Theme
Complex Systems

Topics: Predictability, Fragility vs robustness, Adaptive governance of socio-technical systems, Explainability

Keywords: Systems-of-systems engineering, Emergent behavior, Network resilience, Modeling and simulation, Nonlinear dynamics, Interdisciplinary integration

PANEL #3

BARCELONA
2025

Moderator

Prof. Dr. Fan Wu, Tuskegee University, USA

Panelists

Dr. Jyrki Penttinen, Alphacore Inc., USA

Prof. Dr. Sergei Sawitzki, FH Wedel (University of Applied Sciences), Germany

Prof. Paul Martin, University of Maryland, USA / CEO SE-Scholar / INCOSE, USA

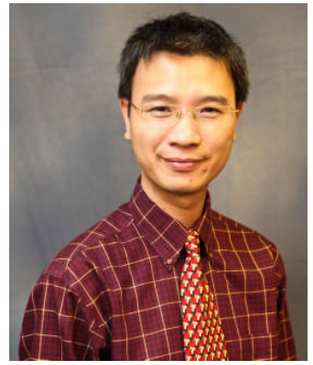
M. Eng. Jessica Mueller, Bosch Rexroth AG, Germany

Prof. Dr. Ray Jones, University of Plymouth, UK

Panelist Position

BARCELONA 2025

- AI Based Anomaly Detection in Cybersecurity
  - Data Representation
  - Classification
  - Machine Learning Techniques such as SVM
  - Cluster Analysis for Anomaly Intrusion Detection
  - Deep Learning for Anomaly Intrusion Detection
- ML for Cybersecurity
  - Develop teaching materials on ML for Cybersecurity with a collection of hands-on materials that will improve the ability of students to develop ML skill set for Cybersecurity and avoiding common security vulnerabilities
  - Ten Learning Modules have been developed (https://sites.google.com/view/ml4cs/home?authuser=0)
  - Pre-Lab, Hands-on Labs, and Post-Labs



Fan Wu
Tuskegee University,
Tuskegee, AL USA

Panelist Position

BARCELONA 2025

- Electronic components are critical in the (B)5G era, driving demand for advanced semiconductors and power-efficient high-frequency devices
  - High-quality data conversion (ADCs, DACs), synchronization (PLLs), and other circuitry functions are essential to enable eMBB, URLLC, and mMTC applications.
  - New millimeter-wave frequency bands require specialized antennas, filters, and amplifiers, and advanced features such as direct sampling ease RF processing.
  - 5G/B5G also requires components that can deliver high performance while consuming less power, which is a critical factor for mobile and IoT devices.
  - For applications like autonomous vehicles and smart manufacturing, (jointly communicating) sensors, LiDAR, radar modules, and advanced processors are crucial for low-latency communications and real-time data.
- Further research and development of advanced semiconductors is essential to provide means for the stakeholders to keep complying with the increasingly demanding performance requirements

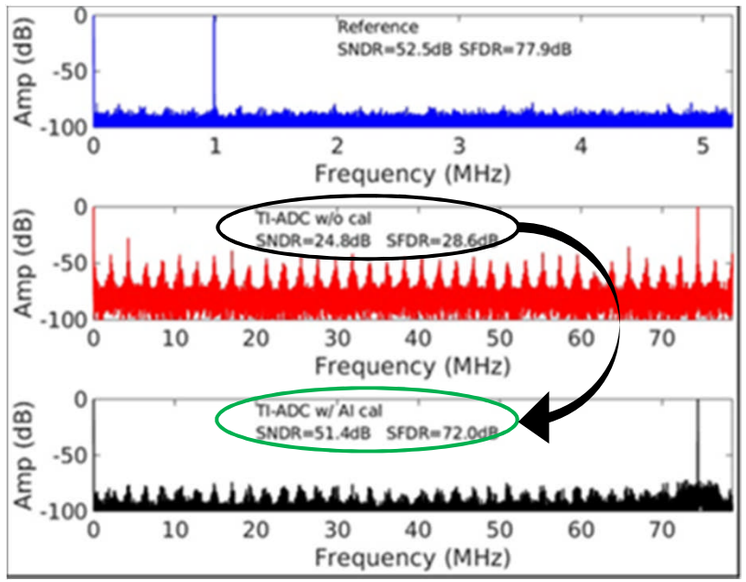
Jyrki T. J. Penttinen
Alphacore Inc., USA

Panelist Position

BARCELONA 2025

- B5G Semiconductor Opportunities
  - Development of terahertz front-ends using new III-V materials.
  - Integrated Communications and Sensing (ICAS).
  - On-chip optical-electrical integration for ultra-fast data handling.
  - AI/ML-assisted circuits[1] and software-defined RF platforms.
- Challenges Ahead
  - Need for new simulation and modeling tools at THz frequencies.
  - Packaging solutions to minimize interconnect losses / parasitics.
  - Long-term reliability in portable, high-temperature environments.
  - Assurance of performance per watt (TOPS/W) for AR processors.
  - Handling of dynamic power at high switching frequencies

ML approach to correcting errors in time-interleaved ADCs through supervised learning



An example of measured FFT of ADC without and with Machine Learning[1]; in this scenario, ML calibration significantly improves both SNDR and SFDR as well as energy efficiency of the ADC; figure reprinted with permission

[1] S. Bhanushali et al. Machine-learning based Blind Digital Calibration of Time-Interleaved ADC (Example of Alphacore's joint research with Arizona State University): https://labs.engineering.asu.edu/mixedsignals/wp-content/uploads/sites/58/2025/07/VTS_TI_ADC_2025.pdf

Panelist Position

BARCELONA 2025

- Example of Trends: (Industrial) Metaverse
  - Metaverse Use Cases Powered by advanced B5G/6G semiconductors include real-time 3D holography, native edge intelligence, and over 100 GHz frequency bands.
  - Remote surgery with real-time tactile feedback via haptic sensors represents one of the most demanding use case.
  - Other challenging use cases for semiconductors include live holographic conferencing over THz links and multi-user VR gaming with persistent shared environments.
- Outlook
  - Further evolved semiconductors are foundational to future system and metaverse evolution.
  - Ongoing R&D in new materials, AI-RF co-design, and modular architecture pave the way for 6G complying with IMT-2030[2].
  - Cross-industry collaboration is needed for scalable and interoperable solutions.

