CSER 2025

conference on systems engineering research

Augmented Intelligence in Systems Engineering and Engineered Systems

Book of Abstracts

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Keynote - Plenary#121

AI and the Future of Aerospace Work

Naveed Naveed Hussain, PhD (Boeing Defense, Space, & Security)

Presented on: Thursday, 09:00-10:00 PDT (Cival)

Biography

Naveed Naveed Hussain, PhD (Boeing Defense, Space, & Security)

Naveed Hussain is vice president and chief engineer for Boeing Defense, Space & Security (BDS), where he is responsible for ensuring world-class technical integrity for all BDS products and services. He leads a 20,000-person international engineering organization that includes teams across each BDS division. Previously, Hussain served as Boeing’s chief technology officer (CTO) and vice president and general manager of Boeing Research & Technology (BR&T), Boeing’s advanced central research and development unit. While overseeing BR&T, he led a team of scientists, technologists, technicians and engineers who collaborate with research and development partners worldwide to solve the aerospace industry's toughest challenges. Before his BR&T assignment, Hussain was the vice president of Aeromechanics Technology for Boeing. Previously, he led Platform & Networked Systems Technology for BR&T; launched the BR&T-India research center in Bangalore; and directed Boeing Defense, Space, & Security Flight Engineering. He is an elected Fellow of the American Institute of Aeronautics and Astronautics and holds fourteen patents in technology areas including extreme environment composites, structural health prognostics, edge computing and autonomy. Hussain earned a Bachelor of Science from Rensselaer Polytechnic Institute and a Master of Science and a Doctor of Philosophy from Stanford University, all in mechanical engineering. He also completed a Master of Business Administration from the Wharton School of the University of Pennsylvania.

Keynote - Plenary#120

AI-Ready Data for U.S. Smart Manufacturing

Dr. Jim Davis (University of California, Los Angeles)

Presented on: Friday, 09:00-10:00 PDT (Salon de Reyes)

Biography

Dr. Jim Davis (University of California, Los Angeles)

Jim recently stepped down from his position as Vice Provost IT at UCLA after serving in executive IT leadership for 30 years. He has been involved with the progression of AI/ML, scaled use of the internet, cyberinfrastructure, cybersecurity, high performance computing, data centered intelligence, and Smart Manufacturing. At UCLA, he formed and had oversight of UCLA’s Office of Advanced Research Computing (OARC) with broad responsibilities for campus data and technology solutions and the impacts of digital research and scholarship. Jim is currently serving as Special Advisor on Smart Manufacturing and Data Science in the Office of Research and Creative Activities (ORCA) at UCLA. As a co-founder of the U.S. Smart Manufacturing Initiative, Jim also remains Principal Investigator of the Clean Energy Smart Manufacturing Innovation Institute (CESMII), with its program home in UCLA/OARC. CESMII is the 3rd national Manufacturing USA Public Private Partnership sponsored by the U.S. Department of Energy. Jim remains active in national planning for Smart Manufacturing which is rooted in AI/ML.

Keynote - Plenary#252

Banquet Keynote: National Academy of Engineering: Preparing the Next Generation of Engineers

Alton Romig (NAE)

Presented on: Thursday, 19:00-21:00 PDT (TBC)

Biography

Alton Romig (NAE)

Alton D. Romig, Jr. is executive officer of the National Academy of Engineering, which is congressionally chartered to provide, when requested, advice to the federal government on matters of engineering and technology. As chief operating officer Dr. Romig is responsible for the Academy's program, financial, and membership operations, reporting to the president.

Before assuming his current position, he was vice president and general manager of Lockheed Martin Aeronautics Company's Advanced Development Programs, better known as the Skunk Works®, the preeminent seat of US aerospace innovation for more than 70 years. He led research and advanced development activities and set the strategic direction for current and future programs for the company's Aeronautics Business Area.

Dr. Romig spent more than 30 years with Sandia National Laboratories (operated by Sandia Corporation, a Lockheed Martin Company) before joining Advanced Development Programs. His senior leadership responsibilities included development and engineering activities providing science, technology, and systems expertise in support of US programs in military technology, nuclear deterrence and proliferation prevention, technology assessments, intelligence and counterintelligence, homeland security, and energy programs. As a member of the technical staff he is one of the few engineers to have worked on every nuclear weapons system currently in the US stockpile.

Dr. Romig was elected to the National Academy of Engineering in 2003 and the Council on Foreign Relations in 2008. He is a fellow of the Minerals, Metals, and Materials Society (TMS), Institute of Electrical and Electronics Engineers (IEEE), American Institute of Aeronautics and Astronautics (AIAA), and American Association for the Advancement of Science (AAAS), and a fellow and honorary member of ASM International, which awarded him the ASM Silver Medal for Materials Research in 1988. In 2023, Dr. Romig also received the IEEE-USA George F. McClure Citation of Honor for his significant contributions to the aerospace industry, national security, and engineering policy.

He received his BS, MS, and PhD in materials science and engineering from Lehigh University in 1975, 1977, and 1979, respectively.

Keynote - Plenary#125

Closing Remarks

Keynote - Plenary#205

Plenary Session - Opening Remark

Ms. Marilee Wheaton (Conference General Co-Chair)

Presented on: Friday, 08:30-09:00 PDT (Salon de Reyes)

Keynote - Plenary#123

Plenary Session - Opening Remark

Dr. Azad M Madni (Conference Honorary Co-Chair)

Presented on: Wednesday, 08:30-09:00 PDT (Cival)

Keynote - Plenary#124

Plenary Session - Opening Remark

Ms. Marilee Wheaton (Conference General Co-Chair)

Presented on: Thursday, 08:30-09:00 PDT (Cival)

Keynote - Plenary#122

The Science of Cause and Effect: From Deep-Learning to Deep Understanding and Personalized Decision-Making

Dr. Judea Pearl (University of California, Los Angeles)

Presented on: Wednesday, 09:00-10:00 PDT (Cival)

Biography

Dr. Judea Pearl (University of California, Los Angeles)

Judea Pearl is currently a professor of computer science and statistics and director of the Cognitive Systems Laboratory at UCLA. Dr. Pearl is best known for championing the probabilistic approach to artificial intelligence and the development of Bayesian networks. He is also credited for developing a theory of causal and counterfactual inference based on structural models. In 2011, the Association for Computing Machinery(ACM) awarded Pearl with the Turing Award, the highest distinction in computer science, "for fundamental contributions to artificial intelligence through the development of a calculus for probabilistic and causal reasoning". He is the author of several books, including the technical Causality: Models, Reasoning and Inference, and The Book of Why, a book on causality aimed at the general public.

He received a B.S. in electrical engineering from the Technion in Israel. He received an M.S. in electrical engineering from the Newark College of Engineering, and went on to receive an M.S. in physics from Rutgers University and a PhD in electrical engineering from the Polytechnic Institute of Brooklyn. He worked at RCA Research Laboratories on superconductive parametric amplifiers and storage devices and at Electronic Memories, Inc., on advanced memory systems. He is one of the founding editors of the Journal of Causal Inference.

Panels

Panels#209

AI Powered Digital Twins for Smart Systems

Satyandra K. (SK) Gupta (USC) - guptask@usc.edu
Jacob Rome - jacob.rome@aero.org
Ram Sriram - ram.sriram@nist.gov
Soundar Tirupatikumara - u1o@psu.edu
Senthil Arul - Senthil.Arul@dla.mil

Presented on: Wednesday, 10:30-12:00 PDT (Cival)

Abstract. AI-powered digital twins are ushering a new era of smart systems with the potential of lowering lifecycle costs, reducing modeling and human errors, improving system quality, increasing system performance, and reducing the environmental footprint. This panel will focus on digital twin technology that can be used to significantly improve performance of smart systems. A digital twin is a digital counterpart of a real-world system. It performs continuous model updates using sensor data to mirror the current state of the physical system. Therefore, information flows from the physical system to the digital twin. A digital twin is also used to influence the operation of the physical system. Therefore, information also flows from the digital twin to the physical system. This two-way information flow makes digital twins different from purely digital models. Digital twins are being used in a wide variety of contexts to provide information to task planners and schedulers to make decisions about the next tasks to perform based on the current state of the system. Digital twins also enable monitoring the performance of the system in real-time and use this data to predict when maintenance is needed, reducing unexpected downtime and preventing machine breakdowns. Digital twins are also being used for identification of defects and perform real-time quality control. By analyzing process data, digital twins are able to identify areas for optimization and recommend changes to realize improvements. Digital twins are able to provide a detailed record of processing/operating conditions to ensure compliance with relevant regulations. Digital twins can be used to optimize manufacturing operations in real-time to support on-demand production of personalized products in a cost-effective manner.This panel will focus on how AI is adding new capabilities to digital twins. For example, simulations are necessary to generate optimal plans for performing autonomous operations. However, traditional simulations lack the speed required when dealing with part models with uncertainties. In this regard, machine learning is being used to create fast simulations based on neural networks, endowing digital twins with new planning and prediction capabilities. Similarly, operations cannot be safely executed using traditional controllers in the presence of uncertainties. In this regard, an AI-based controller can potentially be used to exploit sensor feedback to dynamically adapt operating conditions. In a similar vein, AI-based prognostics and health management can be used by digital twins to ensure that the onset of adverse events can be automatically detected, and corrective actions can be taken in timely fashion.

Panels#208

Architecting or Design: Where’s the Line

Dr. Bryan Mesmer (The University of Alabama in Huntsville) - Bryan.Mesmer@uah.edu
Casey Eaton (The University of Alabama in Huntsville)
Anna-Maria Rivas McGowan, Ph.D (NASA)
Garima Bhatia, Ph.D (Ford Motor Company)
Alejandro Salado, Ph.D (Arizona State University)
TBD (Army)

Presented on: Wednesday, 13:30-15:00 PDT (Cival)

Abstract. Architecting and design do not have consistent definitions or comparisons to each other in the systems engineering community. Contradicting understandings of the terms architecting and design may generate conflict or misunderstandings when assigning tasks to systems engineers, architects, and designers. Ongoing research into the connections of architecting and design have identified conflicts in how the overlap or differentiation of these roles are perceived. This interactive panel investigates the differentiation of architecting from design. Leading the discussion will be four panelists who have expertise in architecting and/or design with careers in academia, industry, and government organizations. The breadth of expertise and experience of the panel will provide varying perspectives on what makes architecting and design different. The moderators will introduce the topic, including an overview of the perceptions identified through active research into the comparison of architecture and design. The panelists will introduce themselves. The Mentimeter tool will be used to elicit opinions from the panel attendees on the differences between architecting and design. The panelists will be asked to share thoughts on the questions and results. Half of the session will be pre-structured questions on three topics: 1) perceived differences, 2) domains, and 3) decision making. Topic 1: The perceived differences impact the tasks and roles for architects and designers. Architecting and design may differ in timing, breadth, size of project, or complexity. Understanding the overlaps can allow individuals to be placed into appropriate roles with coordinating tasks. Topic 2: Systems engineering is acknowledged to be multidisciplinary and apply to broad domains and applications. Exploring the boundaries of architecting and design can clarify use cases. With the terms being used in other fields, it may be worth exploring in the research community. For example, the parallels from a systems architect/designer to a building architect/designer. Panelists can share their experiences with varied applications in architecting and design efforts. Topic 3: Architecting establishes the foundation for decisions to be made for the entire lifecycle of a system. As such, it is important that decisions concerning architectures be rigorous, justifiable, and easily communicated to decision makers and stakeholders. Unfortunately, the current state of architecting has significant challenges in repeatability, justifiability, and communication of decisions. Systems design, if similar to architecting, may offer solutions to these challenges. Examples of questions include: “Are architecting and design the same?”; “How do architecting and design differ?”; “Why should we not differentiate between architecting and design?”; “How does systems engineering relate to architecting and design?”. The remaining half of the session, the moderator will open up questions to the attendees. Research Sponsor: Office of the Under Secretary of Defense for Research & Engineering (OUSD(R&E) and the US Army Combat Capability Development Command (DEVCOM) Aviation and Missile Center (AVMC) Technology Development Directorate (TDD)

