The Impact of Ultra-Large-Scale (ULS) Systems on DoD Operations

Tuesday, January 19th, 2010

Dr. Douglas C. Schmidt
d.schmidt@vanderbilt.edu
www.dre.vanderbilt.edu/~schmidt

Institute for Software Integrated Systems
Vanderbilt University
Nashville, Tennessee

DoD's Software Challenge

"DoD estimates that it spends about 40% of its RDT&E budget on software - $21B for FY2003" – GAO

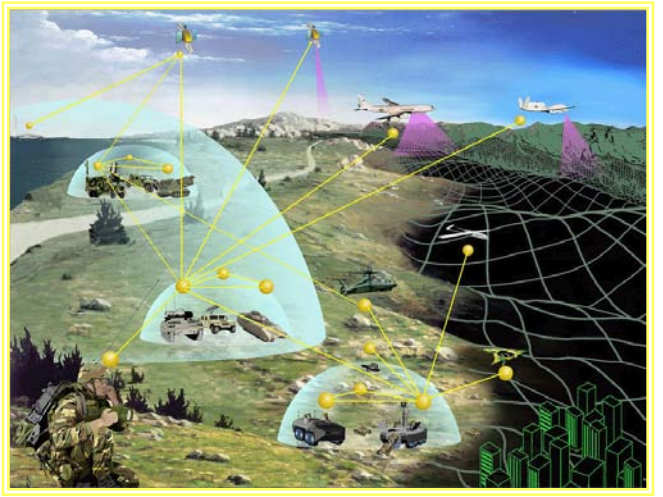
F/A-22

SBIRS High

Joint Tactical Radio Systems (JTRS)

DDG 1000

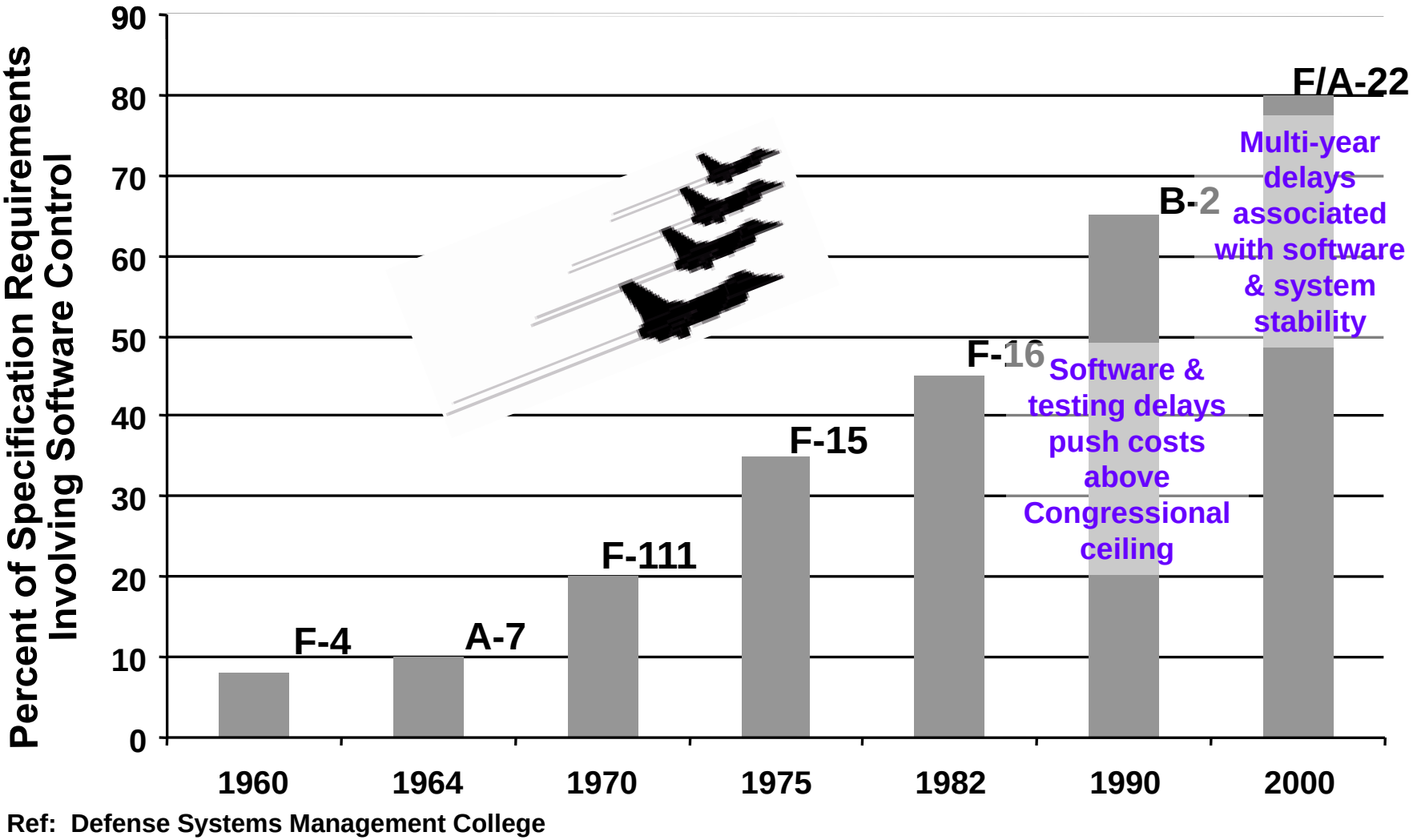
Future Combat System (FCS)



"The software task alone [for FCS] is 5 times larger than required for Joint Strike Fighter & 10 times larger than the F-22, which after two decades is finally meeting its software requirements"

– *Congressman Curt Weldon, House Armed Services Committee tactical air & land forces subcommittee hearing April 1, 2004 quoted in Defense News April 12, 2004*

