SYSTEMS ENGINEERING RESEARCH CENTER

USC Viterbi School of Engineering
Systems Architecting and Engineering

Model Based Tradeoffs for Affordable Resilient Systems

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Outline

- Introduction
- Resilience and Affordability
- Representative Tradeoff Analysis Process
- Technology Platform and Tool Framework
- Way Ahead
- Concluding Comments

Introduction

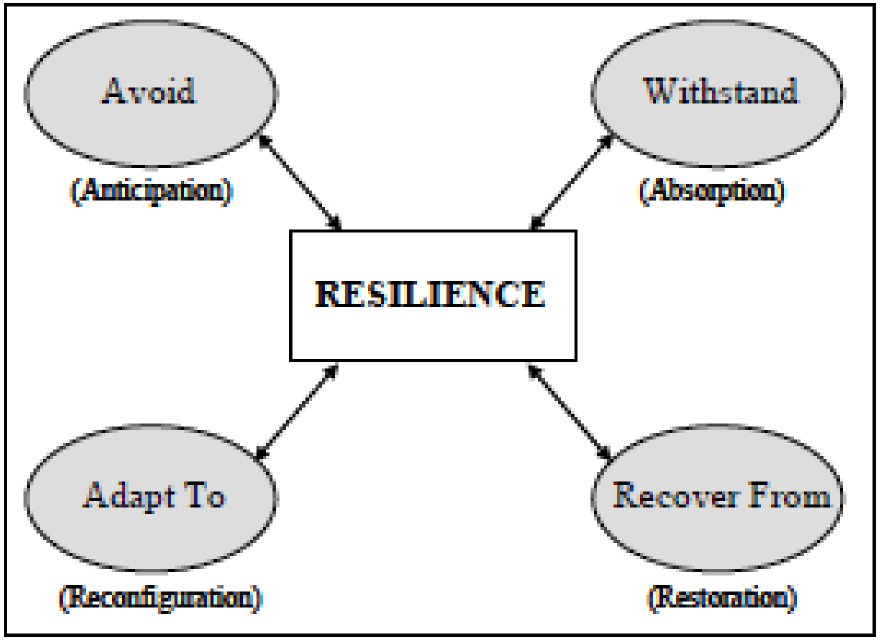
- NSS strategy states that as we invest in next generation space capabilities and fill gaps, we need to include system/SoS resilience as a key criterion in evaluation
- To justify the investment in resilience to decision makers, requires a quantitative assessment of benefits and costs, which in turn requires an analysis of the architecture tradespace
- Resilience requirements are associated with the outcome space, while tradespace analysis is used to answer the question: how much resilience in dimension X can we afford without giving up too much on other dimensions of interest?
- A resilience solution needs to satisfy operational requirements as well as affordability constraints associated with current and anticipated budgetary environments

Resilience and Affordability are Inexorably Linked

- Resilience
  - "The ability to avoid, withstand, adapt to, and recover from perturbations and surprise including unknown-unknowns"
  - For NSS systems, resilience is the "ability of a system architecture to continue providing required capabilities in the face of system failure, environmental challenges, or adversary actions"
- Affordability
  - the degree to which the capability benefits are worth the system's total life-cycle cost and support DoD strategic goals
- Two key aspects of resilience and affordability
  - value engineering and brittleness/fragility

