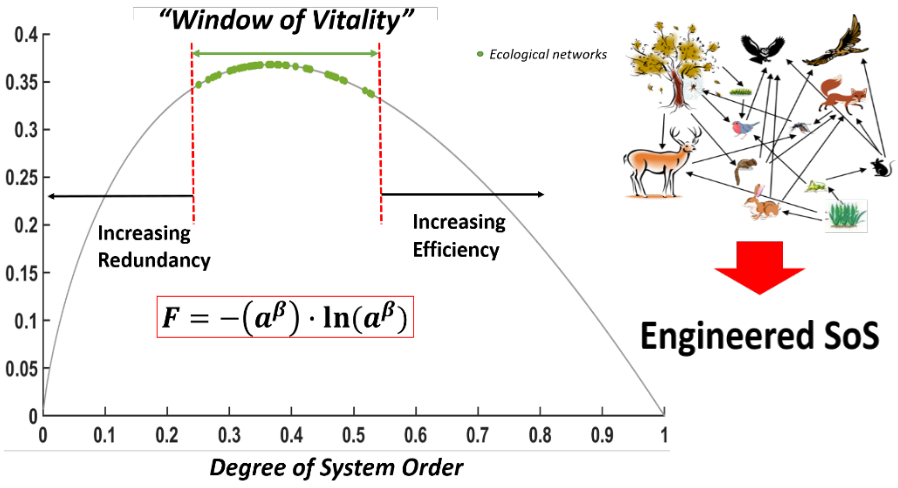
WRT-1011: Ecology-Inspired Technique for Resilient Engineered System of Systems Design

Richard Malak (PI), Astrid Layton (Co-PI)
Abheek Chatterjee

SYSTEMS ENGINEERING RESEARCH CENTER
J. MIKE WALKER '66 DEPARTMENT OF MECHANICAL ENGINEERING, TEXAS A&M UNIVERSITY

Research Task / Overview

Provide a **technique to analyze resilience** of an engineered System of Systems (SoS) *without* the need for **highly detailed simulations and disruption models**



Results from ecology: **highly efficient** networks are **inflexible** and **vulnerable** to perturbations and **highly redundant** networks **fail to utilize resources** effectively; successful networks balance efficiency and redundancy.

Goals & Objectives

System Fitness (***F***) *proposed* as a function of the **degree of system order** (***a***)

$$AMI = \sum_{i=0}^{N+2}\sum_{j=0}^{N+2}\frac{T_{ij}}{TST_p}log_2\left[\frac{T_{ij}\cdot TST_p}{T_{i\cdot}\cdot T_{\cdot j}}\right]$$

$$H = -\sum_{i=0}^{N+2}\sum_{j=0}^{N+2}\frac{T_{ij}}{TST_p}\log_2\left[\frac{T_{ij}}{TST_p}\right]$$

$$a = {}^{AMI}/_{H}$$

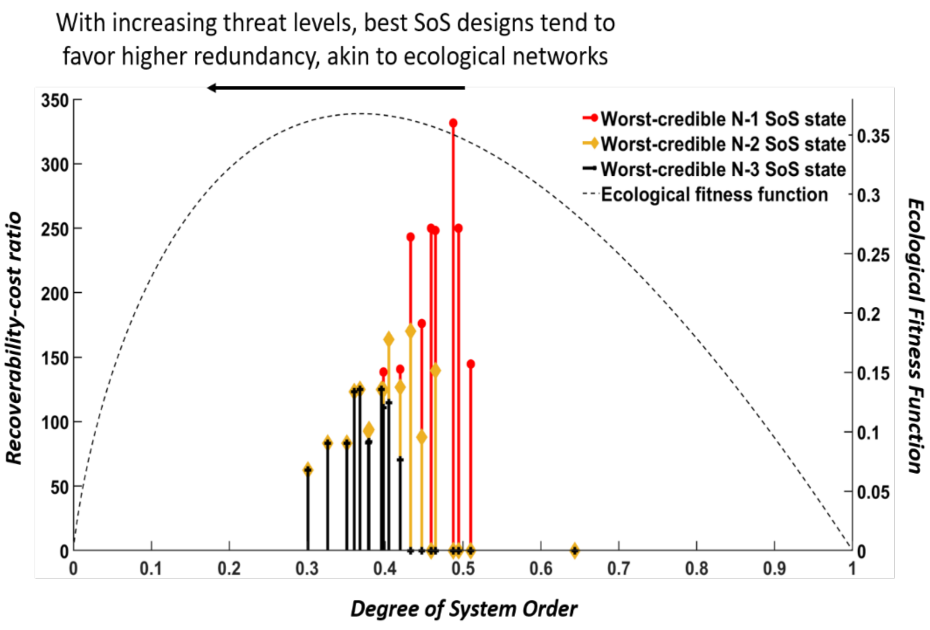
1. What improvements are offered by a **biologically-inspired** *'a'* for **performance, affordability, and resilience** in human-engineered SoS, compared to highly efficient/redundant architectures?

