Domain Engineering: The Challenge, Status, and Trends

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Abstract

Naval Surface Warfare Center Dahlgren Division; under joint sponsorship of the Office of Naval Research; the Naval Command, Control, and Ocean Surveillance Center; and the Naval Surface Warfare Center; has initiated a thrust to examine the ongoing trends in engineering complex systems, to enrich and enhance the state-of-the-art in engineering methods and practices, and to facilitate the implementation of desired improvements. To support that thrust, the Second Annual Workshop on Engineering of Systems in the 21st Century: Facing the Challenge was held in June 1995. One hundred and seventy five technical and organizational leaders from industry, government agencies, and academia were invited. Each participated in one of thirteen Focus Groups. This paper summarizes the results of the Domain Engineering Focus Group.

Background

Domain engineering addresses knowledge and asset development, capture, and evolution for a family of systems. It is the process of identifying and recording commonalities and variables in a domain and using that information to create reusable assets and new systems. Domain engineering creates a "space" of solutions from which application engineers will later draw point solutions. A domain is a clearly delineated application area containing systems that share design decisions. Domains can pertain to functional capabilities, such as navigation or stores management, or can cross functional areas; e.g., user interfaces, reliability, and security. Domain engineering can be applied across all phases of system development and at different levels of abstraction to develop systems, subsystems, components, subcomponents, and engineering environments. For example, domain engineering might be applied to ships, sensors, networks, workstations or operating systems. The technology includes engineering of domain models, architectures, components, generators, processes, methods, and tools. Domain engineering can be a critical technique in defining system requirements and exploring potential architectures. There has been significant research in applying domain engineering to software applications [3,4,7], but domain engineering approaches have not been widely applied and are in various states of development. There is little awareness or research at the systems engineering level, and negligible work has been done on integrating domain engineering with an overall systems engineering process.

The domain engineering process should be integral with the systems engineering process. Domains are defined based on business objectives and product lines. Engineers performing domain engineering capture product line technical and process knowledge. Assets they develop meet common requirements across the domain and are tailorable to support the differences. Application engineers use these tailorable products to produce product line systems. When these systems are used, additional customer requirements are fed to application engineers, who in turn pass them on to the domain engineers, helping to refine domain products (FIGURE 1).

Approach

The Domain Engineering FG represented a mix of participants from DoD, industry programs, and domain engineering research efforts. This combination of talent provided a unique interaction that proposed an interesting challenge. FG members felt that domain engineering has reached a sufficient level of maturity, and bringing domain engineering into the mainstream

