INCOSE Healthcare Working Group

4th Annual Systems Engineering in Healthcare Conference

Improving Operating Room Design through Innovative Systems Engineering Methodology

By: Anthony Millán

Johns Hopkins Whiting School of Engineering

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Background

Presenter: Anthony Millán

- Missile Defense Engineer – Johns Hopkins Applied Physics Laboratory
  - System-level performance analysis of ballistic missile defense systems
- BS Mechanical Engineering – University of Puerto Rico
- MSE Systems Engineering – Johns Hopkins University
  - Master's Thesis – Tailoring a Systems Engineering Methodology for the META Design Flow
  - Inspired by exposure to the META Design Flow while working as an analysis software beta tester as part of DARPA FANG 2 program in 2013
- The purpose of this presentation is to discuss the potential benefits of applying the META Design Flow to the field of operating room (OR) design
  - Potential case study to demonstrate the feasibility of an end-to-end META Design Flow methodology

META Design Flow Origin

DARPA Adaptive Vehicle Make (AVM) Portfolio

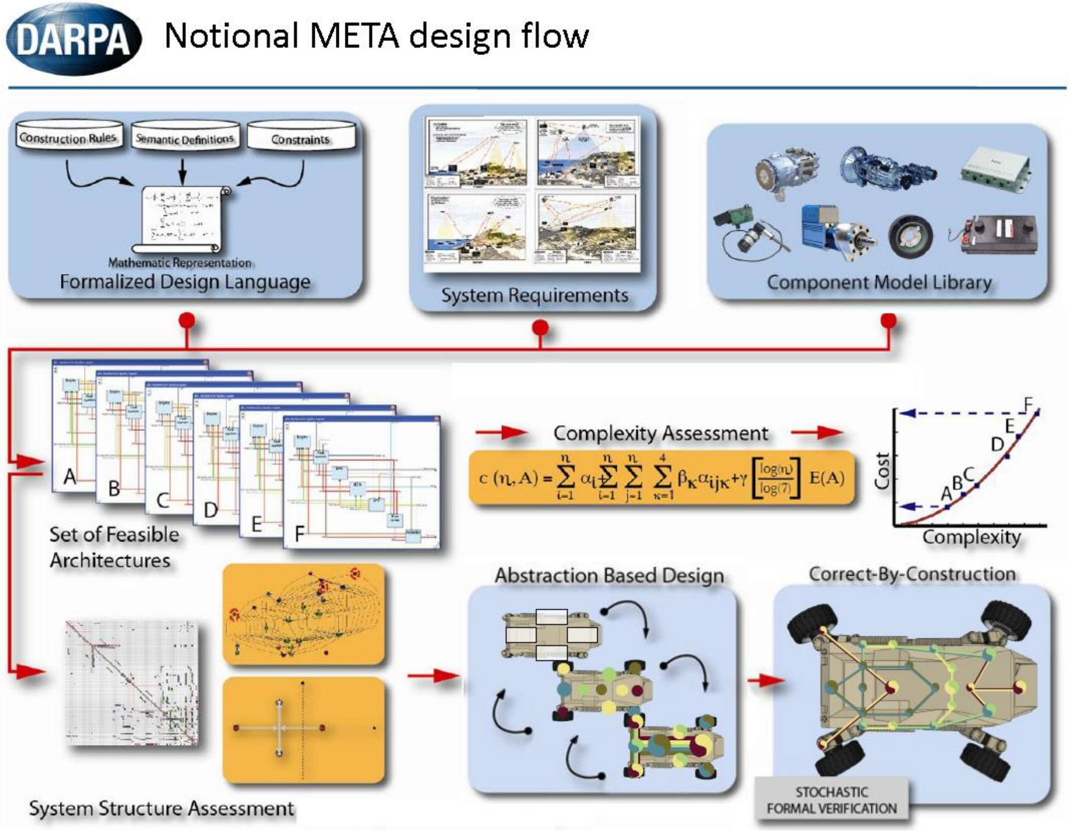
- Motivation
  - Around 2010, DARPA identified shortcomings in the application of traditional Systems Engineering to military system, which were failing to cope with increasing complexity
- Purpose
  - Fundamentally transform design, analysis, verification and manufacture of systems to overcome observed trends of increasing system complexity
  - Compress the development timelines for new complex cyber-physical systems by at least 5X
- Programs
  - META – focused on the transformation of the systems engineering design, analysis and verification processes for military systems
  - iFab – focused on developing a reconfigurable manufacturing facility to adjust to specific manufacturing needs
  - VehicleFORGE – Focused on methods for crowdsourcing the system development effort supported by the tools from the other programs