2. What **factors** influence a *favorable* **"window of vitality"** and **peak fitness** for an engineered SoS?

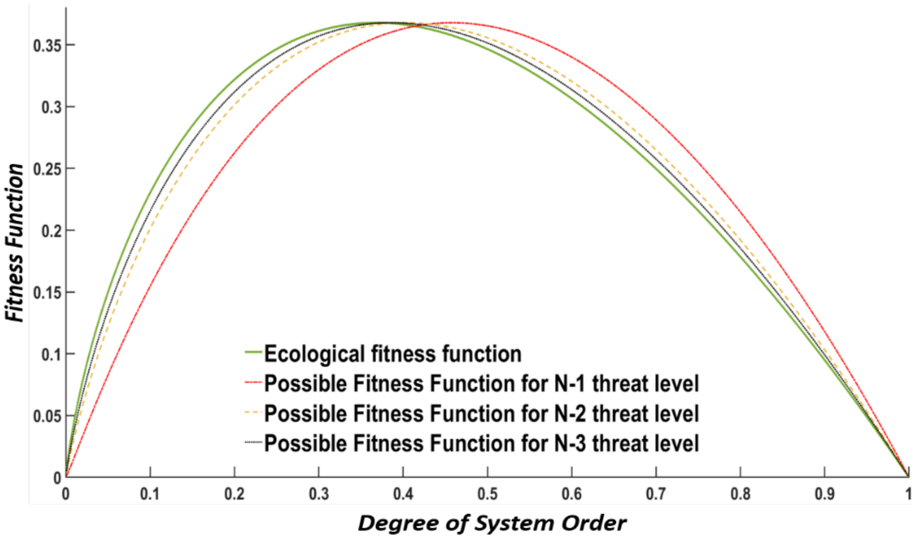
*The quantities AMI and H are derived in ecological literature using the concepts of Information Theory, β controls the peak of the fitness curve, *n* is the number of SoS components

Data & Analysis

Recoverability-Cost Ratio: The level of SoS performance that can be recovered by surviving systems after the **worst credible N-X disruptions**, normalized by operational cost



- *Highly-efficient* SoS **fail catastrophically** under disruptions & *highly-redundant* SoS are **expensive**
- Results indicate fitness trends seen in biological ecosystems are **similar** for human-engineered SoS
- Fitness functions for the N-1, N-2 and N-3 scenarios (figure below) estimated based on SoS architectures with best recoverability-cost ratios (figure above)
- Results indicate the **peak fitness** for engineered SoS favor an **ecologically similar degree of system order at higher threat levels**



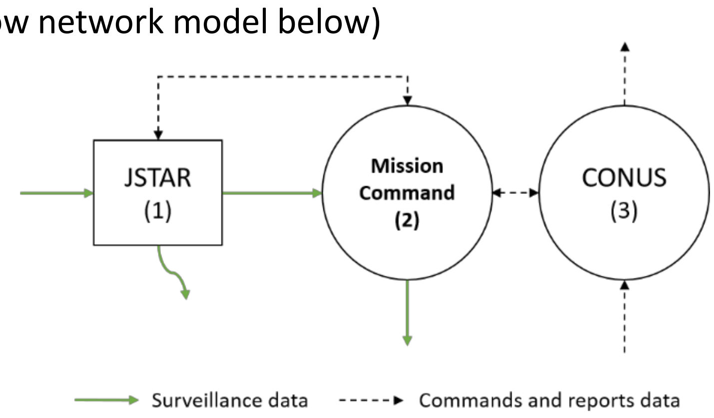
Methodology

Step 1 — • *Evaluate* **performance** and **operational cost** of notional SoS architectures

Step 2 — • *Model* SoS architectures as **flow networks** and evaluate their **degree of system order**

Step 3 — • *Simulate* random N-1, N-2, N-3 disruptions and *compare* SoS's **recoverability to cost ratio** to the **degree of system order**

Twenty feasible architectures of a hypothetical notional hostiles surveillance SoS were investigated (example flow network model below)



Future Research

- **Additional testing** of SoS with increasing size/complexity
- **Analytical approach** needed to *identify* the 'window of vitality'/**peak fitness** for SoS of interest
- **Guidelines** needed for SoS 'window of vitality' *design* that uses bio-inspiration for trade-offs between performance, affordability, and resilience

Contacts/References

Dr. Astrid Layton: alayton@tamu.edu
Dr. Richard Malak: rmalak@tamu.edu

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