients in Clinical Trials

Abstract: For most diseases, individual risk is influenced by genetic and non-genetic factors (including diet, socio-economic status, etc.). Microbiome, a collection of bacteria, viruses and fungi, within a human host has an important function in a variety of biological processes. Predominantly shaped by the environment, microbiome has been linked to a plethora of diseases, including cancer, metabolic syndromes and neurological disorders, as well as, response to certain drugs. By jointly investigating genetic and microbiome effects we aim to shed light on their cause / effect relationship on diseases etiology and response to treatment in patients in clinical trials.

Bio: Petar Šćepanović was born in Cetinje, Montenegro. After Gymnasium "Slobodan Škerović" in Podgorica, he enrolled at University of Turin, Italy studying Biotechnology. After obtaining his Bachelors, he continued his Master's studies in Molecular Biotechnology at the same University. He continued his education by obtaining a PhD in Human Genomics at EPFL in Lausanne, Switzerland. He then continued his research activities at the University of Cambridge, UK where he was a Research Associate in the Department of Public Health and Primary Care. He is currently a Senior Scientist at pRED (Pharma Research and Early Development) of Roche in Basel, Switzerland.

Ranko Šćepanović V.P. Intel, USA

Advances in Microprocessor Technologies and Applications

SEE THE INTERVIEW AT THE WEB PORTAL OF UOM, TO APPEAR SOON.

Bio: Dr Ranko Šćepanović is a Vice President of Intel Corporation, Santa Clara, California, USA. Prior to that he was a Vice president of LSI Logic, x, California, USA. He spent some time at Stanford University as a postdoc. His PhD is in Matematics, from Moscow, Russia. His basic degree, also in Matematics, is from Belgrade, Serbia. He was an award-winning High school student of The Matematics Gymnasium in Belgrade, Serbia. He was born in Kolašin, Montenegro. He completed his Elementary school education in Kolašin and Podgorica.

ABSTRACTS & BIOSKETCHES

Petar Tadić Yale, USA

Bootstraping Quantum Field Theories

Abstract: Quantum field theories are the fundamental framework for contemporary high-energy physics. Their solutions can be bounded or sometimes obtained exactly by utilizing consistency conditions and symmetry of a particular theory. We discuss this bootstrapping procedure in quantum field theories with conformal symmetry. These theories are ubiquitous in modern physics; for instance, they describe the second-order phase transitions in condensed matter systems and provide a valuable tool to gain insight into black hole physics and quantum gravity through holographic duality. We review some of the current results of conformal bootstrap and discuss the various options for future work on this topic.

Bio: Petar got his bachelor›s degree from the University of Belgrade, Faculty of Physics. He obtained his master›s degree at the University of Oxford, UK, and his Ph.D. at Trinity College Dublin, Ireland. He is a postdoctoral associate in the Physics department at Yale University, USA. He is elected assistant professor in the Scientific Computing Laboratory at the Institute of Physics, Belgrade. He was awarded the best young scientist award by the Montenegrin Ministry of Science in 2012. He works in theoretical high-energy physics. He is the author of nine papers, which have garnered 352 citations (according to Google Scholar).

Demetrios Theophylactou Harvard University, USA & Cosmos Open University, CYP

Sinergizing Technology and Social Studies

Abstract: Science and technology, on one hand, and social studies and diplomatic activity, on the other, help each other advance. Scientific knowledge is used to create new technologies. New technologies allow scientists to explore nature in different ways and make new discoveries. Economic and social development of a country rely on advanced science and technology, skilled, educated workforce as well as constant synergies between scientific and social institutions. Economic diplomacy plays an active role to this end, particularly in so far as promoting scientific and educational collaboration with other advanced states, and directly engaging diaspora in the social, economic and scientific activities of a country.

Bio: Demetrios A. Theophylactou was trained in University of Oxford, Harvard University and Washington State University, and possesses B.A. and M.A. degrees in Communication, and a Ph.D. in Political Science. He worked for both Cyprus and international media until 1990, including the Cyprus Broadcasting Corporation and CNN. He joined the Diplomatic Service at the Permanent Mission of Cyprus to the United Nations in NY, in 1994, and then served at the High Commission of Cyprus to Australia. He moved on to the Permanent Representation of Cyprus to the European Union in Brussels and then was appointed as High Commissioner of Cyprus in India, with parallel accreditations in eight SE Asian countries. Between his posts, he served at the headquarters of the Ministry of Foreign Affairs, including as Head of Department for Development Cooperation, Humanitarian Aid and International Economic Organisations. From 2020 until 2023, he served as Ambassador to Serbia with parallel accreditations to Montenegro and North Macedonia.

Milo Tomašević School of Electrical Engineering, UBG, SRB

Time-Memory Trade-off in Computer Applications

Abstract: Time of execution and memory space are among the most important resources in both software and hardware applications, so a primary goal is to minimize their consumption. Unfortunately, most often it is hard to achieve since these requirements are opposed. Consequently, finding an optimal balance is a key concern in the design and implementation of such applications. This talk will bring various illustrations of this problem. Special attention will be devoted to the application of time-memory trade-off in two recent related research approaches: 'perfect' chain-based cryptanalytical process and performance improvement of the OSK protocol used in the RFID device identification.

Bio: Milo Tomašević was born in Nikšić, Montenegro, where he completed elementary and high school. He obtained BSc, MSc, and PhD degrees from the School of Electrical Engineering, Belgrade (UB SEE). First, he was with Mihajlo Pupin Institute, Belgrade, and then with the UB SEE, where he is a full professor. In the period 2017-21. he was the Dean of the UB SEE. He was visiting researcher at Purdue University, USA. Among other universities, for two decades he was visiting professor at the University of Montenegro, Podgorica. He published 130 scientific papers and obtained awards for some of them. His work is cited 1200 times (GS, H-index 16). He participated in more than thirty projects that resulted in innovative software/hardware realizations. He was a reviewer and member of the program boards for international and domestic journals and conferences. With coauthors, he delivered invited talks and tutorials abroad in companies, universities, and conferences. He is a co-author of two books published by IEEE Computer Society Press. His main research interests are computer architecture and organization, parallel systems, algorithms and data structures, cryptanalysis.

ABSTRACTS & BIOSKETCHES

Vuk Uskoković SDSU, San Diego, USA

Selected Research from the Past Decade and Development Opportunities

Abstract: In this series of presentations, I will elaborate on some of the personal R&D accomplishments from the last decade. The primary emphasis will be on biomaterials for various applications in medical engineering and pharmaceutics. Research findings with the potential for product development and commercialization through technology transfer will be highlighted. Factors governing the transfer of technologies to developing countries, including Montenegro, will be discussed. The vision for the scientific and technological progress of Montenegro will be shared with the audience and brought up for the debate.

Bio: Vuk Uskoković is the co-founder and chief scientific officer at the biotech startup, TardigradeNano, and a lecturer in engineering at San Diego State University. Formerly a professor at University of Illinois in Chicago, Chapman University and University of California in Irvine, and a principal investigator at University of California in San Francisco, Dr. Uskoković is a world-renowned expert in solid state chemistry, biomaterials, medical devices, and nanotechnologies. Dr. Uskoković is the recipient of the prestigious Pathway to Independence Award from the National Institutes of Health and an author of over 200 research papers, reviews and essays from various fields of natural science and humanities.

Milica Vujković Faculty of Physical Chemistry, UBG, SRB

Looking at the Future Through the Prism of Battery Systems

Abstract: We are witnessing a low-carbon energy transition, where electrochemical power sources, including batteries, supercapacitors, and fuel cells, lie at the heart of a more sustainable energy supply. If we look at the future through battery lenses and periodic table, the long-term perspective of Li-ion technology is not so promising, despite its high energy. Lithium is a limited resource so more sustainable, alternative solutions must be found, first in low- and then in high-energy applications. In that regard, several energy storage systems, based on plentiful elements, have been developing rapidly. The talk will cover the most promising ones.

Bio: Milica Vujković was born in Nikšić, Montenegro. She is employed at the University of Belgrade – Faculty of Physical Chemistry, where she graduated and received PhD in the area of Li-ion batteries. Her research interests are focused on energy-related applications. Milica received many awards and held various lectures, including courses within the prestigious MESC+ master program. She organized COIN2022 Belgrade symposium held in SASA. She coordinates several projects including the ongoing NATOSPS project and holds 48 scientific papers, 1 book chapter and 3 nationally approved patents. Her papers, published since 2011, have been cited more than 1100 times with h=20.

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Ministry of Science and Technological Development

Scientific Symposium
Days of Diaspora and (Scientific) **Partners** (of Montenegro)
Naučni simpozijum
Dani Dijaspore i (Akademskih) **Prijatelja** (Crne Gore)
Podgorica
October **18-19** Oktobar **2023**

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UCG University of Montenegro

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Women and the Heart - A New Role of High-sensitive Troponin I in the Prevention of Cardiovascular Disease

Goran Krstačić[1,2,3], **Antonija Krstačić**[2,3,4]

[1] Institute for Cardiovascular Prevention and Rehabilitation (Srčana), Zagreb, Croatia
[2] J. J. Strossmayer University of Osijek Faculty of Dental Medicine and Health Osijek
[3] J. J. Strossmayer University of Osijek Faculty of Medicine Osijek
[4] University Hospital Center "Sisters of Mercy", Zagreb, Croatia

*Corresponding author: **Goran Krstačić**

ABSTRACT

Aim: To introduce and to estimate the effectiveness of a high-sensitive troponin-I (hsTnI) guided screening program for cardiovascular disease (CVD) and evaluate potential clinical and health economic consequences of applying this program.

Background: Existing tests for assessing the risk of cardiovascular diseases such as Framingham Heart study or SCORE I and II are not cardio-specific and they most often use only the parameters of age, gender, total cholesterol, smoking, and blood pressure.

Results: A study of asymptomatic women aged above 45 years with no specific symptoms and no confirmed or known coronary artery disease who voluntarily participated in a risk assessment and screening program for CVD in Zagreb, Woman Heart Project (WHP) was performed. Participants were stratified into three risk categories according to their hsTnI level. Subjects in the moderate and high-risk class were referred to further non-invasive cardiovascular diagnostic test and coronary angiography or PCI (Percutaneous Coronary Intervention), if required. The number of CVD events and deaths, direct and indirect costs, and quality-adjusted life years (QALY) were assessed over 10 years from a societal perspective. In the model, WHP reduced the incidence of acute CVD events by 180 per 10,000 subjects, equal to a number-needed-to-screen of 56. CVD-related mortality decreased by 40%.

Conclusion: Screening asymptomatic female subjects with hsTnI and guiding those at higher risk to further cardiac testing, identified women with coronary artery disease and referred those at high risk to further diagnostic tests. In a cost-effectiveness analysis, this strategy might reduce the CVD related burden and mortality and would likely be cost-effective.

Clinical significance: High-sensitivity troponin-I (hsTnI) should be a part of daily preventative test for cardiovascular disease.

BACKGROUND

Cardiovascular disease (CVD) is a major contributor to the worldwide health burden and the number one cause of death globally (1), and it is expected that by 2030 this number of deaths will increase from the current 20.5 million to 23 million. In Europe, about 4 million people die annually from cardiovascular diseases, or 45% of all deaths. In Croatia, CVD's are also at the top of the mortality scale, and about 22,300 people died from them in 2022, i.e.35% of the total number of deaths.

The total economic burden of CVD in the EU was estimated to €210 billion in 2015 with 53% and 21% accounted for by direct medical costs and productivity losses (2). In Croatia, although mortality from CVD has decreased over the last decade, CVD remains the leading cause of death and accounts for 48% of deaths in women and 37% in men (3, 4). The general mortality rate from CVD is higher in women than in men, and CVD in women have received special interest in the last ten years (4). Due to a wide distribution of behavioral risk factors in Croatia including tobacco smoking and low physical activity, the mortality

from preventable causes in Croatia is above the EU average (5). With a share of almost 13%, CVD is the leading cause of hospitalization in Croatia with an average length of hospital stay of 7.2 days for men and 7.8 days for women (4). To decrease the burden of CVD, reliable tools are required to identify persons without known CVD who are at high cardiovascular risk and to guide those persons to lifestyle modifications or preventive medication (6-8). Several risk assessment strategies have been used based on large prospective cohort studies, such as the Framingham Heart study (9). In European countries, the SCORE (Systematic Coronary Risk Evaluation) risk calculator has been created and recently updated to estimate the 10-year risk of fatal CVD in asymptomatic individuals (10, 11).

The cardiac specific protein high-sensitivity troponin-I (hsTnI) that is found detectable in over 90% of the general population (12), has proven to be the most promising biomarker for determining the individual cardiac risk (13). It has been shown that elevated hsTnI values are associated with incident fatal and non-fatal CV events, and act as an independent predictor for future CVD events (14, 15). Although hsTnI is being discussed for targeted primary prevention of asymptomatic individuals, a consensus on a uniform algorithm has not been proposed yet (13).

The objective of this study is to test the effectiveness of a hsTnI guided screening program in a voluntary women health program and estimate potential clinical and health economic consequences of applying this program at a national level in Croatia.

METHODS:

The Women & Heart Project (WHP) was implemented at the Institute for Cardiovascular Prevention and Rehabilitation (Srčana) in Zagreb as a voluntary program to assess cardiovascular risk in women aged above 45 years, with no specific symptoms and no confirmed or known coronary artery disease. All participants provided written informed consent an agreement in accordance with the General Data Protection Regulation of the EU and following the ethical principles outlined in the Declaration of Helsinki. Participants completed an online questionnaire about their principal characteristics, medical history, and self-reported awareness of cardiovascular risk factors. A blood sample was taken for the evaluation of laboratory parameters including hsTnI. According to their hsTnI level, participants were stratified into three risk categories: Low-risk (hsTnI <4ng/L), moderate-risk (hsTnI ≥4 – ≤10ng/L), or high-risk category (hsTnI>10ng/L). Subjects at low risk were discharged home without further intervention or follow-up. All subjects in the moderate and high-risk class were referred for non-invasive cardiac workup that consisted of examination by a cardiologist, electrocardiogram at rest (ECG), echocardiography, exercise ECG test and 24-hour ECG. If the left ventricular ejection fraction on the echocardiography was less than 50%, or a ST-segment depression (≥1mm) was observed in the exercise ECG test or 24h ECG test, subjects were referred for invasive or non-invasive coronary angiography (MSCT coronary angiography or SPECT nuclear cardiology or direct coronary angiography related to according to the findings and agreement with the patient. In subjects with significant obstructive coronary disease (narrowing ≥50% of coronary arteries) or high-risk plaques, percutaneous coronary intervention was recommended and subsequently performed. Subjects in the high and moderate hsTnI category with no findings in coronary angiography were considered for preventive treatment (mostly lifestyle changes, high-dose statin, aspirin or beta receptor blockers).

