Summary points from the final report of the Committee on Advancing Software-Intensive Systems Producibility (ASISP)

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National Research Council (NRC)
Computer Science and Telecommunications Board (CSTB)
The critical role of software for DoD

- Software has emerged as a key enabler of **capability**, **flexibility**, and **integration** in diverse DoD systems
  - Mission capability embodied in software has become a unique source of strategic and military advantage
  - Extent of system function performed in software, examples (DSB)
  - **Multiple DSB, NRC studies**: At the core of the ability to achieve integration and maintain mission agility is the ability of the DoD to produce and evolve software

- **Finding**
  - Software has become essential to a vast range of military system capabilities and operations, and its role is deepening and broadening
    - Increase in scale, complexity, and role in manifesting functional capability
    - Increase in interlinking diverse system elements
    - Increase in use for systems development, modeling and simulation

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**Software’s critical role**

Criticality of Software to DoD Operations

- Ref: Defense Systems Management College
Recognizing the strategic significance of software

- **Software has become a principal force multiplier for DoD**
  - Rapid growth in extent and criticality of software to DoD operations

- **Software is a key competitive factor in commercial business**
  - Software is now a strategic source of competitive advantage in sectors ranging from financial services and health care to telecom and entertainment.

- **Disproportionate benefits from software in economic growth**
  - ICT industries in US since 1995 [NRC economic policy board]
    - ICT sector is 3% of US GDP
    - ICT drives 20% of US economic growth
  - ICT in Europe
    - ICT sector is 5% European GDP
    - ICT drives 25% of overall growth and 40% of the productivity increase
  - And: Most software development is outside the ICT sector
Three goals for software-intensive systems devt

- Improve critical areas of current practice for DoD software devt
  - Enable incremental iterative development at arm’s length
  - Enable architecture leadership, interlinking, flexibility
  - Enable mission assurance at scale, with rich supply chains
Mission goals ↔ Practice improvements ↔ Research

- Improve critical areas of current practice for DoD software devt
  - Enable incremental iterative development at arm’s length
    - Process and measurement
  - Enable architecture leadership, interlinking, flexibility
    - Architecture
  - Enable mission assurance at scale, with rich supply chains
    - Assurance and security

- Undertake research to support the critical areas of practice
  1. Architecture modeling and architectural analysis
  2. Validation, verification, and analysis of design and code
  3. Process support and economic models for assurance
  4. Requirements
  5. Language, modeling, code, and tools
  6. Cyber-physical systems
  7. Human-system interaction
1. **Software has become critical in its role and strategic significance for DoD**
   - Software enables capability, integration, and agility in defense systems
   - DoD needs to actively and directly address its software producibility needs
   - NITRD data reveal the extent of the S&T disengagement that must be reversed

2. **Innovative software-intensive engineering can be managed more effectively**
   - Apply advanced practice and supporting tools for iterative incremental development
   - Update earned-value models and practices to support management process

3. **DoD needs to be a smarter software customer**
   - There is insufficient DoD-aligned software expertise within and around DoD

4. **Assert DoD architectural leadership**
   - In highly complex systems with emphasis on quality attributes, architecture decisions may need to dominate functional capability choices

5. **Adopt a strategic approach to software-intensive mission assurance**
   - Integrate preventive practices into development to support ongoing creation of evidence in support of assurance
   - Do not lose leadership in software evaluation and assurance (DSB’07)

6. **Reinvigorate and focus DoD software engineering research**
   - Apply appropriate criteria in identifying goals for research programs
   - Focus research effort on identified goals in seven technical areas
Adopt a strategic approach to software assurance

- **Finding from DSB2007, reiterated in Critical Code**
  - It is an essential requirement that the United States maintain advanced capability for “test and evaluation” of IT products. Reputation-based or trust-based credentialing of software (“provenance”) needs to be augmented by direct, artifact-focused means to support acceptance evaluation.