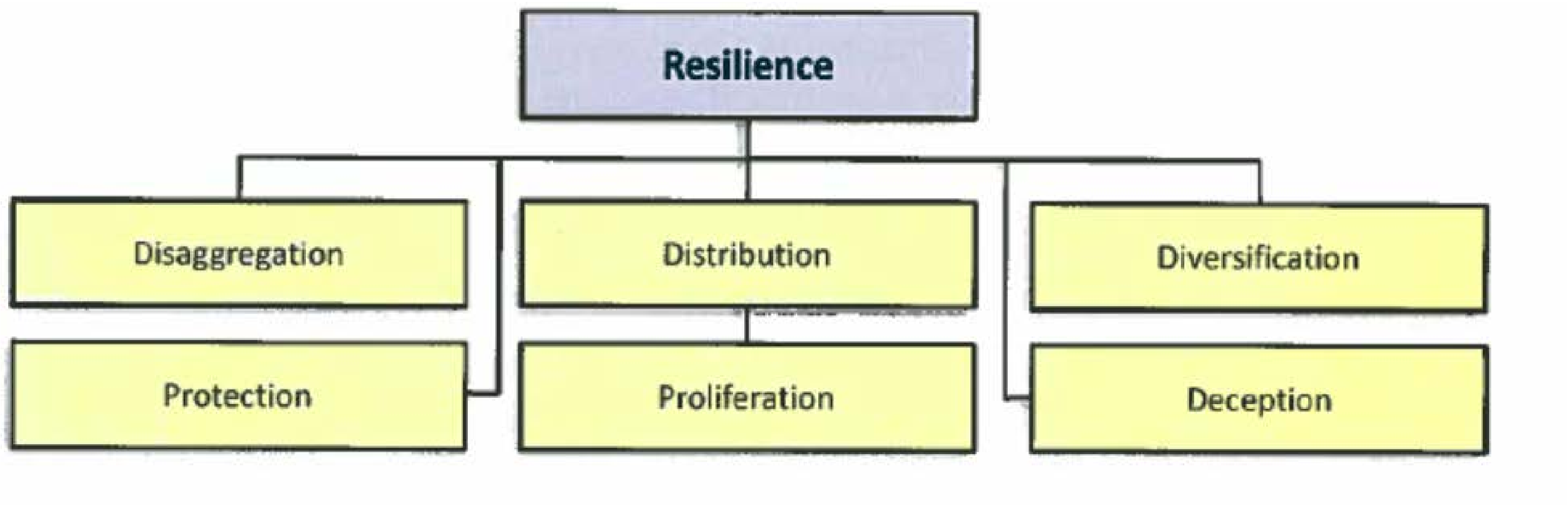
Framework for Resilience

Resilience is a Multi-Faceted Capability



Source: Madni, A.M., Jackson, S., "Towards a conceptual framework for resilience engineering," Systems Journal, IEEE 3.2 (2009): 181-191.

