VT National Security Institute - Complex Systems Division

Advancing Systems Engineering through a Mathematically-Rigorous Co-Pilot

Paul Wach, PhD, Research Assistant Professor

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SERC Workshop on AI4SE

Some Upfront Thank You(s)!

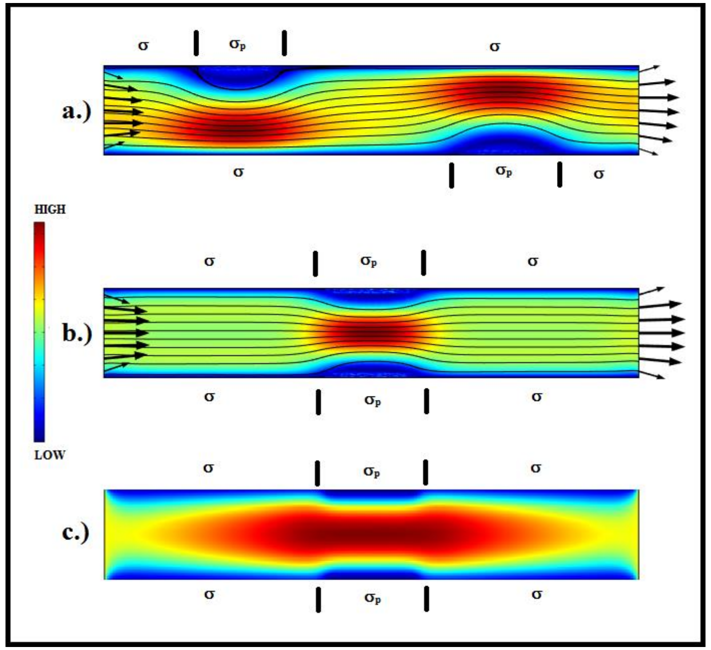
https://ms4systems.com/

- The work has been realized thanks to several contributors and sponsors
- Collaborators include:
  - Bernie Zeigler, DH Kim, and RTSync associates
    - Content shared with permission
  - Brad Philipbar, Senior Wargaming Fellow, Institute for Future Conflict (IFC), USAFA
    - Content shared with permission
  - Peter Beling, Adi Iyer, Grant Anderson, Mary Nerayo, Cameron Curran, Bhavya Shanmugum

How does Systems Engineering Maturity Compare to Other Engineering Domains?

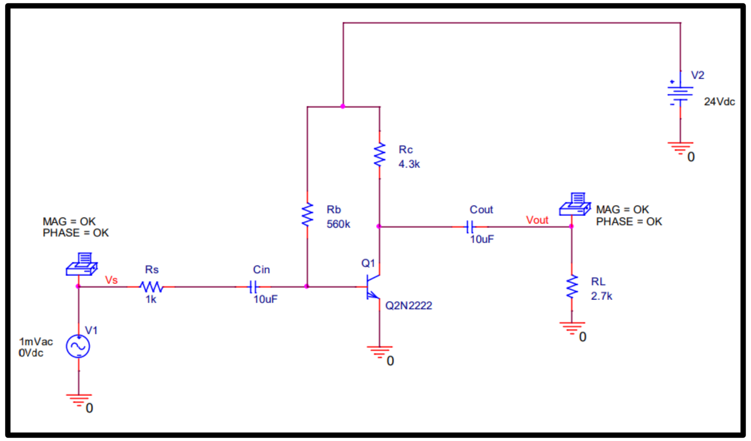
- Engineering domains (other than Systems Engineering) have theoretical foundations upon which software platforms are implemented