- **Context**
  - **Challenges**
    - Inadequate + costly legacy approaches – based on inspection and sampled tests
    - Newly rich and globally diverse supply chains, with arms-length relationships
    - Assurance reqts can dramatically limit systems capability, and vice-versa
  - **Opportunities**
    - Significant advances and potential for preventive/evaluative practices
      - Evidence production – Isolation / encapsulation
      - Architecture design – Configuration management
    - Potential for new approaches to “evaluation standards” for legacy / ongoing / new

- **Conclusion**
  - DoD must directly foster advanced software practice and tools for highly assured high capability systems -- nobody is doing this for DoD
The ASISP committee of the NRC

- National Research Council (NRC) ASISP Committee
  - **ASISP**: Advancing Software-Intensive Systems Producibility
  - **Producibility**: the capacity to design, produce, assure, and evolve software-intensive systems in a predictable manner while effectively managing risk, cost, schedule, quality, and complexity.

- Commissioned by the Office of the Secretary of Defense (OSD)
  - DDR&E focal point, with ONR support and NSF assistance

- NRC charge to committee
  - **Assess national investment** in relevant software research
  - **Recommend improvements** to DoD software practice
  - **Examine needs** relating to DoD software research
  - **Assess research requirements** relating to software producibility
ASISP study committee

- William Scherlis, Carnegie Mellon University, *Chair*
- Robert Behler, The MITRE Corporation
- Barry W. Boehm, University of Southern California
- Lori Clarke, University of Massachusetts at Amherst
- Michael Cusumano, Massachusetts Institute of Technology
- Mary Ann Davidson, Oracle Corporation
- Larry Druffel, Software Engineering Institute
- Russell Frew, Lockheed Martin
- James Larus, Microsoft Corporation
- Greg Morrisett, Harvard University
- Walker Royce, IBM
- Doug C. Schmidt, Vanderbilt University
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- Kevin J. Sullivan, University of Virginia

- **CSTB Staff**
  - Enita Williams, Study Director
  - Jon Eisenberg, CSTB Director
  - Thanks also to: Joan Winston, Lynette Millett, Morgan Motto, Eric Whitaker

- Industry integrators
  - Software vendors
  - Defense primes

- Government
  - Government experience
  - FFDRC advisors

- Research
  - Academia
  - Industry
Reviewers of the ASISP reports

- Rick Buskens, Lockheed Martin ATL (final)
- Grady Campbell, Software Engineering Institute (final)
- William Campbell, BAE Systems (final)
- John Gilligan, Gilligan Group (letter, final)
- William Griswold, University of California, San Diego (final)
- Anita Jones, University of Virginia (letter, final)
- Annette Krygiel, Independent Consultant (final)
- Butler Lampson, Microsoft Corporation (letter)
- Steve Lipner, Microsoft, Inc. (final)
- David Notkin, University of Washington (workshop, letter, final)
- Frank Perry, SAIC (final)
- William Press, U Texas Austin (final review monitor)
- Harry D. Raduege, Jr., Deloitte Center for Network Innovation (letter)
- Alfred Z. Spector, Google, Inc. (workshop, letter, final)
- Daniel C. Sturman, Google, Inc. (final)
- John Swainson, CA, Inc. (final)
- Mark N. Wegman, IBM (final)
- John Vu, Boeing Corporation (workshop)
- Peter Weinberger, Google, Inc. (workshop)
- Jeannette Wing, Carnegie Mellon University (workshop)
PITAC 1999:

Finding: The Nation is underinvesting in fundamental software research.