Taxonomy for Resilience

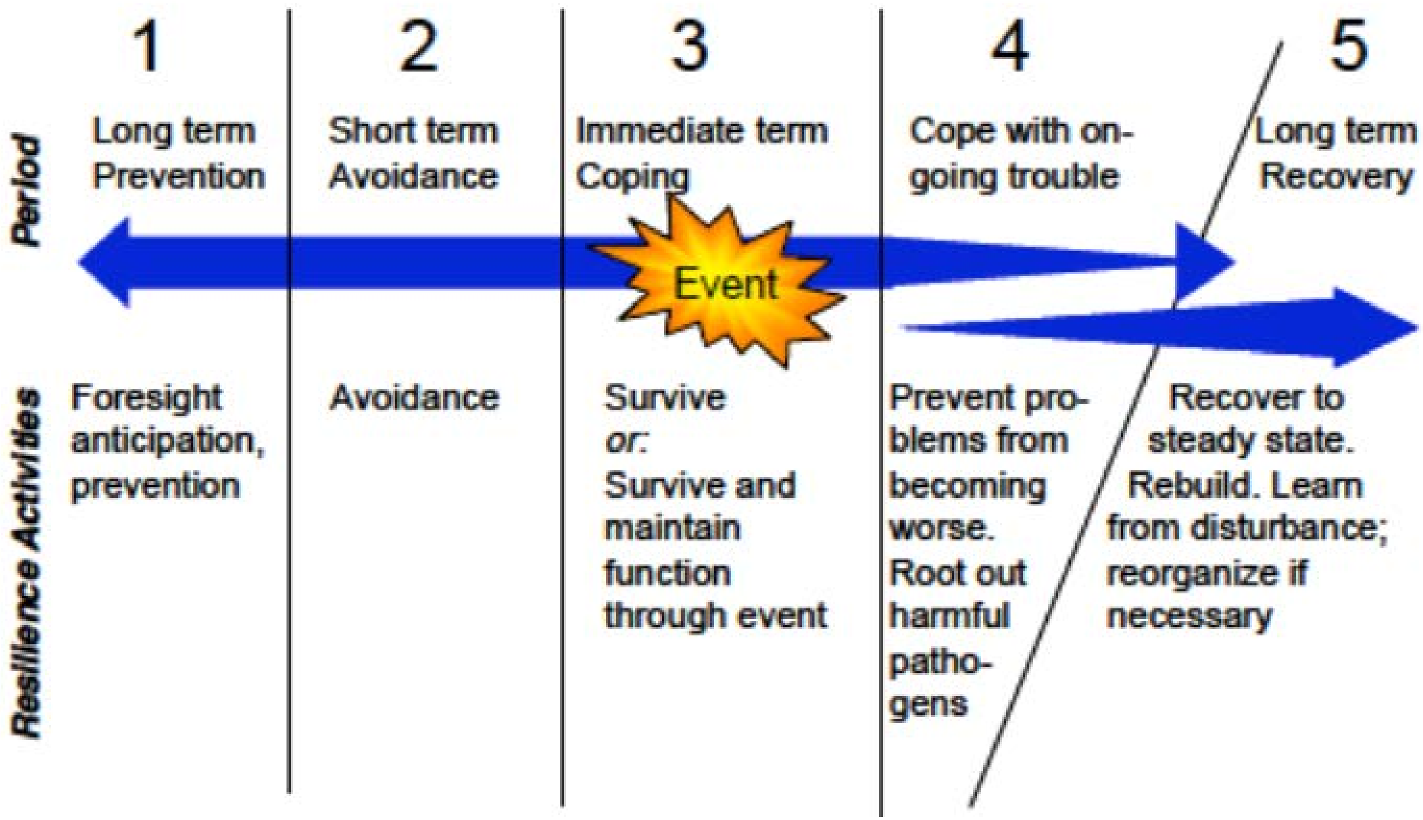


Source: ASD, "Space Domain Mission Assurance: A Resilience Taxonomy", September 2015.

Space System Resilience Factors

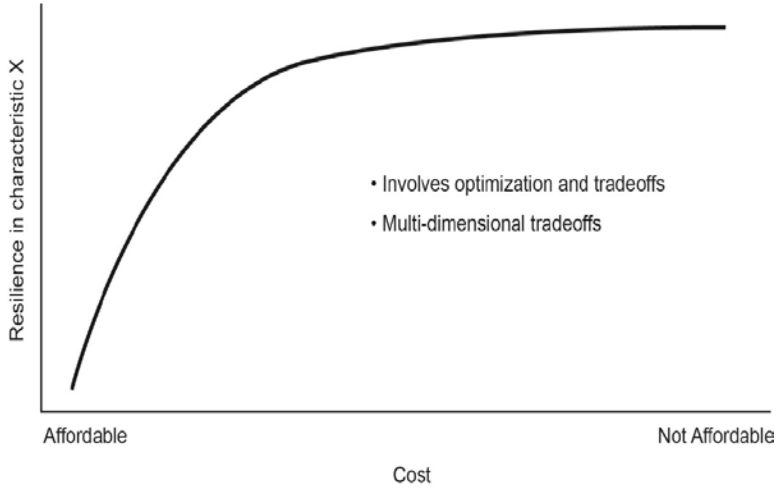
- *Disaggregation:* separation of dissimilar capabilities into separate platforms or payloads
- *Distribution:* utilizing a number of nodes, working together, to perform the same mission or functions as a single node.
- *Diversification:* contributing to the same mission in multiple ways, using different platforms, different orbits, or systems and capabilities of commercial, civil, or international partners
- *Protection:* active and passive measures to ensure those space systems provide the required quantity and quality of mission support in any operating environment or condition
- *Proliferation:* deploying larger number of the same platforms, payloads or systems of the same types to perform the same mission
- *Deception:* measures taken to confuse or mislead an adversary with respect to the locations, capability, operational status, mission type, and/or robustness of a national security system or payload

