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Bridging Communities in Large-scale Complex and Critical Systems

A White Paper

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Executive Summary

We are at the dawn of what promises to be a new digital age. While enormous benefits are currently being realised, the throughput of digital technologies that can act in the real world is (increasingly) limited. There is a need for more invested effort in longer-term value solutions and for supporting instruments. Particularly to enable the bridging of technology communities, with special focus on the capacity to treat safety, security and real-time properties together. These properties and their integration represent the gatekeepers for technology uptake in real-world applications. More generally, there is a need to significantly invest more in systems engineering research. It is the key ingredient for preparing our national infrastructures to be ready for using the latest technologies. If we can address these bottlenecks, we could expect to at least double the benefits provided by existing technologies for interactions with the real world.

Systems interacting with the real world continue to see increasing technology interconnectivity and distribution. This results in increasing complexity particularly because more interlinking means also the concerns of one side increasingly need to be treated by the other. Of course this is a serious challenge for technology uptake. To realise the great potential of this interconnectivity, there is a need to master how these technologies are integrated and the transitions required for use as products in the real world. We are still a long way from an optimum solution for many reasons. There are two fronts to tackle not only the mechanisms within a system product, but also a need to rethink our approaches for managing, assessing and supporting technology development, where breakthrough advances are reliant on the combination of experts with different domain backgrounds. New supporting instruments are especially required to enable translation between knowledge domains, assessing relevant research proposals and return on investment. There is also a significant need for the means to prepare the ground for such new bridging technologies in relation to product-side or market-side influencers.

Such system products are characterised as cyber-physical systems (CPS), representing physically interactive collaborating products, formed by the aggregation of many contributions among the stakeholder communities. These include influences from the market and product-line, technical advances from functional properties, system-level functionalities, enabling technologies and of course the aggregating tools and techniques for bridging these communities. CPS represents an important part of our future, founded on much national infrastructure across many domains including manufacturing, transport, medicine and robotics.

To support investigation into bridging among technology communities, a newly established segment of CPS workshops has taken place now three times. Their purpose is especially to encourage dialogue on the common interests and concerns between the contributing communities. As there are many contributing communities to physically interacting systems, we split the segment up into groups for a focus on backgrounds in functional properties (FORECAST), at systems level (STEADINESS) and enabler technologies like AI (ENHANCE). These groups represent the foundational background of participants, for instance in FORECAST we could have a sensing specialist bridging to another functional property domain or bridging to AI.

This white paper reflects an overview of discussions by and among the participants, including a description of the presentations and discussions that followed. Recommendations have emerged which are detailed next.

Recommendations

The following R&D goals are formulated as recommendations based on the presentations and discussions during the workshops. They are addressed to the mixed domain industrial, academic and policy stakeholders and to the European Commission.

For Enabling Technologies contributing to CPS (ENHANCE):

- **ET Recommendation 1**. A general and widely accepted uniform terminology is needed for cloud-edge-IoT systems, which can be used in all projects and discussions within the EU.
- **ET Recommendation 2**. Robust (wireless) communications are key to make the transition from monolithic to distributed CPS that can take advantage of edge and edge-cloud computing.
- **ET Recommendation 3**. The use of ML seems promising for CPS but needs to be properly integrated in the overall system design, taking into account its (current) limitations.

For Functional Technologies contributing to CPS (FORECAST):

- **FT Recommendation 1**. Research communities should embrace open-source software communities. Both kinds of communities work best when they work with an interdisciplinary mindset.
- **FT Recommendation 2**. Our community should reach out more into the political decision making process. Politics are slow, but the long-term benefits are undeniable.

For System-level Technologies contributing to CPS (STEADINESS):

- **ST Recommendation 1**. While there exist national clusters for pure research on system engineering, surprisingly we have very little at European level. A pan-European association for system engineering should be established.
- **ST Recommendation 2**. Effectively no automotive industry involved with standards. There should be investigations into how to resolve this.

