Identifying Collaboration and Communication Needs for Complex Systems Design Using Digital Engineering

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By

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7th Annual SERC Doctoral Students Forum

November 18, 2019

FHI 360 CONFERENCE CENTER

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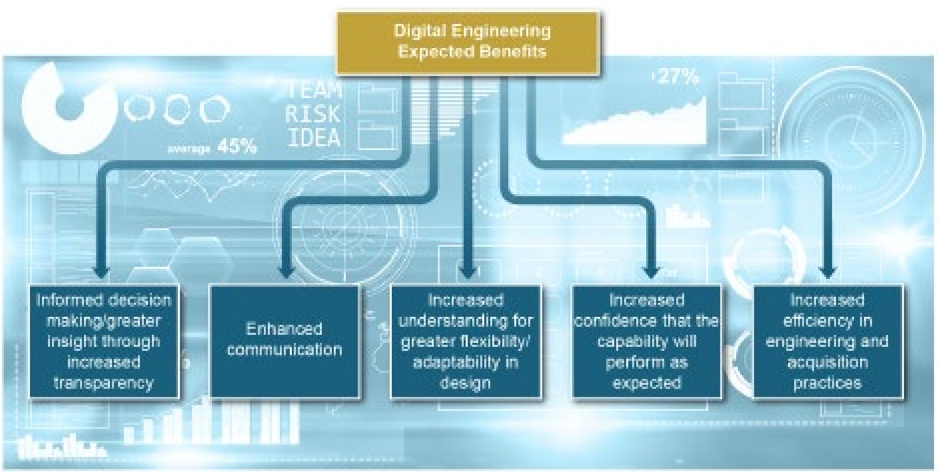
Overview

- Motivation
- Problem Description
- Trade Space Evaluation in Complex System Design
- A Mathematical Surrogate Model for Studying Behaviors
- Evaluation Metrics for Validating the Model
- Future Work

Special thanks to my advisor, Dr. Paul T. Grogan

Motivation

- DoD Digital Engineering Strategy
  - —Published June 2018
  - —Modernize design, development, operation and sustainment
  - —Transform acquisition and implementation
  - —Improve speed for critical capability delivery to the warfighter
  - —Connected data in a digital environment