- Reinvigorated calls for theoretical foundations of SE

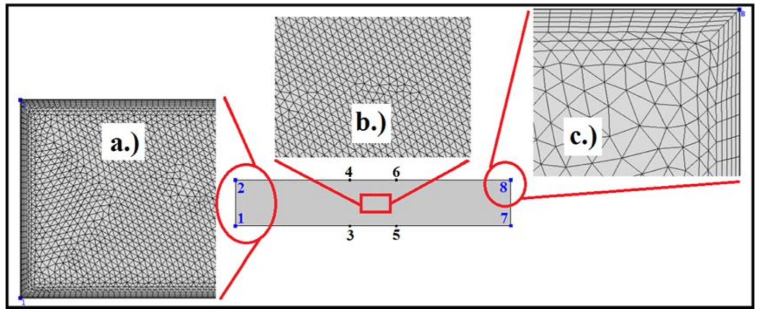


^ Computational fluid dynamics ^

PSpice



https://engineering.purdue.edu/~ee255/lecturesupp_files/PSpice-Tutorial.pdf

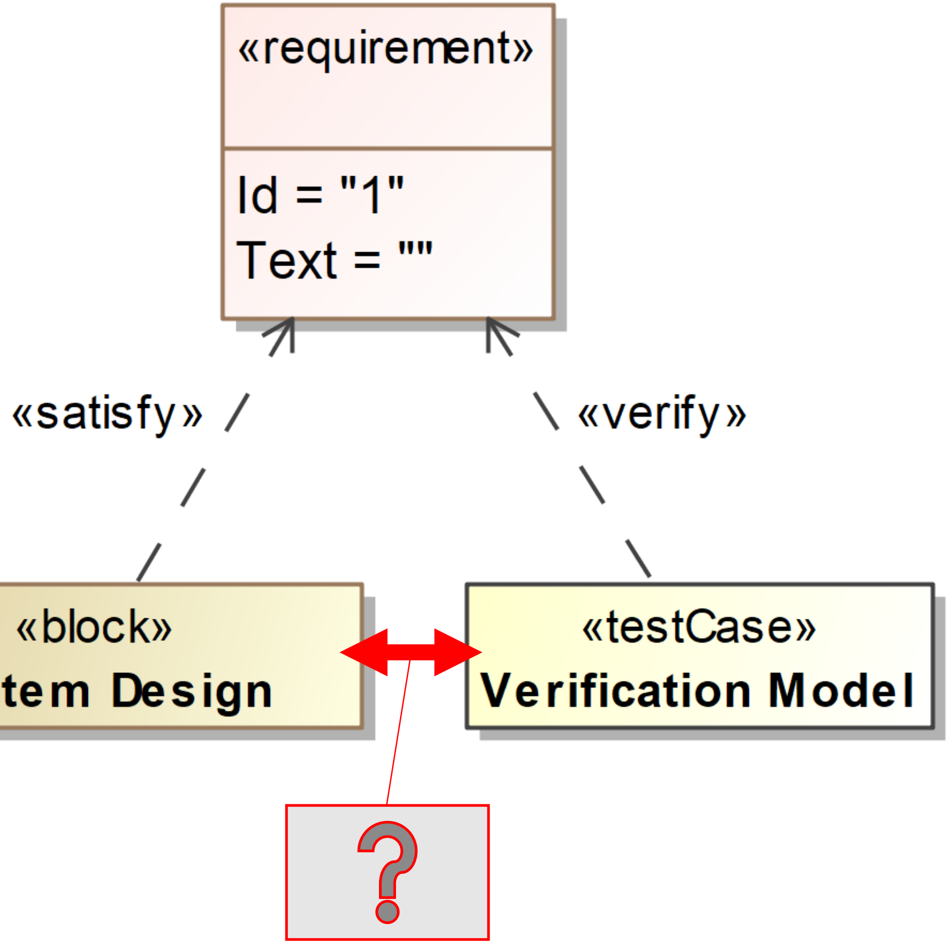


^ Finite element analysis ^

