

## **A National Agenda for Software Engineering Research and Development Architecting the Future of Software Engineering**

*Abstract: Given the ever-growing dependence of the Department of Defense (DoD) and the nation as a whole on software systems, a national imperative exists to maintain and strengthen U.S. leadership and strategic advantage in software engineering. As the DoD's R&D center focused on improving the practice of software engineering, the Carnegie Mellon University Software Engineering Institute (CMU SEI) is leading the community in creating a multi-year research and development vision, strategy, and roadmap for engineering next-generation software and software-reliant systems.*

### **Software is Vital to America's Global Competitiveness, Innovation, and National Security**

Software is essential to our modern standard of living. It is the most important modern-day building material, is extremely flexible, never completely done, and controls functions as diverse as the capabilities of our home appliances, aircraft flight control systems, mobile phones, health care systems, and financial transactions. As computing and software technologies advance, our dependence on them grows. Software has become society's central nervous system. The ability to build software systems (software engineering) is vital to America's global competitiveness, innovation, and national security. Characteristics of future systems will challenge known theories and practices of software engineering.

### **Our Ever-Growing Dependence on Software Systems Makes It Imperative to Maintain our Nation's Leadership and Strategic Advantage in Software Engineering**

In a recent National Academy of Science Study on Air Force software sustainment, the U.S. Air Force recognized "that to continue to be a world-class fighting force, it needs to be a world-class software developer." Clearly, this sentiment generalizes far beyond the Air Force to all aspects of our nation's security including healthcare, commerce, education, energy, and more. These systems will be more data intensive and interconnected, increasingly utilize AI and autonomy, require larger-scale integration, need to be more resilient, and increasingly edge driven. Consequently, investment in software engineering R&D is needed now to enable and ensure future capability.

### **CMU SEI is Leading a National Initiative to Define the Future of Software Engineering**

As the DoD's Federally Funded Research and Development Center (FFRDC) focused on improving the practice of software engineering, the Carnegie Mellon University (CMU) Software Engineering Institute (SEI) is leading the community in creating a multi-year research and development vision, strategy, and roadmap for engineering next-generation software and software-reliant systems.

To be successful, coordination among academic, defense, and commercial communities is vital to both developing the agenda and implementing the results. As shown in Figure 1, this effort is designed to ultimately help drive a more successful software ecosystem.



Figure 1: A Research Roadmap to Shape the Future of Software Engineering

CMU SEI has convened multiple workshops for broad engagement and diverse perspectives, including a workshop on Software Engineering Grand Challenges and Future Visions co-hosted with DARPA. This workshop brought together senior leaders in the software engineering research community to describe (1) an important class or classes of future software and software-reliant systems, and (2) the software engineering challenges, research methods, tools, and practices that are needed to make those systems feasible.

### Engaging With Advisory Board of U.S. Visionaries and Senior Thought Leaders

In June 2020, CMU SEI assembled an advisory board with diverse perspectives from DoD, industry, academia, research labs, and technology companies to provide strategic advice, influence stakeholders, develop connections, assist in executing the roadmap, and advocate for the use of the study. Advisory Board members include

- **Dr. Deb Frincke**, Advisory Board Chair, Associate Laboratory Director for National Security Sciences, Oak Ridge National Laboratory
- **Dr. Michael McQuade**, Carnegie Mellon University Vice President for Research
- **Dr. Vint Cerf**, Vice President and Chief Internet Evangelist for Google
- **Ms. Penny Compton**, Vice President for Software Systems, Cyber, and Operations, Lockheed Martin Space
- **Mr. Tim Dare**, Deputy Director for Prototyping and Software, Office of the Under Secretary of Defense for Research and Engineering
- **Mr. Jeff Dexter**, Senior Director of Flight Software & Cybersecurity, SPACEX
- **Dr. Yolanda Gil**, President of the Association for the Advancement of Artificial Intelligence (AAAI); Director of Knowledge Technologies at the Information Sciences Institute at University of Southern California
- **Ms. Sara Manning Dawson**, General Manager, Microsoft Critical Infrastructure Engineering
- **Mr. Tim McBride**, President, Zoic Studios (Zoic is a leading visual technology firm that started out as a Hollywood special effects and visualization company and is now supporting the DoD. ZOIC is also engaged in COVID-19 tracking and visualization.)
- **Ms. Nancy Pendleton**, Vice President and Senior Chief Engineer for Mission Systems, Payloads and Sensors, Boeing Defense, Space and Security
- **Dr. William Scherlis**, Director DARPA Information Innovation Office

### New Systems, New Research Challenges, and New Research Focus Areas for Future Software-Enabled Systems

New types of systems will continue to push beyond the bounds of what current software engineering theories, tools, and practices can support. For example,

- Systems that do data fusion at huge scale, whether for news or intelligence: We will need to take advantage of vast amounts of open source data streams (e.g. YouTube video). This vast stream of data will also drive new ways of constructing systems.

