SYSTEMS ENGINEERING
Research Center

Annual Review
Research at Missouri S&T

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www.SERCuarc.org

S&T's Systems Engineering Research Capabilities

Systems Engineering Graduate Program at Missouri S&T contributes at different levels to all of the five thrusts of SERC Research Strategy :

- Enterprise Responsiveness
- Systems Science and Complexity
- Systems Engineering Workforce
- Program and SE Integration
- Life Cycle Systems Engineering Processes

through its participation of MPT Technical Task Order (TTO), Research Task (RT) RT-2 and RT-14 , over 340 systems Engineering MS degree graduates , and two PhD degrees graduates. Program currently have over 260 MS and over 10 Systems Engineering PhD students.

S&T's Systems Engineering Research Capabilities

- Systems Engineering Workforce:
  - Collaboration and Education. Research how to use innovative collaborative technologies (i.e., Web 2.0, virtual environments, social networking, etc.) to dramatically improve speed, effectiveness and efficiency of systems engineering education - especially for teams that are geographically, and culturally diverse or for whom educational opportunities are limited.
  - S&T's Network Centric Systems Engineering Graduate Degree Program delivers over 120 graduate courses per semester synchronously throughout the United States and to International locations where DoD contractors are located. The system provides virtual class rooms, making the location of professors and students transparent for learning and research.
  - This Network Centric graduate education system is in operation over the last 10 years and being modified every year based on research and the recent advances in technology.

S&T's Systems Engineering Research Capabilities

- Systems Engineering Workforce:
  - Acceleration. Research how to accelerate the growth of the systems engineering workforce (including those who specialize in systems architecture, systems integration, and software engineering) for DoD, IC and their contractors.
  - Missouri S&T is among the approximately ten universities who offer PhD in Systems Engineering. Most of our PhD students are engineers working for DoD contractors. Recent titles of PhD dissertations are:
    - "Modeling Network Traffic on A Global Network-Centric System with Artificial Neural Networks", Douglas Keith Swift, December 2007 (Currently Lead Systems Engineering at The Boeing Company).
    - "Architecting System of Systems: Artificial Life Analysis of Financial Market Behavior", Nil Hande Kilicay-Ergin, June 2007 (Systems Engineering Faculty at Penn State University)
  - Majority of our MS students works for The Boeing Company or other defense contractors.