Resilience versus Time Period



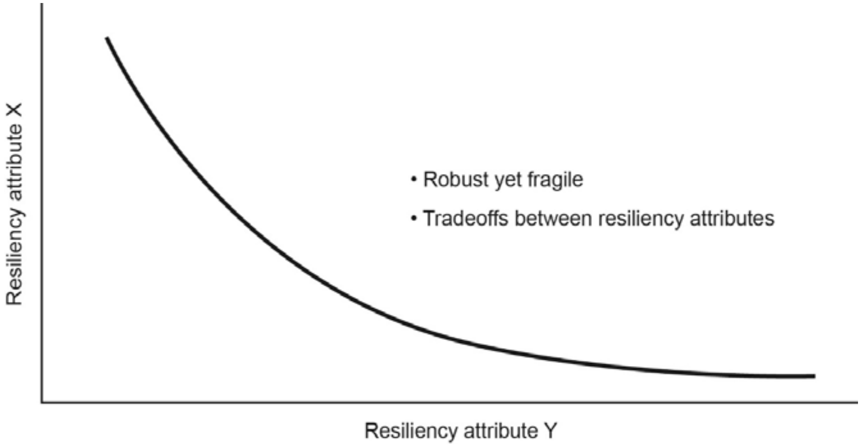
Source: Sheard, S. and Mostashari, A., "A Framework for System Resilience Discussions," 2007