DoD Software is Growing in Size & Complexity

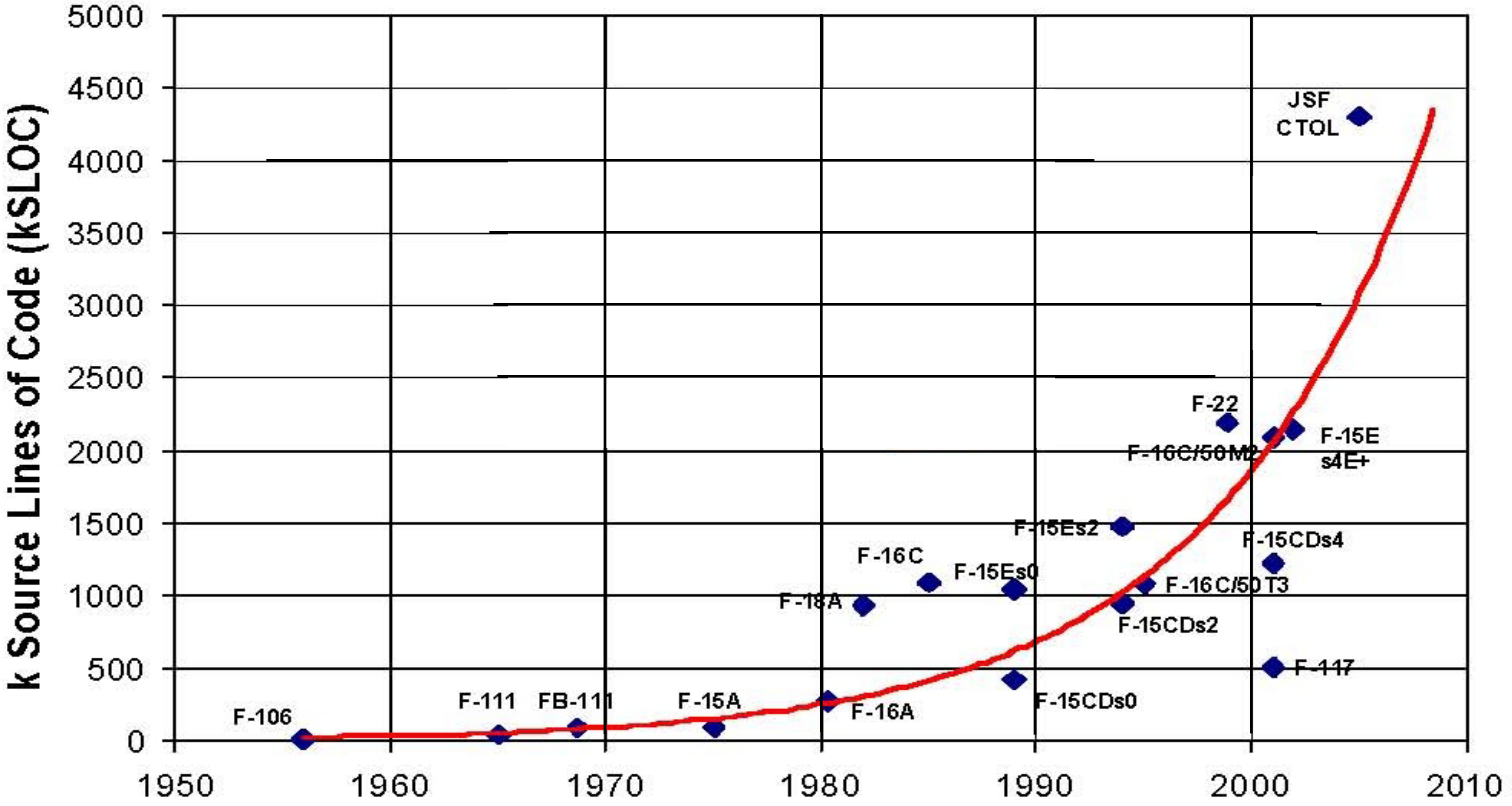


Ref: Defense Systems Management College

"[Software] continues to grow in importance in our weapons systems & remains a significant contributor to program cost, schedule, & performance shortfalls."
– Pete Aldridge, former Under Secretary of Defense, ATL

DoD Software is Growing in Size & Complexity

Total Onboard Computer Capacity for Operational Flight Program



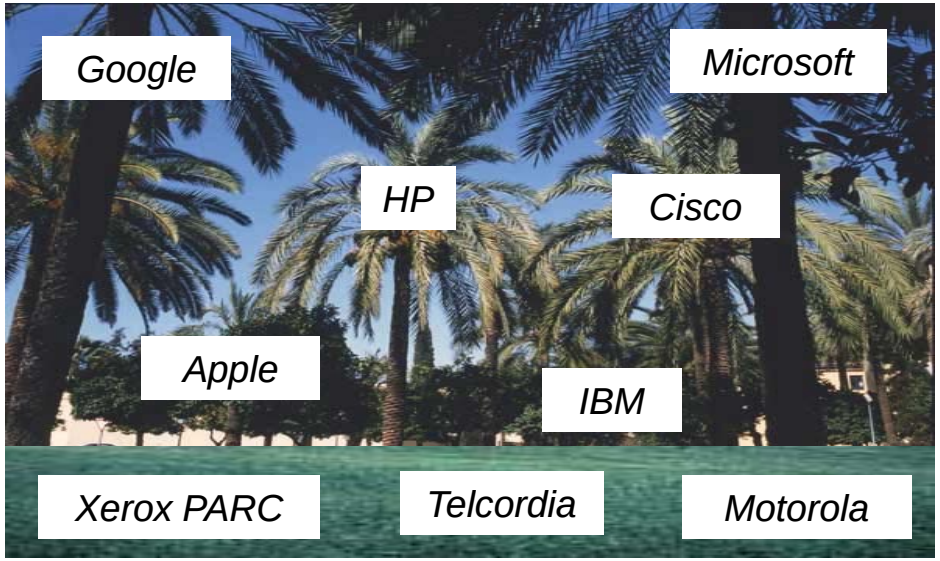
Source: "Avionics Acquisition, Production, & Sustainment: Lessons Learned -- The Hard Way", NDIA Systems Engineering Conference, Mr. D. Gary Van Oss, October 2002.

"[Software] continues to grow in importance in our weapons systems & remains a significant contributor to program cost, schedule, & performance shortfalls."
– Pete Aldridge, former Under Secretary of Defense, ATL

DoD Software Science &Technology Status

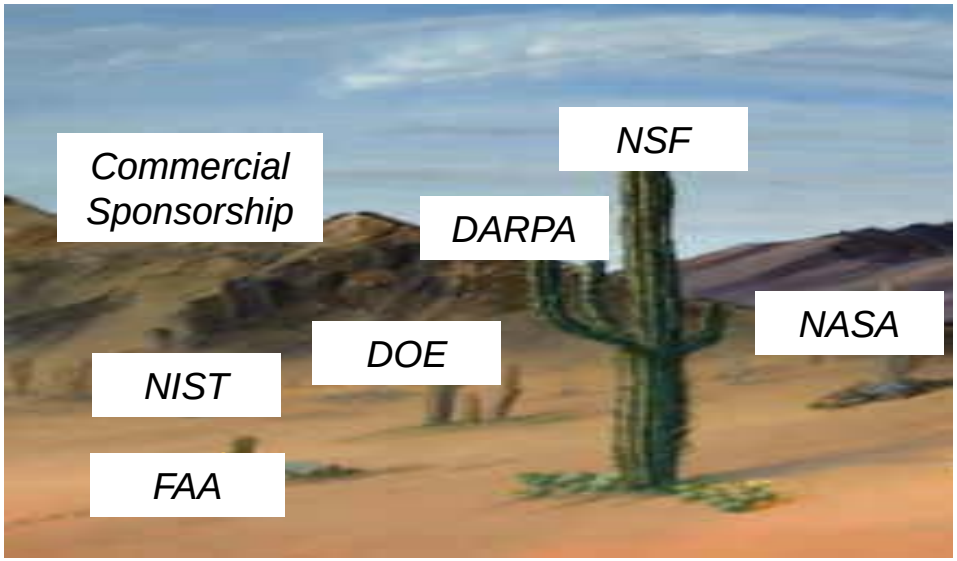
Misconception

The IT industry is a well-populated oasis for DoD programs



Reality

IT R&D investment is needed to seed & transform the IT desert for the DoD



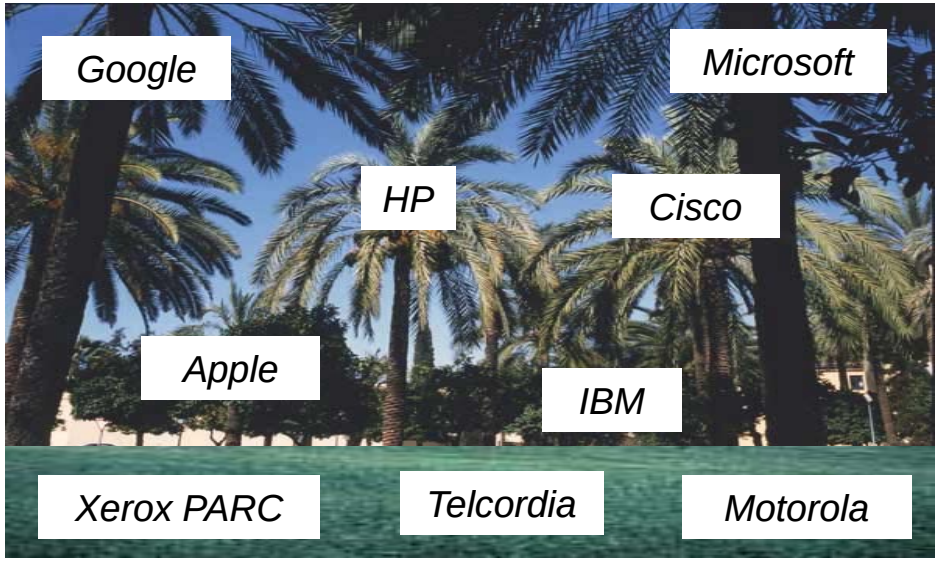
Limitations with software contribute significantly to gap between the IT that the DoD *needs* vs. the IT that the DoD can *afford* given