Recommendation: Make fundamental software research one of the Nation's highest R&D priorities.
DSB2007: It is an essential requirement that the United States maintain advanced capability for “test and evaluation” of IT products. Reputation-based or trust-based credentialing of software (“provenance”) needs to be augmented by direct, artifact-focused means to support acceptance evaluation.
Total NITRD investment ("prior year" amounts)

NIH funding not included in this analysis
SDP+HCSS relative to total NITRD

A 45% reduction in constant dollars for SDP and HCSS

Percentage for software research (SDP and HCSS areas)

Figure 1.5.3 Percentage of total NITRD investment in either SDP or HCSS.
Deliberation and challenges – Software Myths

- Long-standing incorrect folklore regarding defense software producibility (digested from the report)

1. DoD software producibility challenges are predominantly challenges of management and process but **not of technology**.

2. DoD and contractors can **rely on industry to innovate** at a rate fast enough to solve the DoD’s hard technical problems and to stay ahead of its adversaries. Regardless, there is **sufficient software research already underway** through NSF and other sponsors.

3. Software technology is **approaching a plateau**, which diminishes the need to invest in technology innovation.
Deliberation and challenges – Software Myths

- Long-standing incorrect folklore regarding defense software producibility (digested from the report)

4. We will never create perfectly reliable and secure software, so we should focus primarily on provenance—trusted sources—rather than attempting to achieve assurance directly.

5. Earned value management approaches based on code accumulation are a sufficient basis for managing software development programs, including incremental iterative development.
Outline

- Task and prior reports
- Committee, process, background

**Areas of practice**
- Process and measurement
- Software expertise
- Architecture
- Assurance and security

- Topics of research
- Economic argument
- Next steps

Chapter 2 of the report
Incremental and iterative software dev’t practices

- Findings
  - Modern processes for innovative software systems is geared toward incremental identification and mitigation of engineering uncertainties.
    - In other words: **Innovative engineering does not necessarily increase programmatic risk**
    - For defense software, challenges derive from (2) larger scale, (2) linking with systems engineering, and (3) arm’s-length contractor relationships.

- **Technology and improved measurement** have significant roles in enabling modern incremental and iterative software development practices at all levels of scale.
  - Extensions to **earned value management models** are needed to enable incremental iterative development.
    - These include evidence of feasibility and time-certain development.
    - Additionally, supplement the prescription of DoDI 5000.02 to better support ongoing management of engineering risks
Incremental and iterative software dev’t practices

- Engineering risk can be decoupled from programmatic risk
  - Iterative engineering of innovative software can be successfully managed

- Recommendations
  - Take aggressive actions to identify and remove barriers to the broader adoption of incremental development methods.
    - These include iterative approaches, staged acquisition, evidence-based systems and software engineering, and related methods that involve explicit acknowledgment and mitigation of engineering risk.
  - The DoD should take steps to accumulate high-quality data regarding project management experience and technology choices.
    - This data can be used to inform cost estimation models, particularly as they apply to innovative software development.
There is insufficient DoD-aligned software expertise

Finding
- The DoD has a **growing need for software expertise**
- It is not able to meet this need through intrinsic DoD resources.
  - Nor is it able to fully outsource this requirement to DoD primes.
  - The **DoD needs to be a smart software customer**
    - Particularly for large-scale innovative software-intensive projects.
Outline

- Task and prior reports
- Committee, process, background

**Areas of practice**
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- **Architecture**
- Assurance and security

- Topics of research
- Economic argument
- Next steps
Assert architecture leadership

- DoD needs to play an active role in **software architecture**.
  - Software architecture
    - Definition: *The structure or structures of the system, which comprise software components, the externally visible properties of those components, and the relationships among them.*
    - Good architecture entails a **minimum of engineering commitment** that yields a maximum value.
    - Architecture design is an engineering activity that is **separate from ecosystems certification** and other standards-related policy setting