RESULTS

A total of 1,034 women voluntarily agreed to participate in the WHP. Mean age at baseline was 55.6 (interquartile range 49.0 – 62.0) years. Based on the online questionnaire, the prevalence of smokers was 25.0%, 26.6% had hypertension, 45.9% dyslipidemia, and 7.3% diabetes. Depending on the hsTnI-results, 921 (89.1%), 100 (9.7%), or 13 (1.3%) subjects were classified as low, moderate, and high risk, respectively. All subjects at moderate and high risk were assessed with non-invasive cardiac tests (n=113, 10.9% of all). Of these, 26 (2.51% of all) were further referred to invasive cardiac tests, of which 14 and 12 subjects fall into the moderate and high hsTnI risk category, respectively. Despite classified as low risk, one woman was referred to cardiac workup but was found negative in coronary angiography. A total of 12 (1.16% of all) subjects were eventually diagnosed with CAD, three (3.0% of women at moderate risk) and nine (69.2% of women at high risk) of whom were categorized in the moderate or high troponin risk class, respectively.

In the standard strategy, 429 (95%CI 411; 445) CVD events and 89 (81; 91) CVD related deaths occurred per 10,000 subjects over ten years. In the WHP strategy, 53 (95%CI 46-56) per 10,000 screened women were diagnosed with CAD during the workup process. Compared to current practice, the incidence of CVD events was reduced by 180 per 10,000 (95%CI 177; 184) resulting in a 40% decrease of CVD related deaths. The average number of women screened to prevent one CVD event in a period of ten years was 56. The reduced disease burden led to a gain of 15.5 (95%CI 12.8; 17.2) additional QALYs per 1,000 subjects.

Table 1. Management of subjects participating in the Women & Heart Project Zagreb.

Troponin risk class (RC)	N	% of all	Non-invasive work-up		Invasive work-up		CAD		
			N	% of all	N	% in RC	N	% of RC	% of all
All	1034	100.0	114	11.03	27	2.61	12	1.16	1.16
Low	921	89.1	1	0.10	1	0.11	0	0.00	0.00
Moderate	100	9.7	100	9.67	14	14.00	3	3.00	0.29
High	13	1.3	13	1.26	12	92.31	9	69.23	0.87

Troponin risk class: Low (hsTnI <4ng/L) Moderate (hsTnI ≥4 and ≤10ng/L) High (hsTnI >10ng/L). Non-invasive workup: examination by a cardiologist, electrocardiogram (ECG), echocardiography, exercise ECG test and 24-hour ECG. Invasive workup: coronary angiography.

Table 2. Current practice and WHP.

hsTnI risk class	CP				WHP				
	All	%	CVD	Risk, %	WHPP	CAD	Prevention	CVD	Risk %
All	100,000	100.00	4,293	4.3	10,864	531	10,333	2,488	2.5
Low	89,136	89.14	2,315	2.6	0	0	0	2,315	2.6
Moderate	10,086	10.09	1,681	16.7	10,086	238	9,848	169	1.7
High	778	0.78	297	37.3	778	293	485	4	0.5

MS: Microsimulation (n=100,000 trials).

Table 3.

hsTnI risk class	CP	WHP	ARR	RRR	NNS
All	0.043	0.025	0.018	0.420	56
Low	0.026	0.026	0.000	0.000	n/a
Moderate	0.167	0.017	0.150	0.901	7
High	0.373	0.005	0.368	0.986	3

MS: Microsimulation (n=100,000 trials). CP: Current practice. WHP: Women & Heart Project. ARR: Absolute risk reduction. RRR: Relative risk reduction. NNS: Number needed to screen.

DISCUSSION

The WHP is the study that provides prospective observational data for using high-sensitivity troponin I for CVD risk stratification in an asymptomatic population. More than 1,000 women in Zagreb volunteered to participate in the study. Guided by the use of the biomarker hsTnI, participants were excluded or referred to cardiac testing and interventional cardiology, if required. More than 89% of enrolled women fall into the low-risk class for CVD and were excluded from further workup. In

10.6% of subjects referred to further workup, significant CAD was identified and managed, likely preventing acute cardiac event and/or CVD related death. This study confirmed the association between the hsTnI level and the cardiovascular outcome in asymptomatic women. In a trial-based cost-effectiveness model, the WHP strategy was extrapolated to the national level in Croatia. Compared to current practice, WHP reduced the number of CVD events and related deaths by 42% and 40%, respectively, which has a clear public health impact. In summary, this resulted in a statistically significant increase of 15.5 QALYs per 1,000 women over a period of 10 years. Testing women with the WHP protocol increased direct medical costs, but decreased indirect costs caused by CVD related productivity loss. The WHP was a voluntary program and women provided information in a self-reported survey prior the first laboratory test, and the accuracy and quality of cohort characteristics could not be assessed. A study suggests that voluntary screening programs tend to underestimate the disease prevalence. Whether the women who participated in the WHP are representative of the population or whether a selection bias has to be considered, is not clear. Since cost-effectiveness of the WHP strategy increases with risk, however, the results can be considered conservative. Current risk assessment tools have several limitations such as a restricted age range or the difficulty of applying such tools in regions with different baseline risk for CVD. Some limitations have been addressed by the development of the updated SCORE2 to estimate 10-year CVD risk in Europe which is also recommended by the guidelines on CVD prevention by the European Society of Cardiology (ESC). However, the use of risk assessment tools is highly variable, and there is still a lack of evidence in the overall effectiveness and cost-effectiveness of risk assessment tools.[8] Consequently, the implementation of a uniform risk assessment tool including SCORE into routine practice is largely insufficient.[8] Several articles have demonstrated and discussed the usefulness of hsTnI for CVD risk assessment.[14] The most efficient algorithm for using hsTnI for CVD risk assessment is still subject for discussion,[14] and only one article is proposing a potential algorithm. We acknowledge several further limitations. Our study estimated the cost-effectiveness of applying the WHP strategy based on national figures and assumed a full coverage of the tested population, which is not realistic. This should be considered before interpreting potential effects on the national burden of CVD. As discussed, the model was not based on a controlled study, and the actual underlying CVD risk of the tested cohort compared to Croatian data is unknown. We only considered the first CVD event and did not take potential events into account that may occur after detecting CAD. Both aspects likely have an impact on all tested strategies and should be considered to finally assess the value of a new strategy. For CVD risk reduction in our model, we only used a mean value that was informed by the efficacy of statin treatment but did not further address the actual prevention measure. All results should be interpreted against these limitations. Future studies should evaluate specific hsTnI risk assessment algorithms in conjunction with and in comparison, to established risk assessment tool.

CONCLUSION

Assessing the cardiovascular risk in asymptomatic women with hsTnI and guiding those at higher risk to further cardiac testing, identified individuals with CAD and referred those at high risk to preventive measures. This strategy could reduce CVD related burden and mortality and would likely be cost-effective in Croatia. More studies are needed to confirm these findings.

CLINICAL SIGNIFICANCE

Assessing the cardiovascular risk in asymptomatic women with hsTnI and guiding those at higher risk to further cardiac testing.

AUTHOR'S CONTRIBUTION

Each author made substantial contributions to the work and interpretation of data for the work.

ORCID

Goran Krstačić https://orcid.org/0000-0003-0427-7229
Antonija Krstačić https://orcid.org/0000-0001-6932-5215

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Dani Dijaspore i (Akademskih) Prijatelja (Crne Gore)
Podgorica
October 18-19 Oktobar 2023

Time-Memory Trade-off in Computer Applications

Milo Tomašević[1], **Violeta Tomašević**[2]

[1]School of Electrical Engineering, University of Belgrade, Bul. kralja Aleksandra 73, 11120 Belgrade, Serbia, mvt@etf.bg.ac.rs
[2]Singidunum University, Danijelova 32, 11010 Belgrade, Serbia, vitomasevic@singidunum.ac.rs

ABSTRACT

Time of execution and memory space are among the most important resources in computer applications, so a primary goal of the designer is to minimize their consumption. Unfortunately, most often it is hard to achieve since these requirements are usually opposed. Consequently, finding an optimal balance is a key concern in the design and implementation of such applications. This paper presents various illustrations of this problem in the diverse areas of computing algorithms and applications. Special attention is devoted to the application of timememory trade-off in a TMTO-based cryptanalytical process that relies on the 'perfect' chains. Both probabilistic and simulation analyses are performed to obtain the chain characteristics.

Keywords: TMTO, time and memory complexity, cryptanalysis

1. INTRODUCTION

In the last several decades, computer systems have been ubiquitously employed in solving not only scientific and commercial problems and applications, but they are indispensable in everyday human life. There is a broad spectrum of computer systems of variable computing power that are well adapted to the problem size and type from mobile devices and embedded systems to supercomputers, data centers, and cloud computing systems. Although the speed and power of computer systems at each level are ever-increasing due to constant advances in technology and architecture, the problems and requirements constantly increase as well. Hence, it is essential that computer resources are most efficiently exploited.

The two most important resources when running applications in computer systems are the time of execution and the amount of memory used. Unfortunately, most often there is a contradiction between two opposing requirements in minimizing their consumption. Usually, managing one often means compromising on the other and it is not easy to find the *'sweet spot'*. Consequently, a major engineering concern is to find the optimal choice between two contradictory requirements in spending main computing resources, in both software and hardware design.

The balancing between time and memory is the essence of the TMTO (Time-Memory Trade-Off) approach. The TMTO examples are countless and can be found in almost every area of computing. Section 2 presents some illustrative examples of design choices that consider time and memory issues. After that section 3 is focused on a recent research effort that illustrates the application of the TMTO principle in cryptanalysis.

2. EXAMPLES OF BALANCING BETWEEN TIME AND MEMORY

2.1 TMTO in storing and accessing data structures

The problem of searching for an optimal balance between time and memory is very frequently found in storing different data structures. A simple example is the memory representation of a structure (or record) with various fields [1]. The problem arises when some fields are of size less than one memory word. The least amount of memory is consumed if the fields are allocated one after another. However, in this case, some fields may span between two words making the access time longer. Striving to decrease the access time, one word is allocated for each field and the size of the entire structure is larger than the sum of the sizes of all fields. A similar approach is followed when the size of a field is not an integer value of the word size. To make access easier, appropriate padding is added to such a field, so that it is aligned with the beginning of the word.

Quite similar design decisions are possible when the compiler allocates the storage for some array whose element size is not a multiple of a memory word. Fig. 1a shows the continuous allocation that attains 100% memory efficiency; however, access to an element is less time efficient and irregular (depending on its index). If padding or dummy space is added to each element as in Fig. 1b, the access will be more efficient and regular at the expense of lower memory utilization. However, if the size of an element is much less than the word size, such an approach would waste the memory a lot especially if the array length is large. In this case, the packing of several elements in one word with some padding if necessary (as in Fig. 1c) is a compromise between time and space requirements.

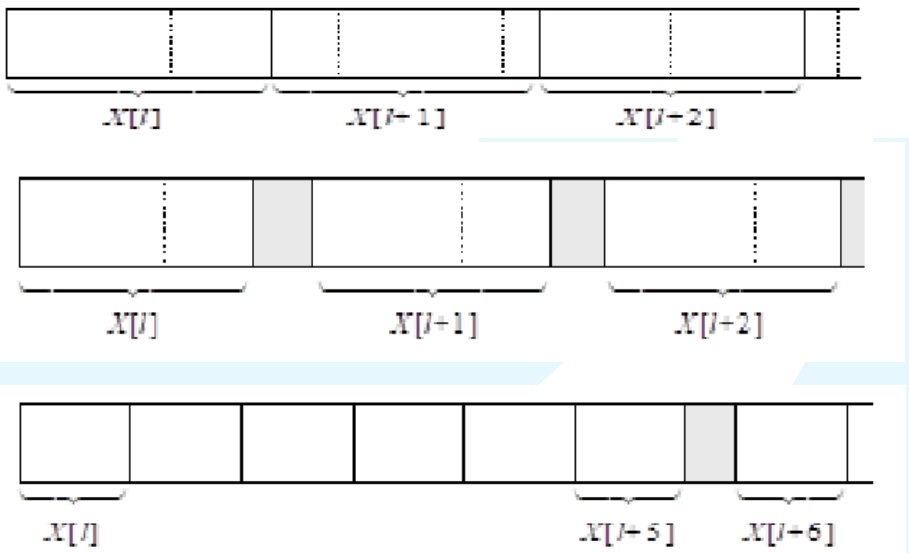

Fig.1 Allocation of an array: a) continuous, b) with padding, c) packing

Although memory is often traded for time in storing data, such an approach can be detrimental and can waste an unacceptable amount of memory. This is just the case in storing sparse arrays where zero-value elements largely prevail. The solution is to allocate the space for nonzero elements only. However, because of the usually irregular positions of nonzero elements, they cannot be accessed by calculating a simple address function, but indexes must be stored together with the value. There are several techniques of this kind: Coordinate of Objects (COO), Compressed Sparse Row (CSR), singly linked lists, the grid of linked lists, etc. Despite the need for additional storing of indexes, a large memory saving can be achieved, but access to an arbitrary element is much slower because the structure must be searched for given indexes. In addition, the insertion of a new nonzero element is now aggravated as well as its deletion, especially in vector-based representations.

Dynamic data structures such as graphs are known for their flexibility and suitability for modeling arbitrary non-linear relations of collections of objects. There are two usual graph memory representations: sequential (adjacency matrix) and linked (adjacency lists) [2]. As for memory, the adjacency matrix has a memory complexity of $O(n^2)$, while the memory complexity of adjacency lists is $O(n+e)$ where n is the number of nodes and e is the number of edges. There is no definite answer to which one is better as it depends on actual n and e values. As a rule of thumb, an adjacency matrix requires less memory for dense graphs especially if they are undirected when the matrix is symmetrical. In such a case, keeping only a triangular matrix makes it possible to save almost 50% of space. For usual relations between n and e values and especially for sparse graphs, adjacency lists are more memory efficient. Graph memory representation also directly determines the time complexity of the particular graph operations and entire algorithms. The adjacency matrix is more suitable for operations on a particular edge ($O(1)$ time for checking, adding, and removing some edge). However, adjacency lists are preferred in many algorithms (BFS and DFS traversals, spanning trees, shortest paths, etc.) since they rely on faster access of some node to all adjacent nodes (traversing its adjacency list instead of $O(n)$ time complexity of scanning the entire row of the adjacency matrix).