ENHANCE: Exchanges on Enabling Technologies and Dependability in Cyber-Physical Systems

Cyber-physical systems (CPS) have become prevalent in many industrial sectors thanks to the development of various new technologies on both the software and hardware sides. Examples of topics driving CPS this CPS adoption include: Artificial Intelligence, model-driven software development, formal modelling and verification, wireless communications, novel embedded and edge controllers. These technologies are evolving at a rapid pace. Yet reliability is an absolute requirement, and we must demonstrate that the lifecycle of CPS always matches it. As CPSs continue to grow in importance around the world, building trustworthy CPS and managing the complexity of their system hierarchies are of paramount importance.

ENHANCE relates to communities representing enabling technologies including IoT, AI and Big Data. Involvement of product-side and market influencers helps prepare the ground for technology transfer.

Topics Presented

IoT-Edge-Cloud Continuum for Manufacturing (Ovidiu Vermesan, SINTEF).

Presented work on a system that was developed to support condition monitoring in a Soya bean factory. The system is highly distributed and heterogeneous, including widely different types of nodes, from embedded IoT devices with special sensors, to network gateways, edge servers, and databases for storing long-term data, integrated with existing SCADA infrastructure. Furthermore, different wireless protocols, such as Bluetooth, LoRaWAN and WiFi, are used by these nodes to send their measurements / data upstream to perform higher-level aggregation and processing. The information collected is used to identify abnormalities and potential breakdown situations as well as to optimise the production process. To this end, different data analysis methods were employed to provide the necessary information for anomaly detection and alarms, including ML algorithms running on the embedded nodes and servers.

P4-based Decentralised Swarm Intelligence for Smart Factory Scenario (Michelangelo Guaitolini, CNIT).

Presented work done in the SmartEdge project with focus on a swarm of autonomous mobile robots (small ground vehicles), which are employed in a smart factory to move materials around the facility. The mobile robots have several onboard sensors (primarily for obstacle detection) and limited onboard computing capacity / intelligence. In addition, fixed cameras are deployed at different locations of the facility to provide visual information, while more powerful servers can be used to perform heavyweight data processing operations. The objective is to support flexible task execution with a minimization of collision risk and adaptive re-planning, to increase productivity and efficiency. The desired coordination is achieved via the P4 middleware, which supports dynamic group management, message exchange and data processing pipelines with full transparency regarding the underlying wireless network topology and technology used for the physical communication.

Towards a Deep Investigation of Cybersecurity Issues in Cyber-Physical Systems Using a Novel Graph Neural Network-Based Threat Analysis (Abdelkader Magdy Shaaban, AIT).

Presented work of the AIMS5.0 project on the detection of potential security issues in the design of cyber-physical systems (CPS). CPS typically comprise multiple heterogeneous physical and cyber system components interconnected with each other to provide specific actions/functions with impact in the physical world, hence it is extremely important to identify and repair security vulnerabilities that could allow cyberattacks to cause problematic situations. This is even more important in the automotive sector where attacks can have catastrophic consequences. However, the complexity of such systems makes it very hard for traditional security analysis methods to deeply investigate all connected components and related security measures to determine if any security issues exist. As an alternative approach, the use of AI is explored. More specifically, Graph Neural Networks (GNNs) are proposed as a suitable candidate, due to their inherent graph-based structure and ability to capture and learn more complex network functions and patterns, matching the intricate interaction between

the components of CPS. The outcomes of this work will support the continuous updating of the system design with an applicable set of security measures to keep cyber risk at an acceptable level.

Methodology for Transforming a Local Safety-Critical Cyber-Physical System into a Distributed Safety-Critical Solution (Krzysztof Oborzyński, Philips; Astrid Rakow, DLR).