- For complex innovative systems:
  - Architecture embodies planning for **flexibility**—defining and encapsulating areas where innovation and change are anticipated.
  - Architecture most strongly influences **quality attributes**
  - Architecture embodies planning for **product lines and interlinking** of systems

continued…
Assert architecture leadership

- For innovative systems
  - Consideration of architecture and quality attributes may best precede commitment to specific functionality.
  - This approach can reduce the overall uncertainty of the engineering process and yield better outcomes.
  - Architecture includes the earliest and often most important design decisions – those that are most difficult to change later
  - Architecture is profoundly influenced by precedent
    - Small changes can open and close opportunities to exploit rich ecosystems, greatly influencing cost, risk, and supply chain structure

- Findings
  - An early focus on architecture is essential for systems with innovative functional or quality requirements.
  - Architecture practice, as seen in industry, is sufficiently mature for DoD to adopt (Finding3-2)
Assert architecture leadership

- **Recommendations (Rec3-2,3-3)**
  - Follow architecture-driven acquisition strategies
    - Use as basis for product-line and for systems with multiple leads
    - Use architecture to encapsulate innovative elements
    - Use architecture to maximize opportunity to build on existing ecosystems
    - Support early and continuous validation of architectural decisions
Outline

- Task and prior reports
- Committee, process, background

**Areas of practice**
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- Architecture
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- Topics of research
- Economic argument
- Next steps

Chapter 4 of the report
Adopt a strategic approach to software assurance

- **Current technical approaches to software assurance are inadequate.**
  - *Assurance*
    - *A human judgment regarding reliability, safety, security, etc.*
  - Current technical approaches need to be augmented
    - Costs range from 30-50% for typical major projects
    - Testing and inspection techniques are inadequate for modern software devt

- **Assurance conclusions are difficult to draw.**
  - Not analogous to reliability models for physical systems
  - Cannot be achieved entirely through *post hoc* acceptance evaluation
    - Quality and security are built in, not “tested in”
Adopt a strategic approach to software assurance

- **DoD faces particular challenges to assurance.**
  1. The *arms-length relationship* between a contractor development team and government stakeholders
  2. Modern systems of all kinds draw on components from **diverse sources**
     - This implies that *supply-chain attacks* must be contemplated, along with attack surfaces within the software application
       - There will necessarily be differences in the levels of trust conferred on components.
       - There may also be opacity in the supply chain for vendor and sub components
     - **Evaluative and preventive approaches** can be integrated to enhance assurance in complex supply chains with diverse sourcing.
  3. **High consequences** due to roles in war-fighting and protection of human lives and national assets
  4. Failure to maintain a lead in the ability to prevent and evaluate confers *advantage to adversaries* (DSB2007, paraphrased)
Assurance: models, process, and traceability

Finding

- Assurance is facilitated by advances in diverse aspects of software engineering practice and technology.
  - These include modeling, analysis, tools and environments, traceability, programming languages, and process support.
  - After many years of slow progress, recent advances have enabled more rapid improvement in assurance-related techniques and tools.
  - Advances focused on simultaneous creation of assurance-related evidence with ongoing development effort have high potential to improve the overall assurance of systems.

Finding from DSB2007

- It is an essential requirement that the United States maintain advanced capability for “test and evaluation” of IT products. Reputation-based or trust-based credentialing of software (“provenance”) needs to be augmented by direct, artifact-focused means to support acceptance evaluation.
**Assurance: models, process, and traceability**

- **Traceability**: Assurance best practice for development
  - Connect code to be executed with functional and quality attributes
    - Create and sustain *chains of evidence* that link software-related artifacts
      - Examples: test cases, inspection reports, analysis, simulation, models, etc.
    - Employ a mix of preventive and evaluative approaches
    - Address assurance considerations throughout the process lifecycle
    - Attend to the means by which design-related information and traceability links are represented
      - Formality, modeling, consistency, and usability

- **Finding**
  - Early engineering choices strongly influence feasibility of achieving high assurance.
    - Successful approaches involve a diverse set of evaluative and preventive techniques
    - Particularly architecture, modeling, tooling
Assurance concepts in the report – examples