2.2 TMTO in searching and sorting

Searching data in some data sets is one of the most frequent operations in computer algorithms and it usually determines the time and memory complexity of programs [3]. If keys are used to identify the data records, the ideal search would access the appropriate data in constant time without time-consuming comparisons of its key with the keys of other records in the data set. Theoretically, it is possible with a directly addressed look-up table with capacity that covers the entire key space so that there is a table entry for each possible key value. Since the key is used to directly index the table and access the entry which is exclusive for a data record, operations such as searching, inserting, and deleting are performed in $O(1)$ time complexity.

However, frequently such a table is not practically feasible for usual key values because its size would be quite huge. For example, if some personal data are searched and the key is the personal ID (13 decimal digits), the size of the table would be 10^{13}, regardless of the amount of data records stored. To keep the natural keys and also restrict the table size, the solution is to employ some function that maps the keys to the entries of the table which size corresponds to the number of data records. This is the essence of the hashing method. However, rarely that 'key to table entry' is 1-1 mapping because there are situations when multiple keys are mapped to the same table entry. When such a *collision* happens, a procedure for its resolution is necessary. Now the data access time is increased with two components: calculation of the hash function for each access and collision resolution (only when collision is detected). Hence, the result is substantial memory savings at the expense of somewhat slower data access and practical feasibility, so performance is traded for memory.

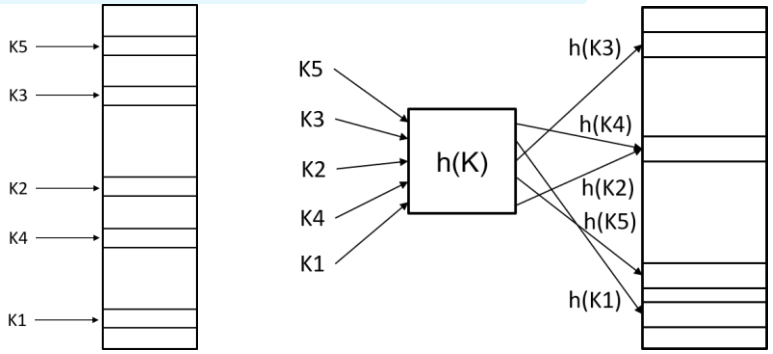

Fig. 2 Searching with a) directly addressed table, b) hash table

Efficient searching of the files stored in external memory (like discs) is extremely important because the access time of external storage is several times of magnitude slower than that of internal memory, especially keeping in mind that the files are usually quite large. External storage is cheap and abundant in size so the usual approach is to spend extra memory to significantly speed up the searching. To ease direct access to data records in a file, appropriate ordered index structures with corresponding keys are built. Examples of such structures are B (as in Fig. 3) or B+ trees. They achieve $O(\log_m n)$ time complexity which is quite acceptable since the value of branching degree m is rather high. The cost is $O(n)$ space overhead.

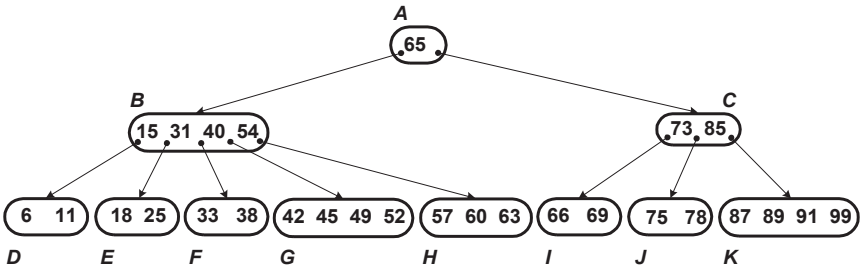

Fig. 3 B-tree as an index structure

2.3 TMTO in compiler optimizations

The execution time of a program and its memory consumption depend not only on the algorithm applied and the amount of data to be processed but also on the efficiency of the compiled code. To this end, optimizing compilers frequently perform some transformations of the compiled code that result in semantically equivalent but much more efficient code in using critical resources.

The most often approach is to decrease execution time at the expense of increased memory usage. One of the best examples is the *inlining* optimization which replaces the function call site with a copy of its body [4]. By its aggressive application, the program can be speeded up a lot because sometimes significant overhead of function calls is avoided. It can also improve the locality of reference and better enable further optimizations as well. On the other side, an evident penalty is paid since it inflates the code size (as in macro expansion). Hence, an excessive inlining can even impair cache performance. Therefore, inlining must be very cautiously applied for efficient spending of the optimization budget. Some heuristics are employed to perform a cost/benefit analysis for achieving an appropriate trade-off.

Quite the opposite logic can be found in *outlining* optimization. It searches for identical sequences of the code, encapsulates them into a separate function, and then replaces them with calls to this function. The obvious advantage is decreasing code size but the overhead of function calling increases execution time. This performance penalty can be mitigated by some additional gains like eliminating the *cold* code from the *hot* functions and, in turn, enabling the inlining of a *hot* code, improving the cache performance, and decreasing instruction cache bandwidth.

The most of program's running time is spent in loops so there are many loop-targeted optimizations intended to decrease this time. Loop control management is an inherent overhead that is observed as a performance impediment. *Loop unrolling* is an optimization where the loop body is repeated multiple times as in Fig. 4 [5]. The result is that the loop maintenance and control as well as the penalty of branch instructions are reduced, but the loop body now requires more space. Again, the factor of multiplication has to be moderate to prevent excessive code increase and a need for large instruction cache bandwidth. A somewhat similar optimization is *loop peeling* which removes the first or last loop iterations (as special cases) from the loop and moves them in front of the loop or after it.

```
for (int i = 0 ; i < 1024 ; i++)
    a[i] = i;
```

```
for (int i = 0 ; i < 1024 ; i += 8) {
    a[i] = i;       a[i+1] = i+1;
    a[i+2] = i+2; a[i+3] = i+3;
    a[i+4] = i+4; a[i+5] = i+5;
    a[i+6] = i+6; a[i+7] = i+7; }
```

Fig 4. Loop unrolling: a) normal loop, b) 8x unrolled loop body

One of the problems that prevents or restricts code optimizations is the existence of merge nodes in the control flow graph. The solution is the elimination of the merge nodes by code duplication. In this way, the preceding basic blocks are enlarged, and precise information about the flow of control is preserved. It enables separate optimizations for resulted blocks such as devirtualization, conditional elimination, constant folding, elimination of redundant memory accesses, etc. However, since this optimization can exponentially inflate the code it should be applied quite selectively.

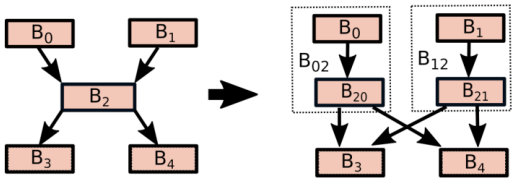

Fig. 5 Code duplication of the merge nodes in the control flow graph

2.4 TMTO in the memory hierarchy of the multiprocessors

Fast data access is crucial for the performance of parallel systems, particularly because the shared data is often located far away from the processors. The memory hierarchies in these systems are deeper than in uniprocessors and data-fetching latencies could be very high. Hence, the solution is to bring the data closer by their replication in the cache hierarchy to improve their locality and greatly speed up the access time. The existence of multiple copies of the same data requires larger overall memory space especially if data are widely shared.

However, writing to a local copy of shared data makes other copies stale. This is the essence of the well-known problem of cache coherence [6]. It implies the employment of either invalidate or update cache coherence protocols to ensure the access of other processors to valid data. This enhanced functionality of cache controllers and network interfaces imposes not only additional transistors and power but also incurs some time overhead for cache maintenance.

The design decisions on building cache hierarchy and protocols are quite sophisticated. One of the basic decisions is between shared or private cache within the processors. The shared cache decreases memory overhead (one copy instead of many) and cost of communication between different cores, eases the coherence maintenance, exhibits positive interference (one fetch for multiple uses), etc. On the other side, private caches have lower latency, higher bandwidth, and lower design complexity. A usual multicore design adopts private caches on the first and second levels closer to the cores for lower access time, and a shared cache at the third level for a higher hit ratio where the capacity is very large (Fig. 6).

Cache hierarchy usually enforces the *inclusion* principle which means that the contents of the higher level caches are supersets of the contents of lower level caches. It implies the existence of multiple copies of the same data throughout the hierarchy. Again, it is an investment of increased memory usage to attain a lower miss penalty at lower level. In addition, the higher level caches protect the lower level caches from unnecessary burden in preserving cache coherence.

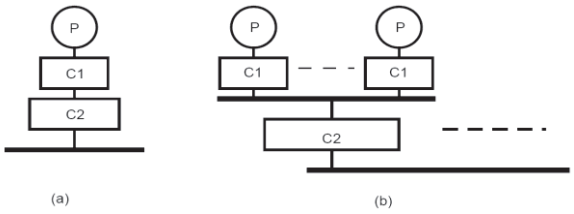

Fig. 6 Cache hierarchy with a) private L2 cache, b) shared L2 cache

Data layout in memory also deeply affects the amount of cache coherency time protocols even when there is no shared data and processes access only private data. That situation happens when logically private data of two processes fit into the same cache block. Since the granularity of coherence is usually at the block level, a detrimental effect of *false sharing* induces unnecessary time overhead. It can be avoided if the data of each process are kept in separate blocks padded with the dummy bytes, performance is gained at the expense of space. A similar approach is followed in the data layout of arrays in which accesses of different processes are interspersed. To avoid the time overhead of cache coherence protocols, the elements are aligned to the cache block boundaries. It can inflate the memory occupancy of the array.

2.5 TMTO (almost) everywhere

Nowadays modern programs handle rather big data sets. The space for their keeping can be saved by exploiting inherent statistical redundancy. Data compression algorithms can find and eliminate this redundancy and achieve a significant compression ratio (especially in lossy compression). Most often the data should be uncompressed for processing and time overhead is paid. The compression saves not only the space but the transmission bandwidth as well making their transfer faster, e.g. in streaming large multimedia data sets.

Graphics processing can be both memory and compute-intensive. If an image is rendered on each change and saved as a bitmap, it consumes a substantial amount of memory but it is immediately available. Abstracting all other pros and cons, keeping an image in the vector format consumes far less memory but the time is needed for its rendering to be displayed. Programming style also has some consequences on the time-memory trade-off. Recursion is a technique that solves a problem by dividing it into parts and calling the same algorithm repeatedly until it is reduced to some simple final calculation [7]. It is quite attractive because it requires low programming effort and produces compact and elegant code. The compiled code usually consumes much less memory than its iterative counterpart which is also more demanding to produce. However, recursive programs are by far less efficient in execution than the iterative versions since the multiple function calls are responsible for high time overhead. More stack space is also needed to keep the calling contexts. An illustrative example is the calculation of Fibonacci numbers where iterative implementation has O(n) time complexity while the recursive variant has exponential time complexity O(c^n).

And there are more and more examples. Each attempt to exhaustively cover this topic would be unsuccessful.

3. A CASE STUDY: TMTO IN CRYPTANALYSIS

The TMTO approach was initially proposed by Martin Hellman in cryptanalysis of the DES block cipher cryptosystem [8] but it is quite general and can be applied to stream cipher systems as well [911]. The essence is to find an appropriate balance between compute-intensive exhaustive searching in a huge key space and memory-bound lookup tables. The goal is to find a secret key K used by the encryption function E for encrypting the plaintext P to the ciphertext C, $C = E(P, K)$.

3.1 Hellman's method

The procedure consists of two steps: preparatory and attack phases. The one-time preparatory phase produces a convenient data structure that would significantly speed up further attacks so the time and memory overhead of the first phase are amortized with multiple attacks.

The preparatory phase covers the key space by producing m chains (logically linked lists) of fixed length t. An arbitrary k-th chain starts with a randomly chosen key, SP_k, and each subsequent node is obtained by applying the function E to encrypt the chosen plaintext block P_0 and produce the ciphertext block C using the previous node value as the secret key. Hence, each node in the chain behaves as the ciphertext block for previous encryption and the secret key for the current encryption. If the lengths of the ciphertext and the key don't match, a justify function J should be employed to adjust them. Therefore, ith node in the chain, key_i, is obtained as $key_i = J(E(P_0, key_{i-1}))$. The nodes are repeatedly generated until the t-th node (EP_k) is obtained. When all chains shown in Fig. 7a are constructed, only the starting and ending nodes of each chain (SP_k, EP_k) are saved in memory for the attack phase.

The goal of the attack phase is to find the secret key used for the encryption of the plaintext that produced the known ciphertext C. For this purpose, the appropriate chain that contains the secret key K, used in the first phase to obtain C, has to be identified and searched until K is found. This chosen plaintext attack is general in essence and doesn't depend on the particular E function. The process starts from the given ciphertext C which is used as the key to produce the next node in exactly the same way as in the preparatory phase. If the obtained node value matches an ending point (e.g., EP_k) from the table produced in the preparatory phase, the appropriate chain is recognized and it can be reconstructed from its corresponding starting point (SP_k) until the node with given ciphertext C is reached. Now, the predecessor of C in this chain is the secret key K (Fig. 7b).

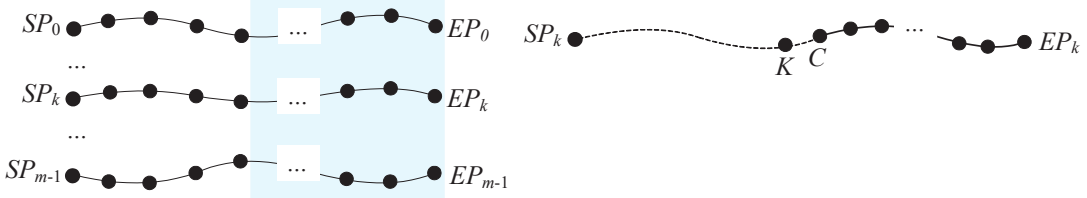

Fig. 7 Hellman's chains: a) chains generated in the preparatory phase, b) reconstruction of the chain with the secret key in the attack phase

Obviously, it will be beneficial for the attack phase if all nodes from the chains generated in the preparatory phase are preserved since the time overhead of calculating the node values would be avoided. However, it would imply huge and even infeasible memory demands so saving only starting and ending points per chain and its later reconstruction is an example of the time-memory trade-off.