Presented work of the TRANSACT project on a structured methodology for transforming a local safety-critical cyber-physical system (CPS) into a distributed safety-critical solution. Nowadays, most safety-critical systems are still deployed as standalone systems, which are usually hard to upgrade or extend while at the same time continuously ensuring the system's safety, performance, security, and privacy. However, the transition from monolithic, isolated CPS to distributed systems that can exploit the potential of edge-cloud computing, is particularly challenging due to the high trustworthiness demands. Different aspects of such a transition were identified, including architectural but also business and organisational concerns, taking into account critical cross-cutting aspects such as safety, performance, security, privacy, regulatory, and certification, based on lessons learned from various domain-specific use-cases, such as automotive, healthcare and wastewater treatment. Furthermore, a generic stepwise process was described for defining requirements when transforming an initial CPS into a system with parts distributed over the edge-cloud continuum. The proposed methodology (named T&V) starts by defining what is expected from the overall distributed solution and ends with having the defined requirements for all the components, leading to the early identification of functionality that could be offloaded, checking if offloading is feasible at all (e.g., from the safety aspect) and determining the conditions under which this can add value to standalone operation.

End-to-end Autonomic Management of Cloud-Edge Continuum Systems using Reinforcement Learning: Design Approach and Formulation (Theodoros Aslanidis, UCD).

Presented work of the MLSysOps project on the end-to-end autonomic management of cloud-edge continuum systems using ML methods. The scale, heterogeneity, and dynamics of cloud-edge continuum systems make applying conventional rule-based approaches to system management hard. While ML methods seem promising, it is unrealistic for a single ML model to be responsible for monitoring and decision-making in such systems. Also, ML models must evolve together with the system, smoothly handling the addition of new devices or system performance affected by different (possibly external) dynamic conditions. To tackle the problem, a three-level hierarchical structure of ML-based agents is proposed to handle node-level, cluster-level, and continuum-level management tasks. Furthermore, the Reinforcement Learning (RL) approach is used to achieve continual learning in highly dynamic and complex systems. RL can handle non-periodic and complex user patterns and provide long-term, strategic decision-making and planning. Still, the formulation in terms of RL raises several challenges, such as selecting the granularity of the telemetry data used to define the state space, translating the global objective into a series of well-defined actions, and ensuring learning convergence, robustness, and efficiency.

Communities Discussion

In the open discussion that followed, the audience posed questions about the effects on performance and robustness when applying different settings in the wireless technologies used to connect nodes to the rest of the system. As expected, the general consensus was that tuning for increased performance

(higher throughput) typically leads to lower reliability (increased data loss), and a good trade-off must be found for each case separately depending on the application requirements.

Power consumption was raised as an important aspect in embedded systems, especially in the context of mobile applications, such as the robots in the smart factory. In the presented use case, however, a general-purpose board was used for fast prototyping purposes without being optimised for energy-efficiency. Still, it was agreed that power constraints can become quite important in a wide range of CPS that include mobile nodes and wireless communication, and this should be considered early in the system design.

The use of GNNs to identify security gaps in automotive systems was received with great interest. A key question was the general suitability of GNNs to detect security issues in complex CPS systems other than the ones that are designed for the automotive sector. While the presented research is still ongoing and has not yet produced concrete results, the gut feeling was that GNNs can indeed be applied to detect security issues in the design of any networked system.

Another topic of discussion was the degree to which robustness can be achieved with hard guarantees in distributed CPS systems, given the open and uncontrollable Internet connectivity. The general conclusion is that all critical functions should be implemented directly on the end-user devices or nearby dedicated edge nodes with which communication is guaranteed to be secure and reliable. Optional, nice-to-have but less critical functions can be implemented on remote regional or cloud datacenters. Also, the system must "opportunistically" take advantage of such optional functionality in a smooth way without disrupting its basic operation.

The prospect of using ML-based methods to manage CPS was discussed. The main concern was the typical lack of guarantees of such methods, which may be acceptable in application domains which do not have very strict safety requirements or where a human always double-checks the outcome of ML. It was agreed that ML should probably not be used in critical functions, especially if these are to be performed fully automatically without a human in the loop, but could still bring significant value in data processing and decision making in the "softer" parts of a complex system. Also, ML could be used in tandem with conventional rule-based approaches, e.g., to detect bugs in the latter.

Finally, it was noted that different projects and presenters use different terminology when it comes to the cloud-edge-IoT landscape. This is obviously confusing and also introduces a lot of synchronisation overhead when discussing system architectures and the placement of different functions in such systems. It was agreed that a unified generally acceptable terminology is needed.