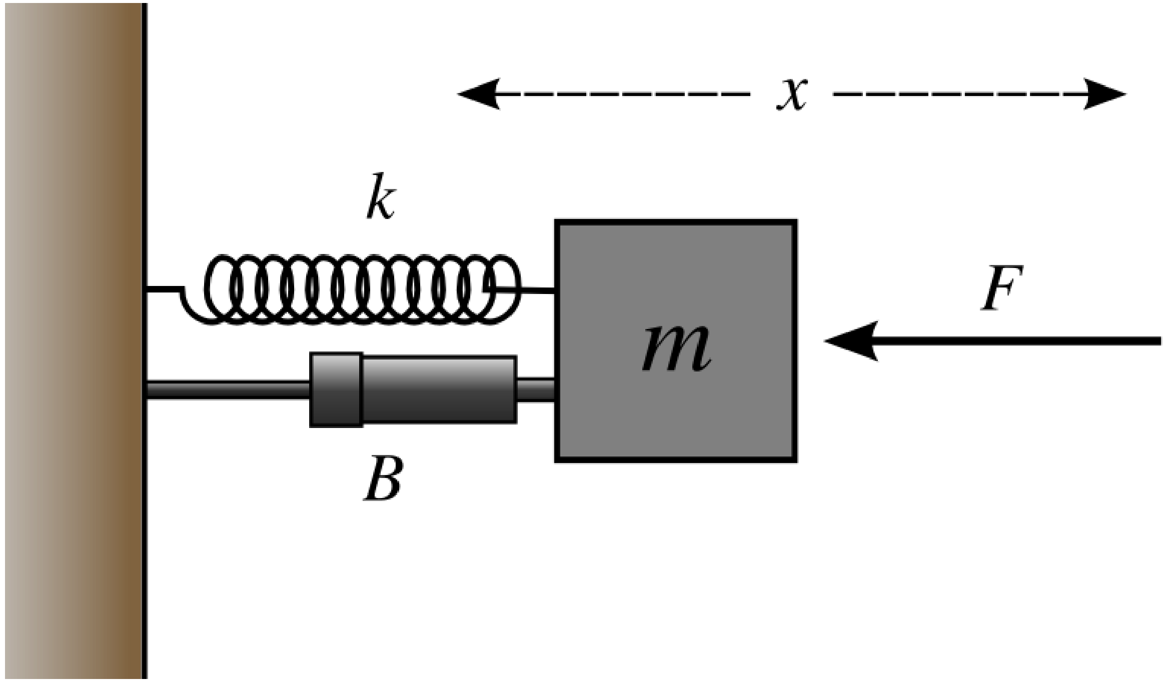
How does Systems Engineering Maturity Compare to Other Engineering Domains?

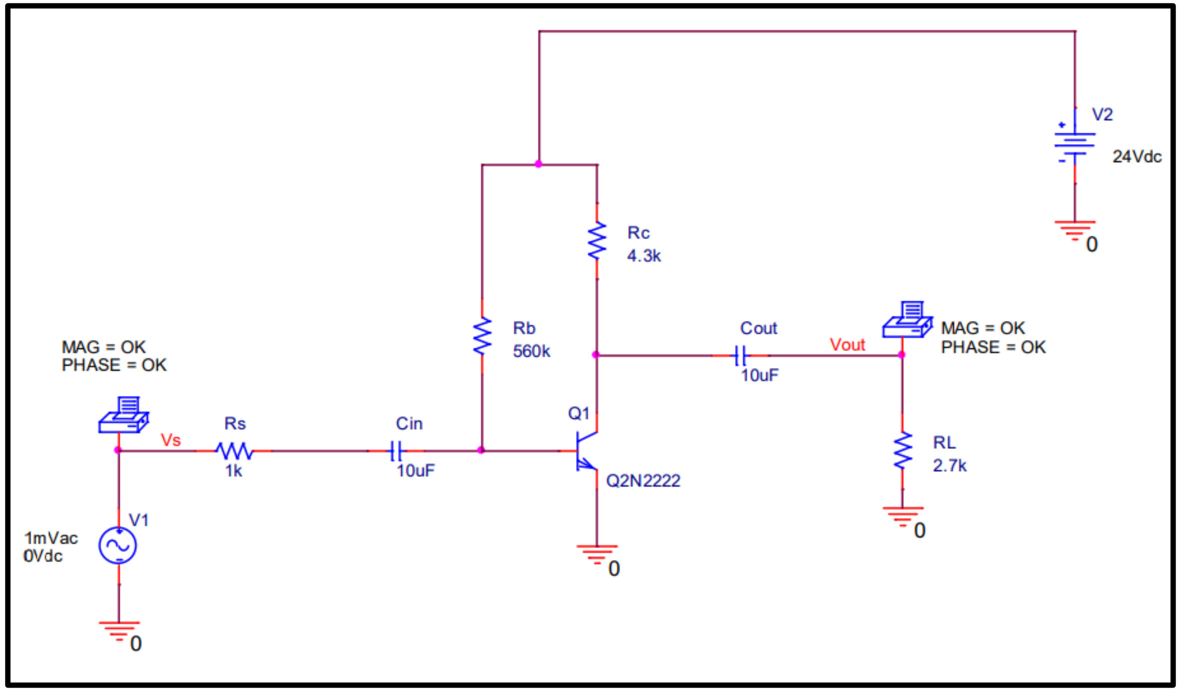
- Current forms of Model-Based Systems Engineering (MBSE) are descriptive and do not have theoretical foundations