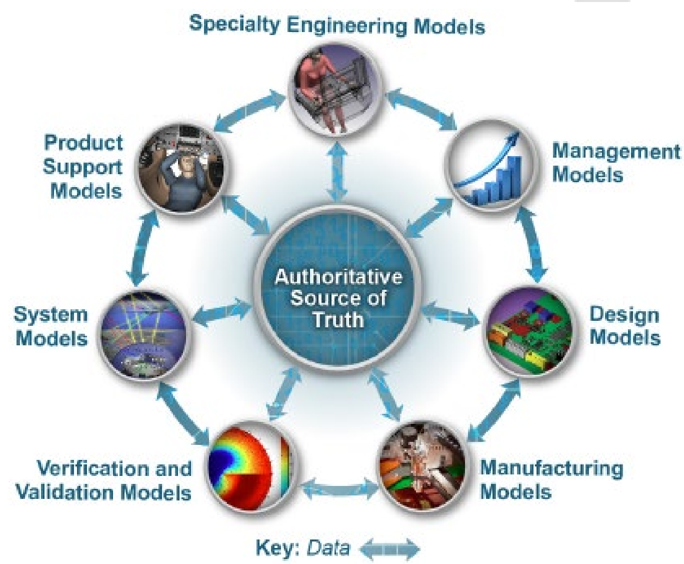


Image credit: DoD Digital Engineering Strategy, June 2018

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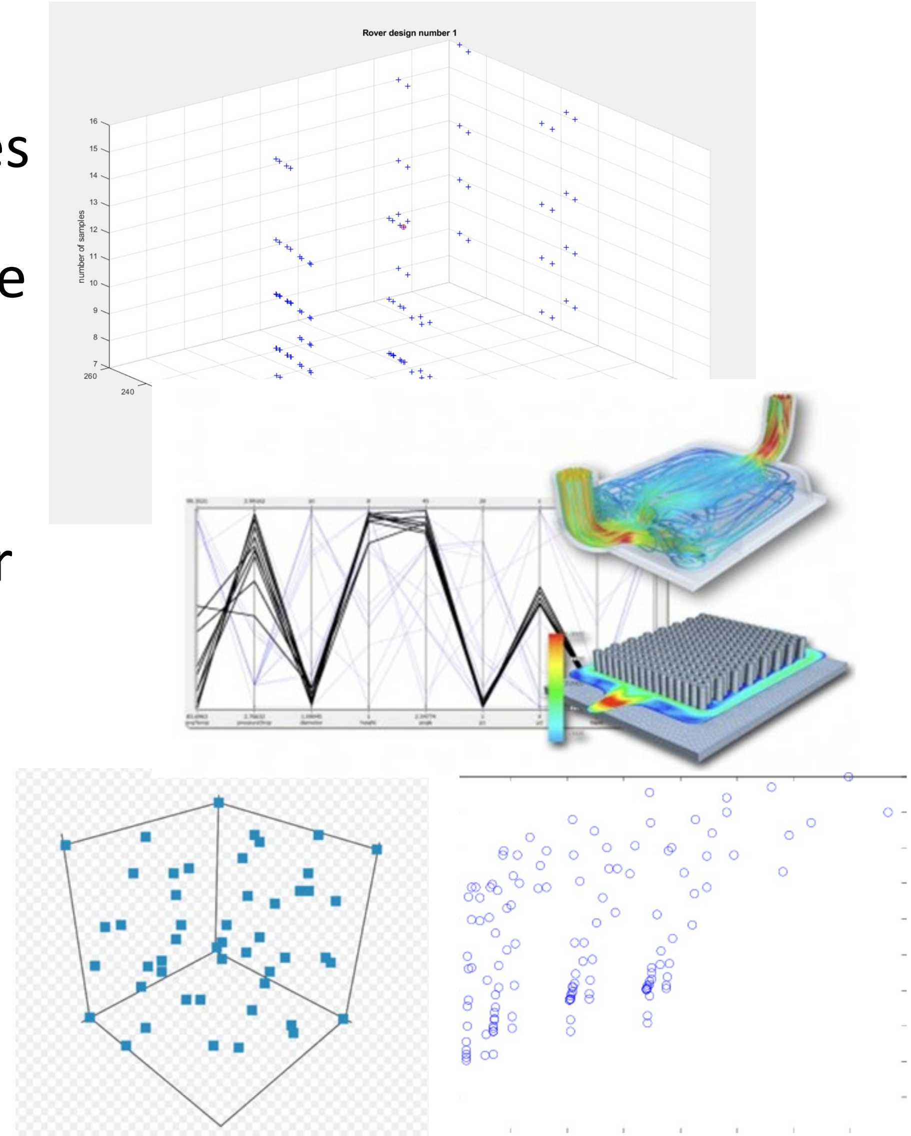
Problem Description

Raytheon

- Lack of theory to suggest how Digital Engineering will change:
  - —Engineering practice
  - —Engineering lifecycle processes
  - —Effect on system performance
- Implementing Digital Engineering goals without this understanding could limit desired results
- Need to study how complex communications and decision-making by individuals and teams impact system performance to identify how to best implement Digital Engineering
  - —To adopt new technologies more rapidly
  - —To design higher performing systems
  - —To address workforce challenges