RT-14 SE Data Standards

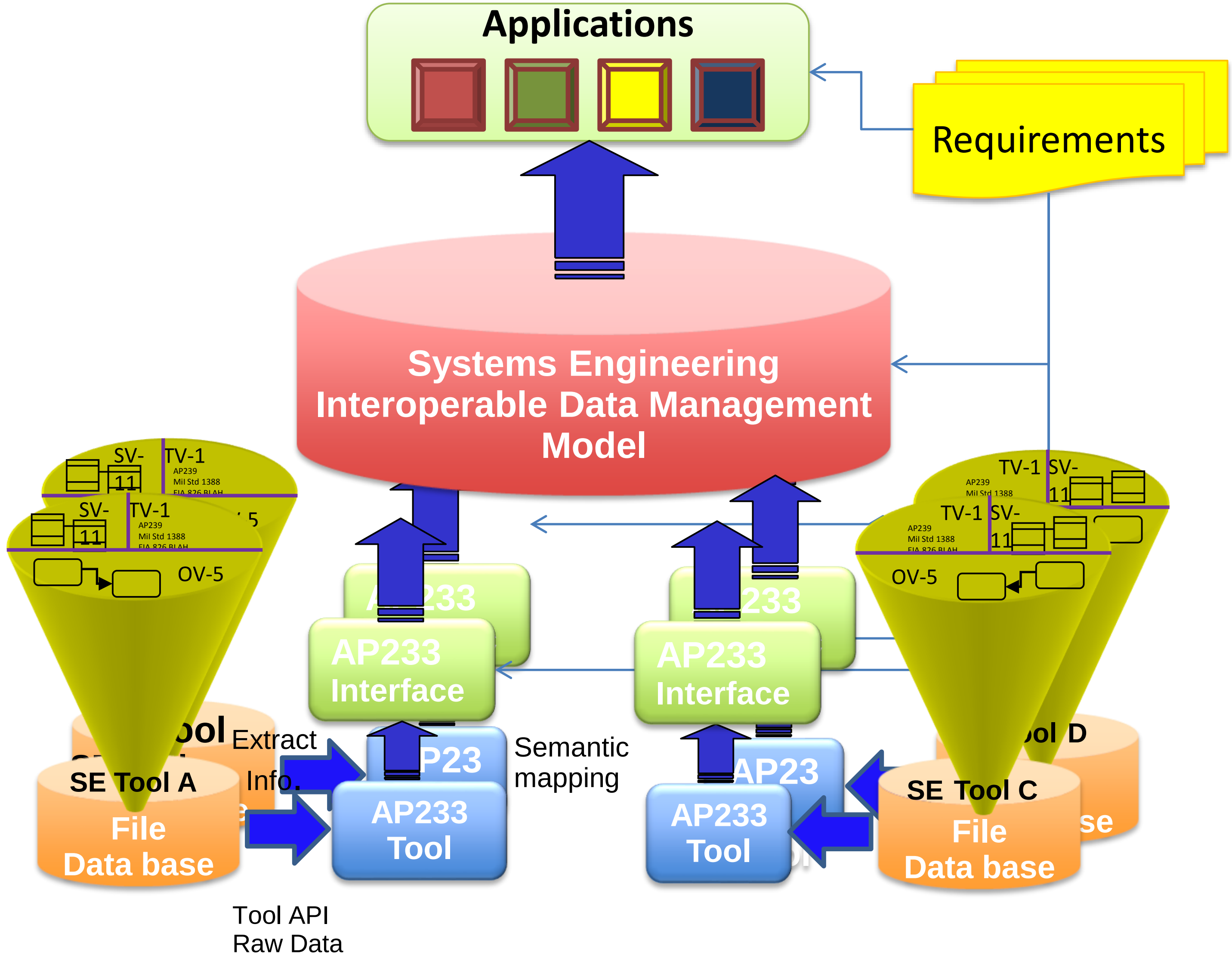
Full Title

Validating the Maturity and Benefits of adopting the International Standards Office (ISO), Standard Exchange Protocol (STEP) 10303; Systems Engineering Application Protocol 233 (AP-233) and Product Life Cycle Program Management Protocol 239 (AP-239) towards a Comprehensive and Integrated Systems Engineering and Program Management Data Exchange Environment.

Collaborators : Missouri S&T, Stevens and Pen State

RT-14 SE Data Standards

1. The current systems engineering tool sets contain inconsistent internal and proprietary data , semantics and technical data exchange formats.
2. It is extremely difficult to integrate system engineering data
3. Current Tools:
    1. Requirements management tools (DOORS, Requisite Pro)
    2. Architecture tools (ARTISAN, System Architect and CORE)
    3. Project management tools (MS Project, Primavera)
4. ISO STEP 10303 protocols enable the capability to develop a common data exchange standard and repository allowing proprietary tools and data to be truly independent.
5. The business case seems compelling because it allows the government and contractors to exchange data without having to dictate vendor applications to develop and exchange data



Applications
Requirements
Systems Engineering Interoperable Data Management Model
AP233 Interface
AP233 Interface
AP233 Tool
AP233 Tool
SE Tool A
File Data base
SE Tool C
File Data base
Extract Info.
Semantic mapping
Tool API Raw Data
SV-11
TV-1
OV-5
AP239
Mil Std 1388

RT-14 SE Data Standards

This research will have an impact on in all of the five thrusts of SERC Research Strategy :

- Enterprise Responsiveness
- Systems Science and Complexity
- Systems Engineering Workforce
- Program and SE Integration
- Life Cycle Systems Engineering Processes

A Methodology for Increased Accuracy in Architecture Assessment

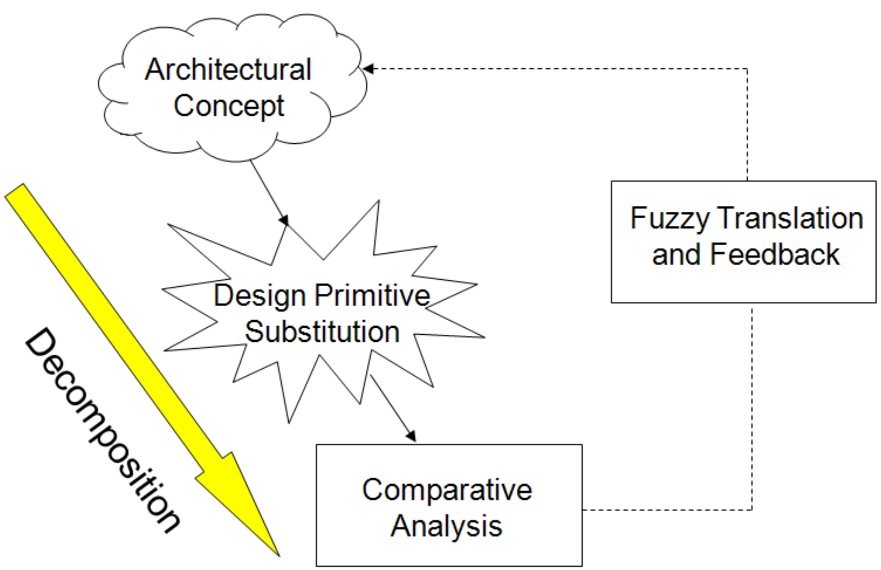
Jason Dauby (PhD Student)