- A systematic literature review of ~2,000 articles suggests that theoretical foundations for MBSE are nascent



Example of Rich Mathematical Foundations for Systems Engineering to Draw Upon





Well-known equivalence between a mechanical mass-spring (left) and electric circuit (right)

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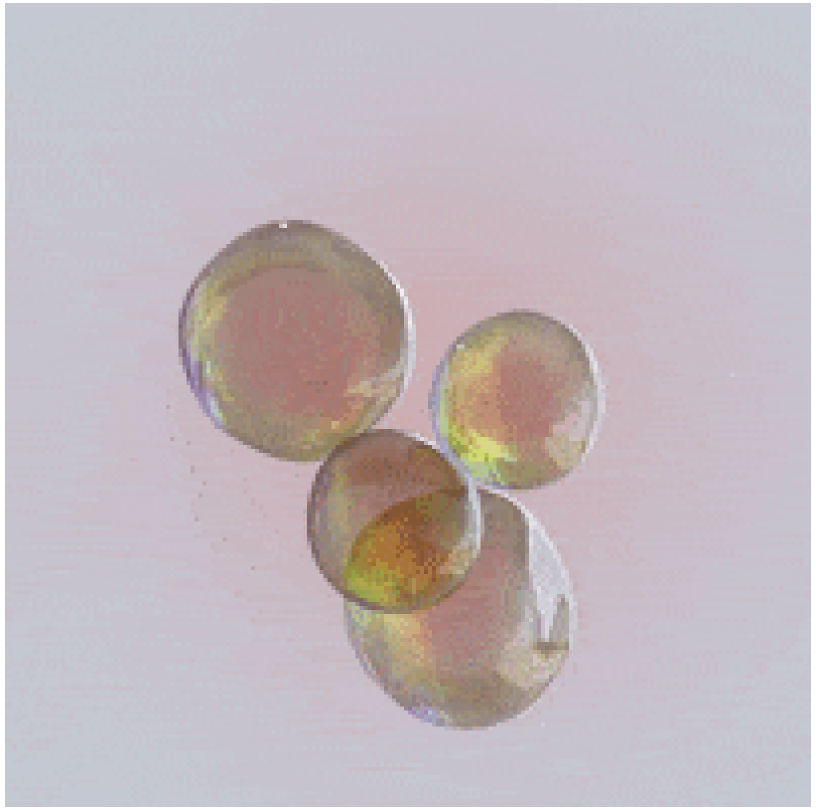
Example of Rich Mathematical Foundations for Systems Engineering to Draw Upon

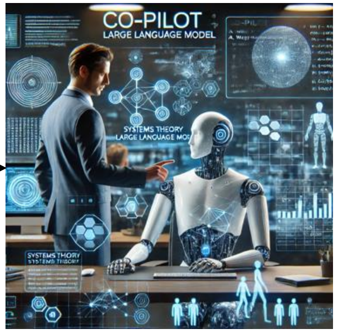


Less-known equivalence between a
Micro-/nanofluidic bubble (left)
and
Capacitor (~right)

Shifting to Agentic AI for the Co-Pilot

User Interface

AI Orchestrator (e.g., LLM)



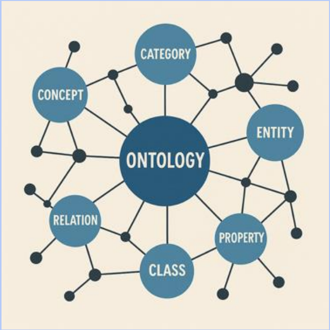
Hybrid Orchestration Framework
(e.g., LangGraph + Strands)
MCP