FORECAST: Exchanges on Functional Properties and Dependability in Cyber-Physical Systems

Safety-relevant applications have been traditionally built upon the KISS (Keep it simple stupid) principle as a way to ensure the dependability of those systems and at the same time control the costs of functional and dependability properties verification. However, the traditional safety assessment approach that relies on system's simplicity is being challenged these days by the increase in complexity and functionality requirements of new Cyber Physical Systems (CPS) applications (e.g autonomous transportation systems).

Recently, there has been a surge of new safety-critical systems fuelled by artificial intelligence (AI) including fully autonomous driving systems, AI-enabled medical devices, and robotics operators. Safety-related functionalities governed by AI tremendously escalate the complexity of achieving functional safety. In this context, researchers and practitioners are struggling with the necessary shift from low complexity hardware governed applications to these increasingly complex software-controlled systems executed on top of very complex processors. At the same time, this comes at a time when society is starting to blindly (and dangerously) rely on such complex computing systems.

FORECAST relates to communities representing **functional properties** for systems, which covers Computation, Sensing, Physical Actions, Energy Support and Coordinated Collaboration. Involvement of product-side and market influencers helps prepare the ground for technology transfer.

Topics Presented

Open Source Driving Multi-communities Bridging (Marco Jahn, Eclipse)

Open Source Software (OSS) is becoming more and more popular in research communities, and for good reasons. OSS aligns well with the goal of making results of public funding accessible to the general public. But it takes more than just a code dump on a public repository to make OSS sustainable. Continuous support is just as important, and ideally this should happen in the form of an active community. The Eclipse Foundation, a European open source foundation, supports communities in building successful open source projects, by providing organisations (from industry, research, and academia alike) with a mature, scalable, and business-friendly environment for open source software collaboration and innovation. Currently, the Eclipse Foundation is home to 21 industry collaborations (e.g. Eclipse Software Defined Vehicle, Eclipse IoT, Eclipse Dataspace, just to name a few) and partner in over 10 research projects helping to sustain research innovations in open source. This aligns very well with the workshop topic of bridging communities.

Physical Unclonable Functions for Authenticating Neuromorphic Accelerators in IoT (Elena-Ioana Vatajelu, Univ. Grenoble Alpes)

With the rising complexity of digital systems, trustworthiness of integrated circuits becomes more and more important. An important building block is reliable identification/authentication, which often uses a physically unclonable function (PUF). Neuromorphic computing devices, including photonics-based ones, offer new opportunities to implement such PUFs. They supply enough variation to implement strong authentication schemes and other use cases with various degrees of resistance against typical attacks.

A Possible Scenario to Study the Security of 5G Communication in IoT Edge Cloud Continuum (Aya Moheddine, INRIA)

While the 5G mobile communications standard is a big security upgrade over previous standards, it is complex enough to allow a wide variety of operation modes with varying degrees of security. At the same time, the Internet of Things creates higher demand for integrity and confidentiality. With typical access patterns of known software, it may become possible to passively uncover transmitted information even without breaking the encryption, simply by training an ML model on captured signal data and its decoded output.

EU Parliament Research Perspective. (Miklós Györffi, Hungarian Research Network)

The EU Parliament often plays a key role for unlocking bottlenecks to R&D that are expected to bring significant benefit to society. From the communities contributing to complex or dependable system development, at these workshops, there is interest to reinforce or build bridges with policy to help both sides be more informed. A first aspect for our communities is to become better informed about how the EU Parliament. Global market drivers are a particular factor in national and EU policies, where we looked at the example of climate change. We then took a deep dive on one of the more recent policy positioning activities by the EU Parliament to establish an AI Act. This has spanned, excluding some preliminary work, about four years with different types of consultations and related legislation development. Finally the EU Parliament develops support instruments to help drive research as a support for the economy, with the Strategic Technologies Europe Platform (STEP) lightly discussed.