Biography

Garima Bhatia, Ph.D (Ford Motor Company)

Panels#212

Compositional methods for systems engineering

Ram Sriram (NIST) - Ram.sriram@nist.gov
Brandon Baylor (Chevron)
Javier Calvo-Amodio (OSU)
Spencer Breiner (NIST)

Presented on: Thursday, 13:30-15:00 PDT (Tikal)

Abstract. Systems engineering (SE) as it is currently practiced lacks a solid foundation in science and mathematics. Whereas our confidence in mechanical or electrical engineering derives from its basis in hard science and mathematics, SE relies somewhat softer methodologies like systems thinking and functional decomposition. Though the importance of these methods is not in doubt, we currently lack the conceptual precision to assess critical questions like the validity and scope of these models. The current trend towards model-based SE is quite encouraging in this regard, but is most successful "in the small", dealing with localized models for specific phenomena, and struggles with more global problems involving multiple scales, methods and domains.For the past five decades, the mathematics of category theory (CT) has been lauded as a potential solution to above impasse, providing formal language for the study of compositional systems such as process (input/output composition), constraint (shared-boundary composition) and hierarchy (branching composition). CT has been called "the mathematics of mathematics", and its internal role as an organizing principle within mathematics (as well as physics and computer science) speaks to the challenges that SE faces today. However, despite long-standing enthusiasm and interest, adoption within SE has been essentially nil due to substantial obstacles translating mathematics into methodology and toy examples into usable tools.This session will start with a high-level overview of CT methods and existing applications, and then move on to a consideration of the potential and the challenge of adapting these methods to an SE context.

Biography

Ram Sriram (NIST) - Ram.sriram@nist.gov

Panels#213

Empowering Women Leaders in Systems Engineering - Data and Algorithm Bias in Generative AI

Dr. Tracee Gilbert (System Innovation) - tracee.gilbert@systeminnovation1.com

Presented on: Wednesday, 15:30-17:30 PDT (Luna)

Abstract. The surge of generative AI into systems engineering brings both innovations and significant challenges. The biases embedded in training data and algorithms are often rooted in historical underrepresentation and systemic inequalities that can skew decision-making processes, reinforce stereotypes, and limit the visibility of diverse contributions within engineering systems. For women in leadership, addressing these biases requires both technical knowledge and strategic advocacy—ensuring that data sources are diverse, algorithms are regularly audited for bias, and ethical considerations are embedded throughout the engineering lifecycle. This session will examine how women leaders in systems engineering can actively shape the development and deployment of generative AI tools, leveraging their unique perspectives to drive inclusive innovation while strengthening their roles as both technical experts and change agents within the profession.

Panels#207

Engineering Futuristic Drones

Randall L Bostick, PhD (OUSD(I&S)) - randall.l.bostick.civ@mail.mil
Douglas Buettner, PhD (Acquisition Innovation Research Center/SERC) - dbuettne@stevens.edu

Presented on: Thursday, 13:30-15:00 PDT (Cival)

Abstract. This special panel session will cover current research and development on small to medium sized unmanned air systems and other advance air mobility systems operating with full or hybrid advanced thrust technologies such as electro- and magneto-hydrodynamics, ion propulsion or other novel mechanisms which reduces the number or size of moving parts. Also included will be technologies using innovative concepts in these areas that either incorporate or are engineered with support from AI-based technologies, for lift (to aid in vertical take-off and landing), automated operation (at distances of up to 10 km from the point of origin) and are deployable from ground or airborne platforms.

Biography

Douglas Buettner, PhD (Acquisition Innovation Research Center/SERC) - dbuettne@stevens.edu

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Panels#204

Executive Leadership Panel on Systems Engineering and Augmented Intelligence

Ms. Marilee J. Wheaton (USC / Aerospace Corporation) - Marilee.wheaton@aero.org
Mr. Peter Brook (Fellow of the Royal Academy of Engineering)
Dr. Elizabeth Davison (The Aerospace Corporation)
Mr. Ryan Sands (Crane Aerospace & Electronics)
Ms. Padma Sundaram (Aurora)

Presented on: Friday, 10:30-12:00 PDT (Salon de Reyes)

Abstract. With AI resurgence paced by recent machine learning advances, several engineering disciplines including systems engineering turn to AI to improve system model accuracy, process flexibility, content exploration and search, and team productivity. More recently, AI has become a means to augment rather than replace human capability. This perspective alters AI's role from autonomous intelligence to augmented intelligence. Inherent in this view, recognizing AI and human together can perform certain tasks better than either could alone. The panel will provide examples of how AI has augmented human engineer capabilities, and also where the human engineering has enhanced AI capabilities, especially in planning and decision-making tasks in systems engineering or in engineered human-machine systems. In addition, the panel will address the following questions:Is Augmented Intelligence the answer to increasing trust in AI? Is Augmented Intelligence key to addressing ethics issues in AI by having the human- in-the-loop?Incorporating AI more deeply into our societal fabric requires understanding AI pros and cons. What are the major pros and cons as systems engineering utilizes more of the AI technologies?

Biography

Ms. Padma Sundaram (Aurora)

Panels#206

Opportunities at the Boundaries between Systems Engineering and Design Theory

Bryan Watson (Embry-Riddle Aeronautical University) - WATSONB3@erau.edu
Dr. Zak Ouzzif (Anduril Industries)
Dr. Taylan Topcu (Virginia Tech)
Dr. Zoe Szajnfarber (George Washington University)

Presented on: Thursday, 10:30-12:00 PDT (Cival)

Abstract. In this panel presentation, we will hear from academic faculty and industry professionals discussing their experiences with unique design challenges that cannot be fully addressed by design theory or system engineering research alone. This panel is comprised of those with extensive experience in academia, private industry, and on federally funded projects. Each panelist will provide insight into specific challenges faced within these various contexts and will describe their efforts to address them. Topics may include bio-inspired design, developments in computer-aided design tools, how personnel and project scale impact process, or how the context of stakeholders constrains the design space. Ultimately, this panel serves as a call to action for systems engineering and design theory researchers to address these contemporary challenges. Attendees of this panel will have opportunities to engage in conversation and share their thoughts during the panel session. In addition, attendees will receive access to a networking tool that continues the conversation after the conclusion of the panel discussion.

Papers

Paper#41

A Comparative Analysis of Digital Engineering Education in Germany and the United States Department of Defense's Digital Engineering Competency Framework

Nicholas Jurczyk (Virginia Tech) - njurczyk@vt.edu
Taylan Topcu (Virginia Tech) - ttopcu@vt.edu

Presented on: Wednesday, 16:00-16:30 PDT (Mirador)

Keywords. Digital Engineering;Systems Engineering;Digital Transformation;Workforce Analysis;Engineering Education;Digital Engineering Competency Framework

Abstract. Digital Engineering (DE) is an Industry 4.0 inspired approach to traditional document-based Systems Engineering (SE) that aims to incorporate modern digital technologies, approaches, and best practices to improve the efficiency of system lifecycle management. Given its emerging nature, there is a significant DE workforce skill gap in the US, and the Department of Defense funded several studies to identify these skills, culminating into the Digital Engineering Competency Framework (DECF). However, aside from a handful of professional development opportunities that only provide some periphery exposure, DE education opportunities in US are nascent. On the other hand, German education system, driven by its automotive industry, has been an early adopter of DE education and offers several accredited degree programs. This study aims to provide insight into existing formal DE educational opportunities in Germany in order to provide a basis for future research into the development of DE educational opportunities in the US and beyond. We investigate the gaps between how German educational programs compare against DECF competencies through a topical analysis, by mining the course catalogs of German DE degree programs and mapping these into DECF sub-competencies. We report findings on program-level coverage and which elements of DE these programs prioritize. We find that while some degree programs fulfill all DECF sub-competencies, there are nuances in both the priority and weighting of the sub-competencies taught. Overall, the average degree program tends to emphasize modeling, simulation, software engineering, and communication while neglecting competencies related to digital model-based reviews and digital environment support.

Paper#40

A Generative AI-Driven Systems Engineering Maturity and Cost Modeling Framework

Raymond Madachy (Naval Postgraduate School) - rjmadach@nps.edu
Ryan Bell (Naval Postgraduate School) - ryan.bell@nps.edu
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Presented on: Thursday, 15:30-16:00 PDT (Tikal)

Keywords. Generative AI;Large Language Models;Maturity Model;Cost Modeling;COSYSMO;COCOMO;Systems Engineering Process

Abstract. Generative Artificial Intelligence (AI) is quickly transforming systems engineering processes in numerous ways including automating tasks, generating architecture and design options, tradeoff analysis, implementation, testing, improving decision-making processes, and many more. An integrated framework is introduced with a harmonized maturity and cost model for using generative AI in systems engineering. By understanding the levels of maturity and their associated cost implications, organizations can develop strategies for effectively leveraging generative AI in their engineering workflows, ensuring continuous improvement, cost reductions, and strategic integration with technological advancements. The maturity and cost model enables a cohesive evaluation of the financial impacts of AI adoption.

Paper#54

A Prototype Simulation Testbed to Evaluate Systems Engineering Methods for Intelligent Systems

Samuel Cornejo (The University of Arizona) - samuelcornejo@arizona.edu
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Presented on: Thursday, 11:00-11:30 PDT (Luna)

Keywords. intelligent systems;systems engineering for AI (SE4AI);test of AI systems

Abstract. Research has suggested that systems engineering methods may need to be evolved to effectively support the engineering of intelligent systems. This paper presents the prototype of a simulation testbed that enables the evaluation of systems engineering methods for intelligent systems. The testbed is a surrogate of an intelligent detection system composed of an optical lens, a camera, and a classification system. While the intelligent algorithm is implemented as part of the classification system, the results of intelligence are a function of the performance of the lens and the camera as well. The models of the three components are designed to enable modifications that represent those that an actual optical detection system may exhibit in real life, including manufacturing variations (such as lens transmission or pixel defects), technology upgrades or obsolescence (such as increase of camera resolution), or operational wear (such as lens transmission deterioration or pixel cracks). We show in this paper that such a design allows for (1) inducing variations that a real system would exhibit and (2) such variations enable the assessment of the effectiveness of systems engineering methods for intelligent systems.