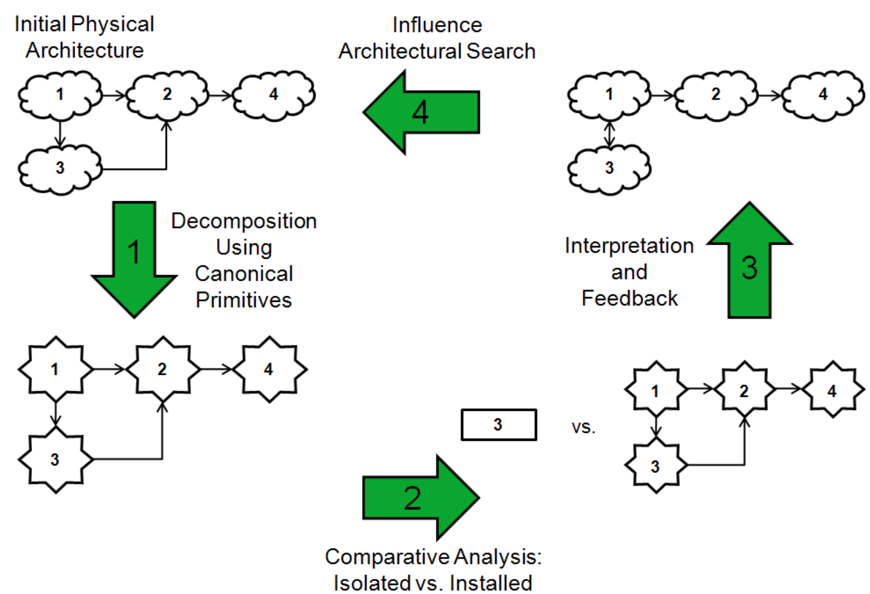
Dr. Cihan H Dagli (Advisor)

Research Need: Current architectural assessment techniques assume severability between system components and rely primarily on heuristics and professional judgment. An assessment technique is needed that can handle the ambiguous nature of system architecting while providing more detailed and realistic assessments of architectural attributes.

A Methodology for Increased Accuracy in Architecture Assessment

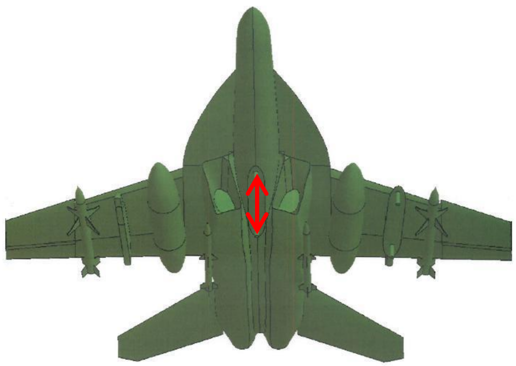
Research Description: This research is attempting to develop a methodology for providing more realistic and objective assessment of physical system architectures. The emerging methodology consists of four parts: extensible modeling, decomposition using canonical design primitives, comparative analysis, and fuzzy translation and feedback



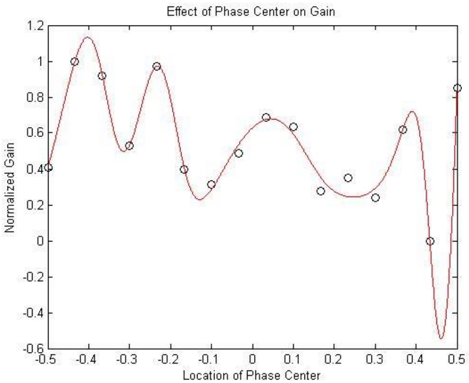


Preliminary Research Results and Status

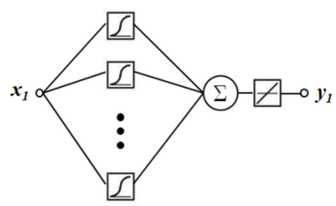
An Initial Physical Architecture:
RF Systems Integrated on an Air Vehicle Centerline