Theoretically, the attack should be successful if $t \cdot m = N$ where N is the key space size. However, even in such a case, the entire key space can't be covered in practice. Since the encryption function expresses random behavior, multiple occurrences of the same node values are not only possible but practically inevitable. Hence, the chains contain only a subset of the key space and there is no guarantee that a key will be found at all which makes the attack procedure probabilistic.

The occurrence of the multiple same key values in different chains is responsible for merging of two or more chains. The common part of two chains is generated twice (e.g., from the merge point until EP_i in Fig. 8a) which decreases the efficiency of the preparatory phase and coverage of the key space. Similarly, a node value that is already included in the same chain can arise which makes a loop at the end of the chain (Fig. 8b). Key repetition induces irregular situations and detrimental phenomenon of false alarms [12,13] that prevent successful key finding. For example, in the attack phase during traversal of j-th chain starting from C, ending point EP_i will be reached instead of corresponding EP_j, the wrong i-th chain will be reconstructed and secret key K can't be found (Fig. 8a).

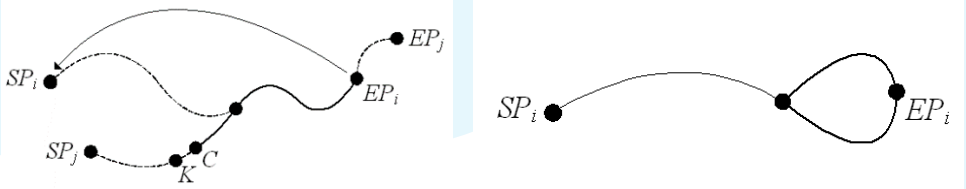

Fig. 8 False alarm situations: a) two chains, b) looping in the chain

Along with his TMTO proposal, Hellman also devised a way to reduce the probability of false alarms by organizing the chains into several tables and associating different random functions F to them. For the same purpose, Oechslin proposed Rainbow Tables (RT) with different reduction functions for each table column [14].

3.2 Perfect chains

All previous proposals can only decrease the probability of false alarms but not eliminate them. In order to completely solve this problem, the perfect chains are proposed in [15]. The proposal relies on keeping the evidence of the keys already included in the chains during their generation in the preparatory phase. To this end, an interval tree is devised. It is a kind of binary search tree where the content of a node is an interval of successive key values instead of a single key value [2].

In the preparatory phase, a generation of the first chain starts with a random key value, and the generation of the chain follows a similar procedure as in the basic Hellman's TMTO method. However, the obtained key value intended for the subsequent node is checked for presence in the interval tree. If this key value is not found in the tree, it is inserted into the current chain, and its generation carries on. Otherwise, if the key value is already in the tree, the current chain is terminated. Then, the next chain is started with a minimal key value not used in the previous chains and not found in the interval tree. The chains are generated until all keys from the key space are included.

The proposal of perfect chains prevents the occurrence of key repetition and achieves full coverage of key space. It completely eliminates the false alarm phenomenon and guarantees a successful key finding. Therefore, the method is fully deterministic.

3.3 Analysis of the perfect chains' characteristics

The practical applicability of the TMTO perfect chains-based method depends on the implementation of interval trees and the chain characteristics as well. The viability of the preparatory phase greatly depends on the interval tree implementation and an analysis conducted in [16] has shown that the time complexity is O(log *n*) while the memory complexity is O(*n*). The performance of the attack phase depends on some characteristics of the perfect chains such as the number of chains, their average lengths, the probabilities that a chain will have a certain length, the coverage of the key space, etc. Therefore, appropriate theoretical and simulation analyses are necessary.

Let u_k be the number of keys already included in chains C_1,..., C_{k-1} plus the first key of the kth chain. Then holds that $u_1 = 1$ and

$$u_k = 1 + \sum_{j=1}^{k-1} l_j \qquad k = [2, m]$$

where m is the overall number of chains, and l_j is the average length of the j-th chain. There follows that $u_k = u_{k-1} + l_{k-1}$.

The k-th chain begins with a new value, SP_k, with the probability of not being used before equal to 1. If the key values are randomly chosen, the probabilities that the k-th chain will be terminated (lower branches) or continued (right branches) are depicted in Fig. 9.

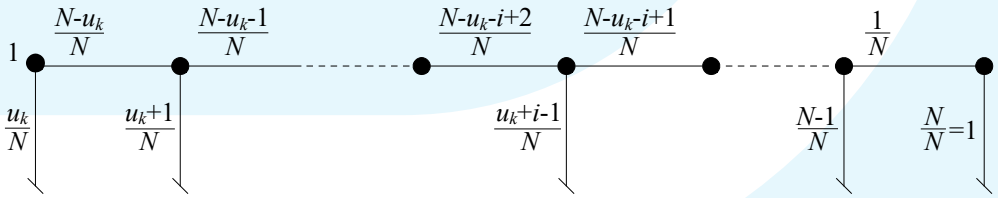

Fig. 9 The probabilities of continuation and termination of the k-th chain in each step

If $p_k(i)$ is the probability of choosing a new key value in the ith step of the k-th chain, and if l_k is the average length of this chain, according to Fig. 9 there follows:

$$p_k(i) = \frac{N - u_k - i + 2}{N} \cdot \frac{u_k + i - 1}{u_k + i - 2} \cdot p_k(i-1) \qquad p_k(1) = \frac{u_k}{N} \qquad i = [2, N - u_k + 1]$$

$$l_k = \sum_{i=1}^{N-u_k+1} i \cdot p_k(i)$$

Elimination of the recurrence gives the probability $p_k(i)$ that the k-th chain will be continued in the i-th step:

$$p_k(i) = \frac{u_k + i - 1}{N^i} \cdot \frac{(N - u_k)!}{(N - u_k - i + 1)!} \qquad i = [1, N - u_k + 1]$$

Since $p_k(i)$ function is discrete, the corresponding interpolation polynomials in the Lagrange form for different chain ordinal numbers k are obtained and presented in Fig. 10 as more descriptive.

The starting and ending points of the curve that correspond to k-th chain are, respectively,

$$(1, p_k(1) = \frac{u_k}{N}) \quad \text{and} \quad (N - u_k + 1, p_k(N - u_k + 1) = \frac{(N - u_k)!}{N^{N-u_k}})$$

There are two characteristic shapes of the curves. The one starts increasing, reaches maximum, and then decreases to zero (e.g., for the first chain). For this type, there is some value i_{kmax}, so that for lower i the probability of extending the chain increases with i, while for higher i it is more probable to terminate the chain. The second type of curve has an ever negative slope (e.g., for the jth chain). In this case, in each further step the probability that the chain will be extended steadily decreases. By derivation of $p_k(i)$ function values of i_{kmax} and the maximum value p_{kmax} are obtained as:

$$(i_{k\max} = \frac{2u_k - 1 - \sqrt{1+4N}}{-2}, p_{k\max}(i_{k\max}) = \frac{u_k + i_{k\max} - 1}{N^{i_{k\max}}} \cdot \frac{(N-u_k)!}{(N-u_k-i_{k\max}+1)!})$$

For the first chain ($u_k = 1$) it is obvious that $i_{1max} \approx \lfloor \sqrt{N} \rfloor$. If we assume that the length of the first chain is $l_1 = i_{1max}$, then follows that $u_2 \approx \lfloor \sqrt{N} \rfloor + 1$. It means that the curve with maximum corresponds to the first chain only, while for the second chain and every other the curves always have a negative slope. As k increases, these curves become steeper, and the probability values at the starting and ending points become higher. Finally, the last chain has only one node (the last unused key).

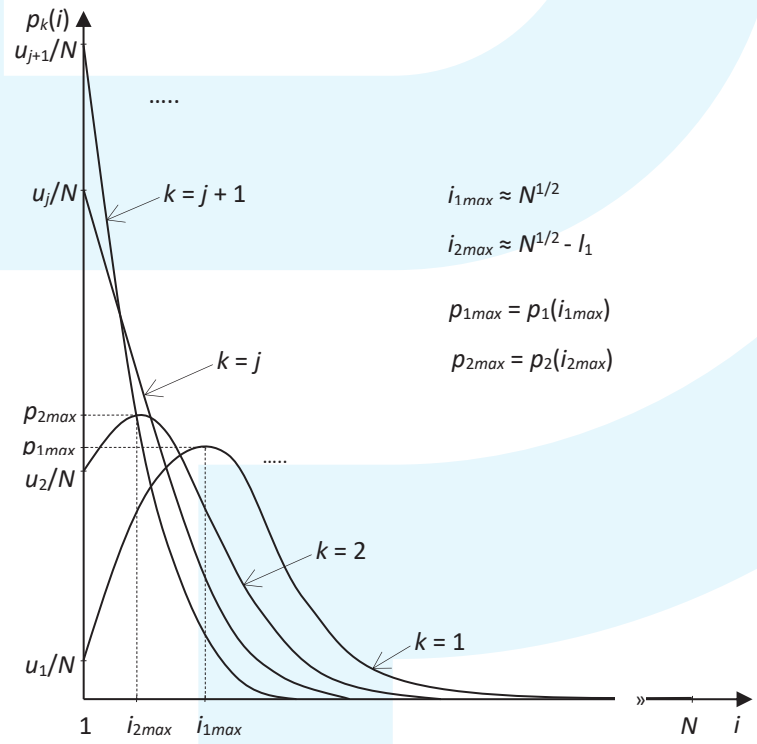

Fig. 10 Function $p_k(i)$ for different chains

With previous results of the probabilistic analysis, some experiments were carried out to find an average number of generated chains m and their average length. They were performed by calculating an average length for each perfect chain and accumulating them until the entire key space was covered. The numerical results obtained in this way for different values of the key space size N are provided in Table 1. They show that the average number of the perfect chains is $m \approx N/2$ while their average length is $l_{avg} \approx 2$. The first chain is the longest one with an approximate length of $l_1 \approx \sqrt{1.5N}$.

Table 1. The average number of chains and their average length

N	m	l_1	$\sqrt{1.5N}$	l_{avg}
2^{12}	2049	79.88	78.38	1.99
2^{16}	32770	320.51	313.53	1.99
2^{20}	524286	1283.06	1254.14	1.99
2^{24}	8388610	5133.24	5016.55	1.99

The fact that an average length of all chains l_{avg} is about two indicates that many chains have only one or two nodes. Further experiments were run to find an average number of these short chains and the numerical results are presented in Table 2. Parameter m_a shows the number of chains that are longer than average, and n_a is the number of nodes included in these m_a chains. Parameter C_a shows the percentage of the key values included in these m_a chains. Table 2 shows that about 25% of chains (or $N/8$) are longer than average and they cover approximately 50% of the key space. It is also evident from Fig. 11 which shows the distribution of the average chain lengths as a function of their ordinal numbers.

Table 2. Statistics about chains with an average length higher than l_{avg}

N	m	m_a	m_a (%)	n_a	C_a (%)
2^{12}	2049	513	25.04	2046	49.95
2^{16}	32770	8194	25.00	32767	50.00
2^{20}	524286	131070	24.99	532864	50.82
2^{24}	8388610	2097152	24.99	8432804	50.26

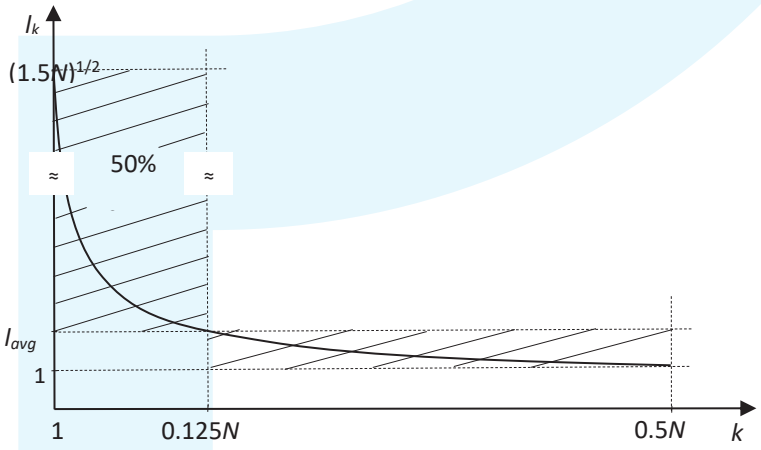

Fig. 11 Distribution of the average chain lengths

In addition to the previous probabilistic analysis, the simulation experiments were carried out to verify that their results are matching. The chains in the preparatory phase are generated using interval trees as a means of avoiding duplicated key values and preventing false alarms. The encryption function is simulated by a random choice of already unused key values. The interval tree enables the efficient insertion and searching of keys in O(log n) time complexity. Its memory complexity is analyzed in [16].

The simulation results are presented in Table 3. The m' is the average number of chains, l_1' is the average length of the first chain, and l_{avg}' and the average length of all chains obtained by simulation. The results of the simulation analysis are quite close to those previously obtained from the analytical probabilistic model. Table 3 also presents the relative difference (indicators denoted by ^{d} and expressed in %) between the corresponding values of the performance indicators obtained from both the analytical and simulation models for the different key space sizes. The fact that relative differences are less than 1% fully validates the analytical model.

Table 3. The simulation results and comparison with the theoretical analysis

N	m'	l_1'	l_{avg}'	m^d (%)	l_1^d (%)	l_{avg}^d (%)
2^{12}	2048	79.60	2.00	- 0.049	- 0.350	0.503
2^{16}	32768	321.99	2.00	- 0.006	0.462	0.503
2^{20}	524303	1264.13	1.99	0.003	- 1.475	0
2^{24}	8389281	5095.72	1.99	0.008	- 0.731	0

4. CONCLUSION

One of the inevitable decisions in the design and implementation of computer applications is how to balance the opposing requirements for spare use of time and memory. This decision is usually governed by the design priorities and limitations. This paper illustrates the time-memory-trade-off in some different fields (allocation of data structures, searching and sorting, compiler optimizations, memory hierarchy, etc.).

Since it is always of utmost importance to decrease the execution time of software algorithms and programs, and having in mind that the capacity of memory at all levels of the memory hierarchy constantly increases due to technological advancements, it can be concluded that the most frequent choice is to obtain speed at the expense of memory footprint. However, occasionally performance must be traded for memory, especially in cases when the memory demands are huge and amounts of memory and chip resources are limited. This is especially true for mobile platforms and embedded systems because of their limited resources and power constraints.