Paper#66

A research and collaboration agenda for advancing descriptive model interoperability for model-based systems engineering in the digital engineering context

Ryan Noguchi (The Aerospace Corporation) - ryan.a.noguchi@aero.org

Presented on: Thursday, 11:00-11:30 PDT (Tikal)

Keywords. Descriptive models interoperability model interoperability MBSE DE model-based systems engineering digital engineering

Abstract. Model-Based Systems Engineering (MBSE) is the modern practice of systems engineering in which descriptive models supplant documents as the formal embodiment of SE knowledge. MBSE is often performed within very localized contexts, creating models that inform their immediate stakeholders but not necessarily suitable for broader use or reuse. However, if the models are intended to serve wider purposes—e.g., to be more broadly used, reused, and federated to enable sharing of the information they contain—standards are needed to advance the quality, value, usability, and interoperability of those models, particularly when the intent is for the MBSE activity to contribute to and participate in a more comprehensive digital engineering (DE) ecosystem. This paper describes the problem of model interoperability in MBSE within a DE context and the role that standards play in facilitating broader use, reuse, and federation of models to achieve greater value from those models. It also describes standards for model quality, content, usability, and interoperability that are needed to advance the MBSE integration maturity not only of individual organizations but also of the broader MBSE community at large.

Paper#6

A Sociotechnical Categorization of Barriers to Digital Engineering Transformation and Their Mapping Against the United States Department of Defense's Policy Goals

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Taylan Topcu (Grado Department of Industrial and Systems Engineering) - ttopcu@vt.edu

Keywords. Digital transformation;digital engineering;MBSE;policy analysis;sociotechnical systems

Abstract. Digital Engineering (DE) represents a paradigm shift in systems engineering, enabling enhanced lifecycle management through the integration of digital models and digital artifacts. Despite the potential of DE, many transformation initiatives prioritize tools and processes, and in return, suffer from sociotechnical barriers that impede their success. This paper addresses these challenges by documenting the sociotechnical barriers to DE transformation, organized into six dimensions: people, technology, processes, culture, infrastructure, and goals. Utilizing a rapid review of the current literature, we identified and classified key barriers in each dimension. We then mapped these barriers to the U.S. Department of Defense's DE policy goals. Our findings reveal that while technical barriers – such as interoperability issues and insufficient IT infrastructure – are significant, many pressing challenges stem from human-related factors, including a lack of digital literacy, resistance to change, and organizational inertia. Additionally, cultural factors and misalignment between strategic goals and technological capabilities further complicate DE implementation. This study highlights the importance of a holistic, sociotechnical approach to DE transformation, emphasizing the need for strong leadership, clear vision, workforce readiness, and long-term organizational cultural shifts to support DE transformation. This study makes two important contributions. First, it supplements the systems engineering literature by identifying, categorizing, and mapping sociotechnical barriers to DE transformation. Second, it provides actionable change management insights for practitioners and managers who are in the process of going through DE transformation efforts. Future research should explore longitudinal studies and practical strategies for overcoming these barriers to ensure sustainable and resilient adoption of DE.

Paper#58

A Survey of Approaches for Aggregating Disparate Evidence in Support of Architectural Decisions on Ilities

Alejandro Salado (The University of Arizona) - alejandrosalado@arizona.edu

Presented on: Thursday, 16:00-16:30 PDT (Luna)

Keywords. system architecture;verification and validation;evidence aggregation

Abstract. This paper surveys various approaches for aggregating disparate evidence to support architectural decision-making, particularly in relation to achieving system ‘ilities’. Recognizing the need to scientify systems architecture, this paper examines how evidence in the form of heuristics, best practices, empirical studies, and experimental findings may be aggregated to substantiate architectural choices. Each approach is assessed for its strengths and limitations, providing a comparative view to enhance rigor, contributing to evidence-based system architecture.

Paper#38

A Systems Theoretic Perspective on Understanding Functional Equivalence in Systems Engineering

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Presented on: Wednesday, 16:30-17:00 PDT (Tikal)

Keywords. Functional equivalence;Functional Analysis;Systems theory;Propositional Logic

Abstract. Functional analysis is fundamental to systems engineering, where complex systems are decomposed into functions that describe transformations from inputs to outputs. These functions are fundamental to system realization - they guide architectural decisions, enable requirements allocation, shape physical implementation, and determine system capabilities. In systems engineering, determining whether two functions are truly equivalent remains a significant challenge. While functional equivalence might seem straightforward, its implications run deeper than simple input-output comparisons. This paper establishes the foundation for understanding the nature of functional equivalence by exploring real-world examples that demonstrate why a formal theory is needed. We examine common misconceptions, challenges, and consequences of inadequate equivalence understanding. Through carefully chosen examples, we demonstrate key conditions that influence functional equivalence and justify the need for a formal theoretical framework based on systems theory, set theory, and propositional logic. The paper concludes by presenting preliminary theorems, setting the stage for a comprehensive theory of functional equivalence.

Paper#10

A Theory Of Development For Complex Engineered Systems

Neil Siegel (USC) - nsiegel@usc.edu

Presented on: Thursday, 17:00-17:30 PDT (Luna)

Abstract. Society depends in an essential way on modern engineered systems, but the development of such systems remains problematic: a significant majority of such efforts fail. The author spent many years in industry “fixing” such problem engineering projects; through that experience, he and his team developed insight regarding what is a common recurring cause of such failures, and also developed a theoretical method for decreasing the probability of that recurring failure mode. In addition, he had the opportunity to apply this method to a large number of actual engineering development projects. In today’s talk, he explains the causes of such failures, his corrective theory, and some of the results of its actual application. A discussion of what role AI / ML / LLMs could play in this area is discussed.

Paper#33

An Analysis of Early-Stage Functional Safety Analysis Methods and Their Integration into Model-Based Systems Engineering

Jannatul Shefa (Grado Department of Industrial and Systems Engineering, Virginia Tech) - shefa@vt.edu
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Presented on: Thursday, 16:00-16:30 PDT (Cival)

Keywords. Model-based Systems Engineering (MBSE);Safety analysis;Functional hazard analysis (FHA);Failure modes and effects analysis (FMEA);Functional failure identification and fault propagation (FFIP)

Abstract. As systems become increasingly complex, conducting effective safety analysis in the earlier phases of a systems' lifecycle is essential to identify and mitigate risks before they escalate. To that end, this paper investigates the capabilities of key safety analysis techniques, namely: Failure Mode and Effects Analysis (FMEA), Functional Hazard Analysis (FHA), and Functional Failure Identification and Propagation (FFIP); along with the current state of the literature in terms of their integration into Model-Based Systems Engineering (MBSE). A two-phase approach is adopted. The first phase is focused on contrasting FMEA, FHA, and FFIP techniques, examining their procedures, along with a documentation of their relative strengths and limitations. Our analysis highlights FFIP's capability in identifying emergent system behaviors, second order effects, and fault propagation; thus, suggesting it is better suited for the safety needs of modern interconnected systems. Second, we review the existing research on the efforts to integrate each of these methods into MBSE. We find that MBSE integration efforts primarily focus on FMEA and integration of FHA and FFIP is nascent. Additionally, FMEA-MBSE integration efforts could be organized in four: model-to-model transformation, use of external customized algorithms, built-in MBSE packages, and manual use of standard MBSE diagrams. While our findings indicate a variety of MBSE integration approaches, there is no universally established framework or standard. This leaves room for an integration approach that could support the ongoing Digital Engineering transformation efforts by enabling a more synergistic lifecycle safety management methods and tools.

Paper#39

An Empirical Exploration of ChatGPT's Ability to Support Problem Formulation Tasks for Mission Engineering and a Documentation of its Performance Variability

Max Ofsa (Virginia Tech) - jaster15@vt.edu
Taylan Topcu (Virginia Tech) - ttopcu@vt.edu

Presented on: Thursday, 11:30-12:00 PDT (Mirador)

Keywords. Systems Engineering;Mission Engineering;Artificial Intelligence for Systems Engineering;AI4SE;Human-AI Collaboration;Problem Formulation

Abstract. Systems engineering (SE) is evolving with the availability of generative artificial intelligence (AI) and the demand for a systems-of-systems perspective, formalized under the purview of mission engineering (ME) in the US Department of Defense. Formulating ME problems is challenging because they are open-ended exercises that involve translation of ill-defined problems into well-defined ones that are amenable for engineering development. It remains to be seen to which extent AI could assist problem formulation objectives. To that end, this paper explores the quality and consistency of multi-purpose Large Language Models (LLM) in supporting ME problem formulation tasks, specifically focusing on stakeholder identification. We identify a relevant reference problem, a NASA space mission design challenge, and document ChatGPT-3.5's ability to perform stakeholder identification tasks. We execute multiple parallel attempts and qualitatively evaluate LLM outputs, focusing on both their quality and variability. Our findings portray a nuanced picture. We find that the LLM performs well in identifying human-focused stakeholders but poorly in recognizing external systems and environmental factors, despite explicit efforts to account for these. Additionally, LLMs struggle with preserving the desired level of abstraction and exhibit a tendency to produce solution specific outputs that are inappropriate for problem formulation. More importantly, we document great variability among parallel threads, highlighting that LLM outputs should be used with caution, ideally by adopting a stochastic view of their abilities. Overall, our findings suggest that, while ChatGPT could reduce some expert workload, its lack of consistency and domain understanding may limit its reliability for problem formulation tasks.

Paper#27

An Exploration of the Robotaxi Problem

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Presented on: Wednesday, 17:00-17:30 PDT (Tikal)

Keywords. Robotaxi;Autonomy;Transportation

Abstract. The rise of autonomous systems has introduced the coming reality of robotaxis—self-driving cars that operate as on-demand taxis into urban transportation systems. This paper explores the complexities associated with a robotaxi system, focusing on critical aspects such as stakeholder perspectives, value-adding processes, and shaping forces. Through this in-depth analysis, the paper addresses the technological, regulatory, infrastructural, environmental, economic, and societal considerations that influence the practicality of robotaxis. By examining the roles of key stakeholders, the paper also sheds light on the diverse priorities that must be balanced in the development of this advanced transportation solution. The findings contribute to a broader understanding of the challenges inherent in integrating robotaxis into existing urban environments.

Paper#3

An Integrated Product and Process Development Framework for High Technological Complexity Defense Systems

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Paper not presented

Keywords. Defense Systems Life Cycle Management;Integrated Product Development;IPPD;IPDT;Defense Acquisition

Abstract. The existence of a close relationship between the defense industry and defense government agencies in developing defense systems with high technological complexity requires the use of methodologies that integrate the product development and production processes, which will positively impact the execution of Defense Acquisition Programs. The use of the Integrated Product and Process Development (IPPD) methodology has been one of the solutions for this context because, with the increase in the technological complexity of projects, which perform several simultaneous activities, going through several iterations before the delivery of each stage is completed, it brought the need to improve the methods employed. A framework based on the life cycle theory and its management process, developed from the systems engineering approach, has been proposed for the application of the IPPD concept. This framework involves technical teams and aims to enhance the execution of Brazilian Defense Acquisition Programs for obtaining high technological complexity defense systems.

Paper#52

Application of Bayesian Statistics to Refine Digital Twins

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Presented on: Wednesday, 14:30-15:00 PDT (Tikal)

Keywords. digital twin;Bayesian statistics;modelling and simulation;Artificial intelligence (AI)

Abstract. When developing a digital twin (DT) of a physical system, the model that the DT uses must be verified and validated. However, when developing verification and validation (V&V) strategies, the dynamic nature of the physical twin is not considered. Therefore, there are questions on whether the DT remains valid as the physical system undergoes changes during its lifetime, e.g., due to wear. In this paper, we introduce the use of Bayesian Statistics to dynamically update the DT as the data provided by the physical counterpart is received by the DT. This paper aims to advance the application of Digital Twins by improving V&V strategies.