- Current level of technology maturity
- Decade-long tailing off of DoD software R&D investments (especially 6.2 investments)
- Atrophy of government expertise-base

DoD Software Science &Technology Status

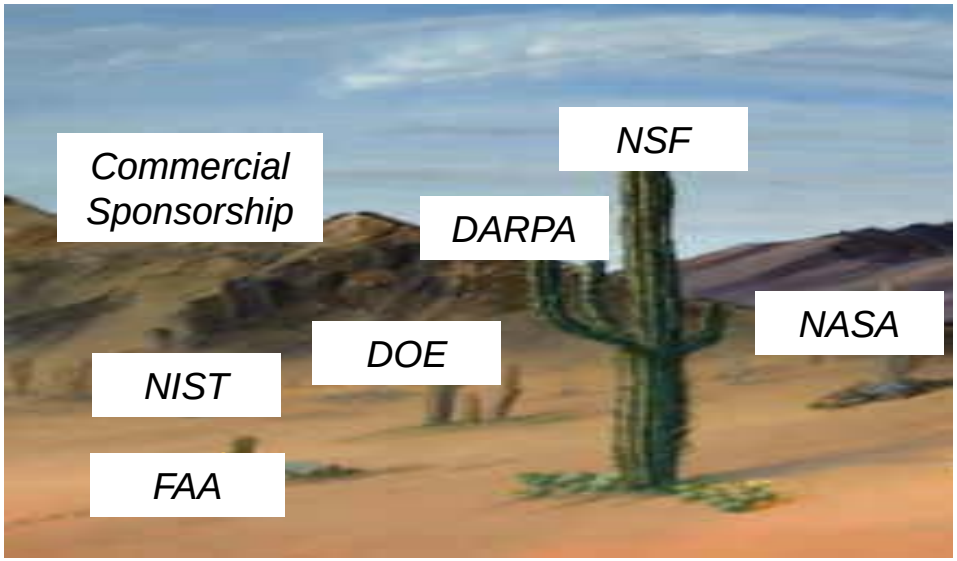
Misconception

The IT industry is a well-populated oasis for DoD programs



Reality

IT R&D investment is needed to seed & transform the IT desert for the DoD



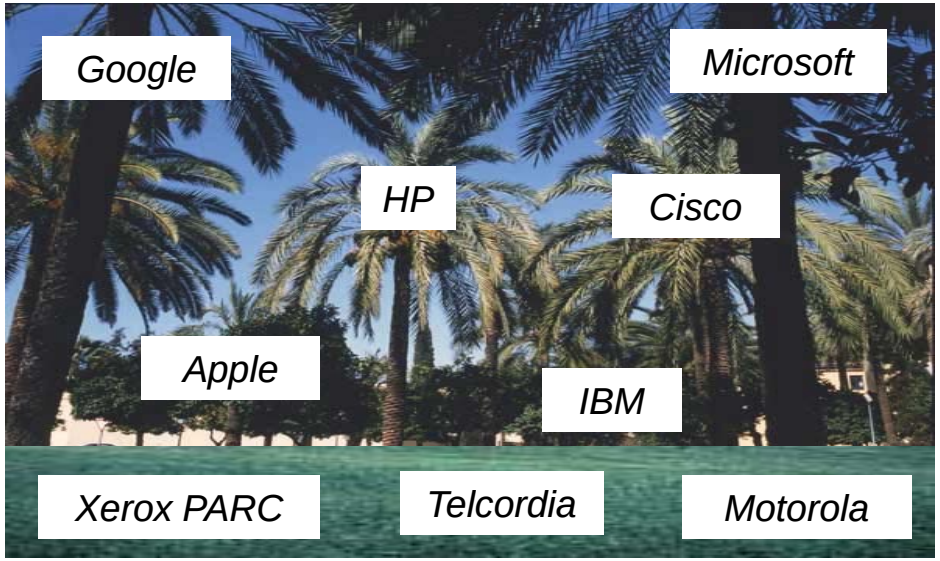
Why Industry Alone Won't Solve the DoD Software Problem

- Commercial R&D often inappropriate for DoD problems
  - It's targeted for specific products, not long-term tech improvement
  - Focused on selling products – dependability is lower priority
  - Global resourcing/competition for R&D limits applicability to DoD

DoD Software Science &Technology Status

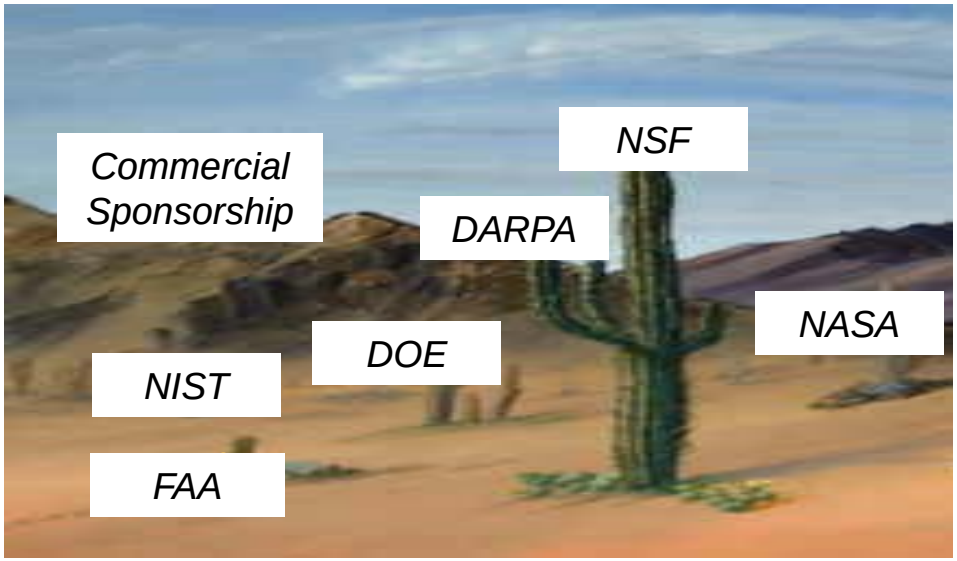
Misconception

The IT industry is a well-populated oasis for DoD programs



Reality

IT R&D investment is needed to seed & transform the IT desert for the DoD



Why Industry Alone Won't Solve the DoD Software Problem

- For Defense contractors
  - R&D targeted at company-specific projects
  - Software enhances competitiveness but not a direct profit driver for many DoD activities
  - Less interest in retaining software technologies as company IP

Increasing Scale In DoD Systems

DoD is creating increasingly complex ultra-large-scale, network-centric, real-time, cyber-physical-social systems

- 1,000's of platforms, sensors, decision nodes, weapons, & warfighters
- connected through heterogeneous wired & wireless networks

Goal: Information Dominance

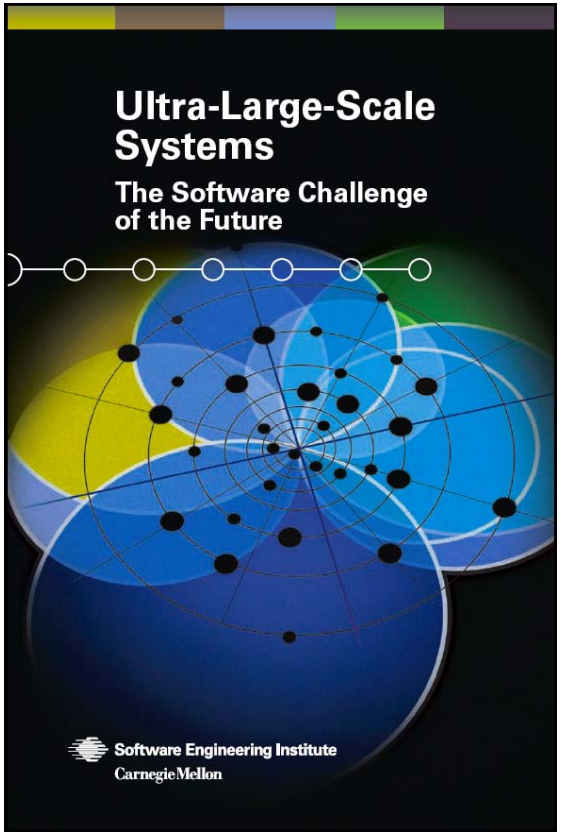
- *Pervasive resource constraints & failures*
- *Continuous adaptation*
  - changes in mission requirements
  - changes in operating environments
  - changes in force structure
  - perpetual systems' evolution
  - addition of new systems
- *Sustainable*
  - legally, technically, politically, environmentally, & economically