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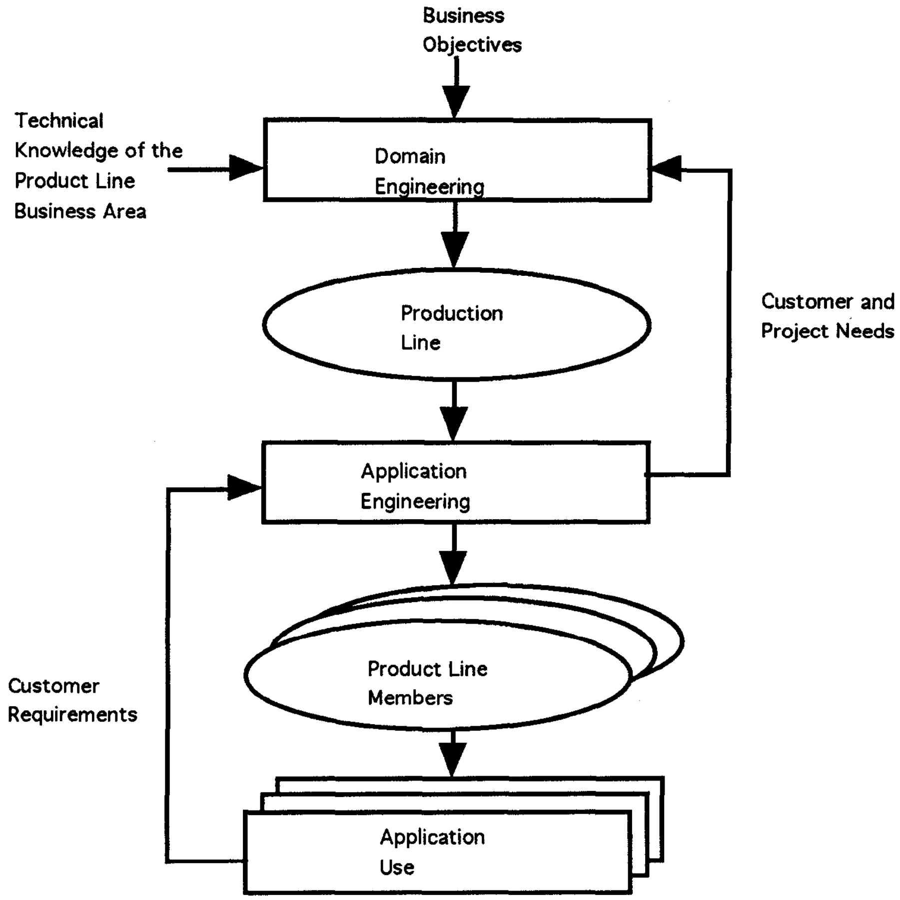

FIGURE 1 DOMAIN ENGINEERING PROCESS[1]

is the most critical need. The challenges are convincing practitioners that domain engineering can improve their products and productivity, and laying the proper groundwork within the DoD acquisition process to make this happen.

Figure 2 indicates that technical enthusiasts and visionaries have developed domain engineering processes and tools that would be valuable assets to the systems engineering community, but most systems engineers have not embraced this technology, as represented by the chasm in the diagram. The chasm exists because practitioners cannot gain significant payoffs from domain engineering until models and asset bases have been developed for their domain. These models will only be developed by practitioners after they embrace the concept of domain engineering. Group members believe that this catch-22 is only solvable with funding and commitment to build those initial models and assets. The group asserted that it was necessary to define recommendations to solve this problem, so that DoD and the systems engineering community could reap the overwhelming benefits of domain engineering. In arriving at the above observation, the group examined trends of domain engineering since the early eighties and where the state of domain engineering is today. The group then set goals as to where domain engineering should be by 2010, discussed the barriers and drivers, and laid out some initial steps to get there. Recommendations focused primarily on getting domain engineering into mainstream systems engineering, with some discussion

[1] Adapted from J. W. Brackett and A. B. Pyster, [1]

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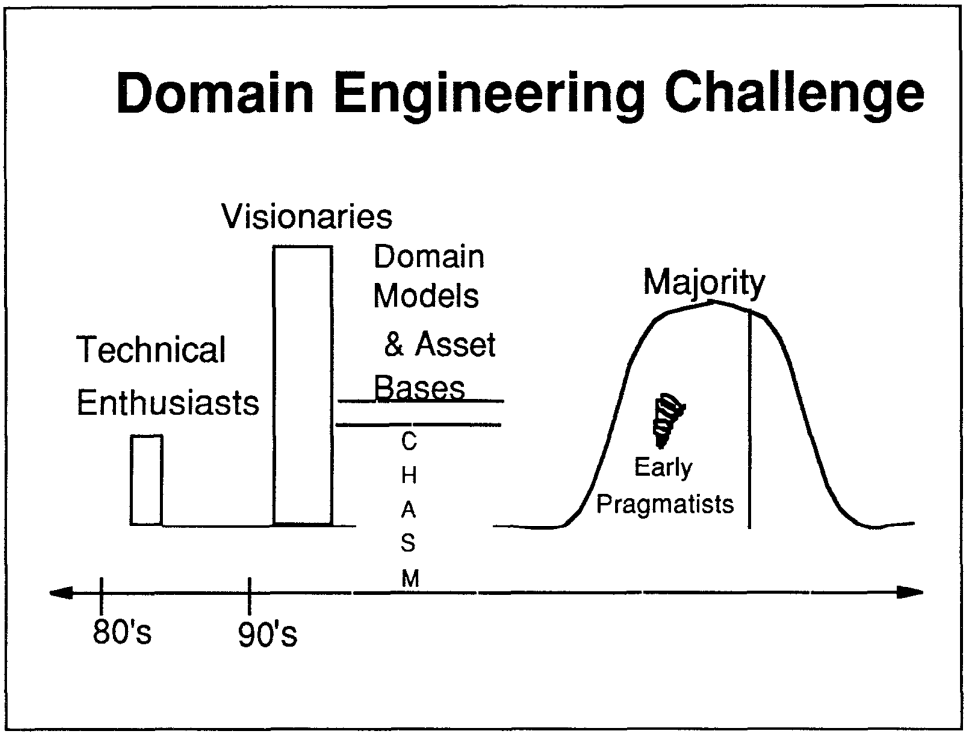