Paper#68

Applying sustainable systems material flow analysis to achieve targets for SDGs 11 and 12

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Presented on: Thursday, 14:00-14:30 PDT (Mirador)

Keywords. Sustainable Systems Engineering;Construction and Demolition Waste;Circular Economy;Waste Diversion;Deconstruction;Waste Management;Material Flow Analysis;Material Intensity

Abstract. Fifty-five percent of the global population lives in urban areas, and this is expected to grow to 70% by 20501. Cities represent complex challenges about social, economic, and environmental systems. The urban built environment has interconnections with all three of these systems. As cities work to address anthropogenic greenhouse gas emissions, one area of focus is the reduction of methane emissions from landfills 2–4. SDG 11: Sustainable Cities and Communities and SDG 12: Responsible Consumption and Production have targets that relate to waste reduction. Sustainable Systems Engineering offers a holistic, systems approach to solving complex challenges. Together with the UN Sustainable Development Goals (SDGs) and targets, they address the challenges of sustainable material and waste management and sustainable, equitable urban growth. In this paper, we use a case study of Boulder, Colorado's existing building stock to demonstrate how material flow analysis can contribute to a local circular economy and help achieve targets in SDGs 11 and 12.

Paper#8

Assessing Modularity: Putting models to work in model-based systems engineering

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Presented on: Wednesday, 11:30-12:00 PDT (Tikal)

Keywords. verification;modelling;complexity;knowledge graph;verification complexity

Abstract. The complexity of systems is considered an invaluable information in the system development life cycle. While verification is a pervasive process also integral to system development, the verification complexity is a rarely studied principle in the field of systems engineering. A lack of consensus on its definition causes limited attempts at measuring such complexity both in academia and industry. We propose a multifactorial verification complexity definition with the Verification Complexity Framework. Multiple factors of verification complexity are stacked in layers, covering verification designs, structures, external factors, and information transfer between systems. Each layer is then represented as a three-dimensional object visualizing multiple complexity aspects such as human factors and time. The framework is proposed to initiate discussion on the verification complexity definitions and its measures, aiming to provide a common mathematical vocabulary to the verification engineers in the field.

Paper#50

Auto-generating scalable co-simulation structures for use in systems research utilizing the functional mockup interface

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Presented on: Thursday, 17:00-17:30 PDT (Mirador)

Keywords. systems engineering;systems research;simulation;modeling;synthetic data

Abstract. Research on engineered technological systems often involves evaluation of newly developed concepts through benchmarking against example systems. Sometimes data can either not be acquired for technical reasons or due to legal limitations. In this scenario, auto-generating co-simulation networks of engineered systems could be helpful. The main challenge is to find a common denominator of a broad variety of engineered systems, and define what constitutes an engineered system. Based on a set of core features of engineering, a minimal viable product that helps define the requirements for a tool to auto-generate user defined co-simulation networks is proposed. A new Python-based tool supports auto generation of co-simulation networks of arbitrary size. Leveraging the functional mock-up interface standard where nodes are represented by functional mock-up units, the structures interconnections are created arbitrarily by the tool with the scale of the structure being selectable by the user. This allows for a black box approach in a systems research context, and avoids confirmation bias from incomplete example structures. This means an additional option to objectively test to-be-developed systems analysis methods.

Paper#53

Automated Generation of Bayesian Verification Strategies using Semantic Web Technologies

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Presented on: Thursday, 10:30-11:00 PDT (Luna)

Abstract. Verification activities, which usually take the form of a combination of analyses, inspections, and tests, consume a significant part, if not the biggest part, of the development costs of large-scale engineered systems. Bayesian networks can be used to support the planning and execution of verification strategies. In this paper, the authors describe the generation of Bayesian networks from ontological representations of test strategies in a digital engineering environment. This approach enables the integration of data from multiple sources and automates the process of delivering Bayesian networks to engineers. We demonstrate this approach by applying it to a notional Attitude Determination and Control System.

Paper#32

Automation of multi-model analysis thread based on graph representation

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Presented on: Wednesday, 14:00-14:30 PDT (Tikal)

Keywords. digital engineering;ontology;graph;digital thread

Abstract. This paper explores a method for extracting sequence data related to a digital thread system of analysis from a graph-based representation of system data in a way that enables automation of the execution of the digital thread. It builds on research using the Digital Engineering Framework for Integration and Interoperability (DEFII) as a framework for incorporation of ontology-aligned data into a digital engineering ecosystem. This contribution demonstrates how automation methods in the digital engineering context can be generalized and reused across analyses to enable more efficient execution of multi-model analysis. This moves digital engineering models beyond descriptive representations of digital threads to executable instances that are not bound to a specific tool or automation enabling software.

Paper#28

Bio-Inspired Metrics for Real-Time Detection of Denial-of-Service Power System Attacks

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Presented on: Wednesday, 16:00-16:30 PDT (Cival)

Keywords. Cyber-physical systems;graph-theory;bio-inspired system design;systems engineering;ecological network analysis;resilience

Abstract. Cyber-attacks are occurring frequently as our power systems become more integrated with cyber components. This directly impacts the reliability of the power delivery capabilities of the physical grid. Protection strategies must encompass adaptable and robust quantitative assessment tools capable of keeping pace with technological advancements and emerging cyber threats while ensuring the continuous monitoring and maintenance of system health. This bio-inspired systems study offers unique insights into cyber-physical power systems disrupted by prevalent cyber network traffic pathways and Denial-of-Service attacks. Ecological food webs, known for their robust disturbance response characteristics, are quantitatively analyzed using graph and information theory. Applying these characteristics to design and analyze physical power networks for resilience has proven successful when applied to information-flow cyber networks there are fundamental modeling challenges. The proposed methodology enables cyber information flows to be compatible with the bio-inspired approach, helping to better understand time-dependent cyber-attacks within cyber-physical power system networks. The ecological metric known as the Degree of System Order, which has been directly linked to the resilience of ecological food webs, is calculated for cyber packet information and Round-Trip-Times. Disturbance scenarios highlight that each power system substation forms unique clusters based on their Degree of System Order at varying Round Trip Times. Moreover, by tracking packet transmissions per device, the approach uniquely enables the quantitative analysis of the location and spread of cyber-attacks across the system.

Paper#29

BiOp-CPS: A Bio-inspired Method for Resilient Cyber-Physical Power System Interface Optimization

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Presented on: Wednesday, 16:30-17:00 PDT (Cival)

Keywords. Cyber-physical systems;bio-inspired system design;resilience

Abstract. The evolving complexity of Cyber-Physical Systems (CPS) requires innovative approaches to enhance system resilience against potential cyber threats, such as Denial-of-Service (DoS) attacks. This study introduces BiOp-CPS, a bio-inspired optimization framework leveraging bipartite networks to redesign power grids for improved performance and robustness. The methodology includes analyzing the WSCC 9-bus system under traditional and bio-inspired redesigns. Key network metrics adopted from the ecological analysis of food webs, such as modularity, nestedness, and bipartite robustness, are used to quantify the system's ability to resist and recover from Denial-of-Service cyber-attacks. The results find that the bio-inspired redesigns outperform the traditional design regarding system resilience by reducing modularity while increasing nestedness and robustness, thereby demonstrating the potential of adopting system inspiration from biological ecosystems in CPS design and optimization. The findings suggest that further explorations of bio-inspired frameworks for CPS could provide valuable strategies for enhancing the resilience of power grid systems and related cyber-physical infrastructures.

Paper#65

Building Discrete Event Simulations in SysML

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Presented on: Thursday, 11:30-12:00 PDT (Luna)

Keywords. Simulation;SysML;MBSE;Systems Architecture;Systems Design

Abstract. This paper discusses challenges and current approaches for building Discrete Event (DE) simulation models using the Systems Modeling Language (SysML). DE Simulation software typically provide a Simulation Executive/Simulator that supports time flow and synchronized execution of time dependent events in a simulation. SysML on the other hand, is a general-purpose modeling language and supporting tools are usually not as feature rich. However, there is significant interest in simulation-based analysis of SysML conceptual models developed for architecture description and design in Model Based Systems Engineering (MBSE). The dominant strategy provided in the literature for DE simulation of SysML models is Model Transformation. This approach comes with challenges regarding continuity and cohesion of conceptual models developed in SysML and corresponding executable models run in external simulation tools. To address this challenge this paper offers a SysML based Simulation Executive and a basic User Model that facilitates native DE simulation in a SysML modeling tool. Additionally, a proof of concept implementation of this framework and example simulation in the Magic Draw tool is provided.

Paper#12

Characterizing the micro-interactions that drive Human-AI collaboration: insights from the design process

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Presented on: Wednesday, 10:30-11:00 PDT (Mirador)

Keywords. Human-AI;Micro-interactions;Human in the pattern of micro-interaction;AI in the pattern of micro-interaction

Abstract. The past few years have seen a drastic rise in the capabilities and usage of AI models in the workforce. A common form of AI being used is Large Language Models and yet, not much is known about how exactly people work with these models. Drawing on empirical observation of multiple design sessions, this research established a preliminary set of architypes to characterize the micro-interact patterns of humans and AI collaboration. Specifically, it found that there are five common types of these interactions – Branch, C, Parallel Lines, Triangle, and Circle - with different user's varying their usage of them. The types of patterns are stable across users despite significant variation in the way they are combined the relative emphasis of each pattern. This may be related to how much the users are comfortable relying on the AI output (before independent variation) which will be explored in future work. Future work will expand the study done here to include explicit variation in user experience level with a topic and how their trust in the AI effects their usage.

Paper#49

Co-Simulation of the Intervention and Realization Systems

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Presented on: Thursday, 16:30-17:00 PDT (Mirador)

Keywords. Intervention System;Realization System;Heuristics

Abstract. This paper presents a novel co-simulation that integrates the performance models of an intervention system and its corresponding realization system, with a focus on the provision of electrical power as a case study. This approach addresses a significant challenge in system architecture, where decisions within one system impact the performance of the other, leading to complex interdependencies. Through this co-simulation, we aim to bridge the art and science of system architecture by providing a holistic perspective that allows architects to consider both intervention effectiveness and realization constraints at once. This framework offers practical insights for optimizing both system performance and resource allocation, making it a valuable tool for system designers and decision-makers alike.

Paper#21

Concept-knowledge theory as a means to evaluate uncertainties in large complex projects

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Presented on: Wednesday, 10:30-11:00 PDT (Luna)

Keywords. Megaprojects;Project complexity;Concept-Knowledge theory;Management of uncertainty

Abstract. This article explores the application of a novel approach to identify, track, and manage uncertainties that affect the performance of large complex projects. The approach uses Concept-Knowledge Design Theory and its visual mapping formats as a means to elicit project uncertainties in order to build mitigation plans. An ongoing project is testing this as a methodology to extend risk management into uncertainty management. This article explains the methods using a historical case study of a successful megaproject: Heathrow Terminal 5.