- **Scenario structure – combine evaluation and prevention**
  1. Hazard and requirements analysis
  2. Architecture and component identification
  3. Component-level error and failure modeling
  4. Supply-chain and development history appraisal
  5. Analysis of architecture and component models
  6. Identify high-interest components
  7. Develop a component evaluation plan
  8. Assess individual components
  9. Select courses of action for custom components
  10. Select courses of action for opaque components and services
  11. Refine system-level assessment

- **Two additional security-related challenges**
  - Separation
    - E.g., red / green and finer grained
    - Isolation and sandboxing
  - Configuration
    - Including issues related to dynamism

**Preventive**
- Requirements analysis
- Architecture design
- Ecosystem choice
- Detail design
- Specification and documentation
- Modeling and simulation
- Coding
- Programming language
- Tooling

**Evaluative**
- Inspection
- Testing
- Direct analysis
- Measurement
- Monitoring
- Verification
Engineering choices influence ability to assure

- **Recommendations**
  - Institute effective incentives for preventive software assurance practices and production of evidence across the lifecycle.
    - Do this throughout the supply chain
    - **Examine commercial best practices for transitioning** assurance-related best practices into development projects (Rec4-3)
    - Including contracted custom development, supply-chain practice, and in-house development practice.
  - **Expand research/investment focus** on assurance-related software engineering technologies and practices (Rec4-2)
Critical Code
Software Producibility for Defense

Supplementary Material
Outline

- Task and prior reports
- Committee, process, background
- Areas of practice

  **Topics of research**
  - Seven technology areas
  - Four considerations
  - Reinvigoration plan

- Economic argument
- Next steps

Chapter 5 of the report
Focus research effort in seven technology areas that directly enable producibility improvements

1. **Architecture modeling and architectural analysis**
   Goals:
   (1) Early validation for architecture decisions
   (2) Architecture-aware systems management
      - Including: Rich supply chains, ecosystems, and infrastructure
   (3) Component-based development
      - Including: Architectural designs for particular domains.

2. **Validation, verification, and analysis of design and code**
   Goals:
   (1) Effective evaluation for critical quality attributes
   (2) Components in large heterogeneous systems
   (3) Preventive methods to achieve assurance
      - Including: Process improvement, architectural building blocks, programming languages, coding practice, etc.

3. **Process support and economic models for assurance**
   Goals:
   (1) Enhanced process support for assured software development
   (2) Models for evidence production in software supply chains
   (3) Application of economic principles to process decision-making

continued…
Reinvigorate DoD software engineering research

- Focus research effort in seven technology areas that directly enable producibility improvements

4. **Requirements**
   Goals:
   (1) Expressive models, supporting tools for functional and quality attributes
   (2) Improved support for traceability and early validation

5. **Language, modeling, coding, and tools**
   Goals:
   (1) Expressive programming languages for emerging challenges
   (2) Exploit modern concurrency: shared-memory and scalable distributed
   (3) Developer productivity for new development and evolution

6. **Cyber-physical systems**
   Goals:
   (1) New conventional architectures for control systems
   (2) Improved architectures for embedded applications

7. **Human-system interaction**
   Goal:
   (1) Engineering practices for systems in which humans play critical roles
   *(This area is elaborated in another NRC report)*
Considerations in identifying research topic areas

(1) **Significant potential value** for DoD software producibility
   - Process and measurement, architecture, and assurance (chapters 2, 3, 4)

(2) **Feasible progress** in a well-managed research program
   - Well-managed with respect to “Heilmeier Questions” (Box5.1)
     - For the identified “Goals” within the seven areas
   - There is past success in software research
     - This is now well documented (Box5.2)

(3) **Not addressed sufficiently** by other federal agencies
   - Primarily other NITRD-coordinated agencies

(4) **Might not otherwise develop** at a sufficient pace
   - In industry or through research sponsored elsewhere
Reinvigorate DoD software engineering research