FIGURE 2 DOMAIN ENGINEERING CHALLENGE

concerning possible improvements in domain engineering technology.

The group believes that domain engineering will become a major component of systems engineering in the 21st Century. The DoD will recognize that it cannot afford to build the same functionality over and over within each system. The services will demand tailorable products. Most major corporations will recognize that they need to engineer product lines, not systems, to remain competitive. A corporation will not be competitive unless it has tailorable assets for its product lines that can be tailored to the current program. Prime contractors will have tailorable assets for their core competencies and the types of systems they build. Others will own tailorable assets for subsystems and components. Those that have these assets will survive. Others will perish.

Where Are We Today?

Today there are proven domain engineering processes that have been applied primarily to software [5,6], and these processes are applicable to systems. There is also some tooling but not full automation, and there have been very favorable experiences in a number of domains[2], such as air defense (Hughes), telephone switching (AT&T), printer firmware (HP), trainers (STARS/Boeing), Intelligence and Electronic Warfare (STARS/Unisys), simulation (Northrop Grumman), and shipboard sensors and battle management (Bofors/NobelTech/CelsiusTech).

Figure 3 illustrates the use of domain engineering across product lines. For example, Hughes has developed domain assets to support the Air Defense domain and is now using these tailorable assets in the Air Traffic Control domain. While domain engineering has been used successfully in production, it is not institutionalized. The STARS project and ARPA have demonstrated a cooperative model in which DoD and industry work together to create domain assets, but this model is not widely used. Visionaries such as the chief architect in Air Defense at Hughes have accepted domain engineering, but most engineers are either unaware or not convinced.

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[2] Note: Those companies recognized as leaders in domain engineering for the specified domain are indicated in parentheses.