TOOLS

Data storage/library

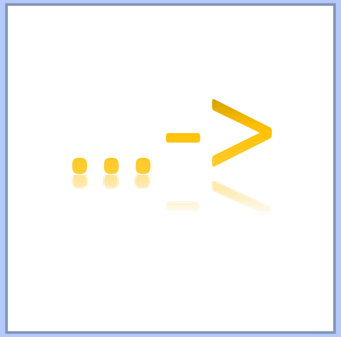
Science-based algorithms

Ontology



GPS Domain specific knowledge/tools

Domain specific knowledge/tools



ArcadeDB GNURadio THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

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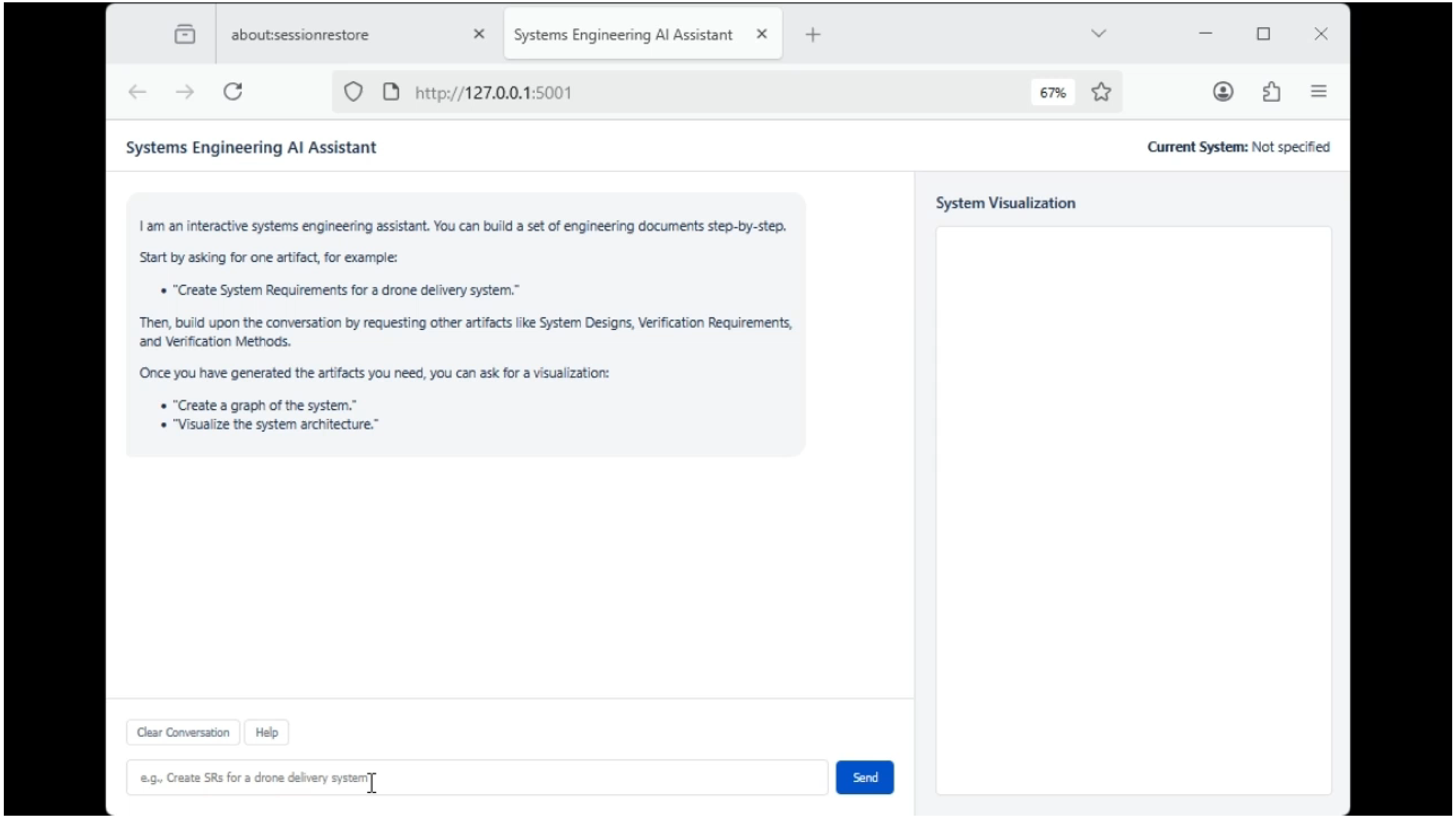
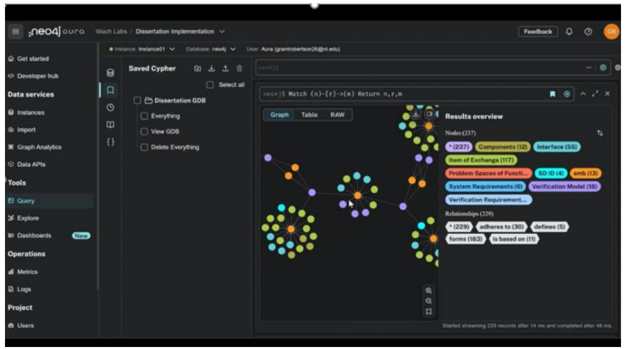
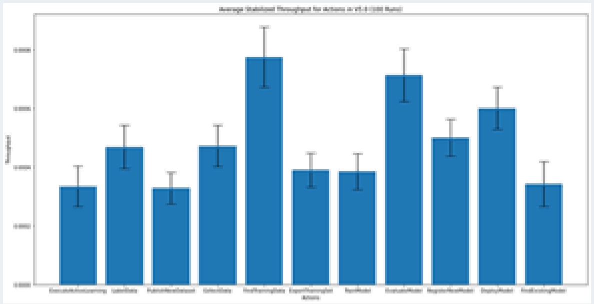
Demo Video 2: Current State of the Co-Pilot