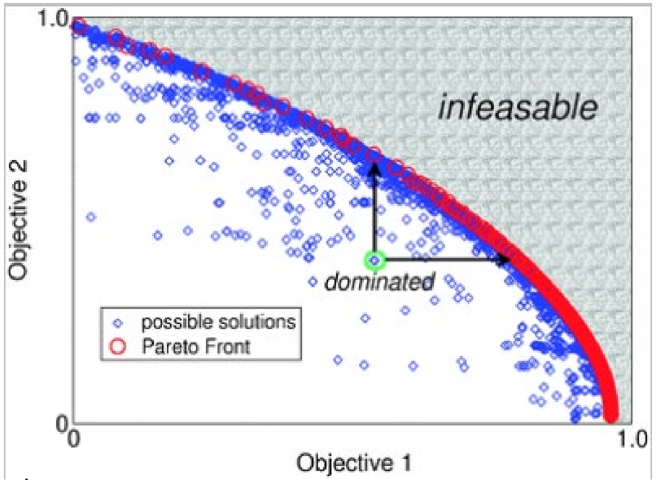
Complex System Design and Analysis

- Multidimensional and Multidisciplinary problem spaces
- Requires trade space to evaluate and determine best solution
- Can be very expensive and lengthy to create the models for the trades to be evaluated
- Solution choice still subject to stakeholder viewpoints
  - —Priorities of budget, schedule, performance
  - —Quantification of utility



Selecting the Best Solution – Current Practice

- Evaluation techniques
  - —Pareto front comparisons
  - —Detailed performance models
  - —Utility models
- Limitations of these techniques
  - —Dependent model variables limit coupled or emergent behavior analysis
  - —Can be impacted by:
    - ○ Team or Contract organization
    - ○ Task structure
    - ○ Data accessibility
    - ○ Subject Matter Expert availability
  - —Decision making authority dependent
  - —Time to create versus decision need date



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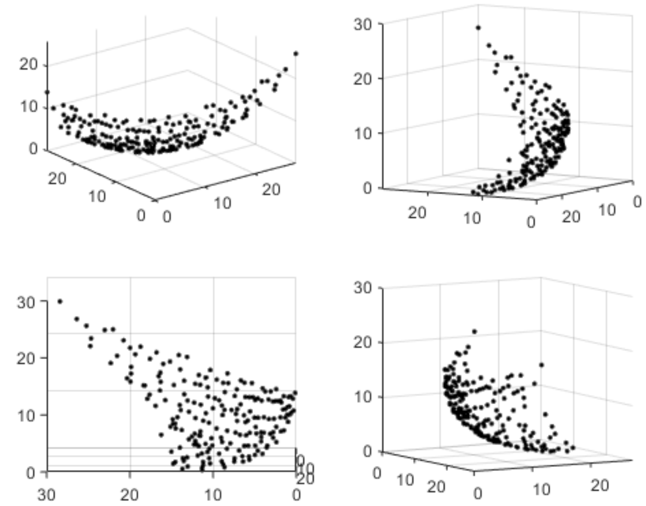

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Using a Mathematical Analog to Study DE Influences on Solution Performance

- Mathematical model as a surrogate for detailed design or utility models
  - Used to study impact of coupled behavior on system performance
  - Have been used to analyze adaptive evolution in immune response and organizational performance
- An enabler to studying the impact of DE on:
  - Decision analysis of individuals, groups, human/machine teaming
  - Without detailed design model development
  - Behavior changes based on change in data and connected information
- Candidate mathematical models exist to evaluate the approach
  - First investigated is the NK model and variants

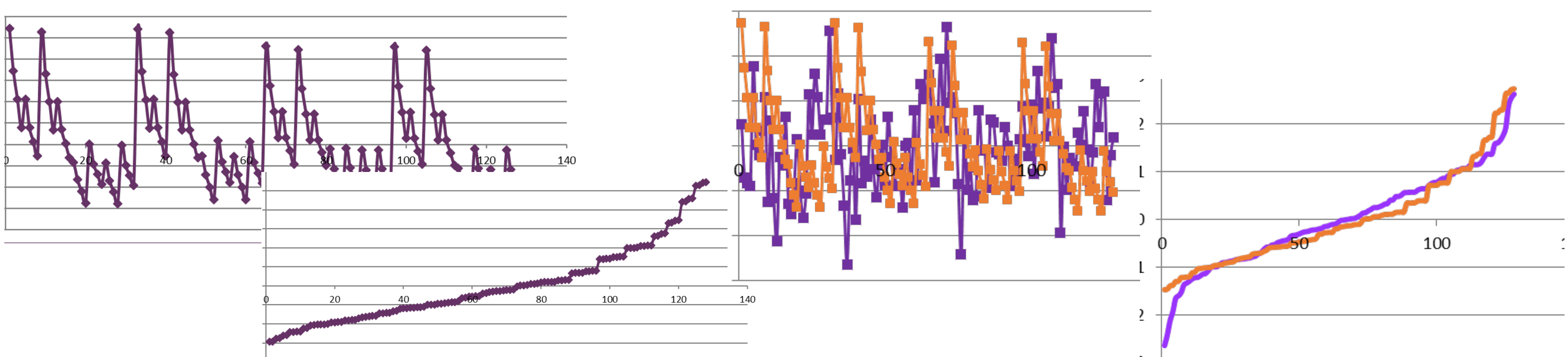
Aligning real world elements to Surrogate model elements

