Advancing Producibility for Software-Intensive Systems

THE PRIMARY MOTIVATION FOR SISPI IS TO IDENTIFY AND SOLVE THE UNDERLYING PROBLEMS THAT IMPEDE EFFECTIVE PRODUCTION OF SOFTWARE-INTENSIVE SYSTEMS.

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The Role of Software in DoD Systems

As discussed in a recent issue (October 2007) of Software Tech News, software is a critical enabler of DoD system capabilities. As needed software capabilities grow in complexity, the challenges of building this software correctly, predictably, rapidly, and cost-effectively increase. The only hope for getting ahead of these challenges is to fundamentally improve the means and methods by which we build software. We have the opportunity to achieve substantial improvements over the next 10-20 years if we begin to invest systematically for software producibility.

Producibility is a comprehensive term for the ability to deliver needed capability in a timely, cost-effective, and predictable manner. OSD, as part of an exploratory effort with service Science and Technology representatives, has sponsored preliminary work toward establishing a Software-intensive Systems Producibility Initiative (SiSPI). The SiSPI is envisioned as a collaborative government-industry effort to create technology that will enhance producibility benefiting DoD acquisition and sustainment of software-intensive systems. SiSPI-associated work has included workshops with researchers and industry that have led to the development of a draft technology vision and roadmap [1]. The purpose of this roadmap is to frame and guide future investments toward making improved producibility a practical reality.

The need for producibility improvements has been recognized, lamented, and analyzed for largely the entire history of software engineering as a concept. Nevertheless, improvements in practice have occurred at only a modest rate even as DoD's dependence on software continues to grow (productivity improvements of perhaps 5-10 percent per year, with increasing size and complexity and undetermined effects on quality). True improvement requires technological advances that will provide the means for predictable, streamlined production of software and systems.

Producibility Problems in Practice

Over the last ten years there have been periodic attempts to characterize key software challenges and to advocate research efforts that could address them. With each such attempt, promising ideas emerge, often reiterating conclusions of past attempts, but all have failed to gain backing of decision makers for needed funding. Many government and industry executives seem confident that commercial approaches and routine incremental advances in software tools and methods will suffice to meet future DoD needs, precluding the need to invest further in research or development of such technology. Nevertheless, the costs, schedule uncertainties and delays, and product quality issues resulting with current production approaches remain high.

The SiSPI is an attempt to remedy this by addressing several aspects that past efforts have neglected: establishing a guiding vision and comprehensive evolving framework rather than focusing on specific technologies or approaches; focusing on improvements that address acquisition, production, and sustainment challenges rather than encompassing the infinite horizon of potential advances in end-use system capabilities; and measuring progress in terms of technologies actually adopted and showing benefit in practice rather than being satisfied with demonstrations of concept and hoping productization and adoption will occur naturally.

The primary motivation for SiSPI is to identify and solve the underlying problems that impede effective production of software-intensive systems. These problems pervade current acquisition and engineering approaches and are not likely to be solved with simple narrowly focused tools. Problems that the SiSPI work has identified as needing to be addressed to achieve producibility improvements, representative of most past such analyses, can be summarized briefly as:

- Requirements inadequately define the problem and over-specify a solution.
- Accommodations are not made in anticipation of likely future changes in requirements or technology.
- Testing consumes inordinate resources to find product flaws late.
- Projects ineffectively balance function, quality, and cost-schedule.
- Decisions made to achieve first delivery increase life cycle costs.

- System designs fail to explore software alternatives and tradeoffs.
- System properties due to software are not estimated and engineered but "fixed" through trial-and-error.
- Development tools do little to enhance development efforts, being useful only for recording as-built descriptions of a product.

Addressing all of these problems requires a comprehensive reconception of how we build and evolve software-intensive systems.

The Manufacturing of Software

These producibility problems are not inevitable or unavoidable; they are the symptoms of a flawed approach to the production and evolution of software-intensive systems. Current approaches to software and systems engineering trace to a time when software was a minor element of systems and needs were modestly conceived and easily understood. However, completed software was not easily changed so requirements had to be fixed early for an effort to succeed.

A major phase of the acquisition process is concerned with determining how components will be manufactured, arranging supply of raw materials, and constructing and testing the needed manufacturing facilities.

Although the ease of identical replication of software suggests that manufacturing has no relevance to software, the mass customization approach to manufacturing offers a model that is highly applicable to software. This model has been realized and shown to work for software in the form of product line approaches. SiSPI proposes extending this thinking to software production in general with the perspective that accommodating changing needs and technology, during both development and sustainment, are key challenges for software-intensive systems.