META Design Flow

- As part of the META program, DARPA proposed a new system development "design flow" to overcome complexity in military system development – the META Design Flow

Prerequisites

1. Formalized design language to support Model-Based Systems Engineering (MBSE) complete with standardized modeling rules and logic, semantic definitions and constraints
2. Defined system-level requirements and concept
3. Component model library with fully defined structural and performance-based models of all possible system components

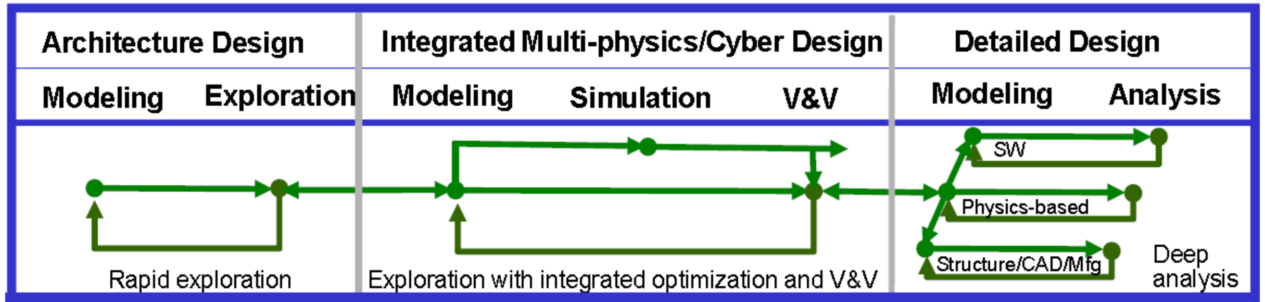


Source: DARPA - iFAB Foundry / FANG Proposers' Day

META Design Flow (Continued)

Stages

- Develop an optimized system-level logical architecture taking into account the requirements and the available components
- Define physical architecture alternatives from all possible component combinations
- Execute the architecture alternatives through automated analysis tools to exclude from consideration poor performers
- Increase modeling and analysis fidelity and iterate until final architecture is selected



Architecture Design	Integrated Multi-physics/Cyber Design	Detailed Design
• Architecture Modeling • Design Space + Static Constraint Modeling • Static Component Modeling (multiphysics)	• Design Space + Behavioral Constraint Modeling • Architecture Modeling • Dynamics Modeling (multiple abstractions and multiphysics) • CAD/assembly modeling • Coarse Manufacturing Constraint Modeling	• Architecture Modeling • Detailed Domain Modeling – CAD – FEA; thermal, fluid… – Surrogate gen. • Detailed Mfg. modeling • RT SW modeling

Source: ISIS/Vanderbilt University - The META Toolchain: Accomplishments and Open Challenges

Potential to Improve SE Practice

MBSE Benefits

- Promotes use of modular, open systems approach (MOSA)
- Promotes design of tightly bound, loosely coupled architectures
- Shift in SE effort to early stages of development
- Increased level of abstraction in design
- Model-based verification
- Faster requirement-based trade studies

Additional Benefits

- Composing system design from pre-defined lower level models
- Reduced development time for complex systems
- Correct-by-construction designs
- Optimizing for system complexity and adaptability instead of functional performance metrics
- Increasing return on investment for repeated uses

The META Design Flow leverages and expands benefits of using MBSE

Applicability to OR Design

Operating room (OR) design was identified early as a potential candidate for the application for the META Design Flow outside of military system development

- Why?