Opportunities to Advance Decision Making in Systems Engineering



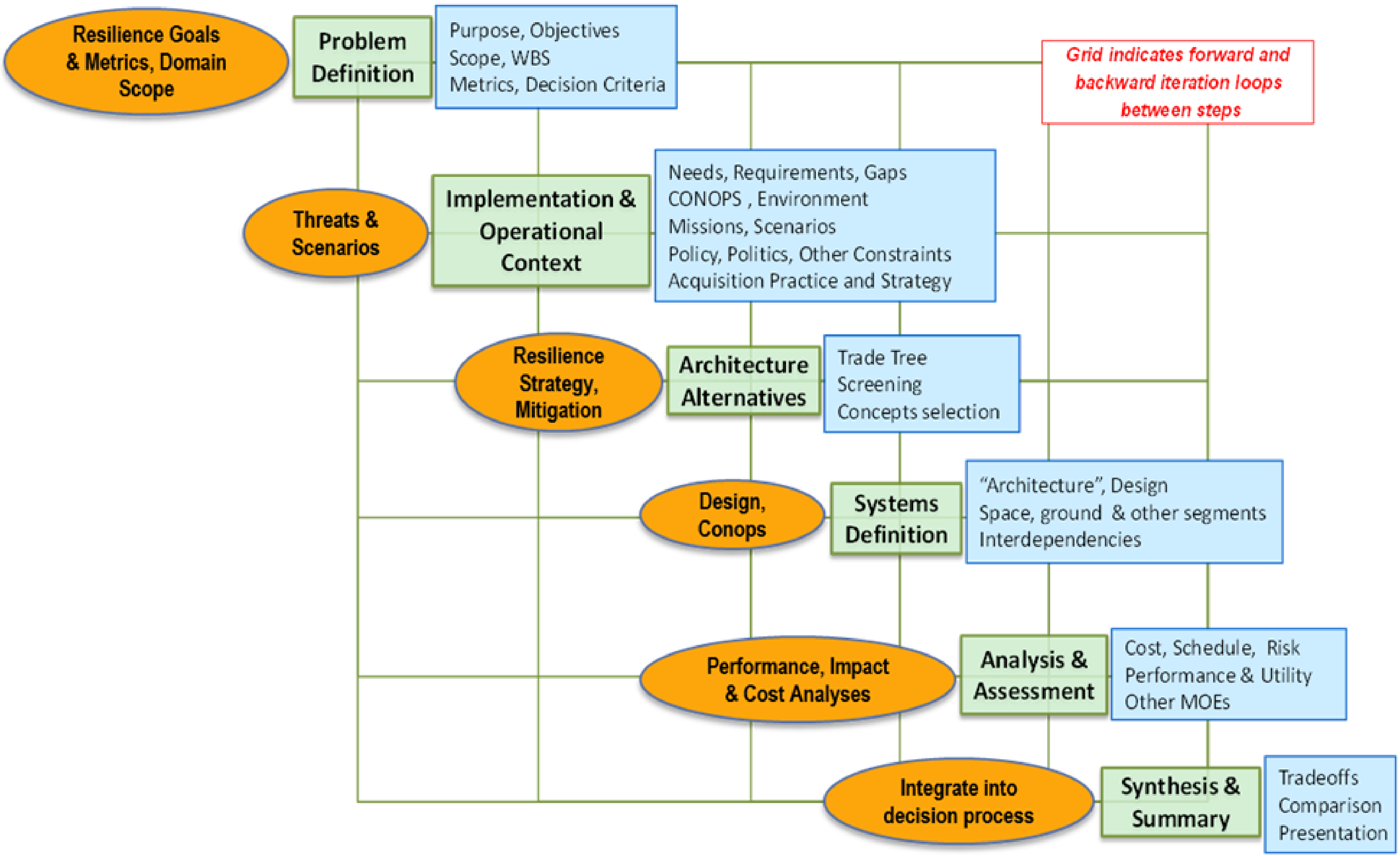
Resiliency versus Affordability

Relationship of Resiliency Attributes



Source: Marilee J. Wheaton and Azad M. Madni, *Resiliency and Affordability Attributes in a System Integration Tradespace*, AIAA Space 2015, Sep 1, 2015

Representative Framework for Architecture Design and Evaluation



Source: Min, I.A., Noguchi R.A., "The Architecture Design and Evaluation Process: A Decision Support Framework for Conducting and Evaluating Architecture Studies," IEEE Aerospace Conference, March 2016

Tradeoff Analysis Process

- Problem Definition: Defining the study approach, assumptions, parameters, and scope
- Implementation and Operational Context: Full range of operations scenarios and uses cases
- Alternative Explorations and Down-select: Full range of options are laid out and then pruned to a representative set
- Systems Concept Definition: Selected alternatives are further defined in order to perform analysis and evaluations
- Analysis and Evaluation: Multiple dimension reflecting the multiple objectives are performed to assess how well each alternative achieves each objective.
- Integration and Tradespace Depiction: Roll up and summary mapping of the solution options against the problem space to show how the stakeholder needs are satisfied to different degrees by the various alternatives

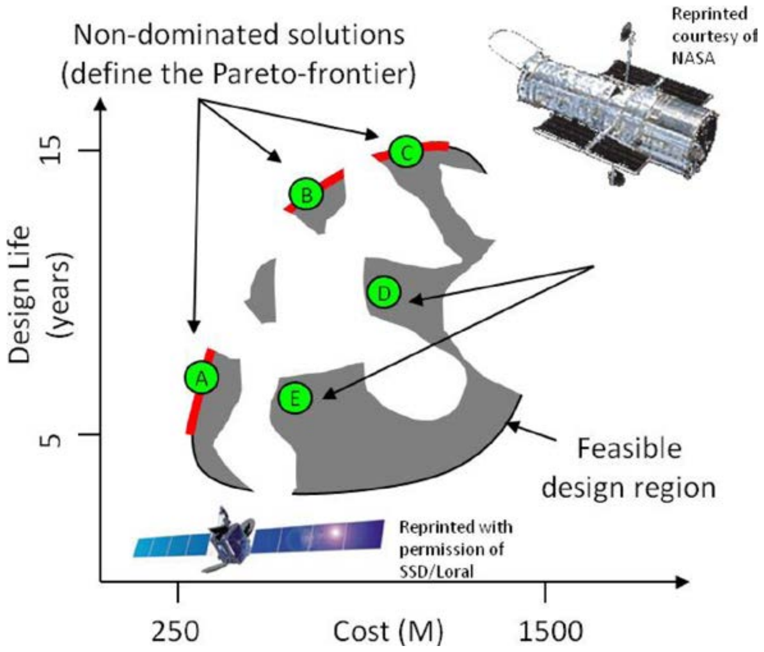
Candidate Decision Making Challenges Related to Resiliency

- Severe production pressure/tight schedule
- Pressing need for safety, but eroding safety margins
- Over-confidence (based on past success) replacing "due diligence"
- Failure to revisit it and revise initial assessments with new evidence
- Breakdown in communications at organization boundaries
- Unchecked risk buildup because of schedule pressure
- Failure to re-interpret previous facts in light of new evidence

Source: A. M. Madni and S. Jackson, "*Towards a Conceptual Framework for Resilience Engineering*," IEEE Systems Journal, Vol. 3, No. 2, June 2009