Overview of DoD Ultra-Large-Scale (ULS) Systems

ULS systems are socio-technical ecosystems comprised of software-intensive systems, people, policies, cultures, & economics

DoD ULS systems have unprecedented scale in the following dimensions:

- # of lines of software code
- # of connections & interdependencies
- # of hardware elements
- # of computational elements
- # of purposes & user perception of purposes
- # of routine processes & "emergent behaviors"
- # of (overlapping) policy domains & enforceable mechanisms
- # of people involved in some way
- Amount of data stored, accessed, & manipulated
- … etc …



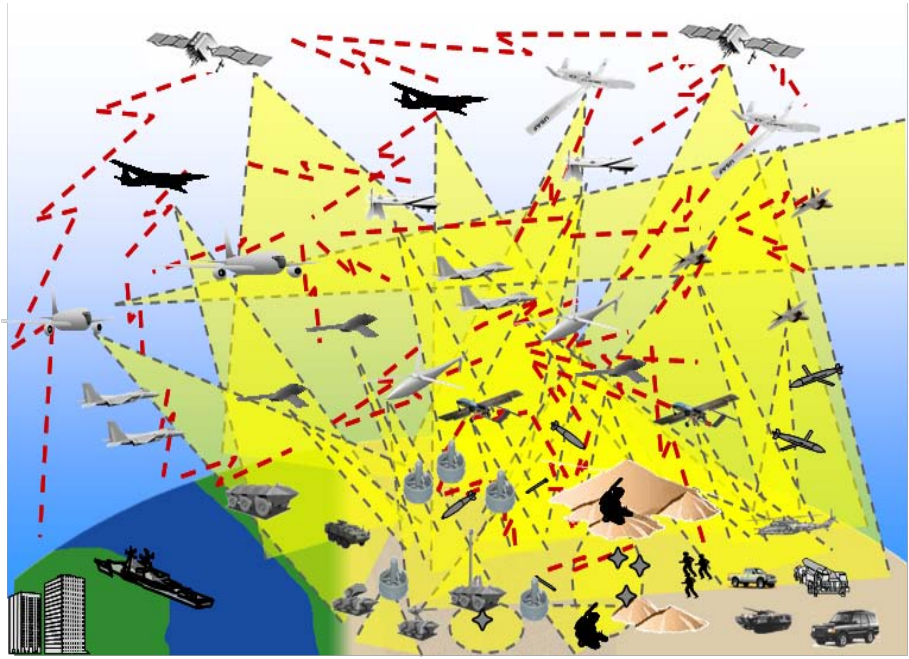
Software Engineering Institute
Carnegie Mellon

ULS systems report & related information available from www.sei.cmu.edu/uls

Scale Changes Everything in DoD ULS Systems

Characteristics of DoD ULS systems that arise because of their scale include

- Decentralization
- Inherently conflicting, unknowable, & diverse requirements
- Continuous evolution & deployment
- Heterogeneous, inconsistent, & changing elements
- Erosion of the people/system boundary
- “Normal” failures
- New paradigms for acquisition & policy

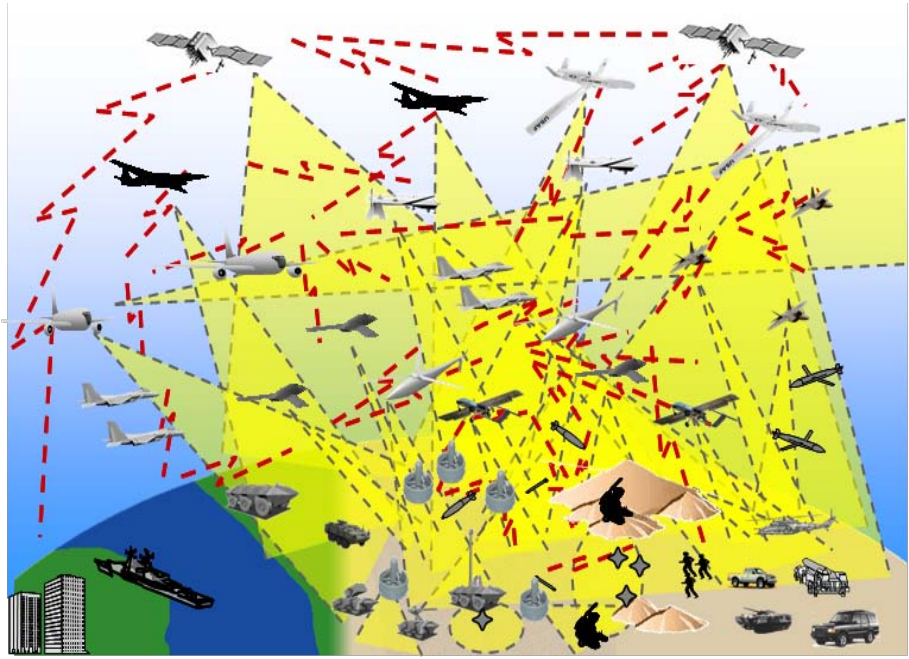


These characteristics appear in some of today’s DoD systems, but in ULS systems they dominate, undermining assumptions that underlie today’s technologies, rendering incremental solutions inadequate

DoD ULS Systems: A Cause for Concern

DoD ULS systems are becoming larger & more complex than any seen before

- very serious technical challenges, some obvious & some to be discovered
- many vendors, many technologies, many systems, etc.
- evolving doctrine + evolving technology + ill-defined requirements



"Our soldiers depend on software & will depend more on software in the future.

