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A SE4AI Framework for the Systems Engineering of Autonomous Systems with a focus on the Curation of Data across the Lifecycle

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Abstract. AI-enabled systems incorporating Machine Learning (ML) are offering significant societal benefits, making their adoption inevitable. The benefits of AI-enabled systems are balanced by associated increases in complexity and the challenges encountered in verifying designs and explaining autonomous behaviour in safety critical domains (Giray, 2021). There is also a parallel recognition that societal needs and technological advances are driving rapid AI innovation resulting in the building blocks of these innovative technologies being put together in ad-hoc ways, in the absence of defined developmental frameworks (Jordan, 2019).

Systems Engineering (SE) is highly effective and has defined developmental frameworks for over 70 years that span the design, realisation, and evolution of complex systems. Traditional SE uses pre-definition wherein projects commence with a clear, comprehensive set of requirements. This works well for major hardware platforms but has limitations for software intensive systems that are required to change to meet unforeseen needs and technological developments. SE itself is evolving and has progressed from pre-definition to more flexible, Agile approaches that are well suited to software-intensive systems. Agile SE (Dove and Schindel, 2019) only requires a high-level intent to be defined that is elaborated with episodic development tranches in a way that effectively becomes continuous evolution. However, in contrast to conventional software-based systems that employ fixed algorithms and display pre-determined behaviour, the behaviour of AI-based systems is subject to change during operation based on operational experience.

There are four parts to the research to address this need. The first is the refinement of extant SE frameworks and methodologies to enable the end-to-end SE of AI-Intensive systems (SE4AI). This will be the focus of the presentation. The second is the assurance of built AI-Intensive systems (AS4AI). The third part comes from the realisation that the breadth of behaviour possible from AI-intensive systems requires extensive verification, training and validation programs across a large number of operational scenarios. This is unlikely to be feasible with conventional real-world physical model training and validation programs. This drives the increased but judicious use of simulated environments for the development, training, and validation of AI-intensive systems and the need for standardised approaches for the SE of such Simulated Environments (SE4SimE). The final part of the research is into approaches to assure such simulated environments (As4SimE).

The material that forms the basis of this presentation results from research being undertaken by the lead presenter at the University of Adelaide, as part of an industry sponsored PhD program (iPhD) on an

Australian Government Research Training Program (RTP) scholarship, with industry partner, Shoal Group, looking into the SE and Assurance of Autonomous Systems. It builds on insights and thought leadership across a 25+ year career that focused on a similar challenge to autonomous systems, requiring innovation in the application of SE for flight training and mission rehearsal systems in a defence context. The need then was to assure human competencies, that could be considered the “human intelligence” that give rise to high levels of safety in flight and mission operation. The SE frameworks for Modelling and Simulation (M&S) developed subsequently expanded to support the development, assurance, and sustainment of accredited high-fidelity flight and mission simulators delivering individual, team, tactics, and collective training in a military context (Bhalla, 2013a, Bhalla, 2013b, Bhalla, 2013c, Bhalla, 2014b, Bhalla, 2014a, Bhalla, 2018). Key insights of particular exaptive relevance to this research included the formalisation of enabling M&S competencies, the criticality of reference data used to objectively establish the fidelity of the models employed in the simulations and the tailoring of SE best practice to develop, assure and sustain high-fidelity and safety critical flight and mission training systems that delivered the right situational awareness (SA) to enable experimentation, training and certification of “human intelligence” to perform safety critical tasks in complex operational environments (Figure 1).

This presentation will start by contextualising the four-part framework of SE4AI, As4AI, SE4SimE and As4SImE (Figure 3), that can underpin the development, delivery, and evolution of safe, robust, efficient and effective AI-enabled (autonomous) systems. It will then expand on the SE4AI area of practice, to propose refinement of SE best-practice applicable to AI-intensive autonomous systems, with a particular focus on their high reliance on data for ML-model design verification, training and validation. The presentation will include a review of contemporary ML development approaches that concludes that there would be value in employing a more holistic SE “end-to-end” evolutionary whole of life perspective.

It will then present concepts and principles from contemporary best-practices in SE (Walden et al., 2023, ISO/IEC/IEEE, 2021, Bhalla, 2020, Boehm et al., 2014, Cook and Wilson, 2019) highlighting how a disciplined SE approach enables the establishment (and retention) of system design integrity through key activities and related artefacts that establish configuration baselines across functional, logical and physical constructs progressively through life-cycle phases. It will highlight how the ongoing integrity of these baselines (in an evolutionary development and delivery context), in conjunction with end-to-end traceability (requirements to design to development), complimented by verification and validation (V&V), are central to building-in integrity of design and assuring confidence in suitability of fielded systems (Figure 4).

It will present definitional concepts on M&S, and illustrate the concept of fidelity as a measure of “goodness” and “suitability” of models employed in credible simulations (Bhalla, 2018, Wang et al., 2020, Rogers and Mitchell, 2021, Defense, 2011, Box, 1979). It will expand on SA, as a foundational design goal in aviation and military contexts and on the criticality of sensed data to right SA in both a human and autonomous systems context (Figure 5) (Endsley, 1995, Pitts et al., 1990, Bhalla, 2020).

The presentation will then describe how the concepts from SE, M&S and SA discussed earlier can be integrated into a tailored, evolutionary SE best-practice for AI-intensive autonomous systems that recognises the criticality of reference data for ML-model design verification, model training, and model validation. A refinement of the established SE pillars of requirements engineering, architectural design, V&V, and configuration management follows. A discussion on how these refinements support design integrity and assurance through end-to-end traceability and the introduction of an additional configuration baseline concludes the body of the presentation (Figure 6).

The presentation concludes with an outline of the status and future intent of the research program.

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