- Smart (highly engineered) cities, buildings, roads, cars, and transport: How will we balance autonomy against group efficiency. How we live in these highly connected systems? How will the systems be integrated? How will we enable safe transportation and safe living?
- Highly engineered business enterprises: These will feature thorough integration of suppliers and customers, of engineering, of production, of every other aspect of the business.
- Personal assistants: These will really assist, learn, adapt, engage in home and business workflows.
- Dynamically integrated healthcare: Data from your personal device will be combined with hospital data for example. How do we make safety claims given this vision; how do we evaluate quality; what does enforcing assurance mean in a highly data driven environment?
- Very adaptive DoD systems/mission-level adaptation: These systems will feature mission-level construction of new integrated systems combining intel, weapons, human/machine teaming, etc. The DoD is already moving in this direction, but what does it mean to do this as a matter of course? Military systems need a level of reliability way above civilian systems.

New types of systems will continue to push beyond the bounds of what current software engineering theories, tools, and practices can support. Challenges and research focus areas include

- Using AI-Augmented Software Development to Enhance the Software Engineering Workforce.
- Research at scale: Performing software engineering research in situ on actual large-scale software-enabled systems, which are usually not easily accessible / available to the research community.
- Composability with Assurance: Changing the paradigm for how software is created by composing large-scale system from much smaller, provably correct pieces. This requires a theory of software composition.
- Assuring Continuously Evolving Systems: Building systems and supporting evidence that provide appropriate level of trust that the system will work correctly, in a context of emergent behaviors and constant updates.
- Human-Machine Teaming to Build Software: Democratizing the building of software: making software development more accessible for different skillsets and domain expertise; human-machine optimization for the developer; software factories of the future.
- Software (Program) Synthesis: Automatically generating software that satisfies the specification from the user.
- Designing in Ethics in Societal-Scale Software Systems.

### **CMU SEI is Serving as a Catalyst for the Software Engineering Community to Create a Compelling Research and Development Roadmap for Next-Generation Software Systems**

Software has become central to all aspects of our national security including defense, infrastructure, healthcare, commerce, and education. To maintain our competitive advantage in these areas, we need to be the best engineers of software in the world. CMU SEI envisions the contributions of this study to include

- Serving as a catalyst for the software engineering community to create a compelling 10-year vision, strategy, and roadmap for the research and development of next-generation software and software reliant systems on which national security depend. It is envisioned that the roadmap would discuss motivation (including vision and strategy), focus of the study, alternative futures, software engineering challenges, research priorities, research infrastructure, and action plan.
- Contributing to the development of an ecosystem for software engineering that engages academic, defense, and commercial communities to work together on solving future problems and developing critical abilities.

- Contributing to national security by informing future decisions, policies, and investments in software engineering.

## Further Reading

- Design and Acquisition of Software for Defense Systems 2018 Defense Science Board report, <http://www.dtic.mil/dtic/tr/fulltext/u2/1048883.pdf>
- DoD Digital Engineering Strategy 2018 Department of Defense <https://www.acq.osd.mil/se/docs/2018-DES.pdf>
- Moris, F., 2019. *Software R&D: Revised Treatment in U.S. National Accounts and Related Trends in Business R&D Expenditures*, s.l.: National Center for Science and Engineering Statistics InfoBrief.
- Software is Never Done: Refactoring the Acquisition Code for Competitive Advantage. Defense Innovation Board, May 2019. [https://media.defense.gov/2019/Apr/30/2002124828/-1/-1/0/SOFTWAREISNEVERDONE\\_REFACTORINGTHEACQUISITIONCODEFORCOMPETITIVEADVANTAGE\\_FINAL.SWAP.REPORT.PDF](https://media.defense.gov/2019/Apr/30/2002124828/-1/-1/0/SOFTWAREISNEVERDONE_REFACTORINGTHEACQUISITIONCODEFORCOMPETITIVEADVANTAGE_FINAL.SWAP.REPORT.PDF)

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