The cryptanalytical attack is known for extreme time and memory requirements. Consequently, it is quite natural to apply some kind of time-memory trade-off. This paper briefly describes the TMTO method which relies on the perfect chains and guarantees the finding of the secret key. The time complexity of the attack phase is considerably faster at the expense of the processing and memory demands in the preparatory phase. Although for very large key spaces, these demands might make the preparatory phase practically infeasible, the conducted probabilistic and simulation analysis provided a deeper understanding of this method. Experience gained from this analysis motivated another related research effort which resulted in the OSK/TMTO^2 protocol for efficient identification of the RFID tags [17]. It is also chain-based and recursively applies the TMTO principle twice and greatly reduces the overhead of the hash function calculations.

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Kompromis između zahteva vremena i prostora u računarstvu

Milo Tomašević, Violeta Tomašević

SAŽETAK

Vrijeme izvršavanja i potrebni memorijski prostor su najvažniji resursi u računarskim algortmima i aplikacijama, pa je veoma važno cilj da se oni minimizuju. Nažalost, u najvećem broju slučajeva ovo je teško istovremeno postići jer su ovi zahtjevi, po pravilu, kontradiktorni. Zato je nalaženje optimalnog balansa jedna od ključnih odluka u projektovanju i implementaciji aplikacija. U ovom radu problem nalaženja optimalnog balansa je ilustrovan kroz više primjera iz različitih oblasti. Posebno su prikazani rezultati istraživanja koje primjenjuje princip kompromisa imeđu vremena i prostora u procesu kriptoanalize zasnovanog na 'savršenim' lancima ključeva. Sprovedena je detaljna probabilistička i simulaciona analiza za razne veličine prostora ključeva radi karakterizacije ovih lanaca

Scientific Symposium
Days of Diaspora and (Scientific) Partners (of Montenegro)
Naučni simpozijum
Dani Dijaspore i (Akademskih) Prijatelja (Crne Gore)
Podgorica
October 18-19 Oktobar 2023

Science and Technologies of and for the Poor

Vuk Uskoković[1,2,3,*]

[1] TardigradeNano LLC, 7 Park Vista, Irvine, CA 92604, USA
[2] Department of Mechanical Engineering, San Diego State University, 8500 Campanile Dr., San Diego, CA 92182, USA
[3] University of Montenegro, Cetinjska 2, 81000 Podgorica, Montenegro
* Corresponding author: vuk21@yahoo.com, vuskokovic@sdsu.edu, vuk.uskokovic@tardigradenano.com.

ABSTRACT

Meager resources for research are nearly uniformly considered a demerit by researchers in developing countries. It is rarely recognized that this state of comparative poverty can be a driver of progressive thought, especially when the tendency to reach prominence via an incremental improvement of concepts predefined by the trends in the field is substituted with the fosterage of creative ideas that clash with the convention and stun with their degree of independence. To illustrate this provocative parallel, I provide a succinct snapshot into my career path and how its taking me from prosperous pastures to poverty rejuvenated my research and opened up creative avenues that otherwise might have been impossible to reach. This path can be instructive for scientists all across the developing world, who have become accustomed to thinking that greater research funds would solve all their problems, when it is often quite the opposite: an all-around inert reliance on the mainstream trends would ensue, skilled merchants would emerge on the tops of the academic pyramids, knowledge would surrender itself to capital as a seat of power, and science would increasingly start to resemble a corporate enterprise more than a wellspring of revolutionary new ideas and a training ground for the neoromantic scholarly marvels.

SAŽETAK

Naučni istraživači u zemljama u razvoju po pravilu stavljaju oskudne resurse za istraživanje na prvo mesto poteškoća sa kojima se susreću. Retko biva prepoznato da ovo stanje, tako reći, siromaštva može biti ključni izvor naprednih ideja, posebno kada se težnja ka postizanju uspeha kroz skromna unapređenja koncepata predefinisanih trendovima u oblasti zameni negovanjem kreativnih ideja koje su u sukobu sa konvencijom i koje zadivljuju svojim stepenom nezavisnosti. U cilju ilustracije ove paralele, ovom prilikom prikazujem kratak i jezgrovit opis toga kako je prelaz iz prosperiteta u siromaštvo u mojoj karijeri i ličnom životu revitalizovao moje istraživanje i otvorio kreativne puteve do kojih bi drugačije bilo nemoguće doći. Ovaj opis može biti poučan za naučnike širom sveta u razvoju, koji po navici smatraju da bi veća istraživačka sredstva rešila sve njihove naučne probleme. Često je, međutim, situacija sasvim suprotna od njihovih očekivanja. Naime, sa uvećanjem kapitala u nauci usledilo bi inertno robovanje svetskim trendovima, vešti trgovci bi se ustalili na vrhovima akademskih piramida, kapital bi izgurao znanje i zauzeo mesto na sedištu moći, dok bi nauka više počela da liči na korporativna preduzeća nego na inspirativni izvor revolucionarnih novih ideja i poligon za obuku naučnika neoromantičara.

On Thursday, October 18, 2023, as a part of the symposium titled *Days of Diaspora and Scientific Partners of Montenegro*, held at the Rectorate of the University of Montenegro in Podgorica, I gave two lectures that described the results and thoughts that emerged from different parts of my scientific career. Both lectures were crafted specifically for this occasion.

In the longer of the two talks, presented within the session on Informatics, I took the other panelists and attendees on a 30-minute ride through some of the milestones of my research career, from its beginnings at the University of Belgrade in the early 2000s to this day, when I work as a part-time lecturer in engineering at San Diego State University in the United States and a chief scientific officer of the biotech, educational and social advocacy startup nonprofit I cofounded in 2020, called TardigradeNano. The shorter of the two talks was presented to a broader audience and in it I shared some ideas relevant for the conceiving of a path for the scientific progress of a small developing country such as Montenegro. These ideas sprang to life from decades of rumination on this topic and its meticulous scholarly analyses[1].

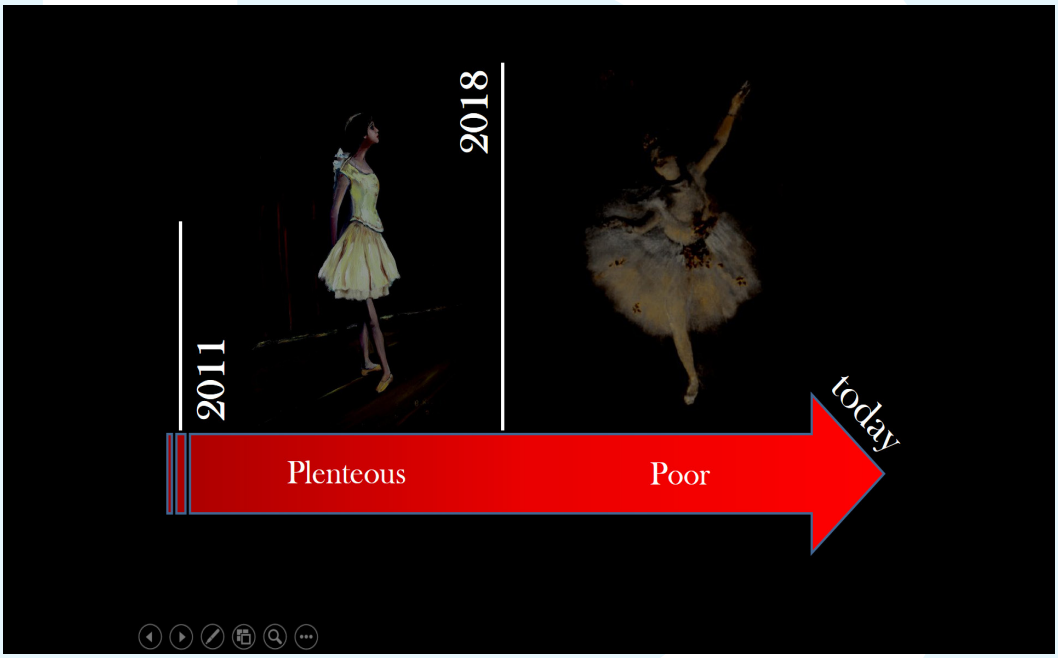

Figure 1. The independent section of my scientific career was divided to two periods: the plenteous and the poor. Examples of research findings from both periods were shared with the audience, which was then free to make its own conclusion as to which of the two it preferred more. The poses struck by Degas' dancers representing the two periods hint at which of the two periods has been dearer to this lecturer's heart.

The title of this shorter, 15-minute talk was the same as the title of this essay, namely *Science and Technologies of and for the Poor*. I warned the audience in the opening lines that I rarely toss facts and results on them in my talks and that the latter are, usually, stories, of one kind or another. Hence, the talk began with the brief description of the institutional path I took throughout my education from undergraduate to postdoctoral levels and the subsequent employment, with a special emphasis on the period since my establishment as an independent researcher, at University of California in San Francisco in 2011. This independent period I further divided to two parts, where the point of separation corresponded to my loss of funding and employment opportunities in the spring of 2018 (Figure 2). At this point I announced to the audience that some of the major research results from both of these periods would be presented and that the listeners would later on be free to pick their preference for one or the other. Research accomplishments from the first period, dominated by abundant funding and a prolific lab I ran in different institutions, included calcium phosphate nanoparticles for controlled release of therapeutics[2,3] and the ability to simultaneously exhibit osteogenic and antibacterial properties[4,5]; injectable antimicrobial putties with thermosetting properties[6]; calcium phosphate nanoparticles for gene delivery[7] and reversal of the propensity of cancer cells to uptake magnetic nanoparticles more abundantly than the healthy cells do[8]; and so on. The culmination of the examples from this prolific period was that of an earthicle (Figure 1), the first nanoparticle designed after a celestial body, born under the umbrella of the idea of astromimetics in the materials science universe. The moment in time when this seminal idea was shared with the scientific community I have often compared with the opening of a Pandora's box, or, as I explicitly told the audience, with Thales of Miletus' being so mesmerized by the starry skies that he fell into a ditch, the fate that was mine too, albeit in the context of my profession as a scientist and a university professor at the time. This fall into a ditch marked the point of transition between the first and the second of the two aforementioned periods in my career. The fall was brought about to a large extent by my political engagements, as a faculty senator and president of numerous academic associations, where I stood strongly against the unjust, exploitative capitalist principles based on which today's science in America operates[9,10,11]; however, this was by no means the topic for discussion for this particular time and place.

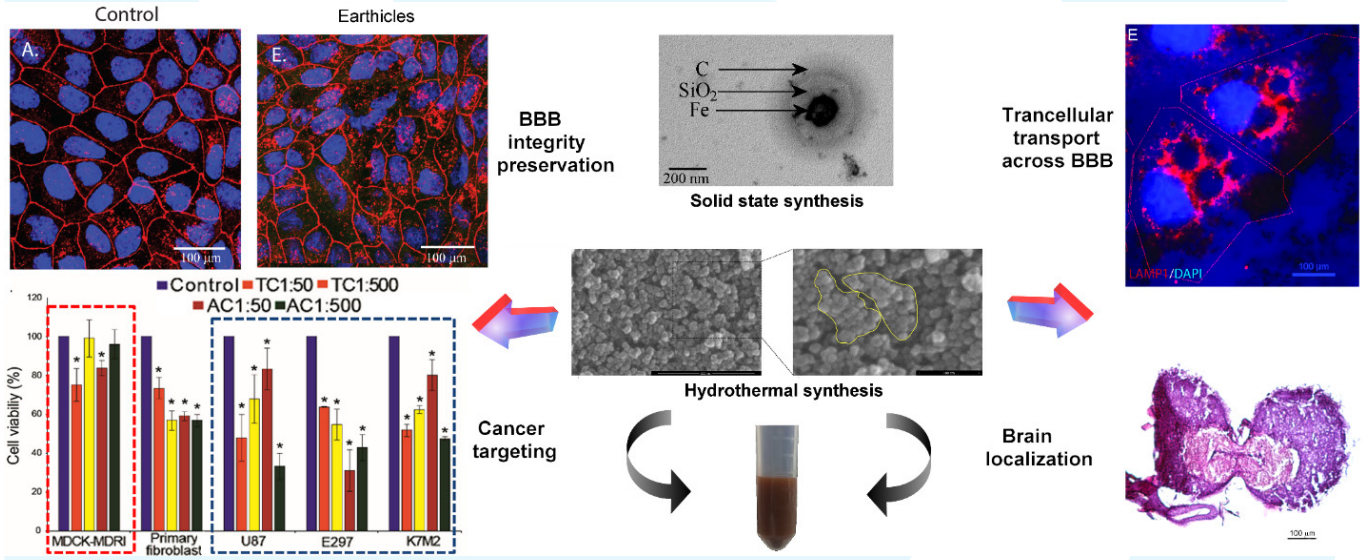

Figure 2. Biomimetics has been a long-reigning concept in materials science, representing collective efforts going into the design of new materials by mimicking the materials produced by Nature. Astromimetics, in contrast, representing the design of materials after the structures of celestial bodies is a concept I proposed in 2018[12], three years after the work on the creation of the world's first such particle began in my lab at University of Illinois and a year after the work on it was published[13]. The particle is also known as the earthicle, which mimics the stratified structure of the planet Earth despite having under 100 nm in size. Its future iterations would display an array of interesting properties, from the selective cancer vs. healthy cell activity to the traversal of the blood-brain barrier (BBB)[14] to the targeted magnetic separation of biomolecules and cells[15]. The concept, however, provoked ridicule in the social media, bordering cyberbullying at times, marking a turning point in my career as a scientist – not only did the acceptance of the scientific community began to matter nil from this point on, but the conceptual science, that is, science exploring revolutionary new concepts, became all that mattered from the days of the earthicle on.

Cherry-picking of the few research feats from this first period of my independence was followed by my mentioning a number of interesting research findings and ideas that resulted from the second period, which was marked by the nil income and the nil opportunities to acquire any funding for research save personal savings. The first example mentioned was that of the first study that came out of my moving from indoor academic labs to outdoor spaces, be it of parks[16] or playgrounds[17] or backyards[18] or swimming pools[19] or ocean shores[20], in search of spaces for the conductance of revolutionary research. In that particular study, flowers were plucked, with the help of children, from the great outdoors, and I managed to turn one of them into the world's first flower model for the assessment of biocompatibility of nanoparticles, alongside turning my daughter into the world's youngest author of a scientific paper at the time[21]. She was engaged in measuring the flower petal dimensions with a ruler, organizing the flowers in the test tubes and plotting the little tables with data, which were filled by her older brother, another coauthor of the study. The model is meant to complement the pricier and low-throughput *in vitro, ex vivo* and *in vivo* testing, and is also exceptionally children-friendly, which is why it has been used as an educational model, helping the budding scientists to learn about nanoparticles in biology[22].