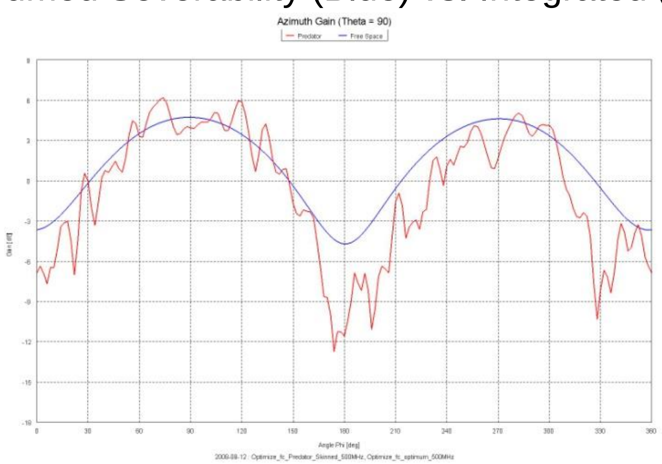
Comparative Analysis:
Integration Sensitivity Function and Response Surfaces

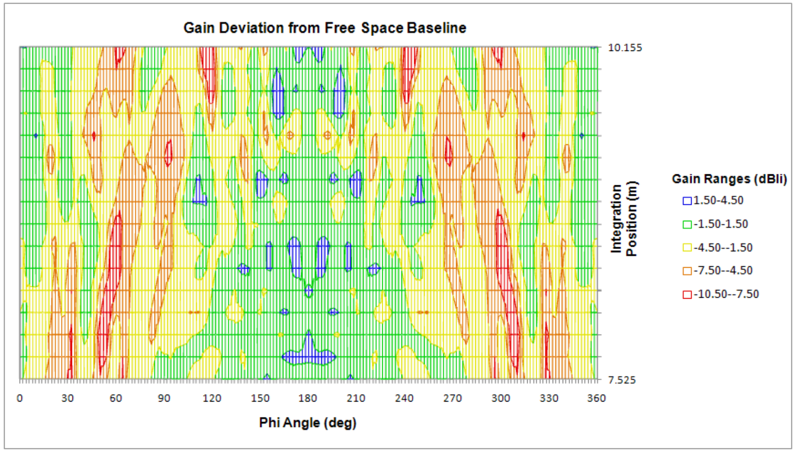


$$P_{INT} = P_{ISO} E_{INT} f(\phi, x)$$



Antenna Canonical Design Primitive:
Assumed Severability (Blue) vs. Integrated (Red)





Future Work: Fuzzy Translation and Feedback

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A Methodology for Increased Accuracy in Architecture Assessment

1. **Enterprise Responsiveness:**
   Modeling and Simulation. Research how to more rapidly and easily develop modeling and simulation tools that help validate concepts of operation, architectures, and other key systems engineering artifacts.

This research addresses the goal of validating architectural concepts and evolving designs through an innovative process of model sharing, using design tools from specialty domains, comparative analysis, and fuzzy assessments. The research strives to expose architectural sensitivities resulting from system integration and installation thereby allowing the architect to refine their search. It also allows systems engineers to understand and plan for the inherent characteristics of a physical architecture.

A Methodology for Increased Accuracy in Architecture Assessment

2. Basic Systems Science and Complexity Theory: Advance systems science and systems thinking as applied to the DoD's and IC's broad landscape of systems problems (complex systems)

Composition. Research how to determine key properties of a system (assurance, scalability, availability, producibility, interoperability, lethality, resilience, …) when (a) the properties of its subsystems are known, (b) the system architecture that links those subsystems is known, and (c) the concept of operations (use cases, scenarios, …) for the overall system is known.

The research characterizes the coupling variables that exist in system architecture. These coupling variables are often severed in the name of simplicity or lack of understanding. The result of this separation is an inability to determine the key properties identified in this thrust sub-goal. In this way, the research contributes to the ability to better understand key system properties.

A Methodology for Increased Accuracy in Architecture Assessment

5. Life Cycle Systems Engineering Processes: Advance system engineering life cycle processes (as defined in the Defense Acquisition Guidebook Chapter 4, Systems Engineering) to meet DoD and IC needs (weapons, SoS, cyber, net-centric services)

Architecting. Research how to create architectures that demonstrably and quantifiably support key system properties such as assurance, scalability, availability, producibility, interoperability, l ethality, and resilience, and how to derive architectural component characteristics and constraints from desired system properties.

This research focuses on quantitative predictors of fuzzy attributes. By incorporating coupling effects in architectural assessments, estimators of system properties are more realistic and accurate.