New Support Capacities for Complex Multi-Community Interactions. (Charles Robinson, Thales)

For complex and dependable systems, the key challenge for their creation is the combination of technologies coming from different contributing communities. This requires technologies supporting interfacing, integration and orchestration. However, the barriers for adoption of such bridging technologies are much higher than for component technologies. This calls for consideration of the supporting environment that facilitates the uptake and equipping such interdisciplinary specialists with the capacity to support the bridging.

Multi-Community Research Calls for Complex and Critical Systems. (Luis Miguel Pinho, ISEP & INESC TEC)

This is a new exploratory activity for this CPS segment of workshops. The goal is to present and discuss several calls that seek the integrations of technologies across multiple communities, considering for example the call origins, the driving needs behind them and relevance to communities in the room. Two programmes were considered, with particular interest in the automotive industry:

- the KDT-Chips typically larger consortiums with broader research topics and mixed funding – two particular calls were discussed (HORIZON-Chips-2024-1-IA Topic 2 and HORIZON-Chips-2024-1-IA Topic 3)
- the Horizon Europe, which at least for lower TRLs are typically smaller and more focused consortiums (HORIZON-CL5-2024-D6-01-01)

It is useful to analyse aspects such as the motivation for the calls, the organisations behind the call and where the advances will provide most benefit.

Communities Discussion

In the discussion about the presented talks, two main areas of interest emerged: security and community building and support in general.

Two talks were addressing security-related topics, and these were met with interest by participants who were familiar with relevant blocking points. Other participants asked for clarification on a more fundamental level. This shows that even though security in cyber-physical systems is of utmost importance, the research community is still quite fragmented in this regard.

In the discussion arising from the talk about 5G security, it was mentioned that by 2025, there might be more than 40 billion devices in the network. In such a hyper-connected world of IoT-Devices, functional safety cannot exist without security. Yet the discussion showed that many communities do not yet embrace security as a basic aspect of their work. On the other hand, the photonic PUF talk demonstrates that latest security research can deal with very specific topics that only apply to a very small audience.

From this, we draw the conclusion that we need to find a way to also create a bridge between functional and security communities. There needs to be a way to make security research more accessible for other researchers who want to create solutions in their field of expertise, but with basic security as part of the design. Additionally, security itself has many dimensions, so for an efficient discussion it is important to more clearly highlight what security aspect is of interest, e.g. privacy, integrity, or confidentiality.

The other talks concerned themselves with different aspects of community-building and community action. They were met with great interest, which shows that there is significant interest in this kind of activity.

The open-source talk is an obvious example, and the participants of the workshop emphasised that in the cyber-physical world, hardware is also quite relevant. Open source also works for hardware, not just software (see OpenHW as an example). Given the prolific activities of entities like the Eclipse Foundation, most workshop participants were familiar with open source in general. Community bridging in this area seems to work out well when done right.

The keynote gave the participants an insight into the legislative process around EU regulation that affects our communities, using the currently ongoing process around the topic of artificial intelligence as an example. Here the feedback was characterised by the fact that most participants were not aware of the lengthy and convoluted process of real-world lawmaking in the EU. A weak consensus was that the affected communities should be more actively searching for participation opportunities, especially since some public consultation periods are rather short.

STEADINESS: Exchanges on System Engineering and Dependability in Cyber-Physical Systems

Systems engineering [INCOSE], especially in complex scenarios like the design and production of Cyber-Physical Systems, is facing a dual challenge nowadays, resulting in a wish for a paradigm shift driven by both research and industry. On the one hand, state-of-the-art digital engineering ecosystems are still hampered by various kinds of engineering data remaining trapped in domain- and tool-specific silos, with a lack of interoperability between different tools and platforms. This problem is even more serious as such engineering tasks are often deeply involved with rigorous expectations around standards and other, notably safety- and security-related, regulations. On the other hand, for the

industry to move on and live up with modern software-technical expectations around efficiency, integration and flexibility, these ecosystems and toolchains should enjoy novel levels of interconnectedness and vendor independence.

STEADINESS relates to communities representing the **system level** including system modelling, validation and verification and the product lifecycle. Involvement of product-side and market influencers helps prepare the ground for technology transfer.