The second example presented to the audience fell along the line of my effort to reinvent the form of the scientific paper as a medium for the transmission of scientific results and ideas across the scientific community. Toward this fully original goal, unique in the history of science, I have crafted scientific papers that do maintain the rigor of good science, but also adopt various unusual forms. The sole example presented during this lecture was that of a research study presented in the form of a theatrical play, containing four characters and three acts, where the second act happens in none other but a dream[23]. This more artistic form of the scientific paper makes room for the tackling of a number of subjects that are of importance for the current state and evolution of modern science, but that do not get to be talked about, in nearly any venue these days. Yet, all

of them are essential for directing the progress of science and technologies as we know them. Already in the early 2000s, in a domestic literary domain[24], I showed interest in questioning these contexts under which science grows and develops, and have remained true to it to this very day. In addition to this, it is of paramount importance that the quality of science in such unorthodox and novel forms of scientific paper does not get diluted. In the example presented, the common sense prediction that vertical, gravity-driven segregation in colloidal dispersions with heterogeneous particle size distributions would be such that the larger particles would settle toward the bottom and the lighter ones would drift to the top was refuted and it was shown instead for the very first time that the segregation of mechanically agitated colloidal nanoparticles in the vertical direction conforms to the Brazil nut effect. A series of interesting scientific observations ensued the demonstration of this curious phenomenon.

A plethora of studies from this "poor" period has been such that modest means were shown to be capable of producing remarkable and, oftentimes, very practical effects. One example presented to the audience was that of circumventing the functionalization of nanoparticles with expensive organic ligands and complex chemical processes, and instead simply immersing the nanoparticles in comparatively cheap mixtures of water and ethanol[25]. Since polar water and nonpolar ethanol differently alter the surface energy of the material, a number of material properties can be tuned by controlling the ratio of water to ethanol in the medium where the nanoparticles are incubated, including the electronic structure of the material surface, but also its various biological properties (Figure 3).

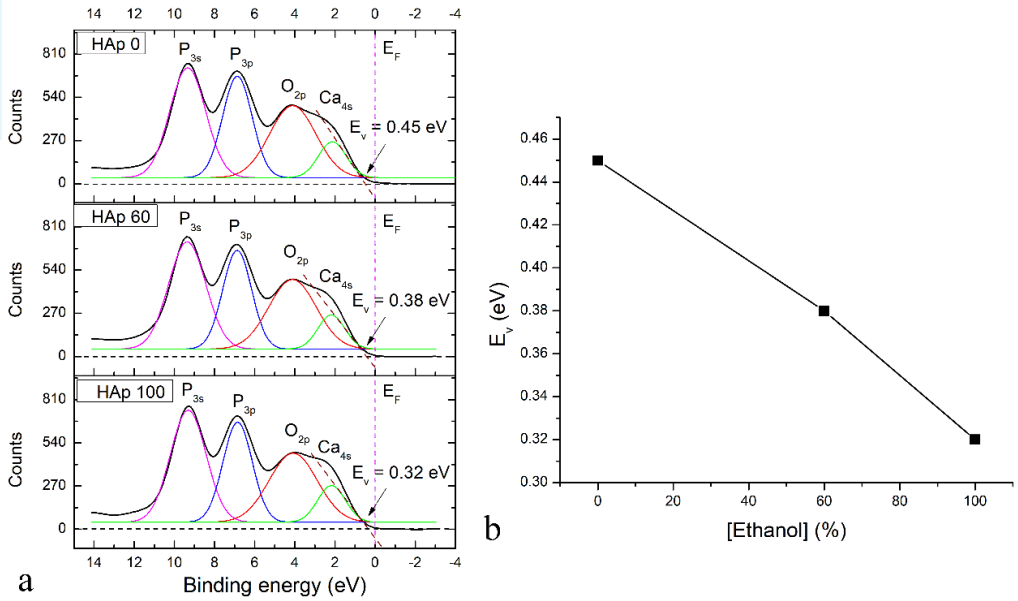

Figure 3. Valence energy level of hydroxyapatite, as measured using X-ray photoelectron spectroscopy, varies in direct proportion with the ratio of water to ethanol in the medium in which the material is incubated.

When funds for expensive experimental work subside, the space opens for the engagement in more literature-reliant research, be it in the form of metastudies, more theoretical research, studies that are rooted in social sciences and humanities, or other. More than a few of such studies that I engaged in in the absence of funding have been about probing the history behind specific scientific phenomena and trends. The example presented during the lecture was that of an anticolonial materials science paper where the doping of hydroxyapatite with elements of the Periodic Table was studied from historical angles[26]. Among many other things, it was shown and shared with the audience how what once used to be a trendy topic studied only in the rich countries of the world is now considered little interesting in their research centers and is more popular in the developing world. And whenever trends in lieu of more objective qualities drive the progress of a discipline, it should be approached as a concern rather than brushed off as a normal state of affairs. Another science history study de-

scribed was that of trying to decipher the reasons for an enormous popularity of the configurational model devised by the Soviet materials scientist and physicist, G. V. Samsonov in the 1960s in Eastern Europe, and a complete obliviousness of the western world to it, both then and now[27]. The unsaid subtext of this project was pertaining to the goal of bringing peace to the ongoing conflict between Russia and Ukraine, given that Samsonov was a Russian scientist who performed the bulk of his work in today's Ukraine and that the first presentation of these findings was at a meeting held in Kyiv, which took place only three months after the onset of the 2022 invasion of Ukraine by the Russian forces.

Another one of such socially responsible studies that was shared at the lecture was that of tackling the habit of coffee making and drinking in today's Bosnia and Herzegovina, which is said to be a common way of bringing people of various nationalities together and thus healing the wounds of the civil war of the 1990s. Complying with the objective of fusing good science with good humanities, I used the procedure for making coffee that is unique to today's Bosnia and Herzegovina as an inspiration for improving the stability of colloidal suspensions of nanoparticles[28]. Perhaps the full range of potential and causes governing this effect were not explored in most detail, but such are the limitations of ambitious science run with little to no funds: at best, it remains limited to the proof of new concepts, without engaging either in thorough optimizations of conditions under which these concepts work best or in covering every square feet of the grounds serving as mechanistic causes thereof, or both. It, in other words, is a science of concepts rather than conventions. In analogy with conceptual arts, it is also, ideally, a type of science that implicitly questions the trends in science of its times in just about the same extent as it provides meaningful scientific findings[29].

The last example from this second period fell along the same line of efforts as its antecedent, namely that of creating science with a peacemaking message. In that final case, I described how my idea to connect Serbian and Albanian scientists working at now split central University in Kosovo for the first time since the Kosovo War of the 1990s and engage them in a common project was implemented in reality[30]. In a world where politicians often tend to put fuel to the fire of hostilities between separated ethnic groups because it boosts their popular vote, scientists may have a crucial role in producing the opposite effect, namely that of bringing the divided people together, even when they, the scientists, would be destined to remain in the shadow – this, exactly, is the penultimate goal of this science with "the human face". The ultimate goal, of course, is to produce good and meaningful science that educates and inspires those whom it is being communicated to.

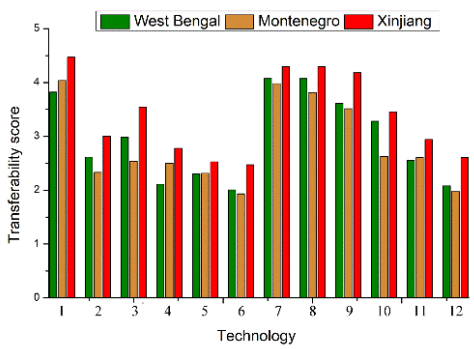

Table 3. Twelve advanced medical technologies of choice rated for their transferability scores.

Technology
1. Origami paper-based diagnostic assay
2. Microfluidic lab-on-a-chip for electrochemical immuno-biosensing
3. Telemedicine with unmanned aerial vehicles
4. Multimodal MRI/PET/CT imaging
5. Imaging-guided, nanoagent-mediated photodynamic therapy
6. Glassy carbon brain-machine neural signal interference
7. Topical inorganic nanoparticle antimicrobials
8. Nanoparticles functionalized with ligands for cell-targeted drug delivery
9. Injectable hydrogels for tissue regeneration
10. High-throughput screening of traditional medicines for personalized treatments
11. Bioprinted cardiac patches
12. Graphene e-skin for tactile perception

Figure 4. Transferability of twelve different advanced medical technologies to the three different comparatively poor regions of the world - Xinjiang, West Bengal, and Montenegro – is the highest for technologies that are intrinsically "poor", requiring less resources to produce, operate and maintain.

At this point in the talk, gears were shifted and it was time to elaborate how science and technologies *of* the poor can be beneficial *for* the poor. Only one example was presented here, namely that of a quantitative method for calculating the transferability of technologies across the rich-poor divide. Needless to add, the fact that many of the most advanced technologies developed and commercialized in what is commonly deemed the "developed" world cannot be either easily or at all transferred to the developing or underdeveloped regions of the world constitutes a perennial problem that technologists have tried to solve. I, myself, was prompted to think about a model that could assign a transferability score early on, in the

embryonic stages of the development of new technologies, after I demonstrated that the most effective vaccines against COVID-19 utilized lipid nanoparticles incorporating immunostimulatory RNA, yet they were by more than an order of magnitude on average pricier than the more traditional vaccines and were virtually unaffordable to low-income countries[31]. This inspired me to think about a world where the funding of ideas for innovation would take into account their global impact and the capacity to be utilized not only to benefit the rich, but also to benefit the poor. This thinking, further on, resulted in the model I developed to assess one such transferability score, by considering not only the solely scientific or science policy criteria, but also the communal and social tradition characteristics of the area where these new technologies are to be implemented[32]. To test the validity of the model, three relatively poor regions of the world were compared, including Xinjiang in China, West Bengal in India, and Montenegro, with respect to twelve advanced medical technologies of choice (Figure 4). It was shown that the overall transferability was higher in Xinjiang than in Montenegro despite their identical gross domestic products per capita, the reason being the influence of the factors other than the economic only. Moreover, technologies that are cheaper to produce and are also portable and easier to install, operate and repair are those that are more transferable to the poorer regions of the world, meaning that there is hope for products conceived and developed under poor conditions. In other words, abundance of resources forces the researchers to utilize them and come up, in turn, with rather exquisite technologies, which may hardly become relevant in the developing world under any realistic technology-maturation scenarios. In contrast, working under dire conditions for research may be exhausting and depressing, but it is often a gateway to products that may become meaningful for the entire globe.

This is one of the reasons why I have considered poverty more of a blessing than a constraint all throughout my career. As inferable from the preceding discourse and based on my personal preferences regarding what constitutes excellence in science, poverty has guided me to more extraordinary products of scholarly work than the indulgence in abundance did. Lest I be misunderstood here, I am not saying that the long period of work under the conditions of bountifulness produced poorer research results than the subsequent period marked by objective poverty. Neither did this transition change the way I have approached the scientific work, as throughout both periods, the goal was the same: to create science that inspires and enlightens with its content. This goal, moreover, was pursued in exactly the same way, that is, independently on tenures, salaries, bonuses or any other professional rewards or accolades, which, frankly, I have always perceived as a nuisance and never paid even a slightest attention to. The horizons on which my eyes rest have always been the same: to be of a free mind and to be free to create science that bedazzles with its creativity and has a wealth of soul to it. This freedom and the pinnacle of my creative output I, interestingly, reached only when I left the institutional bonds behind, or they left me, to be more precise, having perceived my intellectual independence, my political and social activism, and, more than anything, my unorthodox, neoromantic approach to science as blasphemies to the norms of the establishment. Yes, the capacity to perform research dwindled thereby, but it was compensated for by imagination, by crude proofs of novel concepts, and by radical cross-fertilizations of science with arts.

To be clear, I do not impose on the audience any opinion as to which science is better and more meaningful – *i.e.*, science of the rich or science of the poor – but my personal opinion is that, globally, there should be room for both. To be honest, however, following everything I have gone through and having had a chance to experience both the extreme abundance and the extreme poverty, if I had to pick between the two, I would always opt for the latter. Experience has taught me unequivocally that poverty is the best ground for the flourishing of creative concepts that challenge the trends set and perpetuated by the affluent. When those who have are tied to the inert barreling of the wheels of the paradigm, those who haven't are free to challenge these trends and come up with something extraordinarily new, for the benefit of all. Furthermore, through the aforementioned prism of conceptual arts, one such science that comes out of the hands of the poor has the moral and the aesthetic task of questioning the obsessive dependence on these trends in our society. With this questioning, relentless and bold, notwithstanding the risks it entails for the career of the questioner, critical thinking is promoted, that heart and soul of every progressive scientific community. In such a way, dangerous obsolescence can be recognized in those who claim for themselves the title of the developed and their mistakes can be eluded before they have even occurred.

Need it be said that this message is the message of hope for the developing small country like Montenegro? Instead of blindly following the paths set forth by the bigger and richer countries of the world, with this in mind, the overarching policy of progress could be turned into something completely new and original – something that has not been tested on the world's stage before.

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Scientific Symposium
Days of Diaspora and (Scientific) Partners (of Montenegro)
Naučni simpozijum
Dani Dijaspore i (Akademskih) Prijatelja (Crne Gore)
Podgorica
October 18-19 Oktobar 2023

Looking at the Future Through the Prism of Battery Systems

Milica Vujković[1,2]

[1] University of Belgrade – Faculty of Physical Chemistry
[2] Center for Interdisciplinary and Multidisciplinary Studies, University of Montenegro
e-mail: milica.vujkovic@ffh.bg.ac.rs

ABSTRACT

We are witnessing a low-carbon energy transition, where electrochemical power sources, including batteries, supercapacitors, and fuel cells, lie at the heart of a more sustainable energy supply. If we look at the future through battery lenses and the periodic table, the long-term perspective of Li-ion technology is not so promising, despite its high energy. Lithium is a limited resource so more sustainable, alternative solutions must be found, first in low- and then in high-energy applications. In that regard, several energy storage systems, based on plentiful elements (Na,Ca, Mg, Al, K, Zn), have been developing rapidly. These alternatives fall short of Li-ion battery energy density, which makes them primarily suitable for grid stationary storage. Through the survey of existing chemistry (anodes, cathodes, and electrolytes), the paper highlights the potential of Na-ion batteries as one of the most promising solutions, while suggesting future avenues in this area.