- Basic NK model description
  - —A system has N variables, each variable can take on A possible values
  - —The model assigns a “fitness contribution” to each variable (w_i)
    - ○ This can be assigned at random from the uniform distribution on (0,1)
  - —The total fitness (W) of a system is an average of the fitness contributions of each variable
  - —K defines the number of coupled variables influencing the fitness value of w_i
- Some parts of the real-world problem easily align to the NK model elements:

Complex System Design Element	NK Model Element
Design variables	N
Design variable alternatives	A
Coupled behavior	K
Performance/Utility Value	w_i, W

First look at alignment of complex system models and NK model - Structure

- Need to determine if the mathematical model can be utilized to perform simulations to study the practices, processes, behaviors and how DE changes them
  - —Performance and utility models differ
  - —Can the mathematical surrogate be tuned to represent those differences
- What is our evaluation metric for alignment to proceed
  - —Previously compared normalized results from detailed performance model to the mathematical model to look at the performance (W) predicted by each



Look at System Performance Evaluation to Correlate Surrogate Model

Evaluating the Surrogate Model for the Application – Looking at Behavior

- Initial abstractions describe the structure of the trade space
- Need abstractions to represent the intricate roles involved in evaluating and decision-making for system performance
  - To evaluate how those behaviors are impacted by DE
- Define agents that represent the behaviors of those roles
  - Utilize different decision-making strategies
  - Represent different collaboration and communication techniques

Complex System Design Element	Agent Element Definition
Design engineer	Individual decision-maker, consumes and produces data
Subject matter expert	Individual decision-maker, set knowledge base, consumes and produces data
Integrated Product Team	Group decision, consume and produce data

Comparing Walking the Fitness Landscape to Systems Engineering Design Activities

- How do engineers explore the trade space to find better performing solutions
  - —Set number of design iterations
  - —Set number of dependent variables to be explored
  - —Constraints on technical solutions to be selected
  - —Limits on design dimensions used to make decisions
- How can the mathematical fitness landscape be explored to imitate the same
  - —Local neighborhood search of the solutions
  - —Constraints on number of evaluations performed to improve performance
  - —Incorporate probability into decision analysis rubric
  - —Change dependency structure of the model for different technology infusion or strategy

Composing the Agents to Represent Engineers, SMEs and Teams

Future Work

- Develop agents and behavior evaluation criteria for exercising on surrogate mathematical models
  - Correlate these to real world techniques for selecting system designs of desired performance and utility
  - Correlate to engineering practice, processes and lifecycle stages
- Identify how Digital Engineering could change these agents and behaviors
  - Data access and awareness
  - Design decision influence of data
  - Calibration of engineering decision-making
  - Needed level of expertise to evaluate
- Perform simulations and evaluate against the potential metrics
  - Expand comparison to other detailed design model representations

Acknowledgements and Dedication

- Special thanks for continued research guidance and support:
  - —Dr. Paul T. Grogan, Stevens Institute of Technology, Assistant Professor, School of Systems and Enterprises
  - —Dr. Marshall Mattingly, Raytheon Missile Systems
  - —The Collective Design (CoDe) Lab students and researchers, Stevens Institute of Technology, School of Systems and Enterprises
- Dedicated to Charles Andrew Sharo
  - —August 18, 1948 – April 18, 2019