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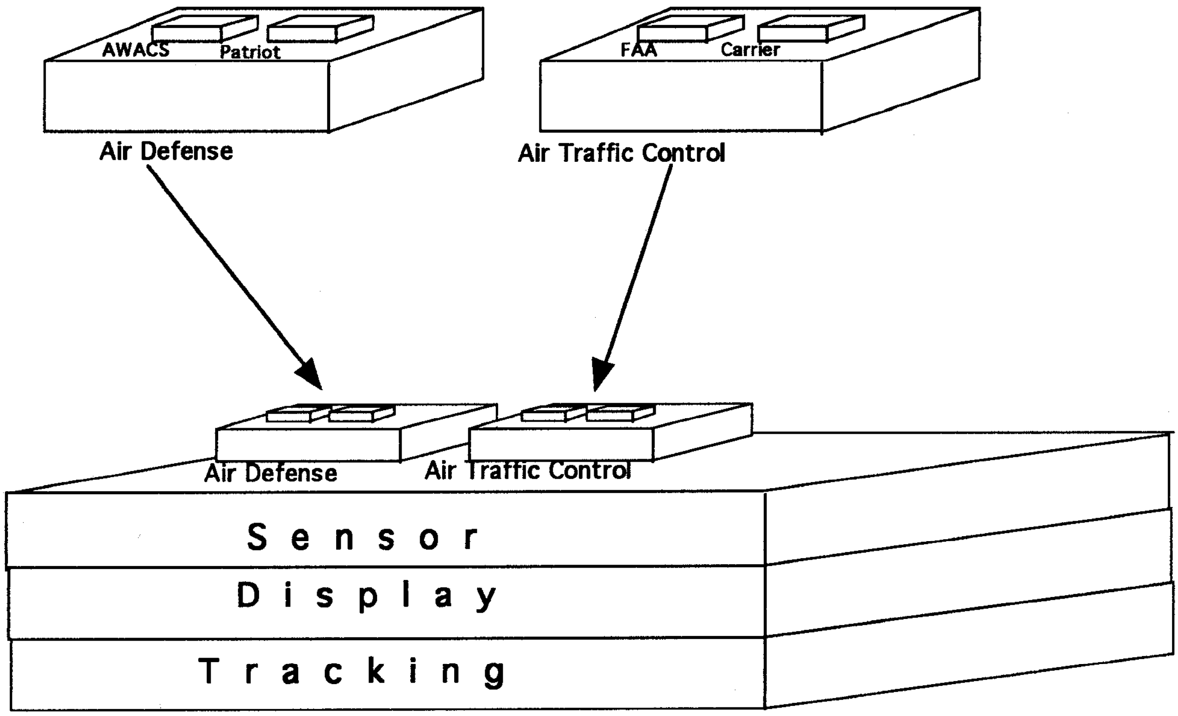

FIGURE 3 DOMAIN ENGINEERING IN AIR SPACE MANAGEMENT AND CONTROL

Domain engineering technology has improved enormously over the last decade, as highlighted in Figure 4. In the early eighties, engineers were primarily doing ad-hoc domain engineering and were experimenting with new processes. During this period, software engineers built the first reusable software library, the CAMP library of reusable parts for building missile software. Mechanical engineers defined commonalities and variations for replenishment ship winches, and developed a common architecture [2]. These winches have much in common, but there are variations based on the type of replenishment ship. Currently we have programs such as the Software Technology Project for Adaptable Reliable Systems (STARS) and the Advanced Research Projects Agency Domain Specific Software Architecture (DSSA) Project that have developed domain engineering processes and domain assets. Some corporations (e.g., Hughes, HP, AT&T, and Toshiba) are investing heavily in domain assets, which has given them a significant competitive advantage in winning contracts. It is a good point in time for other DoD agencies and industries to explore and exploit domain engineering for both new and modernized systems.

Today DoD policy mandates reuse in the three services. The DoD STARS Project, the ARPA DSSA project, and the Software Productivity Consortium RSP Synthesis Project have codified processes and methods that others are successfully using. The government and industry have developed domain-specific software architectures and assets, such as Hughes assets for Air Defense, ARPA assets for guidance and control, Boeing assets for trainers, Army/Unisys assets for Intelligence and Electronic Warfare (IEW), and Northrop Grumman assets for simulation. Some of these assets are in the public domain.

Where Do We Want To Be?

The FG felt that by 2000, domain engineering technology and tooling should be significantly enhanced to reduce investment costs. By 2010, corporations will have domain assets and knowledge bases supporting their product lines and core competencies. The

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Trends

80's	Early 90's	1995+
SW reuse libraries	Domain-specific software architectures	Product families Domain specific systems architectures
Ad hoc domain eng.	Holistic processes & codified methods Some tools	Automation
Early experimentation	Trials and demos Early DoD policy	Institutionalized

FIGURE 4 DOMAIN ENGINEERING TRENDS

technology should have matured to the point that practitioners are able to produce domain models rapidly, develop configurable prototypes, and build evolvable systems.