1. INTRODUCTION

State-of-the-art

Looking back, there has been a long journey from the initial identification of lithium in 1817 and its early use, as an anode for primary batteries in the 1970s, to the delivery of Sony's first secondary Li-ion battery in 1991 and its current dominance in high-tech applications. The most significant contribution to development of Li-ion batteries can be attributed to three scientists: John Goodenough, Stanley Whittingham, and Akira Yoshino, who received the Nobel Prize in Chemistry in 2019. Whittingham's pioneering patent in 1975 [1]"ISSN":"15206890","PMID":"30500179","abstract":"This Review covers a sequence of key discoveries and technical achievements that eventually led to the birth of the lithium-ion battery. In doing so, it not only sheds light on the history with the advantage of contemporary hindsight but also provides insight and inspiration to aid in the ongoing quest for better batteries of the future. A detailed retrospective on ingenious designs, accidental discoveries, intentional breakthroughs, and deceiving misconceptions is given: from the discovery of the element lithium to its electrochemical synthesis; from intercalation host material development to the concept of dual-intercalation electrodes; and from the misunderstanding of intercalation behavior into graphite to the comprehension of interphases. The onerous demands of bringing all critical components (anode, cathode, electrolyte, solid-electrolyte interphases on electrochemical intercalation/deintercalation of lithium ions into the layered structure of TiS_2 (at ≈2V vs. Li), marked the pivotal first step towards the successful development of Li-ion batteries. This discovery triggered extensive research in the field, which led to the commercialization of the first rechargeable battery, using the lithium anode and MoS_2 cathode with improved properties. Still, the cell was quickly withdrawn, from the market, due to safety concerns. However, the research was not preoccupied with solving this problem, since Goodenough discovered $LiCoO_2$ as a cathode material (1980), capable of intercalating Li^+ ions at the potential of ≈ 4 V vs. Li [2] which was the second key moment in the success of lithium-ion battery development. So, the research focus shifted to this type of material, which doubled the voltage of the battery. Meanwhile, lithium proved unsuitable as an anode because it dissolved during cycling and formed dendrites upon charging, making the electrode spongy and very reactive. This problem was quickly solved by Yoshino who discovered (1985) [3] that carbon could be used as an anode due to its very close potential to lithium, which set the stage for Li-ion battery market to flourish. The replacement of lithium by carbon did not reduce much energy, but it brought benefits of cost, safety, and non-toxicity. The first carbon anode was coke, an amorphous material with a high specific surface area, but the highly ordered graphite with improved properties

replaced the coke very quickly. By combining graphite anode and $LiCoO_2$ oxide cathode, Sony company released the first Li-ion battery in 1991, which has essentially retained its original configuration to this day. Only, $LiCoO_2$ was quickly replaced by $Li(Co\text{-}Mn\text{-}Ni)O_2$ of different chemical composition (so-called NCM) or $LiCo_{0.8}Ni_{0.015}Al_{0.05}O_2$ (so-called NCA). These Co-related materials dominate the contemporary batteries (combined with graphite anode) thus providing the highest energy but with an increased cost, lower safety, and reduced life span (Figure 1). On the other hand, batteries, using $LiFePO_4$(LFP) and $Li_4Ti_5O_{12}$(LTO), are also being commercialized as safer and more sustainable solutions, but with reduced energy density. These materials, combined with graphite anode, present the 1st & 2nd generation of Li-ion batteries.

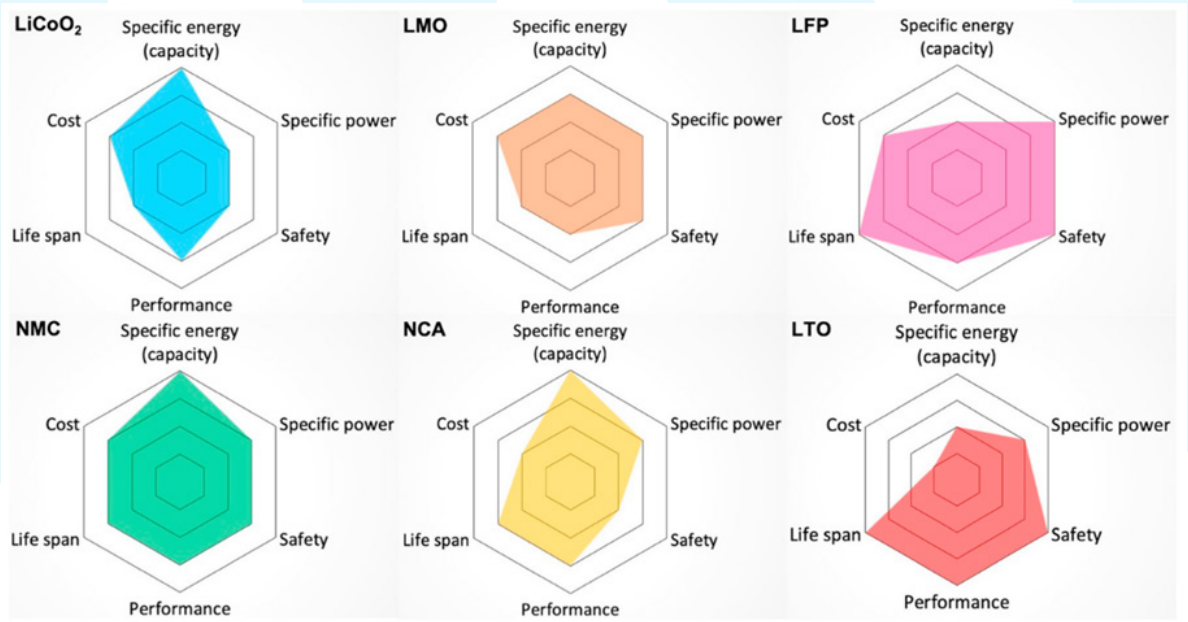

Figure 1. Different cathodic materials from the perspective of Li-ion battery properties: specific energy, power, life span, safety and cost [4]the number of electric vehicles (EVs

Looking at the 2014 map [5] (Figure 2) we can conclude that we still use cobalt-based oxides and phosphates (for the last thirty years actually) and we still want to reach next-generation systems such as batteries based on silicon/graphene anode (3rd generation at 2025 scale), solid-state batteries with metal lithium (4th generation at 2025 -2030 scale), where the solid-state electrolyte will prevent the dendritic lithium growth, and finally metal-air systems (>2030 scale) with the highest theoretical capacity among all batteries. Although graphene- and silicon-based batteries are on the verge of commercialization, the progress of the mentioned next-generation systems is still slow not only due to certain bottlenecks but also a partial shift towards non-lithium solutions. In this paper, we will present alternative solutions to Li-ion batteries that would avoid their main problems associated with critical elements like Li, Co, and Ni as well as safety complications. Main advantages and disadvantages of these energy storage systems, based on plentiful elements, will be briefly outlined. Our central focus is on Na-ion batteries, as one of the solutions that approaches commercial viability.

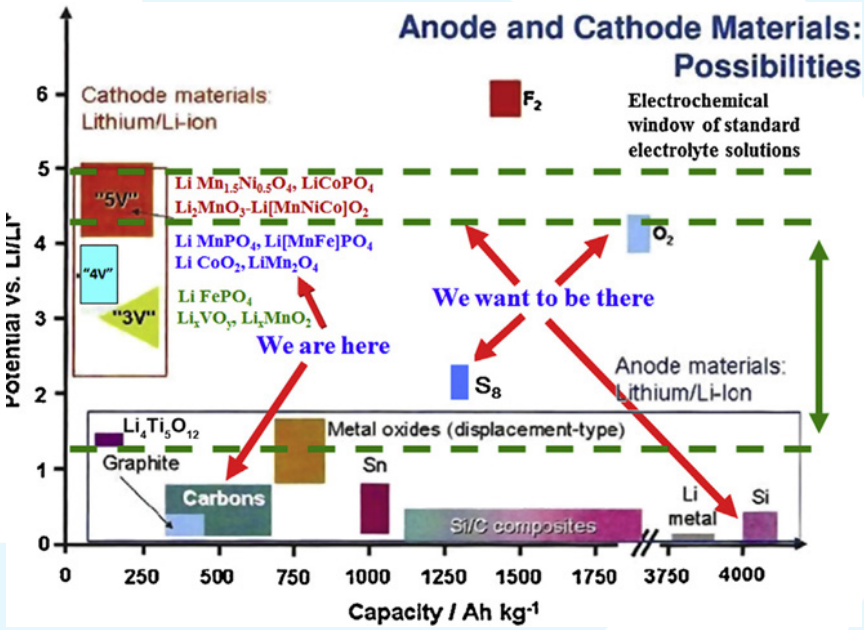

Figure 2. 2014 roadmap published by Auerbach in 2014 [5]

2. PROBLEM STATEMENT

Due to the high energy density, reaching 300-350 Wh kg^{-1}, Li-ion batteries have started to integrate into renewable energy infrastructure and penetrate the market of electric vehicles, resulting in a significant demand for this technology. The European Battery Alliance has reported 25 announced projects on Li-ion battery factories across Europe, spanning from pilot plants to Gigafactories. These projects, when realized, will add ≈ 500 GWh production capacity in total for Europe by 2030. Global demand for batteries is expected to surpass 2600 GWh by 2030, with the most contribution in China. This scenario will increase the pressure on limited and unevenly distributed lithium (lithium is highly concentrated in some countries), potentially raising geopolitical tensions and consequently increasing the Li-ion battery price. Additionally, the exploitation of lithium is ecologically unsuitable, while the recycling process is still unprofitable and insufficient. A similar situation is with toxic cobalt and nickel, which are key components in today's high-energy batteries, and if nothing changes, demand will surpass production in the next two decades. All these problems, coupled with safety issues related to thermal runaway reactions, limit the mass production of Li-ion batteries and shift one part of the research towards alternative, safer and more sustainable solutions.

3. THE BEST EXISTING SOLUTION(S)

Away from Lithium: Secure and Eco-Friendly Alternatives

If we consider the potential of all elements in the periodic table to build safer and more sustainable batteries, we can see that a large number of elements appear below 200 ppm in the earth's crust, thus leaving a few sustainable options on a 2050 scale. Apart from hydrogen, the sustainable alternatives are Na, K, Ca, Mg, Al (Table 1) and those batteries have been the subject of numerous studies over the past decade. Although Zn is not quite abundant (below 200 ppm), these batteries have been widely examined over the past decade and a notable advancement has been achieved. Therefore, the most promising alternative solutions, currently under investigation, include Na-ion, Na-sulfur, Na-air, Zn-ion, Zn-air, Mg-ion, K-ion, Ca metal, and Al-ion batteries.

Table 1: Comparative properties: lithium versus alternative ions [6]

Items/charge carriers	Li^+	Na^+	K^+	Zn^{2+}	Mg^{2+}	Ca^{2+}	Al^{3+}
Atomic weight / g mol^{-1}	6.94	22.99	39.1	65.41	24.31	40.08	26.98
Standard potential /V vs. SHE	-3.04	-2.713	-2.924	-0.763	-2.356	-2.84	-1.676
Ionic radius / Å	0.76	1.02	1.38	0.75	0.72	1	0.53
Hydrated Ionic radius / Å	3.82	3.58	3.31	4.3	4.28	4.12	4.75
Charge density / C mm^{-3}	52	24	11	112	120	52	364
Theoretical specific capacity / mA hg^{-1}	3860	1166	685	820	2206	1337	2980
Volumetric energy density / mA h cm^{-3}	2061	1129	610	5855	3834	2072	8046
Density of the metal / kg m^{-3}	534	968	862	7140	1738	1550	2700
Metal cost / USD kg^{-1}	19.2	3.1	13.1	2.2	2.2	2.28	1.9
Abundance	33	6	7	25	8	5	3

Availability of these alternative ions eliminates the need for using lithium and cobalt, which helps mitigate geopolitical conflicts and reduces dependence on countries holding a monopoly on these resources. Moreover, a significant advantage of these alternative battery systems is an enhanced safety since they do not exhibit thermal runaway reactions and cannot catch fire. Furthermore, there are benefits in terms of using current collectors, temperature operating range, and cycling life, depending on the specific alternative solution. However, all these alternative ions are bigger and have a higher redox potential than lithium (as shown in Table 1), rendering them less appropriate for high-energy batteries. Nonetheless, they can offer advantages in terms of cost, safety, and volumetric energy density [6], which makes them more suitable for grid stationary energy storage. Considering the current situation, Na-ion technology is nearing the point of commercialization, while multivalent batteries are expected to appear on the market soon. Although multivalent ions carry double or triple charges, there are still certain difficulties in chemistry which delay the current commercialization. They include the issue of the multivalent-based electrolyte, the complex interface and disturbed diffusion of multivalent ions through host structure. Herein, we will focus on a brief survey of Na-ion batteries due to their commercial viability. Additionally, we have contributed to this field through realization of the SuperCar NATOSPS project 2020-2023, a collaborative effort between Slovenia, Serbia and Montenegro.

Sodium-ion batteries: A highly promising solution

Research on Na-ion batteries started together with Li^+ ions, in the early 70s, as the first patent on alkaline-ion intercalation into TiS_2, was published by Nobel Laureate Whittingham. However, since Goodenough discovered $LiCoO_2$ as cathode material in the early 80s, Li-ion batteries were capable of delivering a higher energy density than Na-ion batteries and the focus shifted to Li-ion technology. However, the limited lithium resources and demand for sustainable and cheaper alternatives renewed interest in Na-ion technology over the last decade.