Multi-Objective Optimization

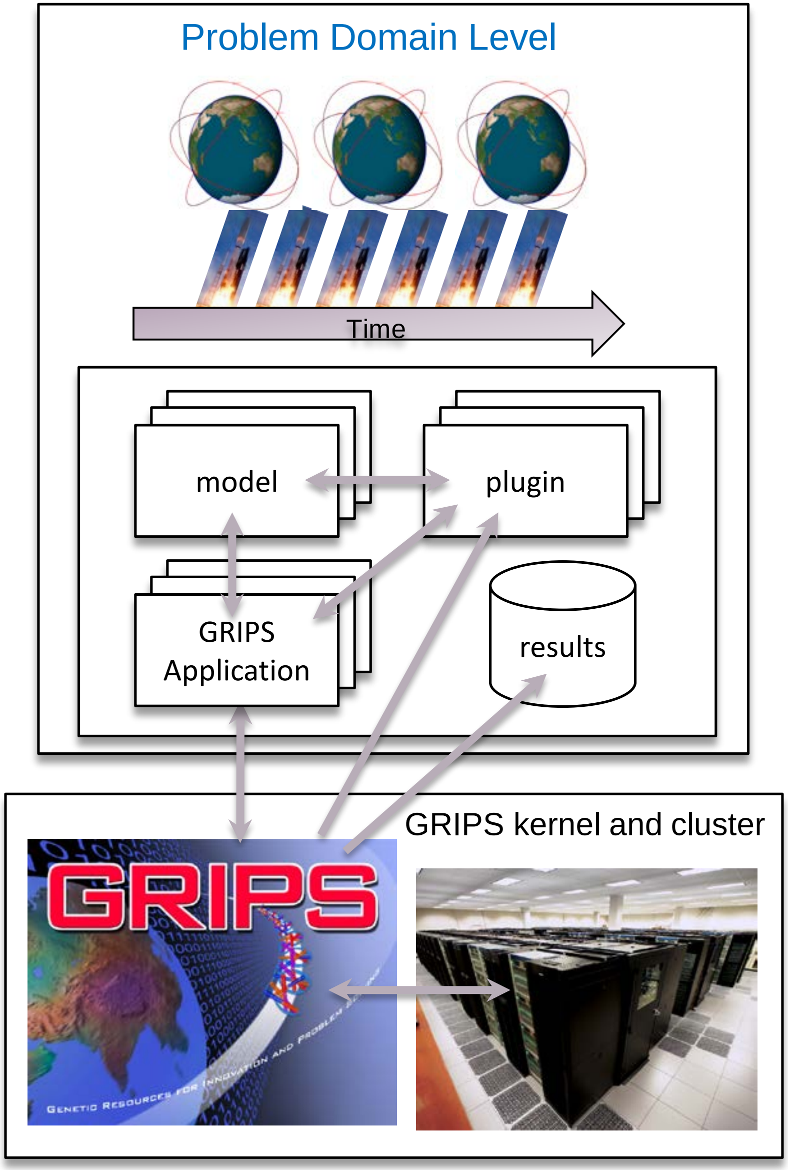
- Maximize and/or minimize multiple measures simultaneously
- No single optimum, rather a set of optimal solutions may be found or approximated
- Example: Provide the set of payload designs that
  - Objective 1: Maximize design life
  - Objective 2: Minimize cost
- GRIPS discovers solution that make up the non-dominated set (red curve – solutions A, B, and C)



GRIPS Tool

GRIPS is a tool to perform general purpose multi-objective optimization of a problem using a model(s) to produce the objective values.

- Models integrated into GRIPS
  - Via shared library
- Discovers a non-dominated set of solutions
  - Using many objective evolutionary computation
- Runs on high-performance computation platforms
  - Parallel processing (near 100% efficiency)



GRIPS Decision Support Process

Problem Conception and Formulation

- Identify Design Parameters
- Identify Key Objectives
- Identify Constraints

Variables
Assumptions
Constants
…

Requirements
Goals
MOPs
MOEs
…

Application Program Interfacing (API)

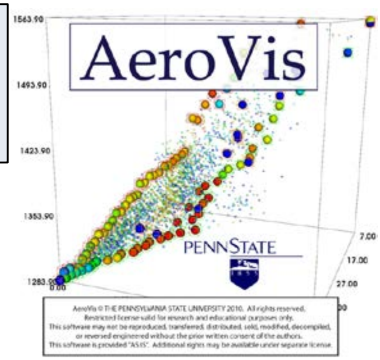
- Identify existing tools that model:
  - Design Parameters
  - Key Objectives
  - Constraints
- Assess feasibility for GRIPS integration via the API
- Build new models if necessary
- Wrap models into GRIPS via API