By 2000, DoD and industry should use domain engineering to promote dual use, defining similarities and differences for products that are required by both defense and commerce. In most cases, DoD technology is not *directly* reusable in commercial products. In some cases, the differences are related to DoD's stringent performance, reliability, packaging, and security requirements. In other cases the differences are due to variance in functionality. Domain engineering will encourage dual use by developing assets that incorporate the similarities and can be tailored to both DoD and commercial arenas. By 2010, effective coordination of DoD and commercial industry should result in significant numbers of common products.

By 2000, captured domain knowledge and infrastructure should be readily accessible within corporations and across industry and government to those that are building products in the domain. As an ancillary benefit, domain knowledge and products will be embedded in training material and simulators for training those working in a new product area. By 2010, DoD and industry will use the same system-level cost of building the initial basis is large when considered only for the first system but may be domains and effectively share domain-engineered products and training.

By 2000, each service should establish product lines such as communication systems, sensors, and tracking systems. By 2010, there will be interservice commonality for the highest leverage domains.

What Are The Realities?

Domain analysis and domain engineering are activities that promise to minimize redundant development efforts, improved opportunities for reuse of components across products within the domain, and reduce costs. However, no individual development project has incentives to pay the costs for the analysis and engineering activities that would produce these benefits. A principal reason is that the prime beneficiaries are other development efforts. The FG identified the need to reorient the PEOs and similar management organizations to the potential benefits of domain engineering so that the necessary financial investment can be accomplished.

The difficulty in recognizing market viable domains is also a significant inhibitor in performing domain engineering. The profitability of a given domain is dependent upon a number of factors. The reasonable when amortized over the family of systems. Also, the cost of tailoring domain models and assets for

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each system needs to be considered. For domains that include a number of similar systems, these costs will be far less than the cost of building each system individually, but this can be difficult to demonstrate. Given that both technical similarities and cost factors need to be considered in determining which domains are most profitable, it is difficult to find the right people to determine the best domains for investment. These factors inhibit domain engineering startup and prevent government and corporations from building the necessary assets.

How Can We Get There?

The FG believes that the key need is to bridge the chasm and achieve widespread domain engineering by building domain models and asset bases (
Figure 2). Key investments should lead to this goal. The primary investment should be in projects that create system-level domain models, infrastructure, and asset bases. One of the primary areas to apply domain engineering is the modernization of existing systems. Existing systems should be examined from a domain viewpoint, identifying domains that have widespread application. Developing and reusing domain assets in these domains will prove the value of this technology. Investments should be made in projects that apply domain engineering processes at the system level, at the subsystems level, and horizontally across subsystems to "—ilities" such as reliability and maintainability. Other projects should apply existing methods and tools in additional software-intensive domains. These investments should apply in cross-service and cross-agency contexts. Also important is the identification of successful applications of domain engineering. These applications should be investigated, and the reasons for success should be identified and quantified. Both of the above activities will lead to a better understanding of the technology gaps in domain engineering, and investments should be made to fill these gaps. Tool enhancement and integration are also extremely important, as automation will help reduce domain development and application costs. Lastly, but of great importance, is education. Investments should be made in educating students, engineers, and managers in the importance and the process of domain engineering and management.

Acquisition reform is necessary to fund asset development that multiple systems can use. Therefore, the key activity recommended for the coming year is: *Influence change in the DoD acquisition strategy to embrace domain engineering*. Recognition that domain engineering is a key activity in systems engineering is also important. The Systems Engineering Capability Maturity Model (SECMM) currently includes a Key Practice Area, Manage Product Line Execution, that covers the practices associated with managing a product line but not the engineering of the products themselves. The SECMM should be extended to include the engineering of the tailorable assets. The FG considered a number of research topics and tool needs, but felt it would be better to contact service schools and appropriate universities, as well as industry researchers and practitioners, before committing to topics.

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