Pros & Cons Na-ion batteries hold all aforementioned advantages, making them a prominent alternative to Li-ion batteries. Sodium is much cheaper, more abundant, and evenly distributed than lithium. Na-ion batteries can operate at lower temperatures and can use aluminum as an anode current collector thus avoiding the need for more expensive copper. They are also safe with no risk of thermal runaway reactions and can provide a longer cycling life. However, the reduced energy density of Na-ion battery originates from the lower theoretical redox potential of Na vs. Li (2.7 V vs. -3 V) [6]. While the research on Na-ion insertion materials aims at compensating for this difference, by enhancing specific capacity, they still cannot match the energy density of Li-ion batteries. Therefore, Na-ion batteries show the greatest potential in stationary applications (for

storing electricity generated by solar and wind power) where cost, safety, and environmental aspects surpass space and battery weight concerns. In this context, Na-ion batteries are most competitive with Li-ion phosphate systems which also have lower energy density than NCM-based Li-ion batteries (used in smartphones, laptops, and electric vehicles) but offer increased safety and longer cycling life.

State-of-the-art materials for Na-ion batteries and different solutions: Regarding anode materials, a wide range of structures has been investigated, encompassing carbon, oxides & sulfides of transition metals, alloy-based materials, and organic compounds etc. The central material is a hard carbon, which can be considered the first generation of anodes for Na-ion batteries. The highly ordered graphite structure (an interlayer spacing of graphene layers is 3.35 Å), which is a well-known anode material for Li-ion batteries (capable of achieving a theoretical capacity of 372 m hg^{-1} corresponds to LiC_6 composition), hardly intercalates Na^+ ions from the typical carbonate-based electrolytes (Figure 3) [7]. The maximal composition upon intercalation can be NaC_{186} or NaC_{64}, which corresponds to the low capacity of 12 or 35 mA hg^{-1}. This limitation is attributed to thermodynamic instability of Na-graphite compounds and significant distortion of C-C bonds (Na^+ ions intercalation into graphite requires potentials below 0 V vs. Na^+/Na[8]. On the other hand, the fully disordered structure of hard carbon (HC) showed a high storage capacity for Na^+ ions which renewed interest in the development of Na^+ ion batteries. The hard carbon structure consists of pseudo-graphite nanodomains with larger interplanar distances (3.7– 4 Å) compared to graphite and soft carbon. These domains are randomly distributed in space (similar to a tower of cards), creating numerous open and closed pores, especially micropores. Unlike soft carbon, hard carbon cannot be graphitized even at extremely high T up to 3000 °C and exhibits an additional plateau very close to the sodium potential that makes it a suitable anode. While graphite's interlayer distance of 3.7 Å is unsuitable for hosting Na ions, the higher interlayer distance, between 3.7 and 4 Å in HC, accommodates Na ions effectively [7]. Their storage in HC involves additional processes such as the adsorption of Na+ ions onto defects/surface groups and pore-filling.

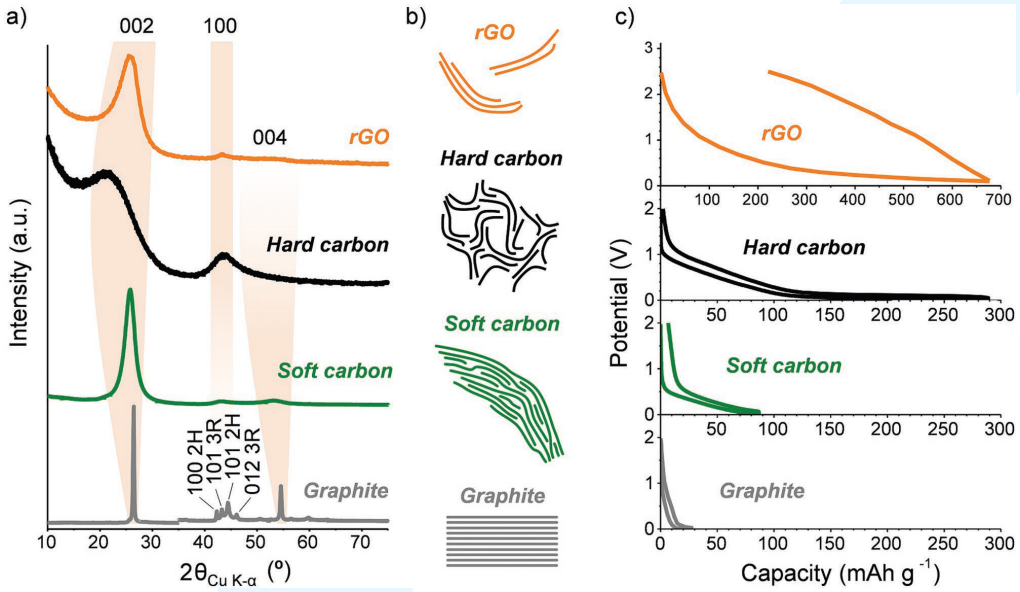

Figure 3. Structure of graphite, soft, hard carbon, and reduced graphene oxides (a) and their charge/discharge curves in a typical Na-containing carbonate-based electrolyte [9].

Hard carbon can be obtained using different precursors such as biopolymers (glucose, sucrose, lignin, citosane...), plastic waste (polyvinyl chloride, polycarbonate…, polymer materials (phenolic resin, polyacrylonitrile, polyaniline....), biomass waste (fruit/vegetable peels, nut shells, plants/trees...), etc [9]carbon serves as a predominant choice of electrode material owing to abundance, electrical conductivity, and control over the intrinsic properties. In this context, biomass, an abundant, inexpensive, and renewable source to produce biochars has gained significant research attention not only to mitigate the

environmental concern, but also to promote the development of sustainable energy storage applications. In this review, recent progresses towards the conversion and efficient utilization of biomass and its derived biochar as electrode materials for energy storage devices, including supercapacitors and batteries (Li-ion, Na-ion, Li–S, and Metal-air. One of the most profitable ways to obtain hard carbon is the carbonization of biomass waste, where different biomass precursors have been used. This diversity in precursors enables tailoring and design of the HC surface to enhance its capacity for hosting a large amount of Na ions.

The greatest challenge, regarding hard carbon electrochemistry, is that there is no consensus regarding the Na-ion storage mechanism as to which process can be attributed to a particular region of the electrochemical curve. Several mechanisms have been postulated [10], some of which are contradictory. The main debate is whether the slope region originates from the intercalation of Na ions between graphene layers and the plateau from adsorption in the pores (sodium filling or plating into pores), as first proposed by Dahn, or the slope comes from the adsorption of ions on surface defects (disordered graphitic sheets) and the plateau region from intercalation followed by Na-ion/atoms filling of the pores. Solving this issue is of key importance for comprehending the basic mechanism and developing a material with greater capacity. Low weight, low redox potential and high capacity (up to 300 mA hg^{-1} at low currents) make HC an excellent choice as a Na-ion battery anode. However, it faces certain challenges including limited capacity utilization at higher current rates and unclarified sodium storage mechanism. So, the main question remains what would be the next generation of anodes- modified HC, with an improved high-rate performance, alternative materials based on graphene, various alloys, organic compounds, or even graphite combined with a specific ether-based electrolyte (this type of electrolytes allow successful intercalation of Na+ ions into ordered graphite structure)[11].

Regarding cathode materials, three classes of materials, namely sodium transition metal oxides, Prussian blue analogs, and polyanionic materials (Fig. 4) are the most investigated to solve the cathode issue of Na-ion batteries and make them competitive with Li-ion technology [12]. Layered transition metal oxides offer advantages in terms of the high theoretical capacity, relatively high redox potential, and wide range of available structures varying from Ti to Cu [13]. However, their full performance is limited by some issues, related to irreversible phase changes and structural instability during cycling. Conversely, Prussian and Polyanionic compounds show stable redox potential and cyclic behavior, with low volume changes during cycling and high-rate capability. While polyanions show outstanding thermal stability, the Prussian compounds face challenges of thermal instability, defect control, and lower density. Despite these drawbacks, certain structures such as Ni–Mn–Fe and Cu-Fe-Mn layered oxides (Faradaion, United Kingdom and HiNa, China), $Na_3V_2(PO_4)_3F_3$ (Taiamat, France), Prussian blue (Novasis, Texas, Natron, California, and Liaoning Starry Sky, China), Prussian white (CATL, China and Altris, Sweden), etc. have been developed as commercial cathodes of Na-ion prototypes.

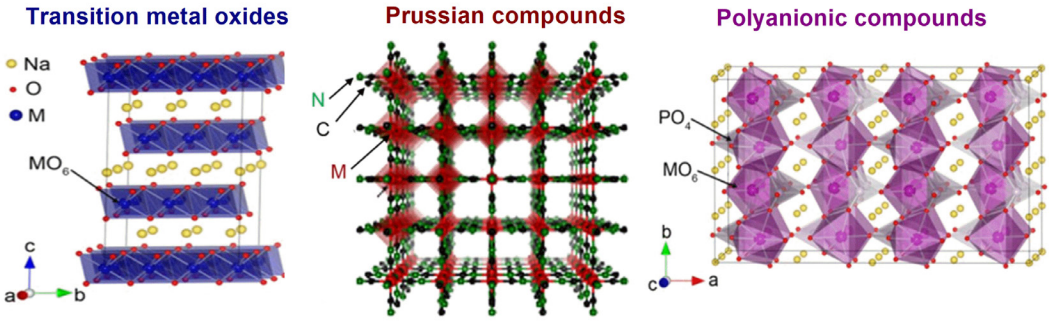

Figure 4. Most investigated cathode materials for Na-ion batteries [14]

Electrolytes for Na-ion batteries typically consist of Na salts (1M $NaPF_6$ or 1M $NaClO_4$) dissolved in a mixture of cyclic carbonates including ethylene and propylene carbonate (EC and PC) and linear carbonates such as dimethyl, ethyl methyl, and diethyl carbonate (DMC, EMC and DEC), often combined with fluoroethylene carbonate (FEC) additive [14]PC, DMC.

These electrolytes can be categorized as the first-generation, where their combination depends on the type of the examined material. Diglyme-based electrolytes are becoming attractive as they offer the potential for graphite to cointercalate a large amount of Na^+ ions [15], while other formulations following lithium-based counterparts, such as solid and gel-polymer electrolytes, molten salts (including ionic liquids) are also being explored. Furthermore, there is a special class of aqueous electrolytes with significant advantages in terms of cost, toxicity, ionic conductivity, and simplified manufacturing process. However, their inferior voltage compared to organic electrolytes remains a significant challenge. Recent demonstrations of using "water-in-salts" electrolytes [16] open up possibilities for eco-friendly, safe, and sustainable high-voltage aqueous batteries, potentially becoming the energy storage solution for future generations.

Our research avenue:

To contribute to Na-ion battery progress and gain a deeper understanding of the sodium charge storage mechanism we have developed both anode and cathode materials within a SuperCar NATOSPS project. The anode is composed of HC using the lignocellulosic residue of vine pruning, specifically vine shoots collected from the Plantaža vineyard [17]. The cathode is a Na, Fe-based polyanion, with the composition of $Na_4Fe_3(PO_4)_2P_2O_7/C$, prepared via sol-gel method [18]. Developed materials are low-cost and eco-friendly electrodes, free of toxic and scarce elements such as lithium, cobalt, nickel, and vanadium, which are key components in contemporary Li- and Na-ion batteries. Their advantages (as outlined in Table 2) include cost-effectiveness, easy synthesis procedures, and high specific capacity. However, further material modification/optimization is required to address the challenges listed in Table 2 and tailor materials for commercial purposes.

Table 2. Advantages and disadvantages of our newly developed anode and cathode materials

Anode	Advantages&Novelties	Challenges
Hard carbon Simple carbonization of a byproduct from vine pruning, first at 300°C and then at 1400 °C	Simple and fast synthesis route, industrially suitable	Low initial efficiency (≈ 70%).
	Cheap, green and abundant precursor	Impurity traces – their removal complicates the procedure
	High capacity (≈ 270 mA hg^{-1} at C/10, 253 mAh g^{-1} at 1C), low redox potential, good cyclic stability, and good rate-capability (up to 20C)	Decreased rate capability when it comes to current rates above 20 C. Still, currents above 10 C are atypical and HC obtained at lower temperatures (700, 1000°C) can retain capacity at 50 C or even 100C.
Cathode		
$Na_4Fe_3(PO_4)_2P_2O_7/C$ (NFPP/C) Li, Co, Ni and V -free cathode Sol-gel method using Citric acid and both phosphate and pyrophosphate precursors	The successful formation of NFPP as the major phase, liberated from $Na_2FeP_2O_7$ (NFP) when synthesis starts from both phosphate and pyrophosphate.	Traces of secondary phase - maricit $NaFePO_4$
	$Na_2FeP_2O_7$ reduces the NFFP/NFP composite performance	Elevated carbon content in the cathode (≈30%) and lower redox potential of NFPP compared to commercial $Na_3V_2(PO_4)_3F_3$ Tiamat cathode.
	High specific capacity (close to theoretical value) and high-rate capability (up to 78 C)	The capacity declines during cycling in an aqueous electrolyte. Still, the capacity is stable in an organic electrolyte

4. CONCLUSION

Due to their high specific energy, extended lifespan, and acceptable environmental characteristics, Li-ion batteries currently dominate the battery industry. However, their mass deployment for stationary energy storage and electric vehicles is hindered by challenges stemming from the high cost, limited availability and toxicity of constituent elements such as lithium and cobalt. Post-lithium battery systems, relying on more abundant elements such as Na, Ca, Mg, Zn, K, Al, would solve Li,Co-related problems. However, their energy density has not reached the competitive level of Li-ion technology yet, making them suitable for stationary grid storage applications which prioritize cost and safety. Multivalent batteries still face chemical challenges, primarily concerning the issue of using multivalent-based electrolyte, hindered diffusion of bivalent/trivalent ions within host structures and their interaction. These difficulties have delayed their commercialization, resulting in the high polarization between charge/discharge curves and the capacity loss during cycling. On the other hand, Na ion battery emerges as the most promising option. The similarity between Li and Na chemistry/technology has accelerated the progress of Na-ion batteries, evidenced through development of several prototypes based on different chemistries (HC anode combined with Prussian white/blue, layered oxides and $Na_3V_2(PO_4)_3F_3$ as cathodes).

In our efforts to contribute to the progress of Na ion batteries, SuperCar NATOSPS project has proposed low-cost and high-capacity electrodes based on C, Na, Fe and P, completely free not only of lithium and cobalt but also of nickel and vanadium, which are key elements in some commercial sodium-based cathode materials. However, there are still several challenges related to the synthesis and chemical composition of developed materials, which need to be addressed in order to reach contemporary alkaline-ion technology.

5. ACKNOWLEDGEMENTS

The research was supported by the NATO Science for Peace and Security Programme under G5836-SuperCar project. The author also acknowledges the University of Montenegro for support.

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