Paper#43

Design and Development of an AI-Enabled Systems Engineering Model Generation Tool

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Presented on: Thursday, 16:00-16:30 PDT (Tikal)

Keywords. MBSE;AI;Large Language Models;SysML

Abstract. This work presents the design and development of an AI-powered tool aimed at streamlining model-based systems engineering (MBSE) workflows. The tool converts natural language inputs into MBSE models by combining large language models and natural language processing techniques with MBSE software APIs. Integrating generative AI into systems engineering processes is highly effective for automating routine tasks, boosting productivity, and supporting the ongoing digital transformation in the field.

Paper#1

Developing a SYSML Model of a Legacy DoD System

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Presented on: Wednesday, 10:30-11:00 PDT (Tikal)

Keywords. Systems Engineering;Model Based Systems Engineering;System Modeling Language

Abstract. As organizations shift from traditional, document-based systems engineering to digital engineering, one of the major challenges is modeling legacy systems that may have multiple variants with different individual components within the same architecture. In addition to the challenge of developing digital model for engineered systems, modeling legacy systems introduced an additional challenge that different variants of the system may be currently fielded. This paper applies model-based systems engineering (MBSE) to a legacy system within the Department of Defense (DoD) using the Systems Modeling Language (SysML). It specifically focuses on the physical aspects of the system architecture and includes both block definition diagrams and internal block diagrams. This provides an example of developing a model of a legacy system's structure and internal connections. Additionally, the model captures different instances of the system which accounts for some of the variants of the actual fielded system. Using a MBSE approach to transition legacy, document-based engineering has several benefits that the paper discusses. First, changes to any of the elements of the system are populated throughout the entire model, making changes more visible to the entire engineering team. Second, the model allows for the system developer to identify obsolete parts within the system as they develop new versions of the system to ensure the legacy system is updated. Finally, by understanding the interfaces of the current system, engineers can determine how to integrate new systems with these legacy systems. Overall, the paper provides a case study for the application of MBSE to legacy systems.

Paper#61

Digital Transformation of Testing & Evaluation: Introducing Operation Safe Passage

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Presented on: Thursday, 10:30-11:00 PDT (Tikal)

Keywords. Test & Evaluation;Systems Engineering;Digital Engineering;Digital Transformation

Abstract. The struggle to realize the digital transformation persists, despite the release of the digital engineering strategy by the US Department of Defense (DoD) in 2018. In DoD, test & evaluation (T&E) is the government owned and conducted version of verification & validation (V&V) of systems. V&V is well documented to have high cost and schedule impacts. However, such activities are conducted to reduce technical risk. With the digital paradigm, many tests may be conducted through digital modeling and analysis as well as data fusion means that combine digital and physical test results. Our research aims to reach the digital transformation of T&E through creation of a framework and testbed to prove-in the methods and tools as we progress through our roadmap of phases of T&E transformation. We present our vision and transformation status using a fictitious case study referred to as Operation Safe Passage and findings following the conduct of a mock interim design review.

Paper#37

Dynamic Alignment Strategies for AI-Driven Systems: An Iterative Evaluation Framework

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Presented on: Thursday, 11:00-11:30 PDT (Mirador)

Keywords. Emergence;systems engineering;artificial intelligence;SE4AI;system of systems;systems theory

Abstract. This paper presents a novel framework for addressing the outer alignment problem in AI-driven complex systems through an iterative evaluation process. The framework leverages systems theory, emphasizing the significance of multi-level modeling and the characterization of emergent behaviors in aligning system objectives with stakeholder-defined outcomes. By representing unknown and unobserved variables within emergent value functions, the framework accommodates the inherent complexity and unpredictability of AI systems operating in dynamic environments. Inspired by the principles of dynamic systems theory and neural network training, this approach iteratively refines system alignment through stakeholder feedback, reducing risks of misalignment and instability. The proposed methodology offers a generalizable structure to enhance system reliability, safety, and ethical alignment, with potential applications across diverse domains. The paper concludes by highlighting the theoretical advancements required to mathematically model emergent behaviors and validate alignment strategies.

Paper#26

Engineering Design Synthesis Simulator: a POMDP approach to training decision support agents for design synthesis

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Presented on: Thursday, 15:30-16:00 PDT (Mirador)

Keywords. engineering design;decision support;deep reinforcement learning

Abstract. We are presenting a proof-of-concept means of training decision support agents to assist in optimally selecting design synthesis activities in a way that incorporates balanced risk avoidance, risk acceptance, and risk mitigation, including the costs (and value) of necessary verification activities. The proof-of-concept simulates synthesis of design specifications using a partially observed Markov decision process (POMDP). These simulations are used to train decision support agents by means of reinforcement learning (RL) and approximate dynamic programming (ADP). Trained agents may be evaluated by analysing their policy preferences given an observation of the design synthesis state.

Paper#19

Evaluating Earth-Observing Satellite Sampling Effectiveness Using Kullback-Leibler Divergence

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Presented on: Wednesday, 11:30-12:00 PDT (Luna)

Keywords. Earth-Observing Satellites;Sampling Effectiveness;Kullback-Leibler Divergence;Observational Representativeness;Monsoon

Abstract. This work presents an objective, repeatable, automatic, and fast methodology for assessing the representativeness of geophysical variables sampled by Earth-observing satellites. The primary goal is to identify and mitigate potential sampling biases attributed to orbit selection during pre-Phase A mission studies. This methodology supports current incubation activities for a future Planetary Boundary Layer observing system by incorporating a sampling effectiveness measure into a broader architectural study. The study evaluates the effectiveness of 20 satellite configurations for observing convective storm activity in the Southwestern U.S. during the North American Monsoon (NAM) season. The primary design variables are the number of satellites, orbit type (sun-synchronous or inclined), and Local Time of Ascending Node (LTAN). Using Kullback-Leibler (KL) divergence to assess observational representativeness and Kernel Density Estimation (KDE) to estimate probability density functions, the study quantifies the discrepancy between observed and ground truth storm features. Results indicate that a two-satellite sun-synchronous system with an 8:00 PM LTAN, achieved the lowest KL divergence, signifying the most representative observation of storm clusters. In contrast, single-satellite configurations, particularly those with late-night LTANs (e.g., 12:00 AM), demonstrated significantly higher KL divergence. The study concludes that dual-satellite configurations in sun-synchronous orbits with evening LTANs outperform single-satellite and inclined configurations in capturing representative convective storm activity.

Biography

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Paper#18

Evaluation of a Biologically-Inspired Multi-Agent System Consensus Algorithm to Develop Application Insights

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Presented on: Wednesday, 15:30-16:00 PDT (Cival)

Keywords. Multi-Agent Systems;robustness;faulted agents;biologically inspired design;sensitivity analysis;uncertainty analysis

Abstract. Multi-agent systems are becoming heavily relied upon as the complexity of the world increases. The effectiveness of these systems depends on consensus algorithms; however, the presence of faulted agents can compromise the security and reliability of these consensus algorithms. Therefore, it is crucial to develop robust consensus methods to maintain system security and reliability. Biologically-Inspired Design previously led the Synchronous Hatching Consensus Algorithm which proved robust up to 20% of faulted agents reporting false positives. This work aims to provide insights for when the Synchronous Hatching Consensus Algorithm can be applied. This is achieved through three methods: comparing robustness to faulted agents reporting false negatives, performing an uncertainty analysis, and performing a sensitivity analysis. First, an agent-based ANYLOGIC model was tested with 0, 1, 5, 10, 15, and 20 faulted agents reporting false negatives (out of at total population of 100). The model was applied to four separate environments. Robustness to faulted agents was measured by how consistent the hours was to reach 66% consensus across any percentage of faulted agents or environment. A total of 650 iterations were run per faulted agent and environment combination, totalling in 15,600 runs. The model was deemed not robust to faulted agents reporting false negatives. The total probability for a run failing to reach consensus was 59%. The slower changing environments most contributed to the probability a run would fail. The percentage of faulted agents had the second highest impact. The findings indicate that the algorithm should be implemented in an environment which quickly reaches its decision threshold and that when a fault occurs consensus should be assumed, because the model is more robust to false positive faults.

Paper#67

Exploiting Augmented Intelligence in Realizing and Operating a Digitally Transformed Enterprise

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Presented on: Thursday, 11:30-12:00 PDT (Tikal)

Keywords. Descriptive models;MBSE;DE;model-based systems engineering;digital engineering;digital twins;needs;requirements

Abstract. Model-based systems engineering (MBSE), digital engineering (DE), and digital twins (DT) are increasingly sought to improve the efficiency and effectiveness of system acquisition, development, operations, and sustainment activities. Many practitioners are advancing the state of the art, prototyping and implementing MBSE, DE, and DT capabilities, but much less effort is being devoted to improving organizations' ability to define, refine, and validate their needs and requirements for these capabilities to drive their purposeful acquisition, development, and validation. This paper describes the landscape of the problem space for MBSE, DE, and DT and describes a framework for developing or tailoring an organization's needs and requirements for those capabilities and their planned evolution over the course of the system's life cycle. A system definition maturity model that standardizes meaningful milestones in a system's life cycle is described to serve as a basis for developing the planned evolution of needs and requirements for MBSE, DE, and DT over the system's life cycle.

Paper#57

Exploring Different Views of Healthcare Sustainability

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Presented on: Wednesday, 14:30-15:00 PDT (Luna)

Keywords. Healthcare sustainability;sustainability;healthcare;implementation science

Abstract. Different mental models of concepts used to engineer systems can lead to conflict between stakeholders due to the resultant differences in expectations. This paper compares two commonly used paradigms of sustainability associated to the healthcare domain. One perspective of sustainability in healthcare is associated with implementation science and typically addresses healthcare interventions. The other focuses on a broader perspective, taking into account considerations such as the three pillars that include social, economic, as well as environment factors. Both perspectives are important within and outside health systems. The paper seeks to provide an understanding of the two perspectives and discusses recommendations for those addressing sustainability concerns in healthcare.

Paper#42

Extending Enterprise Architectures to Support Tactical Network Microservices

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Presented on: Thursday, 15:30-16:00 PDT (Luna)

Keywords. Unified Architecture Framework;Services Architecture;Services;UAF

Abstract. Network capabilities are increasingly becoming implemented in software (i.e., softwarized) and deployed using automated techniques. Organizations are migrating their business applications to cloud environments. Businesses that adopt the development operations (DevOps) methodologies will have options to integrate software and hardware platforms, especially as a cloud pattern becomes prevalent. Because these capabilities meet the needs of a community, they become a part of the value chain of a business. There remains a gap in representing and automating the deployment of business processes and technical architectures from enterprise architectures. Model-driven transformations from an enterprise architecture to automatically configured technology implementations are an elusive goal of architecture modeling and integration. The elements of integrated architectures have been represented and modeled within their respective domains, but there has not been an automated translation that can provision technologies from architecture descriptions.The service pattern is an ideal construct for representing an organization’s repeatable business processes [1]. The concept of services is used in describing network services such as cloud offerings [2, 3] and telecommunications products [4]. Services are units of value that serve a wide customer community and that a customer community can package and offer to its customers. The microservice architecture pattern has been widely applied to enterprise architectures and implementations supporting many business processes [5]. This pattern is increasingly becoming prevalent as tactical network and communication systems become more modular, increase their software content, and support dynamically varying mission requirements.This paper creates an integrated services metamodel that can support modeling of next-generation communications networks and demonstrates how the services architecture concepts of the Unified Architecture Framework (UAF) can be incorporated to represent network capabilities, such as operations and management, communications, provisioning, and performance management. Service viewpoints are especially important in software-intensive systems such as software-defined networks (SDNs). These services can quickly be installed and deliver data capabilities. It is not clear what the touchpoints are between software elements and the underlying system of systems. The services and systems may be described in different viewpoints and architectures.