Kudos to
Aditya (Adi) Iyer and
Grant Anderson

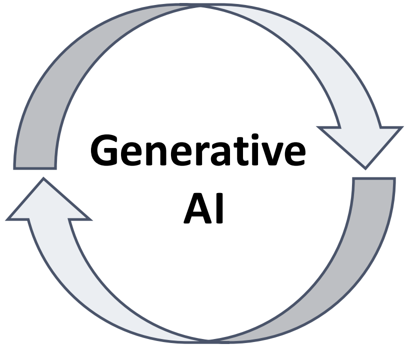


Discrete Event System Specification (DEVS)



System Requirements and Operation Environment

Analysis and Design Optimization



Functional System Architecture

Modeling and Simulation

Integration Support Linking of High-Level Architecture Products and Downstream Models and Simulators

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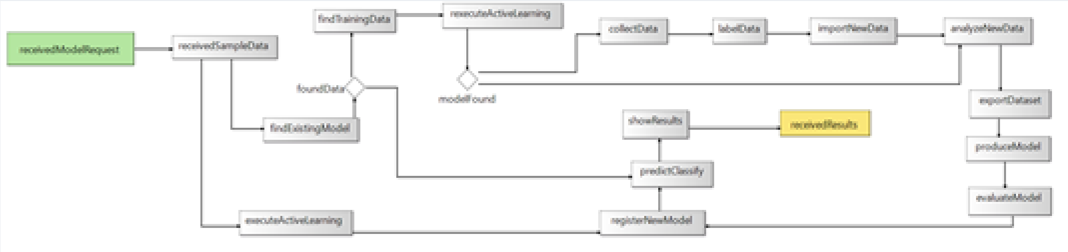

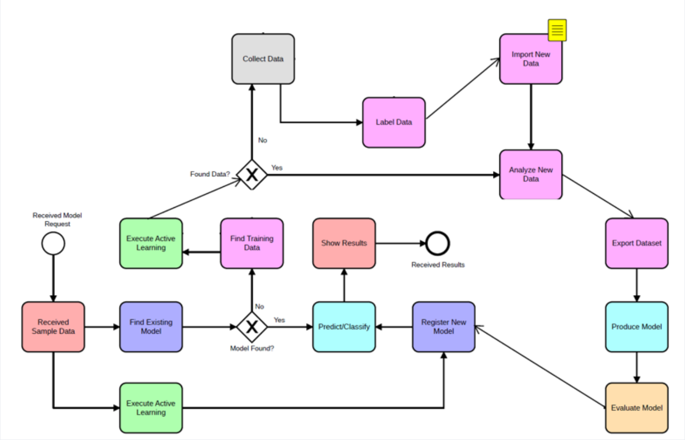

Demonstrated Efficiency Gain

RTSync

	Model Extraction	Model Outline Generation	DEVS Model Code Generation	Code Verification and Validation
Manual Labor *(130 Hours)*	20 Hours	50 Hours	50 Hours	10 Hours
LLM-Assisted DEVS Model Workflow *(Development and Subsequent use: 10 hours)*	2 Hours	3 Hours	3 Hours	2 Hours