Multi-objective optimization

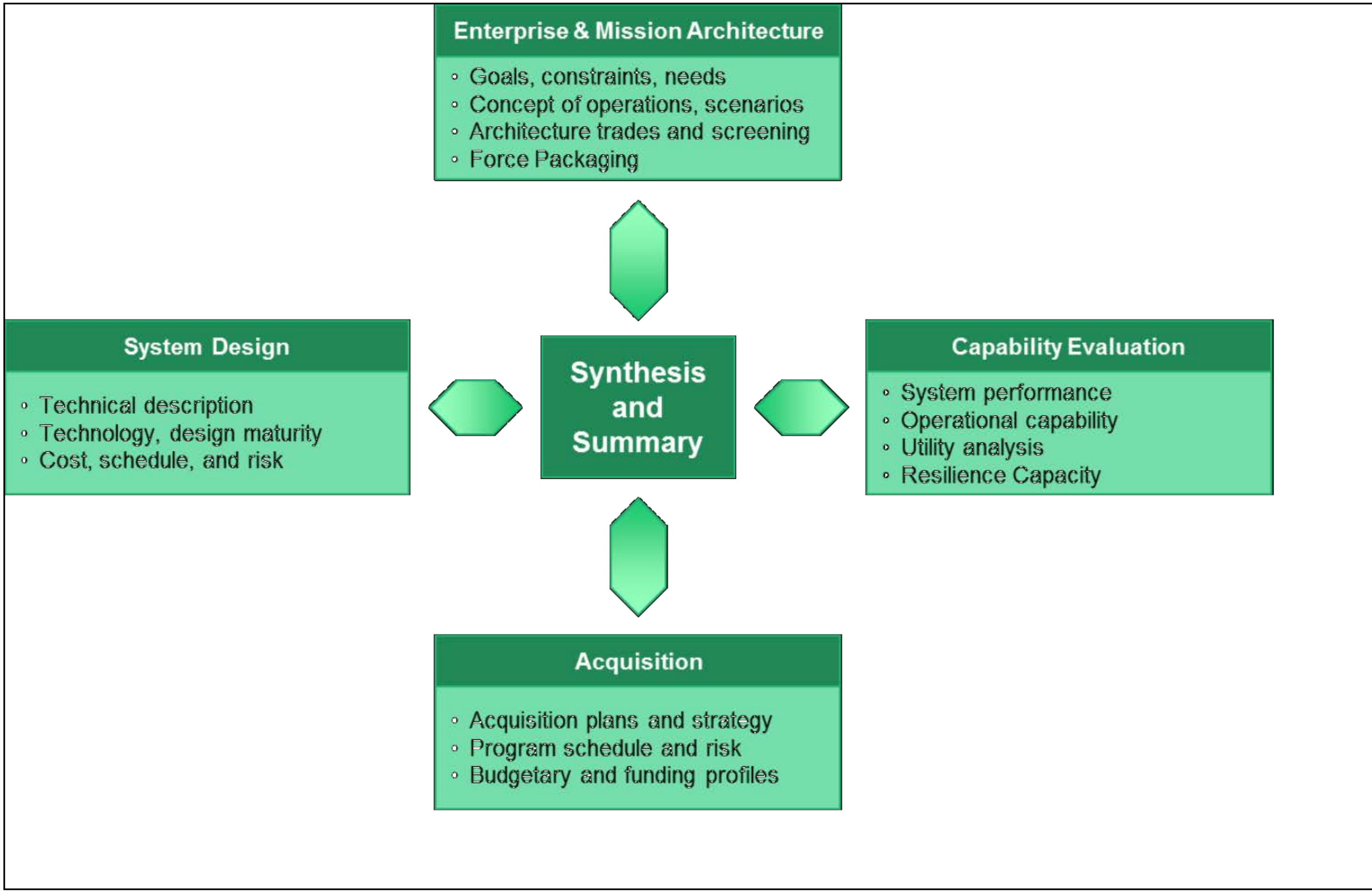
- Search potentially trillions of alternatives using Evolutionary Algorithms with parallel computing
- Find non-dominated tradeoff solutions