- **Technology role** (Finding5-2)
  - Technology has a significant role in enabling modern incremental and iterative software development practices
    - At levels of scale ranging from small teams to large distributed development organizations.
    - In all three areas: Process and measurement, architecture, assurance
    - Myth: DoD’s producibility challenges are predominantly challenges of management and process, not technology (M1)

- **Recommendations** (Rec5-1,2)
  - **DoD take immediate action to reinvigorate its investment in** software producibility research
    - Undertake through diverse research programs throughout DoD
    - Include academia, industry labs, and collaborations
  - Undertake research programs **in the seven areas**, as critical to advancement of defense software producibility

continued...
The research operating environment: challenges and success influences

1. Software engineering is maturing as a research discipline.
   - Improved research methods and lower risk in technology transition
   - Facilitating more satisfactory responses to the Heilmeier Questions

2. Diffusion pathways are complex, and there is variability of timescale.
   - Some results can readily transfer to DoD practice
   - Others, often most significant, take longer and are more indirect – raise all ships

3. Novelty is often more about timeliness.
   - Readiness (infrastructure, exponentials) rather than technical novelty
   - What are the ideas whose time has come? (E.g., thin/rich clients; utility & cloud)

4. We can accept non-quantitative means to assess progress.
   - Often focus of research is on developing such measures
   - Example: how to assess the benefits of strong typing? In a quantitative way?

Context:
- There is a broad challenge in assessing ROI for basic science and for research related to enabling technologies.
  - NRC reports address this difficulty for computing technology and software
Roles for academia and industry in research

- **Recommendation**
  - Academic, industry, and government researchers must all participate (Rec5-1)

- **Understand the scope of value of academic research**
  - **Workforce**
    - University graduates – prepared for emerging new challenges
    - Next generation technical leadership – from PhD programs
  - **New knowledge**
    - Industry labs under greater ROI pressure
    - Game changing and disruptive technologies
      - Ongoing disruption characteristic of the first 50 years of IT innovation
  - **Non-appropriable invention**, as well as appropriable invention
    - Raise all boats
  - **Surprise reduction**
    - Very rapid change in computing technology, at undiminished pace
    - “Surprise” can include rapid shifts of innovation center of gravity
Outline

- Task and prior reports
- Committee, process, background
- Areas of practice
- Topics of research

- Economic argument
  - Software has a critical role for DoD
    - DoD must take action to address its needs
    - DoD must maintain innovation leadership
    - Innovation leadership requires sustained R&D
    - Software technology is not at a plateau

- Next steps

Chapter 1 of the report
Broadening role of software in DoD, with benefits

- Software has emerged as a key enabler of **capability**, **flexibility**, and **integration** in diverse DoD systems
  - Mission capability embodied in software has become a unique source of strategic and military advantage
  - Extent of system function performed in software, examples (DSB)
  - **Multiple DSB, NRC studies:**
    - At the core of the ability to achieve integration and maintain mission agility is the ability of the DoD to produce and evolve software

**Finding**

- **Software has become essential to a vast range of military system capabilities and operations, and its role is deepening and broadening**
  - Increase in scale, complexity, and role in manifesting functional capability
  - Increase in interlinking diverse system elements
  - Increase in use for systems development, modeling and simulation

**Recap:** **Software’s critical role**
The strategic significance of software US and globally

- **Software has become a principal force multiplier for DoD**
  - Rapid growth in extent and criticality of software to DoD operations

- **Software is a key competitive factor in commercial business**
  - Software is now a strategic source of competitive advantage in sectors ranging from financial services and health care to telecom and entertainment.

- **Disproportionate benefits from software in economic growth**
  - ICT industries in US since 1995 [NRC economic policy board]
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  - ICT in Europe
    - ICT sector is 5% European GDP
    - ICT drives 25% of overall growth and 40% of the productivity increase
  - And: Most software development is outside the ICT sector

Recap: Software’s critical role
The growing role of software in systems and organizations is creating both **benefits** and **risks**.