Topics Presented

The topics discussed in STEADINESS' 2024 edition, we have covered a really wide range of topics, bridging platform- and management-level considerations to state-of-the-art solutions in hardware architectures.

Declassified:Standards in Model-Based Systems Engineering(Daniel Siegl, LieberLieber)

In his keynote talk, Daniel Siegl shared his extensive experience with model-based systems engineering standards, spanning over 15 years. Expressing both frustration and motivation, he emphasised the importance of action, especially in light of the emerging SysML v2 standard. Siegl argued that despite the challenges and promises of SysML v2, the field is at a pivotal point where complaints must give way to proactive engagement. His talk served as a wake up call for professionals in the field to embrace and contribute to the evolving standards, ensuring they meet the complex needs of modern systems engineering. This message has also set the tone of the following discussion, see also the next section of the whitepaper.

TRANSACT Reference Architecture: A Universally Applicable Distributed Solution Architecture Concept (Javier Coronel, ITI; Teun Hendriks, TNO)

Presented by Javier Coronel (Instituto Tecnológico de Informática, Valencia, Spain) and Teun Hendriks (TNO-ESI, Eindhoven, The Netherlands), this talk introduced the TRANSACT project's aim to develop a universally applicable distributed architecture. Addressing the integration of computation and physical processes in Cyber-Physical Systems (CPS), the presentation highlighted the challenges of deploying safety-critical systems within strict compliance and high certification costs. The TRANSACT reference architecture proposes a multi-tier approach that leverages edge and cloud computing to enhance flexibility, scalability, and access to advanced technologies without compromising safety, performance, security, or privacy. The architecture, detailed through static and dynamic views, promises to transform standalone safety-critical CPS into distributed solutions, with a medical use case illustrating its potential benefits for cloud-connected advanced imaging workflows in hospitals.

Assessing OpenMP for Adaptivity of Real-Time Critical Applications (Chenle Yu, Collins Aerospace)

Presented by Chenle Yu from the Barcelona Supercomputing Center (Spain) and Collins Aerospace Applied Research & Technology (Ireland), this talk delved into the aerospace industry's shift towards electric-powered, autonomous Urban Air Mobility (UAM) systems. These advanced aircraft require significant computing power to run AI applications and critical tasks simultaneously. The presentation highlighted the limitations of current computing architectures in CPS and the complex challenges of mapping applications to multiprocessor systems on a chip (MPSoCs). It discussed the potential of

OpenMP for parallel programming in addressing adaptivity to dynamic situations, such as component failures, in real-time critical systems. Despite the challenges in accepting OpenMP in the real-time domain, the speakers presented enhancements to the OpenMP infrastructure that could facilitate adaptivity in critical avionics systems, illustrated by a mixed-criticality avionics demonstrator developed on a NVIDIA Jetson Orin NX platform.

Reconfigurable Architectures for Approximate Dense SLAM Computing in Robotics (Nikolaos Bellas, ECE, University of Thessaly)

Nikolaos Bellas from the University of Thessaly, Greece, focused on the role of robots in enhancing CPS's efficiency and functionality. Robots, capable of operating in diverse and unstructured environments, can support the elderly, physically handicapped, and replace humans in dangerous conditions. Bellas's talk evaluated numerous MPSoC FPGA architectures for KinectFusion, emphasizing precise and approximate optimizations. A systematic methodology was proposed to rank the impact of each optimization on performance and accuracy. The findings showed significant performance improvements, achieving almost 28fps, which is 11.55 times faster than the ARM OpenMP implementation. This presentation underscored the importance of reconfigurable architectures in advancing dense SLAM computing for robotics, highlighting their potential to revolutionise interactions in complex environments.

Communities Discussion

The **STEADINESS** workshop involved participants from systems, software or hardware engineering communities, people from the production, marine, avionics, space and automotive domains. The presentations and the lively discussions helped to bridge some of these communities, and realise that some of the local challenges are indeed ubiquitous in all kinds of cyber-physical systems.