System Architecture Development Using Computational Intelligence

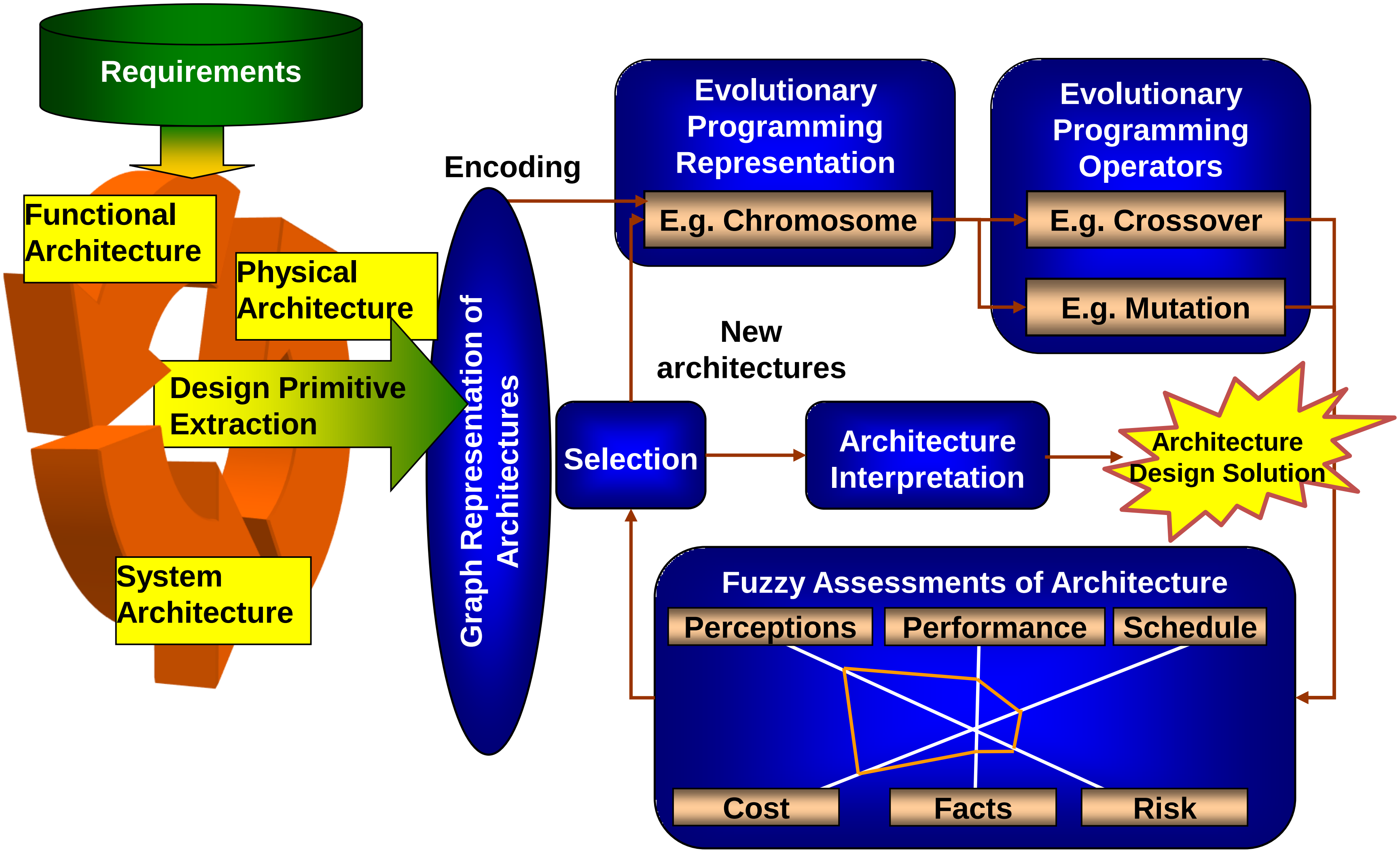
Renzhong Wang(PhD Student) Dr. Cihan H Dagli (Advisor)

- **Motivation:** Architecture design involves conceptual designs at various levels of abstractions, which entail abstract concept formulation and development. Due to its ambiguous, intangible, poorly defined, and uncertain characters, it is poorly supported by computer-aided design tools.
- **Objective:** Develop a set of approaches that supports the generation of system architecture solutions, permitting evolutionary search and exploration of optimum system architecture.
- **Components**: Architecture modeling, design primitive extraction, mathematical representation, architecture assessment, multiple-objective optimization, architecture interpretation.

System Architecture Development Using Computational Intelligence

- **Impact and significance:**
  - Evolve architecture design before commitment to detailed system design, thus reducing time, cost, and risks while improving design quality.
  - Reduce the architecting search space with structured architectural models that can handle ambiguity at different stages of the conceptual design.
  - Effectively address the ambiguity of requirements and performance measurement.
  - Automate architecture development and evolution process.
  - Exploit cross-domain experience and exercise multiple objectives optimization.
  - Architecture representation using graph theory.
  - Integrated architecture development framework / process.