- **Benefit**: Interlinking of systems
  - *Risks for DoD*: Magnitude of failures, cascading failures, security challenges

- **Benefit**: Direct interaction by users
  - *Risks for DoD*: More individuals can take actions with high consequence

- **Benefit**: Immediate enactment
  - *Risks for DoD*: Failures and compromises can occur inside human decision loops

- **Benefit**: Rapid growth in capability and flexibility
  - *Risks for DoD*: Early validation for architecture must be emphasized in the process
  - *Risks for DoD*: Assurance practices and tools need to advance commensurably
Software supply chains are increasing complex and diverse.

- **Benefit:** Diversification and enrichment of supply-chain structure and geography
  - *Risks for DoD:* Supply-chain attacks, over-reaction (provenance, ecosystems denial)
  - Enabled by advances in software componentization technology
  - Architectures, frameworks/ecosystems, libraries, and services
  - Technology improvements have enabled modularization and rapid development
  - *Risks for DoD:* Broad component interfaces, complex rules of engagement, assurance

- **Benefit:** Rich variety of *generally accepted software ecosystems*
  - Ecosystem: conventional structure of infrastructural elements and services that are intended to be combined in a patterned way.
    - Examples: Web services stacks, iPhone, Android, OLAP, LAMP stack, AUTOSAR, SCADA, ERP/SCM/CRM, network hourglasses
  - *Risks for DoD:* security and supply chains, externalities and adoption, compliance practices
DoD software leadership

- **Software capability is strategic**
  - *At the core of the ability to achieve integration and maintain mission agility is the ability of the DoD to produce and evolve software.*
    (Multiple DSB, NRC studies)

- **Findings**
  - Software has become essential to a vast range of military system capabilities and operations, and its role is continuing to deepen and broaden, including interlinking diverse system elements.
  - **The DoD’s needs will not be sufficiently met** through a combination of demand-pull from the military and technology-push from the defense or commercial IT sectors.
  - **The DoD cannot rely on industry alone** to address the long-term software challenges particular to defense.
The role for DoD in its software leadership

- **Findings**
  - Technological leadership in software is a key driver of capability leadership in systems.
    - DoD relies on US industry to sustain this technological leadership.
  - The DoD relies fundamentally on mainstream commercial components, supply chains, and software ecosystems.
    - Nonetheless, the DoD has special needs in its mission systems driven by the growing role of software in systems.

- **Recommendations** (Rec1-1,5-1)
  - DDR&E should regularly undertake an identification of areas of technological need related to software producibility where the DoD has “leading demand” and where accelerated progress is needed
  - DoD take immediate action to reinvigorate its investment in software producibility research
    - Undertake research programs in the seven areas (Rec5-2, recap)
At a plateau?

- **The myth of the plateau**
  - We are not at a plateau or near a plateau in overall software capability or technology for software producibility *(Finding 1-5a)*
    - “Automatic programming” – 1958 (Fortran), 1980s (4GLs), 1980s (AI), etc.
  - Software has intrinsic unboundedness
    - It lacks natural physical limits on scale and complexity
      - Only human intellectual limits and mathematical limits on algorithms
    - New software-manifest capabilities continue to emerge
      - A “continuous improvement” in capability (as distinct from process)
      - Less fine tuning and more order-of-magnitude leaps
    - Enabled by a steady pace of technological breakthroughs in practices, models, languages, tools, and practices
      - Leveraged through ecosystems and infrastructure
  - There is a consequence necessity of ongoing innovation in software
    - Software innovation, once routinized, is then quickly automated
    - Expensive custom dev’t gives way to low-cost component procurement
Consequences of unboundedness

● **Software engineering and other engineering**
  - A relatively *much larger portion* of overall software engineering effort is creating *innovative* functionalities, as compared with other engineering disciplines
  - Hence an ongoing focus on *engineering risk*