Backup

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Rugged Fitness Landscapes

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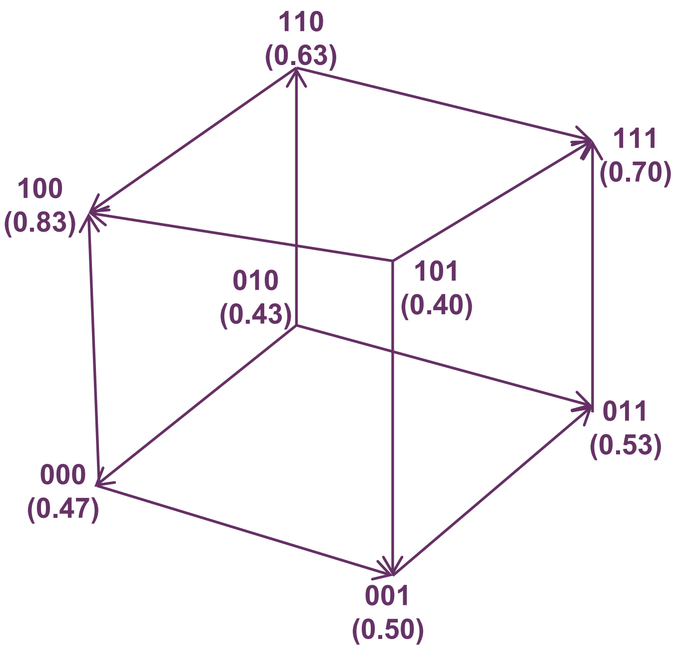
- We need a way to look at the impact of team communication and collaboration on design fitness without relying on a detailed design space model
  - —Valid over a range of design problems
  - —Before lengthy design and development process to build design models
- Candidate approach is an NK model from a class of mathematical (statistical) models
  - —Describe the richness of epistatic interactions
    - The value of a given variable is affected by the values of other variables
  - —Have been used to describe adaptive evolution in immune response as well as fitness of organizations
- Can the NK model can be tuned to show that it can be representative of the fitness space defined by complex design models?

The Basic NK Model

- Basic model description
  - A system has N variables, each variable can take on A possible values
  - The model assigns a "fitness contribution" to each variable (w_i)
  - This can be assigned at random from the uniform distribution on (0,1)
  - The total fitness (W) of a system is an average of the fitness contributions of each variable

$$W = \frac{1}{N}\sum_{i=1}^{N} w_i$$

1	2	3	w_1	w_2	w_3	W
0	0	0	0.6	0.3	0.5	0.47
0	0	1	0.1	0.5	0.9	0.50
0	1	0	0.4	0.8	0.1	0.43
0	1	1	0.3	0.5	0.8	0.53
1	0	0	0.9	0.9	0.7	0.83
1	0	1	0.7	0.2	0.3	0.40
1	1	0	0.6	0.7	0.6	0.63
1	1	1	0.7	0.9	0.5	0.70



Assessing System Fitness

- Contributions to fitness between coupled variables
  - K defines the number of coupled variables influencing the fitness value of w_i
  - K = 0 yields a smooth solution fitness landscape with a single peak for the solution with the optimal fitness
    - The contributions of each variable to the system fitness are entirely independent of all other variables
  - As K increases relative to N, the fitness landscape becomes rugged with multiple peaks representing local optima
    - For K = N-1 the contributions of each variable are entirely dependent of the values for all other variables in the system
- The statistical model could represent local optima and the distance to reach a local optima

2018 Results and Conclusions

- Created a fitness landscape of potential solutions for Mars rover designs to compare to a randomly generated fitness landscape defined by an NK model
  - K=2 and K=6 have promising potential for representing the design dataset using both the unsorted and sorted fitness plots
- Limitations of this preliminary assessment
  - Single snapshot fitness assessment of the NK model as setup
    - Need to apply Monte Carlo analysis and look at confidence intervals to determine if this could be accepted or rejected as a feasible representation
  - Comparison to a single design fitness model
    - Other design fitness models may have different results in terms of fitness and tuning the NK model to it
  - The evaluation metric needs to be assessed for determining potential of the representation
    - Perhaps sorted fitness is not the best way to evaluate the goodness of fit