System Architecture Development Using Computational Intelligence



SERC – Strategy Research Trust

Systems Science and Complexity: Advance systems science and systems thinking for application to engineering and management of complex systems and capabilities.

- This research will develop a system model that can be used to quantitatively access key system performances (e.g., robustness, flexibility, reliability, survivability, cost, risk, scalability, availability, producibility, interoperability, lethality, resilience, etc.) based on various properties and status of subsystems and components, the way that system components/ subsystems are connected through interfaces, the properties of the interfaces, and system requirements definitions (use cases, scenarios, …)

SERC – Strategy Research Trust

Systems Science and Complexity: Advance systems science and systems thinking for application to engineering and management of complex systems and capabilities.

- **Assessment:** This research will develop a way to quantitatively assess overall system performance as a function of system components, composition and configuration, to exploit cross-domain experience, and to exercise multiple objectives optimization.

System Architecture Development Using Computational Intelligence

SERC – Strategy Research Trust

Systems Science and Complexity: Advance systems science and systems thinking for application to engineering and management of complex systems and capabilities.

- **System Conceptualization**. This research involve system models at various levels of abstractions, which entail abstract concept formulation and development. In the earlier iterations of the system model development, requirements are transformed to abstract concepts in the form of design primitives. As system model development proceed, abstraction and ambiguity is reduced. The models developed in this process are then used to visualize and define system. This architecting process can therefore effectively address the ambiguity of requirements and performance measurements.

System Architecture Development Using Computational Intelligence

SERC – Strategy Research Trust

Systems Science and Complexity: Advance systems science and systems thinking for application to engineering and management of complex systems and capabilities.

- **Architecting:** This research will develop an architecting process that generate and evolve architecture designs to support key system properties (e.g., robustness, flexibility, reliability, survivability, cost, risk, scalability, availability, producibility, interoperability, lethality, resilience, etc.) according to requirements specification, and to derive architectural component characteristics and constraints from desired system properties.

System Architecture Development Using Computational Intelligence

SERC – Strategy Research Trust

Systems Science and Complexity: Advance systems science and systems thinking for application to engineering and management of complex systems and capabilities.

- **Integrated architecture development framework process:** This research will develop an architecting process that incorporate various computational intelligence techniques and modeling techniques into one framework, which can automate architecture development and evolution process.
- **Modeling:** This research entail architecture representation using both mathematical model and graphic based model. Graph theory and its application will be explored.

Multi-Objective Evolutionary Algorithm Based Conceptual Design: Search Evaluation and Selection

Atmika Singh(PhD Student) Dr. Cihan H Dagli (Advisor)

Motivation: Information available during the conceptual design stage is marked by uncertainty, imprecision and subjectivity. Research shows that nearly %80 of budgetary and resource allocation decisions are made during this phase. The cost of not exploring all possible concept variants are very high. There exists the need for a computationally in expensive design search and evaluation strategy that assists the decision- maker in exploring the entire design space.

Multi-objective Evolutionary Algorithm Based Conceptual Design: Search, Evaluation and Selection

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Motivation: Information available during the conceptual design phase is marked by uncertainty, imprecision and subjectivity. Research shows that nearly 80% of budgetary and resource allocation decisions are made during this phase. The cost of not exploring all possible concept variants is therefore very high. There exists the need for a computationally inexpensive design search and evaluation strategy that assists the decision-maker in exploring the entire design space.

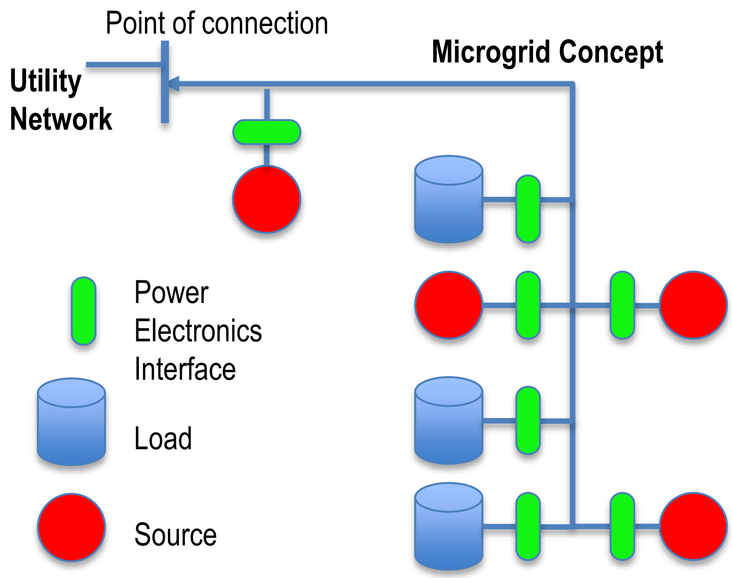
Problem Description: The objective of this research is to use computationally intelligent techniques to generate and evaluate multiple architecture alternatives using decision-maker preferences captured at a high level.