~90% Reduction of Development and Subsequent Use Time

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Rapid Development of Neural Swarm-Optimized Kill Chain Analytics

Introduction and Indo-Pacific Context

Modern military operations in the Indo-Pacific theater demand unprecedented speed and integration across domains. The canonical kill chain — Find, Fix, Track, Target, Engage, Assess (F2T2EA) — must be executed against fast-moving threats (e.g., hypersonic missiles, mobile launchers) in compressed timeframes [1][2]. Adversaries such as China are fielding a resilient *kill web* of networked sensors and shooters, especially in space, to shorten their own kill chains. For instance, China's kill web links hundreds of ISR satellites directly to terrestrial strike units, enabling targeting and engagement within seconds [3]. U.S. Space Force officials warn that this satellite-enabled web can find, fix, and track U.S. forces over vast distances, posing a grave threat in the Indo-Pacific region [3][4].

This page implements the paper's core model: a probabilistic treatment of the sequential F2T2E process following Rice's framework, plus sensitivity analysis, with a focus on Indo-Pacific kill-web implications.

Probabilistic Modeling of F2T2E

Let the times to complete each phase be independent exponentials: $t_i \sim \mathrm{Exp}(\lambda_i)$ with mean $\theta_i = 1/\lambda_i$, for $i = 1, \ldots, 5$ corresponding to Find, Fix, Track, Target, Engage [1][2]. The kill chain succeeds by time T iff the sum $S = \sum_{i=1}^{5} t_i \le T$. For distinct rates, the hypoexponential CDF is:

$$P_{F2T2E}(T) = 1 - \sum_{i=1}^{5} \left(e^{-\lambda_i T} \prod_{\substack{j=1 \\ j \ne i}}^{5} \frac{\lambda_j}{\lambda_j - \lambda_i} \right),$$

$$\text{with } \lambda_i = \frac{1}{\theta_i} \quad \text{and Erlang CDF used if all } \lambda_i \text{ equal.}$$

We expose an interactive calculator (right column) to evaluate $P_{F2T2E}(T)$, visualize it across a chosen time window, and estimate finite-difference sensitivities $\partial P/\partial \theta_i$ at a specified T (sign indicates whether increasing θ_i helps or hurts overall success) [1].

Kill-Web Elasticity (Parallel Sensors)

If multiple independent assets contribute to the same phase (e.g., parallel Find sensors), effective rate increases additively: $\lambda_{\text{find,eff}} = \sum_k \lambda_{\text{find}}^{(k)}$. This reduces θ_{find} and lifts $P_{F2T2E}(T)$, expressing the resilience and elasticity of kill webs under redundancy.

Notes on DEVS & MDP (Structure Only)

The full DEVS/MDP swarming architecture from the paper is structural and simulation-oriented. This HTML focuses on the analytically evaluable component $P_{F2T2E}(T)$ and its sensitivities. For formal details, see [5] (hierarchical MDPs in DEVS) and [6] (DEVS+model-checking).

Model Workspace

F2T2E Calculator | DEVS/MDP Formal Details

Interactive F2T2E Calculator Live

θ_1 (Find) [min]	θ_2 (Fix) [min]	θ_3 (Track) [min]
3	2.5	2

θ_4 (Target) [min]	θ_5 (Engage) [min]	Sensitivity at T [min]
1	0.5	12.35

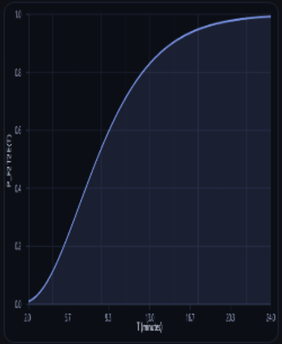
Plot T_{min} [min]	Plot T_{max} [min]	Plot points
2	24	200

Parallel Find Assets (optional)

0 | 3 | Apply to θ_1 | Reset θ_1

Compute & Plot | Load Indo-Pacific Example (Fig.-like)

Export CSV



Point Calculation

$P_{F2T2E}(12.350 \text{ min}) =$ 0.800168
Lambdas: [0.333333, 0.400000, 0.500000, 1.000000, 2.000000] min^{-1}

Finite-Difference Sensitivities (\u2202P/\u2202θ$_i$)

Phase (θ_i)	$dP/d\theta_i$ @ T
θ_1 (Find)	-7.011987e-2
θ_2 (Fix)	-6.957789e-2
θ_3 (Track)	-6.783697e-2
θ_4 (Target)	-5.996014e-2
θ_5 (Engage)	-5.450264e-2

Negative values mean decreasing θ_i (speeding phase i) increases overall success.