For software in particular, based on the perspective that most software produced by a qualified enterprise establishes and follows proven forms appropriate to the needs of that enterprise and its customers, formulating a manufacturing approach to software production based on those forms can enable the elimination of large parts of current acquisition, development, and sustainment efforts. Unfortunately but not surprisingly, current software development tools and methods do not conceive of nor provide appropriate support for such a CAD/CAM approach. This requires that we undertake a program of research, product development, and transition in order to make such an approach feasible for DoD acquisition and sustainment.

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These are no longer the conditions under which software-intensive systems are built: software to a large degree today determines a system's capabilities with hardware as its enabler: requirements are complex and changing, enabling hardware technologies and even the operational environment are all software-based and similarly complex and changing. The result is that the software defining the system must be regularly modified for the system to continue to meet the dependent enterprise's changing needs.

To respond to this increasing complexity, a new vision is needed to describe our conception of how to properly build and evolve software and systems. This vision embodies a manufacturing concept, computer-aided design and manufacturing (CAD/CAM), not just for hardware elements but for software as well and for the system as a whole.

From a production perspective, systems engineers have always understood that hardware components had to be manufactured and that the cost and quality of the resulting product was dependent on the quality of the manufacturing capability used.

A Producibility Vision

From the roadmap, producibility has three dimensions that suggest the capabilities of SiS production that need to be addressed:

- Developer productivity: the efficiency and effectiveness of developers in creating and evolving a product
- Product value: the utility and quality of each product that results
- Acquirer acuity: the insight and foresight that acquirers have in delineating current and future capabilities needed

The producibility vision of CAD/CAM for software-intensive systems (SiS) must address the production challenges that each of these perspectives presents.

Taking a broad view of the meaning of CAD/CAM in industry, CAD is the conception, design, and analysis of a problem and solution in model form while CAM is the manufacture from raw and processed materials of a product that conforms to that model. The roadmap identifies five principles that characterize this vision of CAD/CAM for SiS:

- Model-centric: All problem-solution information is expressed in a comprehensive multi-faceted model of a product and its envisioned context of use.
- Virtualized: A system is defined by building, pre-deploying, and validating in a software form within a hardware/software/user virtual environment.
- Predictable: Software and dependent system properties of interest are able to be accurately predicted and mutually optimized as a product model evolves.
- Decision-focused: Multiple alternative solutions are modeled, produced, and empirically evaluated based on identified customer and engineering decisions.
- Evolvable: The problem-solution is continuously evolved to create variant products that satisfy anticipated differing or changing needs.

The SiSPI technology roadmap provides a framework for identifying and initiating actions to create and transition producibility improvements into practice.

A Roadmap for Producibility Improvement

Improving technology for solving the problems of producibility begins with research advances. However, the larger challenge is getting improved technologies (tools and methods) into actual use. This requires organizational adoption of technologies to be within reasonable cost and effort and not to incur unacceptable disruption or risk. In addition, a long-term SiSPI effort has to show reasonable short-term rewards and substantial long-term improvements across the entire acquisition-sustainment life cycle.

As a result, the SiSPI roadmap describes a framework for research, identifying objectives and milestones for each of five areas of focus; a framework for transition, identifying objectives and milestones for moving technology from concept into actual practice; and a management approach, defining objectives and milestones for prioritizing actions and measuring improvements achieved.

A Framework for Research

The roadmap identifies five areas of research focus required to achieve the producibility vision:

- Model-based development: Bridging the conceptual gap between customers and product developers to rapidly formulate, build, and evaluate alternative solutions to evolving needs
- Predictable software attributes: Measuring, predicting, and controlling SiS software properties and tradeoffs
- System virtualization: Creating virtualized environments for realistically evaluating alternative solutions
- Disciplined methods: Applying effective methods for engineering discipline in the development of software within systems
- Infrastructure and emerging technology: Exploiting changing infrastructure and computing technology capabilities for enhanced producibility

The first area derives directly from the vision whereas the second and third areas address the major impediments to achieving the full objectives of the first. The final two areas reflect the need to accommodate beneficial and inevitable advances in the practices and enabling technologies associated with software development independent of the producibility vision.

A Framework for Transition

Research advances alone do not result in producibility improvements in practice. Many seemingly sound results of research have failed to influence practice. The real challenge for DoD is to transition beneficial technology from research into effective practice. Starting with a proposed improvement based upon promising research results and existing practices, transition comprises three stages:

1. Validation – Evaluating proposed technology
2. Integration and productization – Preparing the technology for production use
3. Adoption – Instituting use of the technology on programs

Technology consists of both tools and methods and must be conceived to operate effectively within the context of other producibility-enhancing technologies, as well as any retained existing practices. These may also require revisions of existing practices and procedures to enable potential improvements. An objective of validation, integration, and productization is to minimize unnecessary disruptions to acquirers and developers, but the objective of adoption is to make organizational changes that would otherwise impede successful use of the technologies that become available as a result.