During the workshop, participants engaged in insightful discussions across various dedicated sessions. The dialogue revolved around the challenges and opportunities in enhancing interoperability, efficiency, and standardisation in engineering workflows, with a particular emphasis on the relevance of standards in the current technological landscape.

As a consequence of the background of the audience, as well as the topic of the keynote talk, standardisation efforts and their consequences and perspectives emerged as a highlight topic. The discussions unearthed a complex landscape marked by divergent attitudes among stakeholders towards establishing open community standards. On one hand, standards are essential for ensuring interoperability, safety, and efficiency, serving as a common language that facilitates collaboration and innovation across sectors. On the other hand, the process of standardisation can be fraught with challenges, including resistance from stakeholders who may perceive standards as constraints on innovation or as vehicles for dominant players to enforce their interests.

The varied perspectives on standardisation reflect underlying conflicts between the drive for open, inclusive standards that support broad-based innovation and the realities of competitive advantage, intellectual property concerns, and the strategic interests of different industry players. Navigating these tensions requires a delicate balance, promoting standards that are sufficiently flexible to accommodate innovation while robust enough to ensure interoperability and safety across the technological ecosystem.

In the keynote and the ensuing discussion, a significant focus was placed on the interaction with SysML v2, reflecting on initial impressions and the dominance of the US in the standardisation scene. This session underscored the critical role of standards in ensuring coherent and unified engineering practices across diverse domains.

Furthermore, the discussion on the TRANSACT session also attached these concerns to the reality of applications and use-cases, exploring their scopes in contexts such as aircraft and maritime navigation, acknowledging the limitations imposed by intermittent cloud connectivity. Discussions also touched upon device certification challenges, emphasising the importance of safety and the ongoing efforts in re-certification within the TRANSACT project, thereby illustrating the project's contributions towards safety and security assurance.

The OpenMP session delved into the integration of parallel processes, addressing concerns about process interference and its impact on execution timelines. The comprehensive view of OpenMP as a runtime system, a means to expose parallelism, and an open initiative was articulated, highlighting its role in balancing performance and portability, and addressing the needs of the high-performance computing community.

Regarding SLAM, the discussion explored performance barriers, seeking parallels with challenges faced by other communities, thereby fostering a cross-disciplinary understanding of common obstacles and potential solutions.

Summarising, the workshop's discussions highlighted the critical role of SE/CPS in advancing interdisciplinary digital engineering, emphasising the need for thoughtful engagement with the complexities of standardisation to foster an environment that supports innovation, collaboration, and efficiency in engineering practices.

Concluding Remarks

There are many promising directions on work bridging technology domains and indeed the scope is very large for considering their integration into dependable systems. A clear common challenge across the communities is that there remains a great deal of fragmentation, where R&D to provide suitable support instruments for cross domain integrations would provide great benefit.

Several key aspects emerged in the focus groups. For *Enabling Technology Communities*: A general and widely accepted uniform terminology is needed for cloud-edge-IoT systems, which can be used in all projects and discussions within the EU; Robust (wireless) communications are key to make the transition from monolithic to distributed CPS that can take advantage of edge and edge-cloud computing; The use of ML seems promising for CPS but needs to be properly integrated in the overall system design, taking into account its (current) limitations. For Functional Technology Communities: Research communities should embrace open-source software communities. Both kinds of communities work best when they work with an interdisciplinary mindset; Our community should reach out more into the political decision making process. Politics are slow, but the long-term benefits are undeniable. For *System-level Technologies Communities*: While there exist national clusters for pure research on system engineering, surprisingly we have very little at European level. A pan-European association for system engineering should be established; Effectively no automotive industry involved with standards. There should be investigations into how to resolve this.

Preparations for follow-up workshops are underway to continue the support and to nurture cross domain technology development. We invite readers that see the importance and potential of this work to get in touch.

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Appendix

Workshop Attendees (and contributors to this paper)

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Jorg Walter	Offis
Krzysztof Oborzynski	Philips
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Sara Royuela	BSC
Sergio Saez	ITI
Spyros Lalis	Uni Thessaly
Teun Hendricks	TNO
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