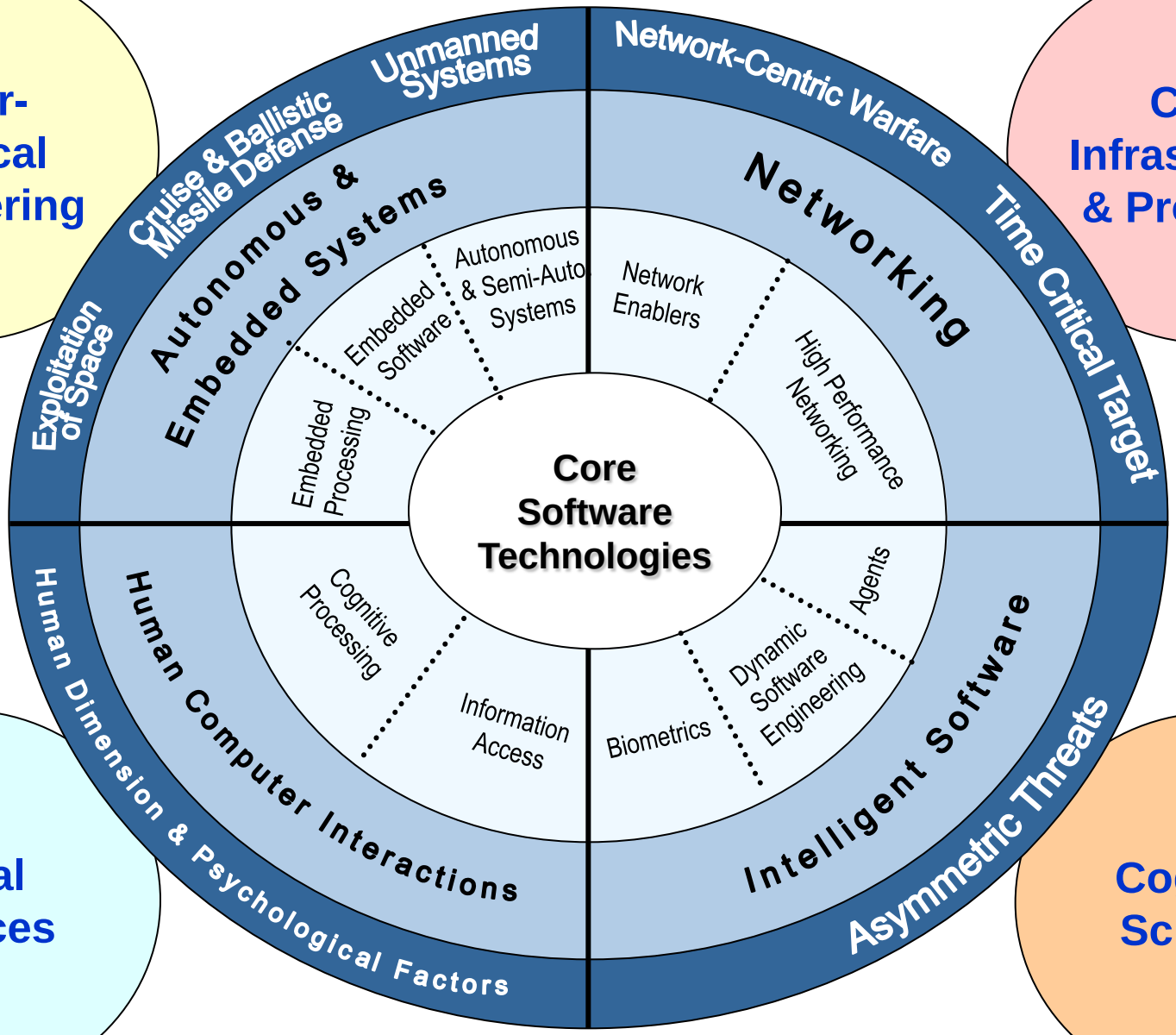
The Army's success depends on software & the software industry.

We need better tools to meet future challenges, & neither industry nor government is working on how to do things light-years faster & cheaper.

How can future systems, which are likely to be a billion lines of code, be built reliably ***if we can't even get today's systems right***?"

— Asst Sec Army Claude Bolton, August 16, 2005

Toward a ULS Systems R&D Roadmap



Cyber-Physical Engineering

Cyber Infrastructure & Protection

Social Sciences

Cognitive Sciences

Interdisciplinary 6.1 & 6.2 R&D is essential

Toward a ULS Systems R&D Roadmap

- The ULS Systems Report presents three possible ways to structure a research program based on
  1. Specific DoD missions & capabilities
  2. DoD research funding types required
  3. Estimates of the relative starting points of the research
- Sponsors with different needs can choose to support different combinations of research

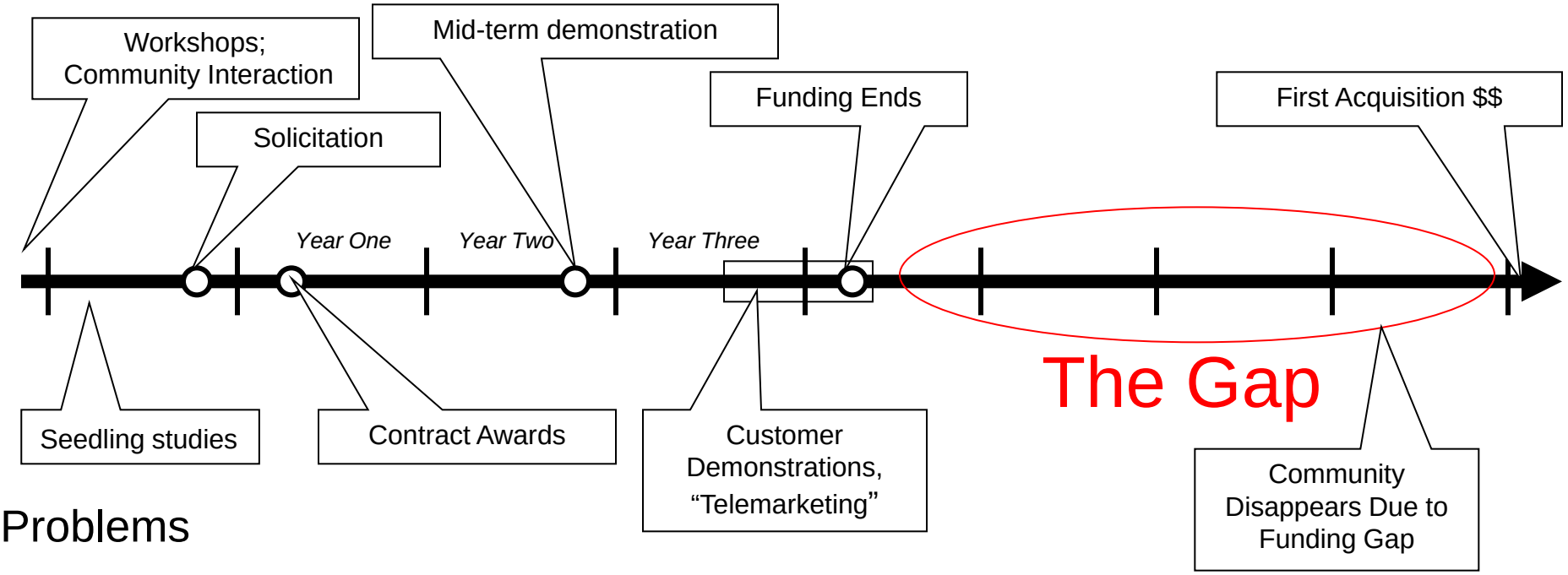
Table 4: Research Areas and Range of Risk/Reward

Research Areas and Topics	Existing Groundwork	Breaking Ground	New Direction
Human Interaction			
6.1.1 Context-Aware Assistive Computing	●		
6.1.2 Understanding Users and Their Contexts	●	●	
6.1.3 Modeling Users and User Communities		◒	●
6.1.4 Fostering Non-Competitive Social Collaboration		●	◒
6.1.5 Longevity	●	◒	◒
Computational Emergence			
6.2.1 Algorithmic Mechanism Design	●	◒	●
6.2.2 Metaheuristics in Software Engineering	●	◒	
6.2.3 Digital Evolution	●	◒	
Design			
6.3.1 Design of All Levels	●	●	◒
6.3.2 Design Spaces and Design Rules		●	●
6.3.3 Harnessing Economics to Promote Good Design	●	●	●
6.3.4 Design Representation and Analysis		●	◒
6.3.5 Assimilation	●	●	●
6.3.6 Determining and Managing Requirements	●	●	◒
Computational Engineering			
6.4.1 Expressive Representation Languages	◒	●	●
6.4.2 Scaled-Up Specification, Verification, and Certification	◒	●	

The envisioned outcome of the research is a spectrum of technologies & methods for developing ULS systems, with national-security, economic, & societal benefits that far extend beyond ULS systems themselves

See Chapter 5 of ULS Systems Report available from www.sei.cmu.edu/uls

Problem: the “Valley of Disappointment”