Application Domain: The developed methodology will be applied to the design of a model micro power grid. A microgrid is a collection of small, distributed power sources, storage devices and power electronics operated as a 'system of energy systems' *.

Search
- Multi-objective evolutionary algorithms to search the space of feasible concept variants.

Evaluation
- Fuzzy Bayesian Decision making techniques to elicit, represent , evaluate and aggregate decision-maker preferences.

Selection
- Graphical representations of concept architectures for an interactive human-in-the-loop design selection and refinement process.



* M. Barnes, J. Kondoh, H. Asano, J. Oyarzabal, G. Ventakaramanan, R. Lasseter, N. Hatziargyriou, and T. Green, "Real-World MicroGrids¿An Overview," *System of Systems Engineering, 2007. SoSE '07. IEEE International Conference on*, 2007, pp. 1-8.

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Multi-objective Evolutionary Algorithm Based Conceptual Design: Search, Evaluation and Selection

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Preliminary Algorithm, Results and Future Work: As a preliminary exercise a model smart grid architecture was evaluated using fuzzy architecture attributes to determine the optimal number of inter-system interfaces. Future work will include improving the fuzzy architecture assessor and developing a graph based architecture visualization technique.

Create and define the evaluation attributes → Create the design vector for architecture representation → Apply search algorithms → Pick a population of designs → Convert the design vector into assessor input → Evaluate using fuzzy assessor → Converge on system architecture with highest fitness

Model Smart Grid Architecture Representation

Systems/Services	Label
Distributed resource management system Distribution management and control system Automated feeder management system Voltage and reactive support system Distributed substation management system	M2 M7 M3 M5 M4
Smart meter operations system Meter and sensor data management system Data storage system Data analysis and forecasting system	M9 M11 M10 M8
Equipment monitoring system Equipment maintenance system	M6 M1
Communication network maintenance system	M12

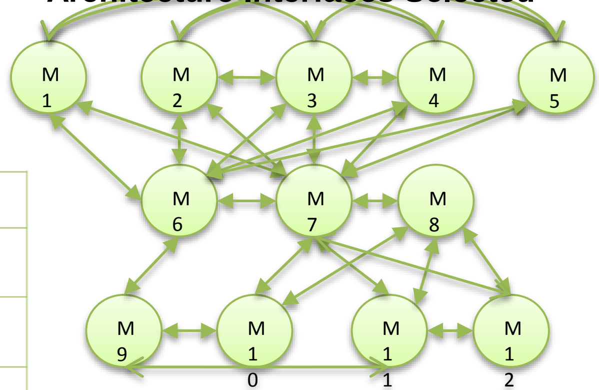
Layer 1	M1, M2, M3, M4, M5
Layer 2	M6, M7, M8
Layer 3	M9, M10, M11, M12

Attributes	Rules
Affordability	$\frac{100}{\text{total no. of connections}} \sum \text{cost weights}$
Complexity	$\frac{100}{\text{total no. of connections}} \sum \text{connection weights}$
Flexibility	1-Complexity
Maintainability	$\frac{100}{\text{total no. of connections}} \sum \text{connection weights to M6}$
Reliability	$\frac{100}{\text{total no. of connections}} \sum \text{connection weights to M7}$

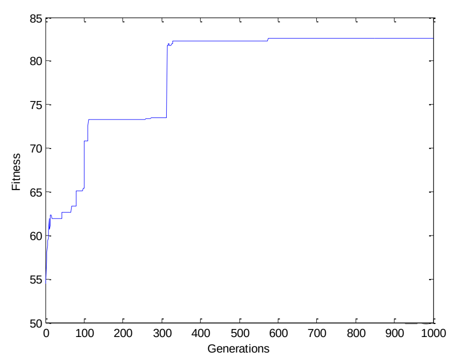
Calculation of inputs to the assessor

The Fuzzy assessor calculates the fitness on the basis of the 5 key attributes shown in the table.

Architecture Interfaces Selected



Generations vs Fitness



SERC – Strategy Research Thrust

Systems Science and Complexity: Advance systems science and systems thinking for application to engineering and management of complex systems and capabilities.

