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A Meta-Case Study of Modeling, Simulation, Visualization, and Analysis for Real-World Software Systems Engineering Education

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Modern technology is a complex system of systems composed of mechanical systems controlled by electrical systems controlled by software systems. Software engineering is not just about software anymore. The systems-engineering processes of analysis, design, implementation, testing, evaluation, verification, validation, and accreditation demand far more than the typical classroom environment can address. This work presents a highly successful reusable software architecture and corresponding holistic pedagogical approach that utilize modeling, simulation, visualization, and analysis at all levels with an overarching focus on software quality assurance. It uses multiagent continuous time-stepped simulations for interactive virtual worlds that capture a vast breadth and depth of multidimensional exposure to realistic systems while still being manageable for students and the instructor. This presentation highlights commonalities and results from a survey of eight recent projects:

- *Unmanned aerial vehicle simulator*: an airplane flight-dynamics model generating control and flight data for cockpit instrumentation.
- *Air traffic control simulator*: aircraft management from the perspectives of ground, tower, departure, enroute, and approach controllers.
- *Fly-by-wire aircraft control system*: a network-based flight control system for aircraft structures and components.
- *Aircraft carrier operations simulator*: a carrier environment of aircraft positioning, launching, refueling, and recovering.
- *Aircraft accident reenactment simulator*: an environment for generating, reproducing, evaluating, and preventing aircraft accidents.
- *Military materiel test range*: a virtual test range of airplanes, ships, and submarines with munitions, sensors, fuzes, and countermeasures.
- *Heavy construction equipment toolkit*: an evaluation system for designs with electrical, mechanical, pneumatic, and hydraulic components.
- *Railroad operations simulator*: a train environment with tracks, engines, cars, and signaling and safety systems.

This approach forces students to develop and apply critical-thinking and technical-communication skills by pushing them outside their comfort zone into overwhelmingly unfamiliar real-world environments. It helps establish the endless dots and their interconnections and interrelationships to learn about the problem domain of the subject matter, to translate it into the solution domain, and to evaluate the results. Modeling and simulation here uses software as a surrogate for the real world to investigate what-if scenarios from many perspectives. It dovetails with the scientific method as a disciplined approach for envisioning, building, and conducting repeatable controlled experiments in support of developing quality software systems of systems. Finally, it emphasizes an array of underutilized visualization techniques as an expressive yet intuitive means of conveying information to all stakeholders in the development process.