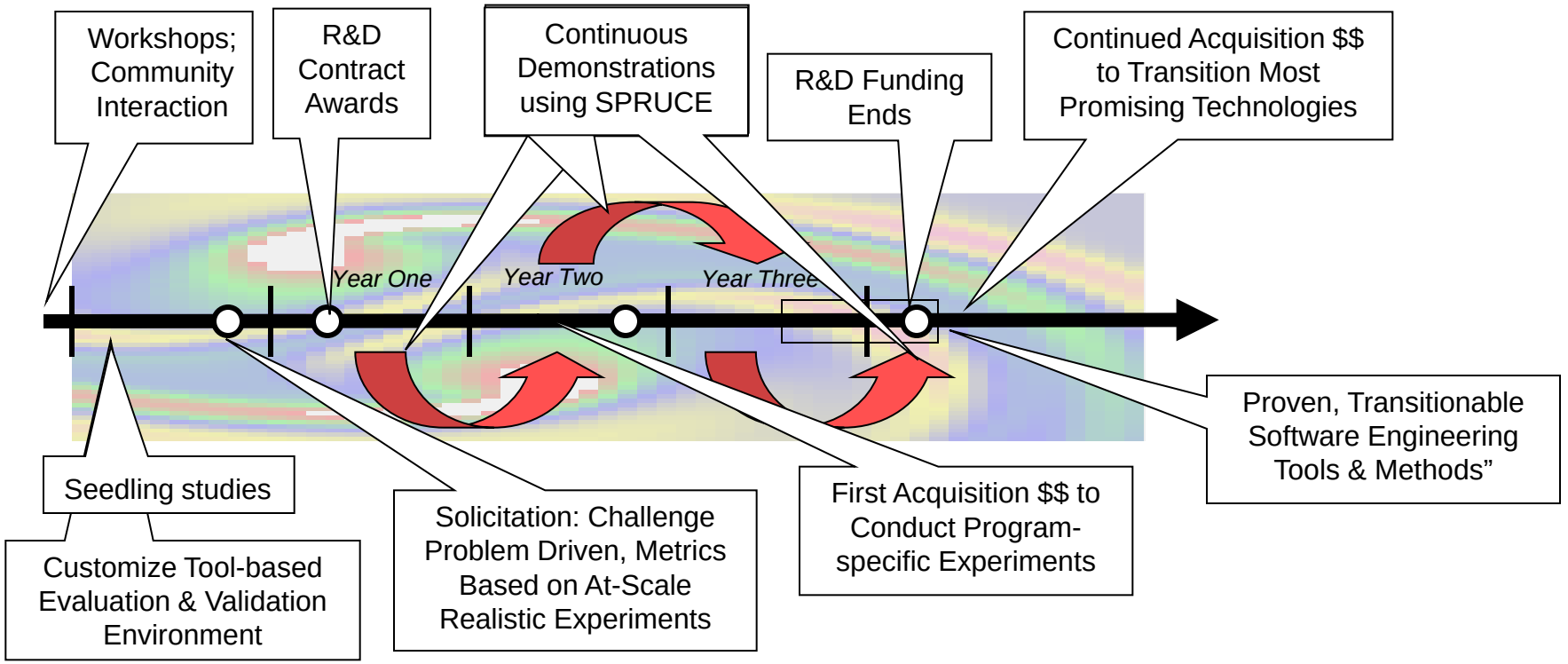
Problems

- Corporate R&D developments gapped
- University path to marketplace is not deterministic
- Results often not even available for future R&D programs
- Problem even worse for “community development programs” since more mouths to feed!

This gap is killing IT R&D for the DoD, which hurts researchers, system integrators, & the DoD

Helping Bridge "Valley of Disappointment"

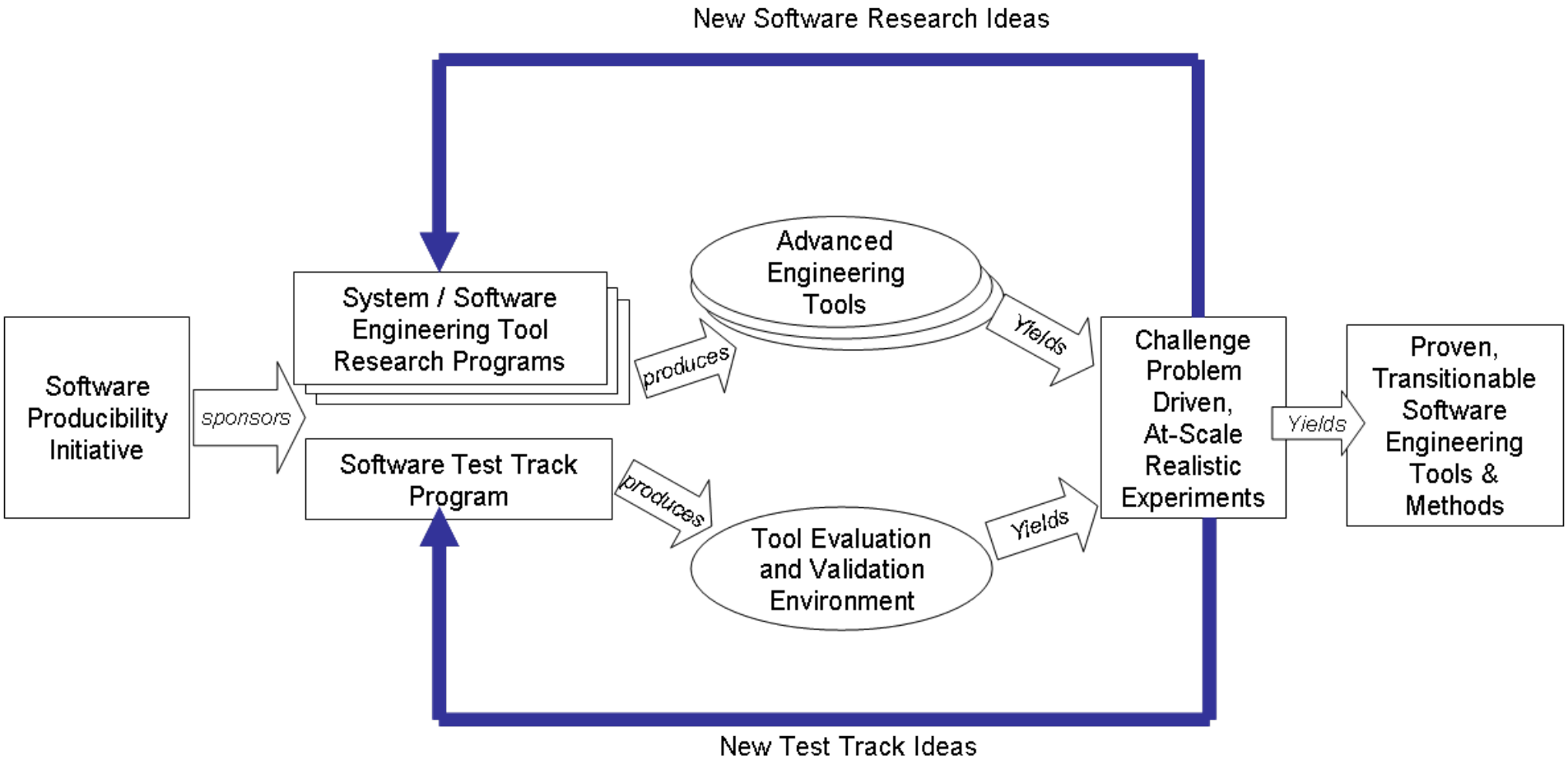
Software & System PRodUcibility Collaboration & Experimentation Environment (SPRUCE) – AFRL/OSD program