Explore, Visualize, Communicate

- Watch architectures "evolve" and identify key interactions between design parameters, objectives, and constraints
- Provide an accessible visualization roadmap of key tradeoffs to Decision Maker
- Engage Decision Marker in real-time "what-if" analysis



GRIPS Integrated Framework



Way Ahead

- There are not very many tools that have the requisite flexibility for tradeoff analysis
- Analysis showed that the combination of GRIPS and a MBSE tool can provide the right technology platform for research
- GRIPS has been used to understand the tradespace and explore the pros and cons of various resilience approaches
  - Strengths are to explore large swaths of tradespace, understand options, trends and obvious “stay away from” areas
  - Inform architects and decision makers about where to focus efforts
- A disciplined trade study process is used to ensure:
  - the right objectives and constraints have been identified
  - the right alternative solutions have been identified and analyzed
  - the key tradeoffs that the decision maker must consider before making a decision have been explicated
- Currently working on incorporating affordability considerations in the objective function defined in GRIPS

Concluding Comments

- Tradeoff analysis is a key systems engineering process that is needed in MBSE
- Decision makers in the national security system domain are required to include system resilience as a key criterion for evaluation of future architectures
- Tradeoff analysis is an important and promising extension of MBSE in its current state
- Tradeoff analysis requires an analysis of the system architecture tradespace to include the levels of desired resiliency attributes, along with cost and benefits
- An integrated framework, based on GRIPS and a MBSE tool is proposed for evaluating satellite architecture options and exploring the tradespace in a systematic, purposeful way before finalizing decisions

References

National Security Space Strategy, January 2011, http://www.defense.gov/News/Special-Reports/National-Security-Space-Strategy

Wheaton M., Madni A.M., "Resiliency and Affordability Attributes in a System Integration Tradespace," AIAA Space 2015 Conference and Exposition, Sep 2015

Madni, A.M., Jackson, S., "Towards a conceptual framework for resilience engineering," Systems Journal, IEEE 3.2 (2009): 181-191

ASD, "Memorandum for DoD Executive Agent for Space: Space Resilience Definition and Evaluation Criteria (u), "October 11, 2011

Defense Acquisition Guidebook, Chapter 4, Affordability – Systems Engineering Trade-Off Analyses, https://acc.dau.mil/, accessed Mar 2016

Air Force Space Command White Paper, Resiliency and Disaggregated Space Architectures, 2013

Resilience of Space Capabilities Fact Sheet, Department of Defense, 2012.

ASD,"Space Domain Mission Assurance: A Resilience Taxonomy", September 2015

Madni, A.M. and Ross, A.M., "Exploring Concept Trade-offs," book chapter in Trade-Off Analytics, John Wiley and Sons, 2017

References

Bahill, T.A. and Madni, A.M., “Tradeoff Decisions in System Design,” Springer International Publishing, 2017

Ferringer, M. P., Clifton, R. S., and Thompson, T. G., “Efficient and Accurate Evolutionary Multi-Objective Optimization Paradigms for Satellite Constellation Design,” *Journal of Spacecraft and Rockets*, Vol. 44, No. 3, May-June 2007, pp. 682-691

Whittecar, W.R. and Ferringer, M.P. Global Coverage Constellation Design Exploration Using Evolutionary Algorithms, AIAA/AAS Astrodynamics Specialist Conference, 2014

Ferringer, M. P., and Spencer, D. B., “Satellite Constellation Design Tradeoffs Using Multiple-Objective Evolutionary Computation,” *Journal of Spacecraft and Rockets*, Vol. 43, No. 6, Nov.-Dec. 2006

Smith, P., Ferringer, M., Kelly, R., and Min, I. “Budget-Constrained Portfolio Trades Using Multiobjective Optimization,” Systems Engineering, Wiley Periodicals, Inc., 2012

Min, I.A., Noguchi R.A., “The Architecture Design and Evaluation Process: A Decision Support Framework for Conducting and Evaluating Architecture Studies,” IEEE Aerospace Conference, March 2016

Sheard, S. and Mostashari, A., “A Framework for System Resilience Discussions,” 2007