Paper#7

Factors of Verification Complexity: A Theoretical Exploration

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Presented on: Wednesday, 16:00-16:30 PDT (Tikal)

Keywords. verification;modelling;complexity;knowledge graph;verification complexity

Abstract. The complexity of systems is considered an invaluable information in the system development life cycle. While verification is a pervasive process also integral to system development, the verification complexity is a rarely studied principle in the field of systems engineering. A lack of consensus on its definition causes limited attempts at measuring such complexity both in academia and industry. We propose a multifactorial verification complexity definition with the Verification Complexity Framework. Multiple factors of verification complexity are stacked in layers, covering verification designs, structures, external factors, and information transfer between systems. Each layer is then represented as a three-dimensional object visualizing multiple complexity aspects such as human factors and time. The framework is proposed to initiate discussion on the verification complexity definitions and its measures, aiming to provide a common mathematical vocabulary to the verification engineers in the field.

Paper#60

Fit-For-Transformation: Initial Tool Evaluation and Method for Model-Based Systems Engineering Tools

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Presented on: Thursday, 17:00-17:30 PDT (Cival)

Keywords. Digital transformation;digital engineering;model-based systems engineering (MBSE);Modular Open Systems Approach (MOSA);tool evaluation

Abstract. As industries and administrations, particularly the Department of Defense (DoD), increasingly adopt digital transformation across organizations, researchers have identified a critical gap: the lack of tailored, secure, and actionable guidance for navigating the myriad strategies and methods available. Tool adoption poses a significant challenge, as the rapid proliferation of digital engineering-focused software and the evolution of modelling languages—driven by the demand for greater interoperability—complicate decision-making processes. This study originated from the need to identify tools that could effectively support a Virginia Tech National Security Institute (NSI) undergraduate research project aimed at advancing systems engineering (SE) and driving digital transformation. Throughout this effort, it became apparent that existing frameworks for evaluating Model-Based Systems Engineering (MBSE) tools or supporting digital transformation often fall short in providing the comprehensive scope needed to address the DoD's unique requirements while remaining adaptable to specific project needs. This study introduces and assesses an initial evaluation method designed to strategically appraise MBSE tools based on their "fit-for-transformation" potential, with a particular focus on their suitability for the DoD. By aligning with current systems and addressing diverse organizational needs, the framework empowers decision-makers to select MBSE tools that not only support digital transformation but are also optimized for the DoD’s unique operational and strategic demands. It will also serve as new instructional material for an undergraduate digital engineering course offered by the Grado Department of Industrial and Systems Engineering at Virginia Tech.

Paper#5

Good samaritans may ruin the world - Applying Systems thinking to identify adverse effects to Norwegian energy export

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Presented on: Wednesday, 15:30-16:00 PDT (Tikal)

Abstract. In the race to combat climate change, Norway has emerged as a leader in renewable energy production and sustainability initiatives. However, well-meaning policies may have unintended consequences that challenge their long-term goals and accomplishments. This paper applies systems thinking methods to analyze and discuss how causing reinforcing loops in these interventions may lead to adverse effects. By looking at the reinforcing and balancing drivers within these policies, it is possible to argue that Norway's efforts to be a leading nation in the global fight against climate change may inadvertently create problems that undermine both domestic and international energy ambitions and goals.

Paper#11

Graph-Based Digital Engineering Ontology for Mission Design and Execution

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Presented on: Wednesday, 13:30-14:00 PDT (Tikal)

Keywords. Digital Engineering;Model Based Systems Engineering;Ontology;Graph Theory;Mission Engineering;Mission Design;Modeling and Simulation

Abstract. As modern operational systems become more interconnected, a system of systems (SoS) approach must be adopted. As part of this, a methodology is needed to decompose, partition, and analyze operational SoS problem spaces. This paper presents a graph-based digital engineering ontology developed to address this need. This is done by developing several logical Systems Modeling Language (SysML) model components and integrating them into a graph-based analysis framework using the developed ontology. This analysis framework serves as a structured way to break down and analyze the combinatorial problem space of the SoS.

Paper#59

Hidden Beliefs in Verification Decisions: An Experimental Study with Aerospace Engineering Students

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Presented on: Wednesday, 17:00-17:30 PDT (Mirador)

Keywords. Verification;Belief;Cognitive science;Bayesian network

Abstract. System verification is used to check that the system has been built in accordance with its requirements. In executing a verification strategy, each verification activity produces certain information artifacts that are then used as evidence in the assessment of the compliance of the system against its requirements. The process of reasoning through verification artifacts is cognitive and subjective, as the engineer combines their knowledge and expertise along with the information available in the evidence collected through verification activities. Through an experimental study with students, this paper shows that engineering students use some of this knowledge implicitly in their verification assessment and do not explicitly express it when formally articulating the justification to declare the compliance of a system.

Paper#22

How to Place Humans ‘in-the-loop’: Tradeoffs of Different Human-AI System Architectures

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Presented on: Wednesday, 11:30-12:00 PDT (Mirador)

Keywords. human-in-the-loop;human-on-the-loop;human-AI teaming;trustworthy AI

Abstract. As concerns about the safety and trustworthiness of AI grow, there has been a growing push for human-in-the-loop system architectures to be mandated by policy [1] [2] [3]. The argument for having a human supervise or partner with an AI system is “grounded in the belief that human-machine teams offer superior results, building trust by inserting human oversight into the AI life cycle” [4]. Increased performance and trust are central to the promise behind placing a human-in-the-loop, but it is not clear how or where the best place to put a human in an AI-enabled system is. To address this lack of clarity, we previously created a framework to decompose the different ways in which humans and AI could be partnered together. By utilizing a notional system, we show that the same system can be architected in the different ways we identified in our framework. We created a simulation of this system in an operating context that allows us to model the tradeoffs between risk mitigation and performance. Early results from our simulation found that human-AI systems can provide advantages in performance over human only systems and advantages in risk mitigation over AI only systems. However, the tradeoffs between risk mitigation and performance are non-linear and highlight the important considerations of how to place humans ‘in-the-loop’ to ensure system designers and policy makers achieve the intended outcomes of well-meaning policy.

Paper#10

Human-AI Teaming Focus for Transplant Surgeon Fuzzy Associative Memory (TSFAM) Model: Capturing the Transplant Surgeon Perspective

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Keywords. Human-AI teaming;Fuzzy associative memory;Deep learning;Organ procurement;Healthcare

Abstract. The proposed Transplant Surgeon Fuzzy Associative Memory (TSFAM) model presents an innovative approach to integrating augmented intelligence in healthcare systems, particularly in organ transplantation. Focusing on Human–AI Teaming, TSFAM emphasizes the central role of human expertise, while AI dynamically adapts to evolving clinical and environmental conditions. By utilizing fuzzy logic, the model addresses uncertainty and ambiguity in decision-making, particularly for evaluating hard-to-place kidneys, where traditional data-driven models fall short. TSFAM blends transplant surgeon knowledge with deep learning, creating a system that is resilient, adaptable, and highly reflective of surgeon-defined rules. These rules, extracted through AI, are based on the surgeon's unique ontology and membership functions, ensuring that decisions align with individual preferences and the local healthcare environment. This adaptive framework, designed with principles of systems engineering, enhances the ability of healthcare teams to respond to dynamic changes, policies, and societal needs. The paper outlines the construction and implementation of TSFAM, showcasing how it improves decision-making in organ transplant scenarios. It highlights the potential for AI to be better integrated into healthcare by tailoring systems to domain-specific challenges, offering a framework for future researchers to advance AI models that meet the complex needs of healthcare professionals and systems.

Paper#14

Integrating Large Language Models with Enterprise Architecture for Enhanced Information Retrieval about System Engineering

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Presented on: Wednesday, 11:00-11:30 PDT (Mirador)

Keywords. System Engineering;Artificial Intelligence;Generative AI;Large Language Models;DoDAF;SysML

Abstract. Many organizations, including the Department of Defense, employ system engineering techniques like SysML to model their enterprise architecture (EA). Regardless of the EA framework in use, such as DoDAF, system engineers develop supplementary EA views to facilitate decision-makers in comprehending their EA landscape and making informed decisions about the evolution of their IT infrastructure. However, creating these EA views requires specialized skills that are often hard to acquire. Moreover, the process is labor-intensive. Furthermore, not all decision-makers may be famil- iar with system engineering techniques, making it challenging to understand the system engineering models related to their business. In this study, we adopted a different approach. We built Respondeo – a Large Language Model (LLM)-based tool – that allows EA stakeholders to retrieve information from EA repositories populated with standard-based system models using natural language. The Respondeo enables stakeholders, such as decision-makers, to retrieve information about their enterprise archi- tectures using domain-specific vocabulary. Decision-makers do not need to understand SysML or EA framework lexicon, such as DoDAF views, as they can express their queries using domain-specific ver- nacular. Respondeo then transforms their domain-specific queries into EA repository requests using the EA Repository API. Respondeo utilizes an open-source LLM to parse natural language queries and convert them into the EA repository query language. In-context learning techniques were employed to tailor the LLM to our specific EA domain. This paper discusses our initial results where Respondeo was implemented to enhance the information retrieval process when an EA repository populated with system engineering models developed according to DoDAF guidelines is used. Preliminary findings indicate that Respondeo effectively transforms EA queries expressed in natural language into accurate EA repository queries and converts the outputs into comprehensible results.

Paper#47

Integration of AI in Data Requirements for Stuttering-Aware Speech Recognition Systems

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Presented on: Thursday, 16:30-17:00 PDT (Tikal)

Keywords. System Requirements;Artificial Intelligence;MBSE;Systems Engineering Models;Automatic Speech Recognition;Stuttering

Abstract. Stuttering is speech that is characterized by the repetition or prolongation of sounds, syllables, words, and hesitation or pauses that disrupt the rhythmic flow of speech. People who stutter (PWS) want to use artificially intelligent automatic speech recognition (AI-ASR) systems but are frequently misunderstood and cut off because AI-ASR models are optimized on data from people who do not stutter. A primary reason for the deficiency in current AI-ASR models is the lack of large, diverse, and specified data on stuttered speech. To remedy this problem, this research proposes an AI for Systems Engineering (AI4SE) approach to data specification and modeling of stuttered speech for AI-ASR. While traditional SE lifecycle and principles have been successful in building heretofore complex systems, current AI-enabled systems have introduced new paradigms that do not fit SE traditions. Despite the difficulty, this research advocates a refined AI4SE approach in establishing design integrity, artifacts, and configuration baselines for such systems.