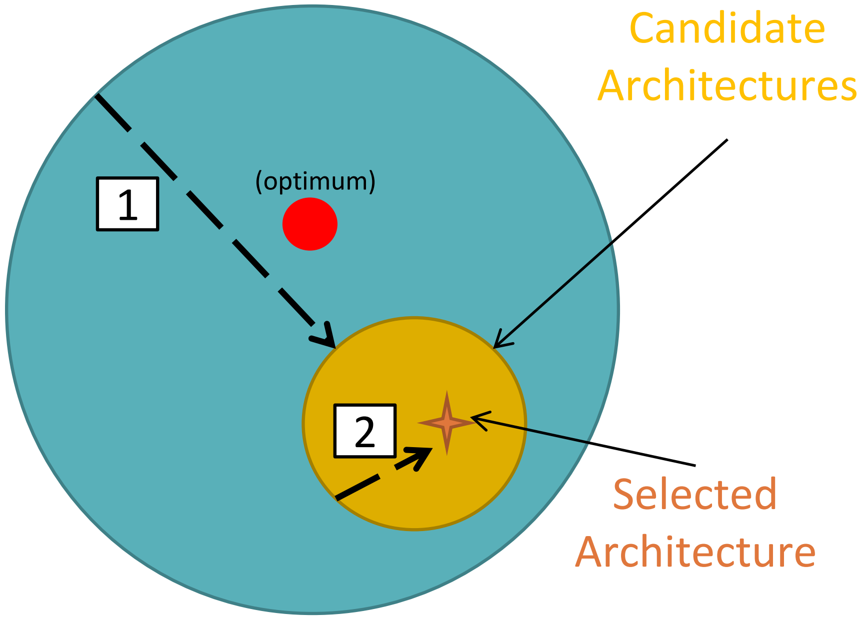
1. The problem is compatible with the META Design Flow:
   - OR design does not follow top-down development (OR architecture developed first, medical equipment developed specifically for the architecture)
   - Instead, medical equipment often developed independently to perform specific functions, and integrated into a federated system based on user needs
   - Modularity and interoperability are virtual necessities of modern medical equipment
   - Medical equipment performance can be modeled in low-fidelity, enabling automated analysis

2. The META Design Flow provides specific benefits when applied to this problem:
   - Shifting the focus of OR design to the system-level architecture reduces unexpected emergent behaviors (such as cable interference, conflicting alerts, display clutter)
   - Reducing system complexity is by itself a source of value in OR design
   - Increased system adaptability reduces cost of equipment changes
   - Increased return on investment for subsequent OR designs (medical equipment models already in place, just change the architecture and optimization function)

OR Design Improvement Example
(From a Systems Engineering Perspective)

Traditional OR Design

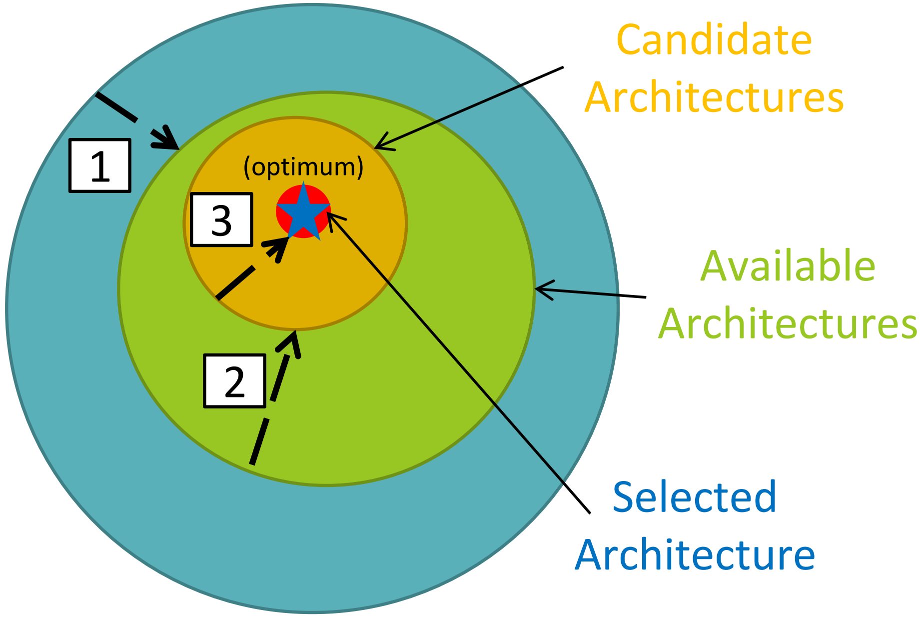
Entire Component Design Space



1. Candidate architectures composed of medical equipment combinations are selected based on performance metrics
2. Final architecture is selected from an analysis of the candidates, often focused on cost-benefit tradeoffs

OR Design Using META Design Flow

Entire Component Design Space



1. Model database of commercially available medical equipment defines alternatives
2. Unfeasible architectures excluded through requirements-based analysis
3. Final architecture selected to optimize performance and adaptability

Motivation for Thesis Research

"If application of the META Design Flow has so many potential benefits, why has it not been broadly applied in fields outside of military system development?"