- SPRUCE is an open collaborative environment to show how novel tools & methods can yield affordable & predictable production of software-intensive systems
- The SPRUCE portal provides collaborative capabilities to support interaction across researchers, developers, domain experts, & acquisition program offices

https://www.sprucecommunity.org/

SPRUCE Enables Software Producibility Initiative

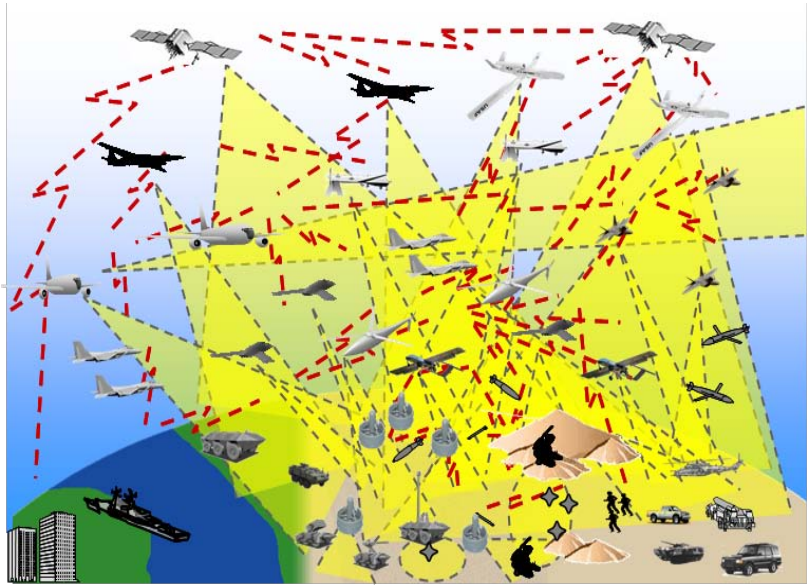


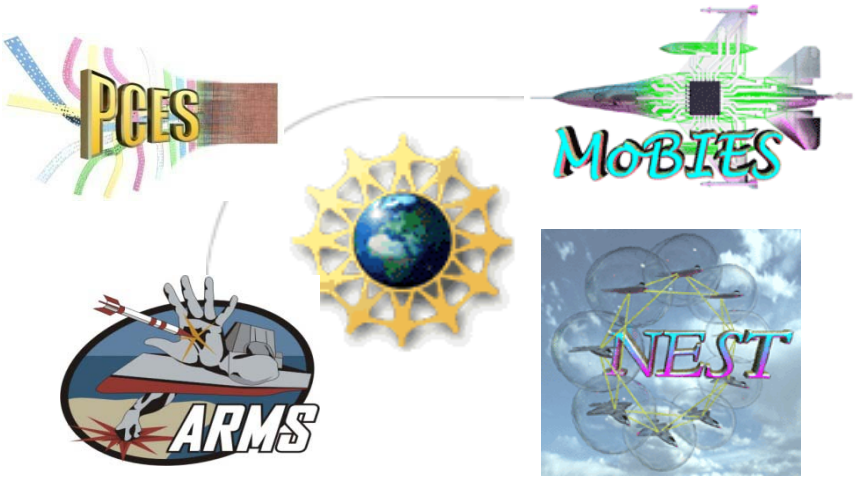
SPRUCE's goal is to enable more effective technology transitions

- Concept studies co-evolve with challenge problems & customized testbed
- Acquisition programs motivated to get involved much earlier in R&D process
- R&D results/artifacts more likely to solve "real" acquisition problems

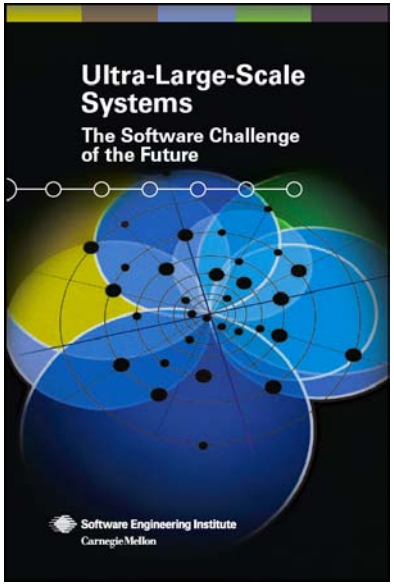
Concluding Remarks

- DoD ULS systems require major innovative advances in software tools & platforms
- Not all technologies provide the precision we're accustomed to in traditional smaller-scale DoD systems
- Fundamental advances in computing technology & related disciplines needed to address DoD ULS systems challenges
- Significant groundwork from earlier R&D programs





- *Much* more R&D needed for DoD ULS systems
  - Both 6.1 & 6.2 R&D investments



Federal investment in software R&D is essential for long-term success

Acknowledgements

Thanks to

- Linda Northrop & her ULS Systems team at the Software Engineering Institute
- Andre Von Tilborg, Principal Deputy, DDR&E
- Rob Gold, Deputy Under Secretary of Defense for Science & Technology
- Shankar Sastry, Dean of Engineering School, University of California, Berkeley
- Janos Stipanovits & Gabor Karsai, Professors of Electrical Engineering & Computer Science, Vanderbilt University

Background on Dr. Douglas C. Schmidt

R&D Focus & Accomplishments

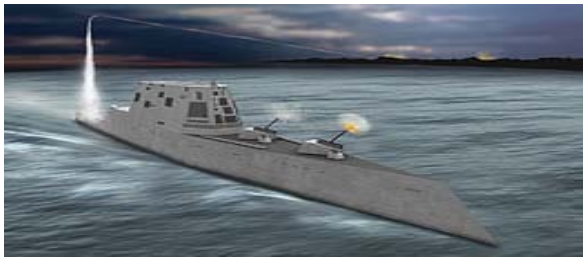
- Professor of Computer Science at Vanderbilt University
- Visiting scientist at the Software Engineering Institute
- Published 9 books & over 425 technical papers on software patterns, optimization techniques, & empirical analyses of object-oriented middleware frameworks & domain-specific modeling environments
- Led the development of ACE & TAO, which are open-source middleware frameworks widely used by DoD & commercial projects

R&D Impact on DoD Acquisition Programs

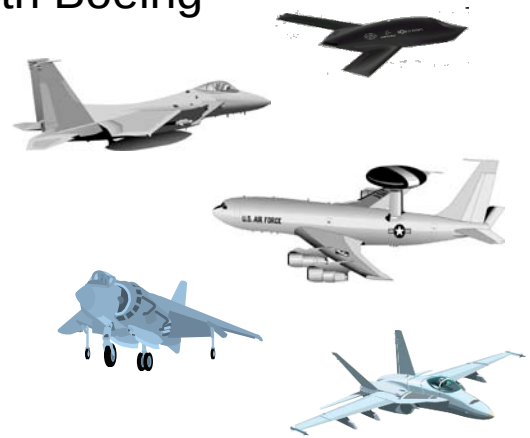
- R&D on middleware, frameworks, patterns, & model-driven tools has created ACE & TAO
- ACE & TAO have transitioned to 100's of DoD programs & projects, including

www.dre.vanderbilt.edu/users.html

- US Navy DDG1000 program with Raytheon, LMCO, & DARPA



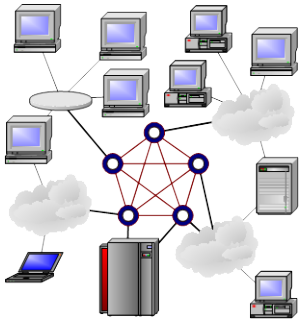
- US Air Force in collaboration with Boeing



- Joint forces with JTRS SCA in collaboration with BAE Systems
- JTT with US Army & Raytheon

- USS Ronald Reagan aircraft carrier advanced tactical displays system with Raytheon