Paper#31

Kinship Infrastructure Design: A Biologically Inspired Approach for Emergency Response Systems

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Presented on: Wednesday, 17:00-17:30 PDT (Cival)

Keywords. Biologically inspired Design;Kinship Coefficients;Resource Allocation;Resilient Infrastructure Design;System Design;Design-for-X

Abstract. Early-stage production decisions for infrastructure significantly influence consumption patterns throughout the system's lifecycle. Achieving a balance between initial production and lifecycle consumption becomes increasingly complex when factoring in unpredictable system faults during the use phase, particularly in the context of evolving sustainable and resilient systems. For example, consider disaster infrastructure response: how do we invest resources to respond to a disaster we do not know the details of yet, especially when performance is critical even under such unpredictable conditions? In response to this gap, we introduce a novel infrastructure design approach inspired by the kinship coefficients observed in eusocial animals like honeybees (Apis mellifera). Our goal is to enable infrastructure design that is both resilient and adaptable, even in the face of uncertainty. By using the kinship coefficient to evaluate potential designs, we offer an approach for efficient resource allocation without detailed fault analysis. We hypothesize that by exploring low-fidelity disaster response architectures with varying kinship coefficients, we can identify their relationship to disaster response performance and validate the kinship coefficient as a design tool. Specifically, this article performs the key first step of validating if a “Goldilocks Zone” for kinship coefficient exists for artificial systems in the same way it does for natural systems. To test this hypothesis, we examined the performance of a set of 60 potential infrastructures for a simulated wildfire case study. The results indicate that, on average, 83.9% of the forest was saved in the goldilocks zone compared to 56.3% outside of it. This means using KID for infrastructure decisions saved 27.6% more forest. The proposed approach can be used to improve the design of a variety of large systems including emergency management, infrastructure planning, and energy systems. These findings provide a framework for designing resilient infrastructure systems throughout the system lifecycle, enhancing their ability to withstand and adapt to unforeseen disasters, while ensuring operational continuity and minimizing resource waste during disaster response. KID aligns with INCOSE Vision 2035 by fostering adaptive systems, leveraging advanced modeling, and balancing societal and environmental needs. Our approach seeks to make impactful interventions in the design phase to improve resilience during the infrastructure’s use phase.

Paper#64

Leveraging Contextual Cues: Improving Redundancy and Safety in Vision Systems for Autonomous Vehicles

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Presented on: Thursday, 16:30-17:00 PDT (Luna)

Keywords. Vision System;Redundancy Management;Autonomous Vehicles

Abstract. This study utilizes the Systems Engineering Method to investigates the incorporation of contextual evidence in decision making for a Vision System that implements redundancy management techniques to make safe decisions for drivers relying on self-driving capabilities.

Paper#20

Leveraging Model-Based Systems Engineering as a Tool to Enhance Traceability in the Design of a Factory in Space (ISM)

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Presented on: Thursday, 15:30-16:00 PDT (Cival)

Keywords. Model-Based Systems Engineering;MBSE;Traceability;In-Space Manufacturing

Abstract. In-space manufacturing (ISM) presents unique challenges, including the need for efficient resource utilization and reliable production processes under microgravity conditions, which can lead to critical failures and costly delays in space missions. The complexity of these systems necessitates a robust approach to system design and management to ensure successful outcomes. Model-Based Systems Engineering (MBSE) offers a promising solution by providing structured methodologies for capturing requirements, designing systems, and verifying functionality. This research explores the application of Capella, to facilitate the development of integrated models to enhance traceability. By utilizing Capella, we explore how interconnected models can facilitate the tracing of artefacts and links between requirements and design elements of the system across the lifecycle, thereby mitigating risks associated with design changes and operational uncertainties. Our findings provide a structured categorization and systematization of approaches for traceability and demonstrate how traceability can work to streamline communication amongst interdisciplinary teams to promote better decision-making. Ultimately, this research highlights the potential of MBSE to be used as tool to facilitate enhanced traceability in complex and unprecedented systems, offering critical insights that could support the transformation of engineering practices and provide improved operational efficiencies.

Paper#51

LLM-Enabled Knowledge Transfer: Modeler to SME

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Presented on: Thursday, 17:00-17:30 PDT (Tikal)

Keywords. LLM;knowledge transfer;SysMLv2

Abstract. Large Language Models (LLMs) are a subset of Generative Artificial Intelligence (AI) that has dramatically increased its capabilities over the past two years. Many LLMs can now consume multimodal media, demonstrating further potential for advancements in digital transformation. Systems Engineering is undergoing this digital transformation as many in the field are exploring ways to simplify and automate tedious drudgery as well as increase efficiency. This paper investigates the effectiveness of both fine-tuned and unmodified Generative Pre-trained Transformer (GPT) models in translating Systems Modeling Language Version 2 (SysMLv2) into textual descriptions. This research aims to bridge the knowledge gap between junior engineering working within SysMLv2 constructs (i.e., the modeler) and senior systems engineers with seasoned knowledge (i.e., the SME). While our overall research explores the bidirectionality between modeler and SME, we focus this article explicitly on the transfer of knowledge from modeler to SME through quantitatively studying the precision and accuracy of conversion of SysMLv2 to textual description. Our discoveries highlight the immense potential of utilizing LLMs to expedite and reimagine the digital transformation.

Paper#23

Pathways for Climate Sustainability with the Accelerated Deployment of Electric Vehicles

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Presented on: Wednesday, 13:30-14:00 PDT (Mirador)

Keywords. Decarbonization;Electric Vehicle;GHG Emissions;Electricity Generation Mix

Abstract. Global warming caused by greenhouse gas releases (GHG) into the atmosphere is now considered an existential threat to society and biodiversity. To limit global warming, the United States and many other countries have submitted a Nationally Determined Contribution (NDC) for the reduction of their net GHG emissions by 2030. The transportation sector, responsible for over a third of GHG emissions in the US, is a major target for reducing carbon intensity. The analysis presented in this paper highlights the challenges and opportunities to de-carbonize the economy through accelerated and large-scale deployment of zero-emission Electric Vehicles (EVs) in the next 10-25 years. The fact that an EV has no tailpipe emissions does not mean that the use of an EV is emission-free. The question needs to be asked – where is the electricity to charge the EV coming from? If an EV is charged by electricity from a coal-fired power plant, then the EV is not emission-free. This paper reports on the number of EVs based on EV registration data, and electricity generation mix in all 50 US states and the District of Columbia. A state's carbon reduction credential from the transportation sector cannot be judged alone by the number of EVs on the road, we need to also know the carbon intensity from electricity generation in the state. The discussion in this paper highlights how states can improve their carbon intensity credentials not just by bringing more EVs onto the roads, but also by bringing low or no-carbon electricity into their electricity generation mix.

Paper#2

Rule-based AI in Model-based Emergency Control

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Keywords. Emergency control;Human errors;Exception management;Human AI teaming;Model-based engineering;Rule-based integration

Abstract. The history of accidents is saturated with examples of accidents that could have been prevented, had the industry found the ways to protect from human errors and to apply the investigation findings across different domains.To protect from human errors, we need to develop affordable methods to opposeaccountability biasing, to constrain operation by the rules, and to detect and alert about exceptions.For cross-domain learning, we need to create a cross domain ontology, comprisingstandards that formulate the generic rules, and to enforce employing them by regulation.

Paper#35

Space Logistics in the Moon-to-Mars Architecture: Functional Coverage, Interdependency and Modularity Analysis

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Presented on: Wednesday, 11:00-11:30 PDT (Luna)

Keywords. Moon-to-Mars Architecture;Space Logistics;Interdependency;Modularity

Abstract. The Moon-to-Mars Architecture is a critical NASA document capturing the broad range of systems and capabilities needed for NASA’s ambitious Moon and Mars mission, translating high-level objectives into actionable requirements. Space Logistics is a key sub-architecture within this unified and integrated architecture. This paper conducts an architectural assessment to evaluate how well the high-level mission architecture supports the space logistics sub-architecture. Logistics life cycle coverage matrix and logistics functional interdependence Design Structure Matrices (DSMs) are proposed, along with the corresponding modularity measurement. Discrepancy analysis is performed to investigate the functional coverage of space logistics requirements and assess whether the architecture captures essential interdependencies between logistics and non-logistics functions. Results indicate that, although the architecture broadly addresses logistics requirements and their interdependency, interpretive ambiguities and the absence of hierarchical structure may lead to practical gaps.

Paper#4

State of Model Based Systems Engineering Model Governance

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Presented on: Wednesday, 11:00-11:30 PDT (Tikal)

Keywords. Model Based Systems Engineering;Model Governance;Systems Engineering

Abstract. Model Based Systems Engineering (MBSE) is increasingly adopted across industries to manage the complexity of modern systems. However, the effectiveness of MBSE depends on leveraging robust model governance practices. This paper presents the findings of a study on the current state of MBSE model governance based on data gathered from a questionnaire administered to professionals across the defense sector. Data were collected from thirteen respondents who provided insight into model governance processes, roles, best practices, successes, and challenges. The results reveal varying degrees of maturity in governance processes and implementation. This paper presents these findings and highlights the need for robust model governance practices to realize the potential of MBSE in complex system development.

Paper#45

Stress and Student Learning: Modeling Community of Learners as a Social System

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Keywords. social system;community of learners;collaborative learning

Abstract. Research on student stress has mainly focused on student-as-individual. Similarly, student cognitive load and student learning outcomes within a classroom have been examined primarily from a student-as-individual perspective. In a classroom setting, especially in an engineering classroom where collaborative learning is the norm, using a community of learners lens to view the students in the classroom and model the community of learners as a social system that has emerging properties (e.g., working in pairs reduces stress and cognitive load) that can affect individual students will yield better outcomes for both the educator and the students. Using the community of learners lens to improve student learning in collaborative engineering classrooms, we developed a Community of Learners as a Social System (CLaSS) conceptual model and presented the methodology to validate our CLaSS conceptual model in this paper.

Paper#44

SysML Metamodeling for Integrating the STRIDE Threat Framework in Cyber-Physical Systems

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Keywords. STRIDE framework;SysML;cybersecurity;cyber-physical systems;threat modeling;metamodeling

Abstract. This paper explores the integration of the STRIDE threat modeling framework into the Systems Modeling Language (SysML) to enhance cybersecurity in cyber-physical systems. As the complexity of these systems increases, so does the challenge of ensuring their security. Traditional SysML does not inherently include provisions for detailed cybersecurity threat analysis, necessitating an extension to accommodate such needs. We propose a methodology for the systematic integration of cybersecurity considerations into SysML through the development of a SysML profile that includes the STRIDE framework. This integration is achieved by mapping Data Flow Diagram (DFD) elements to SysML constructs and extending SysML to include a “threatEnumeration” class that facilitates detailed threat analysis. The findings indicate that this approach not only improves the ability to identify and manage cybersecurity threats, but also contributes to the broader field of systems engineering by providing a structured framework for security analysis. The paper concludes with recommendations for future research and the continued development of SysML extensions to better support cybersecurity analysis.

Paper#62

Systems Theoretic Co-Pilot MVP

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Presented on: Thursday, 13:30-14:00 PDT (Mirador)

Keywords. systems engineering theory;AI4SE;co-pilot;MBSE;LLM

Abstract. Recent research has shown both a desire for and a lack of theoretical underpinning to systems engineering (SE). With the rise of the digital paradigm, advanced data analytics (e.g., AI/ML) are becoming the norm. Algorithms based on rigorously developed mathematical theory are slated to enhance the transformation along with maturation of the discipline and tools of SE. For example, mathematical theory is being used in SE for problem formulation and verification, which are also enhanced when paired with generative AI such large language models (LLMs). Our research leverages the rich mathematical theory from the lineage of A. Wayne Wymore paired with modern digital means to advance the start of the art and practice of SE. Our past research defined a metamodel for sufficient conditions for defining verification models, which we have converted from manual, tabular analysis to software-enabled workflow and platform. In this article, we reveal the minimum viable product (MVP) through describing the architecture and a simple exemplar of its use to facilitate understanding of degrees of equivalence between systems through a mathematical determination of homomorphism.