SiSPI Management Factors

Based on a tentative governance approach that envisions a collaborative government-industry effort, the roadmap focuses on key aspects of initiative management that have the greatest implications for research and transition efforts:

- How potential research and transition efforts are to be identified and prioritized
- How effectiveness of research and transition efforts are to be measured

In light of realistic limits on potential funding and needed expertise, it is essential that the SiSPI target advances that provide near-term benefit while leading to efforts that achieve long-term advancement. The producibility vision provides an objective framework for judging potential contributions to long-term benefits but judging near-term benefits must rely on proper measurement of technology use in practice.

As near-term advances progress, interim visions of effective practice will be formulated to ensure that their adoption is compatible with current practices that are not as advanced. Evaluating the near-term benefit of narrowly focused technologies will require researchers to identify the measurable benefits they expect to achieve and that must be proven before becoming candidates for transition efforts leading to adoption.

Once technologies are proven to have claimed benefits and have been engineered to a level of production quality, the emphasis will shift to reorienting acquisition programs toward rethinking their approach to acquisition, development, and sustainment, leading to the expedited adoption of appropriate enabling technologies. Changes in DoD acquisition policies and practices may be necessary to permit and encourage programs toward undertaking the effort of making such improvements.

A Product Line Perspective on Producibility

For each of the five categories of research identified, the roadmap begins to define goals whose attainment will provide the technological capabilities (tools and methods) needed to implement the producibility vision as a systematic approach for the production of software-intensive systems. In the interim, much of this vision can be implemented today within a product line context. While we may lack the generally applicable scientific insights to apply this vision to build an arbitrary system today, the limiting assumptions that underlie a product line offer a context in which more limited methods are sufficient.

The CAD/CAM vision of producibility revisits the original motivation for the product line concept, which was pragmatically limited to producing a set of similar products corresponding to the scope of a business enterprise [2]. This new vision encompasses product lines while also acknowledging the potential for other bases for limiting the scope of applicability of the production capability that results from domain engineering like activities. This particularly applies to capabilities that span business areas by providing solutions for broadly acknowledged needs with capabilities that are not themselves complete products but that serve as components of other business-directed application products. Similarly, this provides a framework for the development and evolution of one-of-a-kind and one-size-fits-all products that are long-lived and supportive of changing needs.

To realize this vision beyond the product line context still requires significant advances in our understanding of software as an artificial construct that must both correctly sense and represent the world in which it operates and also act effectively within it. It also goes beyond a narrow conception of product lines, that focuses only on software, to encompass systems engineering and customized hardware manufacturing as elements of a complete product that are interdependent and based on a shared view of customer needs and related engineering tradeoffs.

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Software Research Beyond Producibility

The concept of producibility suggests a focus on DoD's need to become more effective, in terms of cost, quality, and timeliness, in providing systems that support future operational capabilities. This can be expressed in the form of a DoD objective for acquisition efforts:

- Acquire improved capabilities, responsive to force objectives and needs, while adhering to schedule, budget, and quality goals.

When thinking about software research, it is natural to focus not on a goal such as this but rather on goals related to software advances that will enhance operational capabilities. The broad applicability of software means that potential research topics have few natural limits. The SiSPI effort focuses on producibility challenges because this has implications across all DoD efforts. If one instead considers specific DoD capability needs of the future, it is possible to characterize other high-level objectives that suggest many other potential areas for software research:

- Accurately observe and represent the evolving (past, present, and projected future) state of the world, exposing the relative quality and timeliness of available data, for more effective situation assessment and action planning.
- Obtain comparative predictions of alternative future operational states as projections of the estimated past and current state and potential actions as aids to action decisions and planning.
- Communicate and collaborate securely among cooperating forces as a virtual enterprise.
- Act over distance and time for predictable results.
- Scale operational capabilities to make most effective use of available resources under fault, failure, and overload conditions, in addition to nominal/routine, maintenance, and training conditions.

Objectives such as these suggest many potential directions for software research. Research into software capabilities supporting such objectives can be traced directly to DoD mission needs and progress against them can be judged from that perspective. Accordingly, other recent proposals have been made to pursue software-focused research that would better address objectives such as these. One concerning the challenges of future Ultra-Large Scale Systems [3] and another concerning Cyber-Physical Systems that achieve more effective integration of computational and physical processes [4] are of particular interest. Proposals such as these anticipate advances in producibility as part of making their advances adoptable in practice, and the SiSPI envisions advancing such capabilities in collaboration with these efforts and others both in the U.S. and internationally.

References

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About the Author

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