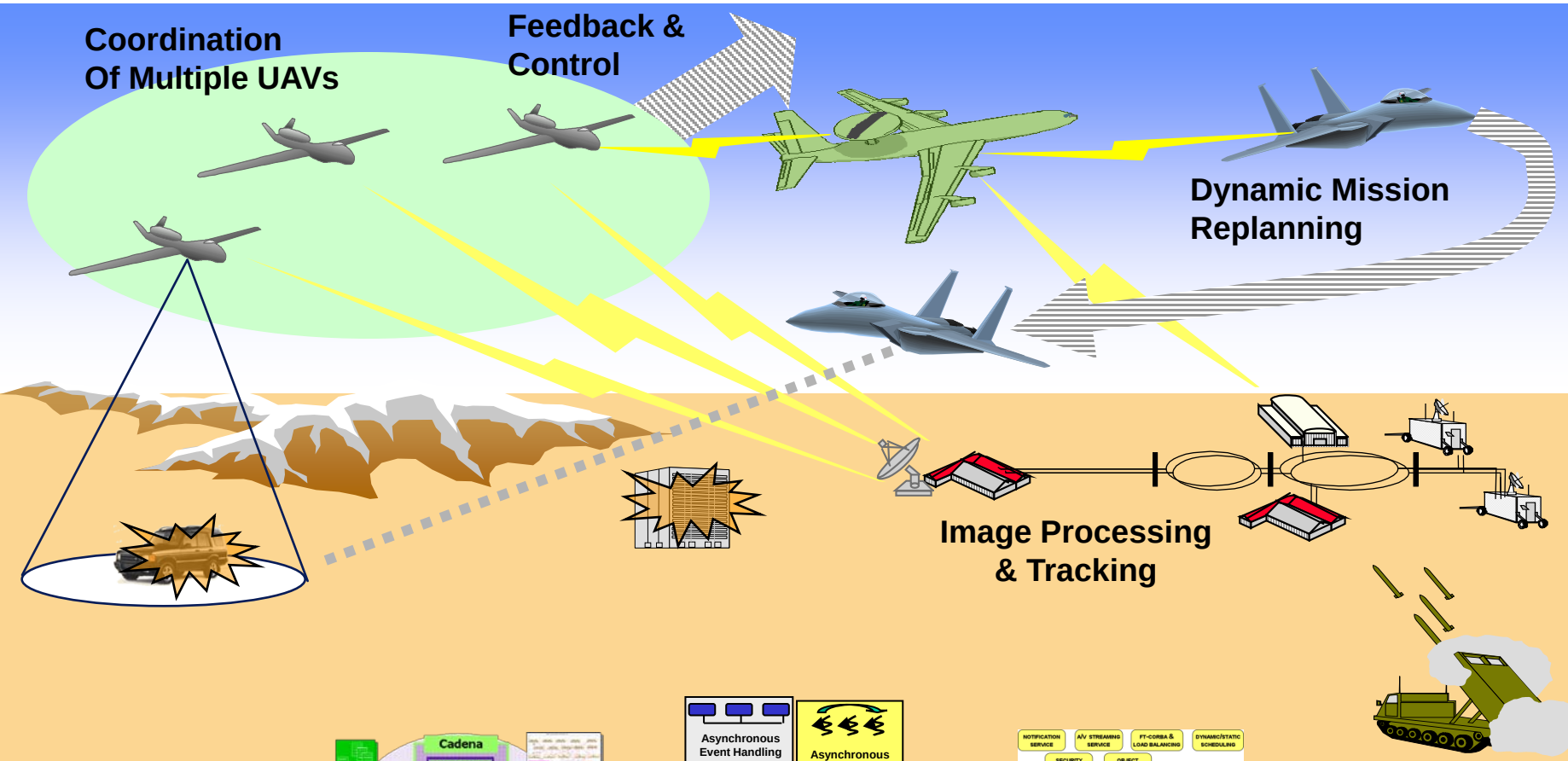
USS Ronald Reagan

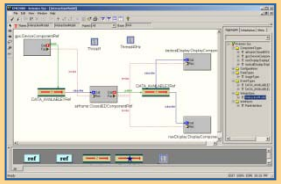


- DMSO HLA/RTI & DISA TENA with SAIC

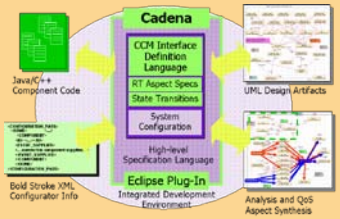
US Government Service

DARPA ITO/IXO Program Manager & Deputy Director: 2000 – 2003

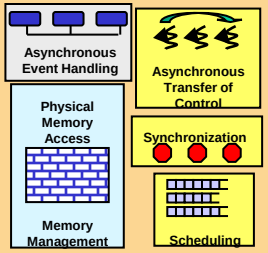




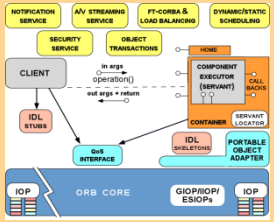
Model-driven Tools



Model Checking



Real-time JVMs



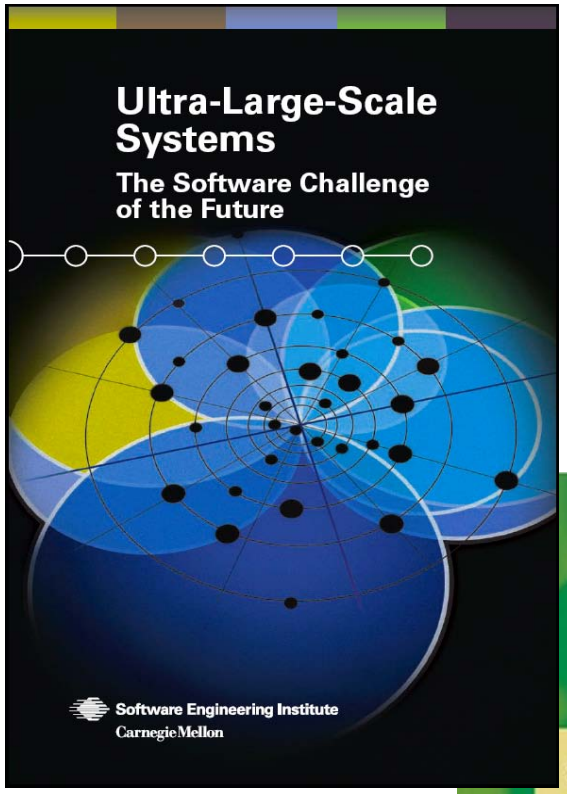
Real-time Middleware

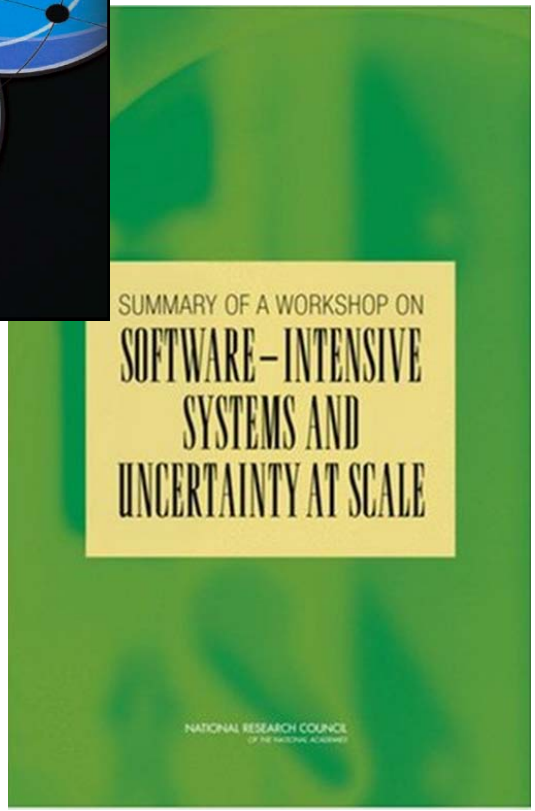
Aspect Languages

DARPA PCES Capstone demo, April 14, '05, White Sands Missile Range

US Government Service

- Member of National Academies study on Advanced Software Intensive Systems Producibility
- Member of the Engineering & Methods Technical Advisory Group for the Software Engineering Institute (SEI)
- Member of US Army & SEI study on Ultra Large Scale (ULS) systems
  - ULS systems report available at www.sei.cmu.edu/uls
- Member of Joshua advisory board for Air Force Research Lab (AFRL)
- Co-chair for Software Design & Productivity (SDP) Coordinating Group of the US Information Technology Research & Development (IT R&D) Program





Software Engineering Institute
Carnegie Mellon