Paper#36

Team of Teams: An Architecture for Distributed Collective Behavior

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Keywords. team of teams;Industry 5.0;team organizational behavior;human-machine collaboration;systems engineering;socio-technical systems;purposeful human activity systems

Abstract. Organization and communication structures evolve to suit the particular needs of systems. In both natural and human engineered systems, success results in replication and future development and refinement. As a result, the evolution of organizational and communication structures has followed the technological and operational needs of each industrial era, progressively moving from rigid hierarchies to flexible networks to accommodate increasing complexity and interconnectivity. Industry 5.0 represents a new era where human creativity and advanced technology converge to create personalized, sustainable, and value-driven outcomes. This paper examines the evolution of organizational and communication structures that have supported industrial organizations through the evolution from Industry 1.0 to 4.0. This paper discusses how Industry 5.0 enables new organizations and organizational structures that are epitomized by Team of Teams (ToTs) in which collaboration, including human-human, human-machine, and machine-machine, become the predominant mode of behavior. This shift supports a deeper integration of social and environmental responsibility, prioritizing ethical practices and long-term sustainability alongside innovation. Industry 5.0's human-centric approach fosters flexible, adaptive organizational structures that blend technology with human insight, enabling organizations to respond dynamically to complex challenges and evolving customer needs. In addition, the fundamental principles necessary to support ToTs are described, with parallels drawn with biological systems. The implications for engineered systems are described, followed by conclusions and a description of future work.

Paper#25

The Growing Importance of Systems Engineering in Medical Device Development: A Comprehensive Overview

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Presented on: Wednesday, 14:00-14:30 PDT (Luna)

Keywords. medical device development;regulatory compliance;healthcare systems;medical devices;systems engineering education

Abstract. The medical devices industry is experiencing an unprecedented era of growth and innovation, fueled by rapid technological advancements and the escalating complexity of healthcare needs. As medical devices become more complicated, the role of systems engineering has become vital and visible within this industry domain. This paper delves into the multifaceted role of systems engineering in medical device development, elucidating its pivotal contributions to ensuring the safety, efficacy, and regulatory compliance of these lifesaving and life-enhancing technologies and systems. It explores the unique challenges faced by systems engineers in this domain, including the imperative for seamless interdisciplinary collaboration, robust risk management strategies, and unwavering adherence to stringent regulatory standards. Furthermore, the paper presents compelling insights gleaned from a survey of seasoned medical device systems engineers, offering a firsthand perspective on the prevailing challenges, indispensable tools, preferred methodologies, and optimal learning formats in this dynamic field. By illuminating the evolving landscape of medical device systems engineering, this paper aspires to enrich the ongoing discourse on best practices and knowledge dissemination, ultimately fostering the development of safer, more effective, and compliant medical devices that cater to the diverse needs of patients and healthcare providers worldwide.

Paper#46

The simulation model for process flow analysis and improvement in the Emergency Department

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Presented on: Thursday, 16:00-16:30 PDT (Mirador)

Keywords. Simulation;Emergency Department;Process Flow

Abstract. Management of Emergency Department (ED) operations is challenging due to the high variability in patient arrivals and medical acuity. Simulators of patient flow can help in analysing and planning of resources and operations. A number of ED simulators are reviewed based on their published descriptions. Their utilization in practical ED operations is discussed.The research objectives were to create a simulation model (SM) to support management decisions for a general class of EDs related to near real-time resources allocations.The SM integrates discrete-event and agent-based simulation approaches. Systems engineering approach has been used in the SM design and development. The patient flow includes two paths, depending on the emergency severity index.The SM is well suited for the patient flow analysis. Initial results confirmed the importance of using the fast track. The SM makes it possible to simulate and analyse both entire patient flows and flow fragments. Patient flow statistics were validated using a specific ED, including discharges and admission to hospital. The SM supports identification and resolution of systemic problems, including waiting waste reduction, which is significant for patient health and satisfaction, as well as quality of hospital operations.Implementation of the SM in a particular ED requires a reference table which provides data on past statistics of patients arrivals, severity, and utilized medical resources. The SM does not perform financial or layout analysis.

Paper#34

Understanding the Value of Verification

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Presented on: Wednesday, 14:00-14:30 PDT (Mirador)

Keywords. Verification;Verification Strategy;Theory of Systems Engineering;Entropy;Information Theory

Abstract. Systems integration requires verification at each level of integration beginning at the atomic part and building its way to full system-level verification. Traditionally, the development of a verification strategy—which determines when and how to perform these activities—relies on heuristics and best practices established early in the system's lifecycle. However, executing verification activities is a significant cost driver in systems integration. Both industry and academia are seeking methods to optimize verification strategies by eliminating excessive activities without diminishing confidence in system performance. To achieve such optimization, we need metrics that effectively capture the inherent value of verification. While various metrics have been proposed, none have offered an approach intrinsic to the verification process itself. This paper proposes that concepts from information theory - specifically entropy and information gain - may provide suitable metrics for quantifying the fundamental value of verification.

Paper#69

Visual Systems Mapping Can Help to Define and Compare LCAs

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Presented on: Thursday, 14:30-15:00 PDT (Mirador)

Keywords. Sustainable Systems Engineering;LCA;Baseline;BAU;Additionality;Biomass;Carbon;Forest

Abstract. The challenge addressed in this research centres on the need to choose between several biomass sources and energy production processes that lower carbon emissions, while supporting rural economies and ecosystem services. A key barrier to effective decision-making for net-zero strategies using biomass is the lack of standardized and transparent life cycle assessment (LCA) baselines. These baselines are critical for assessing the impacts of biomass decarbonization strategies but often vary due to regional factors and chosen simplifying assumptions of the LCAs. However, omitting key variables can mean the LCA omits key feedback and balancing loops relevant to fully assessing impacts of the change or test scenario, as well as impacts on United Nations Sustainable Development Goals (SDGs). To address these complexities, this project employs a systems engineering approach: visual systems mapping. This technique is used to define the boundaries and dynamic behaviours of LCA baselines, enhancing transparency. By examining five literature sources and their documented baseline scenarios, the systems mapping case-studies highlight how assumptions shape the understanding of impacts and demonstrates the importance of documenting and archiving these baselines. Recommendations are that visual systems mapping should be used to document key assumptions, such as baselines, of LCAs. Further, where possible open data repositories should hold key information about LCA baselines and reproducible workflows (e.g., using open-source tools) should be used to improve transparency and comparability in LCAs. Given the consensus within the broader scientific community on the importance of replicable data practices, this research reinforces the need for standardized frameworks and systems engineering tools in LCAs. This research demonstrates a pathway to more transparent, standardized, and comparable LCAs, that may bolster decisions for sustainable biomass systems.

Paper#9

Why systems engineering skills are critical for successful leadership of large complex projects

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Presented on: Wednesday, 15:30-16:00 PDT (Mirador)

Keywords. modular;defense acquisition;open systems;interoperability;system development;system architecture;interface;model-based systems engineering;digital engineering

Abstract. This article presents a method for using a system model to assess the system's compliance with modular and open systems (MOSA) principles. The MOSA assessment method starts by generate a SysML model of the system's physical and behavioral aspects. The model data is exported, processed, and then imported into a MatLab program implementing two modularity measures from the literature and an assessment approach for open interfaces. The model is verified and validated using several idealized systems. The article then demonstrates the method on a testbed for hypersonic missiles, which is desired to support as many experiments as possible by being modular and open. The results of the study show it is possible to extract the relevant data from models and use the data to assess modularity and openness of a system.

Tutorials

Tutorials#200

Augmented Intelligence

Dr. Azad M. Madni (USC)

Presented on: Tuesday, 08:00-12:00 PDT (Cival)

Abstract. With AI resurgence paced by recent machine learning advances, several engineering disciplines including systems engineeringturn to AI to improve system model accuracy, process flexibility, content exploration and search, and team productivity. Morerecently, AI has become a means to augment rather than replace human capability. This perspective alters AI's role from autonomous intelligence to augmented intelligence (AugI). Inherent in this view, recognizing AI and human together can perform certain tasks better than either could alone. This tutorial presents a methodological framework for effectively exploiting AugI in systems engineering and in engineered intelligent human-machine systems.

Tutorials#202

Learning MBSE with SysML

Dr. Mark L. McKelvin, Jr. (The Aerospace Corporation and USC)

Presented on: Tuesday, 08:00-12:00 PDT (Tikal)

Abstract. Model-Based Systems Engineering (MBSE) is an approach to systems engineering and architecting that applies the use of models across a system's lifecycle. The Systems Modeling Language (SysML) is a graphical modeling language used to represent different aspects of systems in a MBSE approach. The use of SysML models in a MBSE to enable system design, analysis, and specification continues to grow across government and industry. Consequently, there is a high demand for engineers with the appropriate skills to manage MBSE projects and develop useful system models. This tutorial is intended to introduce fundamental concepts of MBSE and introduce participants to the Systems Modeling Language (SysML). Features of the SysML will be reinforced with hands-on exercises on examples in space mission systems. Participants will leave this tutorial with a general awareness of MBSE and SysML, and the ability to read, interpret, and build simple models with basic SysML notation.

Tutorials#201

Machine Learning for Systems Engineers

Dr. Michael Sievers (USC)

Presented on: Tuesday, 13:00-17:00 PDT (Cival)

Abstract. Machine learning (ML) is a multidisciplinary form of artificial intelligence that extracts meaning from large training data sets to create algorithms that mimic human learning. ML algorithms look for meaning and patterns relevant to the training set to make decisions about new information. ML continually validates and refines a learning model from inaccuracies accrued by its prediction performance. This tutorial is based on a graduate ML course taught at USC focusing on systems engineering considerations. Topics discussed include:Learning, hypothesis testing, and data biasKnowledge representationLearning algorithms and data miningML models and applicationsPractical engineering applications, strengths, weaknesses, and potential pitfalls

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Tutorials#203

Model-Based Reviews

Fredda Lerner (The Aerospace Corporation)
Greg Mowles (The Aerospace Corporation)
Kevin Sanchez (The Aerospace Corporation)

Presented on: Tuesday, 13:00-17:00 PDT (Tikal)

Abstract. Many program offices in government, industry, and FFRDCs are moving away from traditional document-based systems engineering practices and integrating model-based systems engineering (MBSE) approaches throughout the system lifecycle. Stakeholders now use descriptive models to communicate system definition characteristics such as requirements, V&V activities, architecture, interfaces, and ConOps. Throughout the lifecycle, milestone reviews play an important role in assessing a program’s readiness to proceed to the next phase. The review process relies on experts to assess if the program is meeting established review criteria. Review artifacts are now often captured in models expressed using standardized modeling techniques (such as SysML) rather than documents, so it is critical that reviewers know how to access, mine, read, understand, and evaluate these model products. This tutorial will discuss what MBSE brings to the table in the review process, and what reviews can look like in an environment where systems attributes are captured in “living” descriptive models versus static documents. The tutorial will also include perspectives on how to prepare for and conduct design reviews using MBSE practices.