Multi-Objective Evolutionary Algorithm Based Conceptual Design: Search Evaluation and Selection

SERC Research Thrust Areas	Research Alignment
Composition. Research how to determine key properties of a system (assurance, scalability, availability, producibility, interoperability, lethality, resilience, …) when (a) the properties of its subsystems are known, (b) the system architecture that links those subsystems is known, and (c) the concept of operations (use cases, scenarios, …) for the overall system is known.	• This research will provide a quantitative basis to the design of complex adaptive systems, in particular the smart power grid. • A number of qualitative and heuristic methods do exist but none of these provide a quantifiable and mathematically sound basis to the architecting process. This research aims to fill that void. • This research aims to use fuzzy linguistic techniques to convert decision-maker expectations and system concept of operations into quantitative design evaluation criteria or key system attributes. • The quantified design evaluation criteria will be used to explore design alternatives that quantifiably satisfy key system attributes.

Multi-Objective Evolutionary Algorithm Based Conceptual Design: Search Evaluation and Selection

SERC Research Thrust Areas	Research Alignment
Emergence. Research how to manage emergence in requirements, technology, and system usage in a way that is beneficial or benign rather than disruptive to development and acquisition programs; and how to detect, shape, and possibly mitigate emergent properties and behaviors.	• Evaluation attributes will be designed such that they adequately represent emergence and resilience as key system attributes • Architectural alternatives generated using the proposed methodology will have the ability to evolve based on changing system attributes and emerging requirements

Multi-Objective Evolutionary Algorithm Based Conceptual Design: Search Evaluation and Selection

SERC Research Thrust Areas	Research Alignment
System Conceptualization. Research approaches to better visualize and define system concepts that enable collaboration among multiple stakeholders.	• The main objective of this research is to enable the exploration of all possible concept variants at an early stage in the design process • This will allow decision-makers to visualize the cost and benefits of all design options and enable smoother collaboration among stakeholders.

Requirement Impact and Risk Assessment Tools

Shikhar Acharya (PhD Student) Dr. Ivan Guardiola(Advisor)

Motivation: Through the mathematical formulation of interdependencies and interfaces a rough but reliable assessment of Systems Requirements Impact and Risk can be attained. We look at the combinatorial properties of a proposed architecture and is hierarchy in an effort to quantify the risk associated with requirements. Through the incorporation of mathematical modeling basic architecture schemas can be evaluated for identifying those requirements whose impact is outside of comfort levels. This allows for a proactive risk management rather than reactive. SE efforts can use such a tool in order to highlight requirements that pose as high risk and or are of high impact in order to develop better management of requirements throughout the system’s life cycle.

Requirement Impact and Risk Assessment Tools

Shikhar Acharya (PhD Student) Dr. Ivan Guardiola(Advisor)

Methodologies: Mathematical model representing basic architecture dependencies and interfaces are quantified by looking at the permutations and combinations of requirements. Each requirement can then be classified and weighted through the mathematical model. The weights will allow for better requirement change impact on the overall system architecture. Hence, through a basic mathematical formulation using combinations and permutations can a weight be attributed to a system requirement and its correlation to other system attributes can be determined. This weighing methodology will result in better requirement business practices as high impact requirements can be discovered and their risk be mitigated through proactive planning.

Wireless Mobile Adhoc Networks Architecture Generation using Computational Intelligence

Tom Sapienza (PhD Student) Dr. Ann Miller, Dr. Cihan Dagli (Advisors)

Motivation: Guarantee of Quality of Service (QoS) performance is especially acute for wireless networks which are plagued by sparse bandwidth, atmospheric phenomenon, low battery power, and node mobility. There is a need for an architecture generation algorithms to help the engineers designing these systems so that conflicting performance measures are balanced and viable design alternatives are evaluated.

Proposed Approach: The research is currently in at infancy stage. The intent is to use network simulators to assess a given architecture based Quality of Service performance measures and evolve new architecture using computational intelligence tools.

Research Topics of Systems Engineering MS Students

Jayakanth Jayachandran (MS Student)-Dr. Steven Corns (Advisor)

Virtual Engineering Tools for Systems Engineering Effectiveness

Akshay Kande (MS Student)-Dr. Steven Corns (Advisor)

Coupling Virtual Engineering Environment to SysML

Ashik Chandra (MS Student)-Dr. Cihan Dagli (Advisor)

Synergy between Biology and Systems Resilience

How to obtain Missouri S&T research documents?

Scholarsmine is the data base for S&T Research Documents. Most of the publications of faculty, MS thesis and PhD dissertations are stored digitally in this data base. The site is http://scholarsmine.mst.edu