● **Staying apace**
  - *Mere presence as a software user* requires keeping pace with rapid ongoing innovation and improvement to practices
    ● Applies to custom development, components, and ecosystems
  - *Leadership as software producer or consumer* requires more
    ● An active organizational role in defining the architecture of systems and influencing ecosystems
    ● Participation in technology development
The consequent necessity of ongoing software innovation

**Findings (1-3b, 5b)**

- To avoid loss of leadership, DoD must be more fully engaged in the innovative processes related to software producibility
  - There is strategic value to DoD in sustaining US leadership in software producibility -- compared with other industries that have moved offshore

- It is an **essential requirement** that the United States maintain **advanced capability** for “test and evaluation” of IT products. Reputation-based or trust-based credentialing of software (“provenance”) needs to be augmented by direct, artifact-focused means to support acceptance evaluation. *(DSB2007)*

- DoD needs to address directly the challenge of building on and, where appropriate, contributing to the development of mainstream software that can contribute to its mission.
Outline

- Task and prior reports
- Committee, process, background
- Areas of practice
- Topics and modalities of research
- Economic argument
- Next steps
Mission goals ← Practice improvements ← Research

● Improve critical areas of current **practice**
  - Enable incremental iterative development at arm’s length
    • Process and measurement
  - Enable architecture leadership, interlinking, flexibility
    • Architecture
  - Enable mission assurance at scale, with rich supply chains
    • Assurance and security

● Undertake **research** to support the critical areas of practice
  1. Architecture modeling and architectural analysis
  2. Validation, verification, and analysis of design and code
  3. Process support and economic models for assurance
  4. Requirements
  5. Language, modeling, code, and tools
  6. Cyber-physical systems
  7. Human-system interaction
**Key Findings and Recommendations**

1. **Software has become critical in its role and strategic significance for DoD**
   - Software enables capability, integration, and agility in defense systems
   - DoD needs to actively and directly address its software producibility needs
   - NITRD data reveal the extent of the S&T disengagement that must be reversed

2. **Innovative software-intensive engineering can be managed more effectively**
   - Apply advanced practice and supporting tools for iterative incremental development
   - Update earned-value models and practices to support management process

3. **DoD needs to be a smarter software customer**
   - There is insufficient DoD-aligned software expertise within and around DoD

4. **Assert DoD architectural leadership**
   - In highly complex systems with emphasis on quality attributes, architecture decisions may need to dominate functional capability choices

5. ** Adopt a strategic approach to software-intensive mission assurance**
   - Integrate preventive practices into development to support ongoing creation of evidence in support of assurance
   - Do not lose leadership in software evaluation and assurance (DSB’07)

6. **Reinvigorate and focus DoD software engineering research**
   - Apply appropriate criteria in identifying goals for research programs
   - Focus research effort on identified goals in seven technical areas
Adopt a strategic approach to software assurance

- **Finding from DSB2007, reiterated in Critical Code**
  - It is an essential requirement that the United States maintain advanced capability for “test and evaluation” of IT products. Reputation-based or trust-based credentialing of software (“provenance”) needs to be augmented by direct, artifact-focused means to support acceptance evaluation.

- **Context**
  - **Challenges**
    - Inadequate + costly legacy approaches – based on inspection and sampled tests
    - Newly rich and globally diverse supply chains, with arms-length relationships
    - Assurance reqts can dramatically limit systems capability, and vice-versa
  - **Opportunities**
    - Significant advances and potential for preventive/evaluative practices
      - Evidence production
      - Architecture design
      - Isolation / encapsulation
      - Configuration management
    - Potential for new approaches to “evaluation standards” for legacy / ongoing / new

- **Conclusion**
  - DoD must directly foster advanced software practice and tools for highly assured high capability systems -- nobody is doing this for DoD
Final report of the Committee on Advancing Software-Intensive Systems Producibility (ASISP)

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