- Limited exposure outside of DARPA program
- No documented theoretical support for its applicability in other fields
- No research previously done about modifications required for the SE process and activities to support its application in projects

Philosophical viewpoint

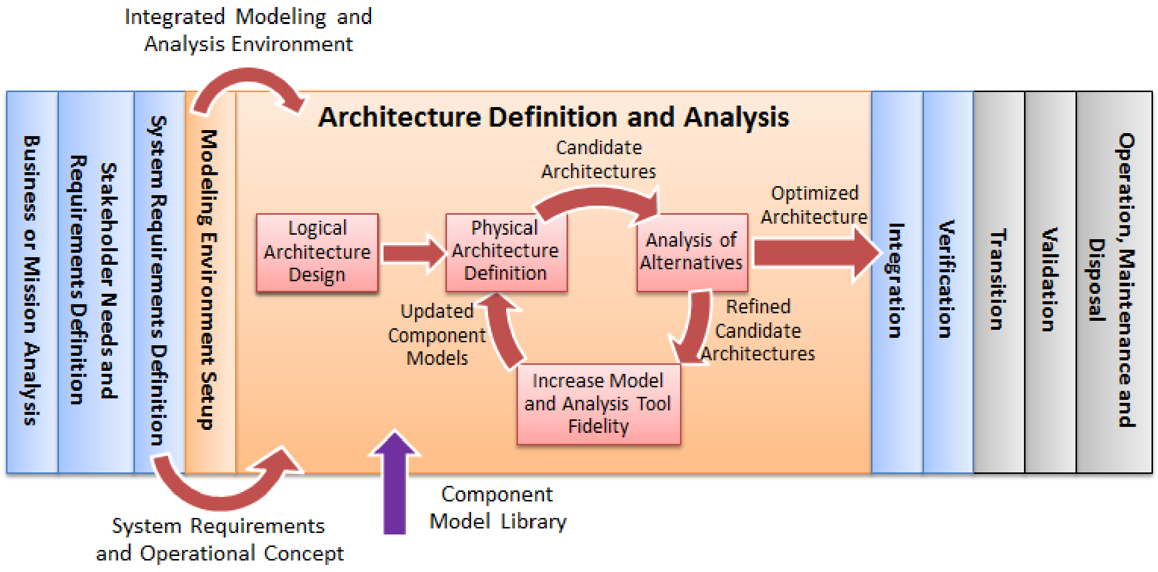
- Traditional SE methodologies are not always the best approach for specific fields or projects
- Development of MBSE tools has provided an opportunity to fundamentally transform SE practice
- Tailoring should also be applied at the methodology level to make better use of available tools and address specific project and enterprise needs

Research Purpose

- Expand the theoretical foundation of the META Design Flow through a specifically tailored end-to-end SE methodology that incorporates it
- Provide additional guidance for its use in other fields where it could improve system development processes

Ongoing Research

- After analyzing 14 Systems Engineering methodologies, one methodology was selected and tailored to incorporate the META Design Flow
  - Process and results to be documented in research paper
  - Due to time constraints, validation of the proposed methodology was limited to a review by subject matter experts and a survey



- Next Step: Further validate and refine the methodology through case studies
  - Potential research extensions currently being explored to provide actual case studies to support the methodology's feasibility:
    - Operating room architecture design from medical equipment model database
    - Missile design optimization from deterministic component models
    - Development of federated system-of-systems using deployed defense systems

Takeaways

- From a Systems Engineering perspective:
  - As technology evolves to provide increasing value to users, system complexity continues to be a challenge of modern system development efforts
  - Emerging advances in Systems Engineering methodologies and tools can be leveraged to come up with innovative solutions to overcome increasing system complexity
  - The specific characteristics of systems in fields such as operating room design and healthcare systems engineering provide an opportunity to break with traditional Systems Engineering approaches and tailor methodologies to meet the system's specific needs

- From an OR design perspective:
  - Treating the entire OR as a system and shifting the focus of OR design towards the system-level architecture can result in improved performance and reduced operational costs
  - There are available and emerging Systems Engineering tools and methods that can facilitate OR design and improve its effectiveness
  - Using a methodology that incorporates the META Design Flow for OR design efforts can provide common benefits of MBSE approaches, increase the probability of achieving a truly optimized architecture, and increase the scope of the analysis to include more components as candidates

Thank you for attending!
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