[2] J. Penttinen. On 6G visions and requirements. Journal of ICT Standardization (Volume: 9, Issue: 3, 2021). https://ieeexplore.ieee.org/document/10255475

Panelist Position

Barcelona 2025

Sergei Sawitzki
FH Wedel, Germany

1) What can we learn from the previous developments in Computer Science and Computer Engineering?

The concept “What was a complex system yesterday will be a basic function tomorrow” is well-known. However, in comparison to Systems-of-Systems Engineering:

- The interfaces and abstraction layers are well-developed, often evolved over decades
- In most cases existing, well-understood methods and tools can be adapted/improved
- There are established standards in many fields

→ Much more difficult to define for evolving systems/environments (+ issues introduced by the socio-technical context)

1) Opportunities and threats related to global digitalization (IoT, ubiquitous computing, ...)

The amount of data already available today is tremendous (environmental data, public transportation, energy and water supply, ...)

- Improves the quality of life, allows better feedback and control on the global scale (smart/digital cities, urban digital twins, ...)
- Introduces new (old) problems: security, transparency, energy demand, availability, digital inequality, trust and governance

→ Technology is only one side of the coin, not the whole story

Panelist Position

BARCELONA 2025

- ***Emergence*** is a key to Complexity …
  - … and ***Emergence*** CAN NOT be understood “scientifically”
  - WHY?
    - Science relies on a reductionist approach
    - Emergence is a phenomena that is created when system elements interact between themselves -- The complete opposite of the reductionist approach
  - What then?
    - We need a new approach

A holistic, nonlinear, synergistic, iterative methods for harnessing complexity[1]

Paul Martin
CEO, SE Scholar
UMBC Adjunct Professor II

[1] D. D. Walden, Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities. Hoboken: John Wiley & Sons, Inc., 2023. – Section 1.3.7 Complexity

Panelist Position

BARCELONA 2025

Predictability of Systems-of-Systems

Jessica Müller
Bosch Rexroth AG

Emergent Unpredictability

- Determinism of single components does not ensure predictable system behavior
- Shared I/O and CPU resources cause temporal coupling and emergent interference
- Predictability becomes a property of coordinated interaction, not of isolation

Interference-Aware Coordination

- Classification of vCPUs by dominant I/O type prevents concurrent resource access
- Cross-layer visibility through paravirtual profiling enables temporal awareness
- Adaptive scheduling balances determinism and efficiency under real-time load

Quantifiable Predictability

- Stable utilization and reduced peaks indicate deterministic behavior
- Balanced run-queues and constant I/O load improve cycle-time reliability
- Predictability metrics can be linked directly to safety and certification goals

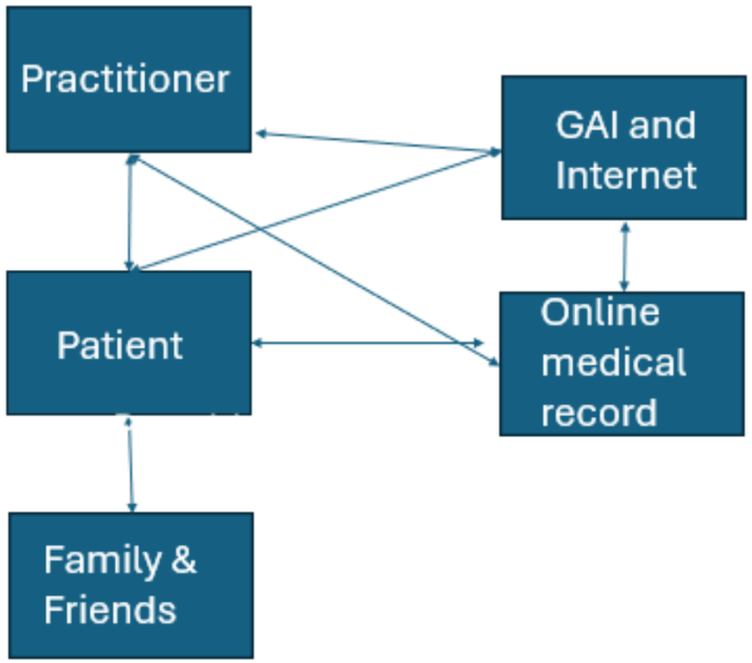
Towards Self-Adaptive SoS

- Systems must continuously monitor and re-balance interference
- Learning-based schedulers enhance resilience and runtime stability
- Predictability evolves dynamically as an emergent property of the SoS

Panelist Position

BARCELONA 2025

- The need for codesign to introduce AI and Explainability in health services
  - Interaction between practitioner, patient, record, AI, family is complex so practitioners and patients need to ‘get together’ to codesign how this should/could best work addressing issues such as ‘trust’ (in AI and practitioner).



Professor Ray Jones
University of Plymouth UK

THE STAGE IS YOURS