Live demo

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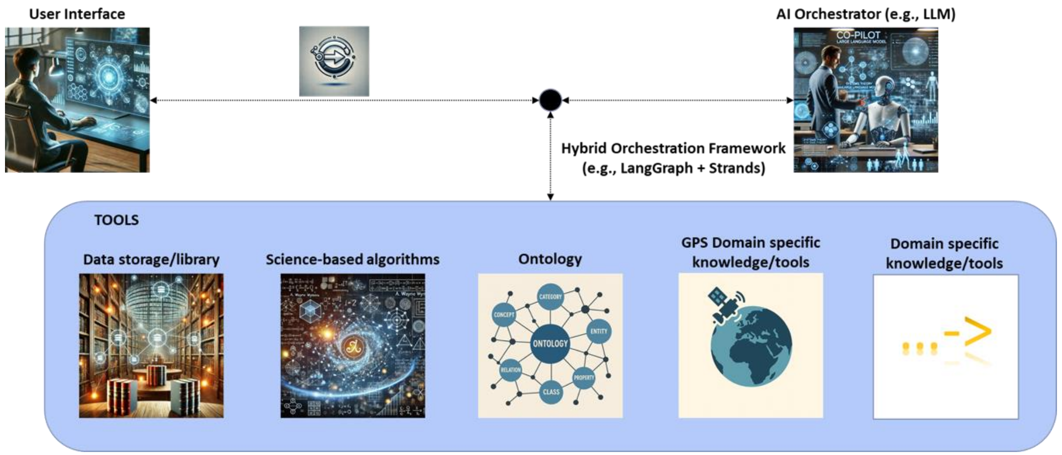
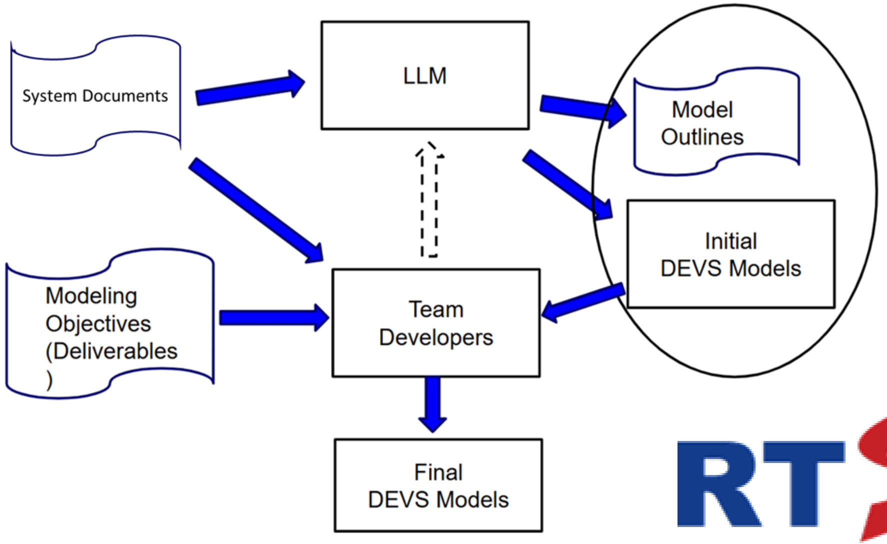
Concluding Summary

- **<u>Main theme:</u>** mathematically underpinned methods and tools enable both efficiency and effectiveness

- Demos shown:
  - ✓ Systems Engineering assistant focused on system requirements, system design, and verification
  - ✓ Modeling & Simulation efficiency gains and use for kill chain analysis





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Questions?

Contact:

Paul Wach, paulw86@vt.edu

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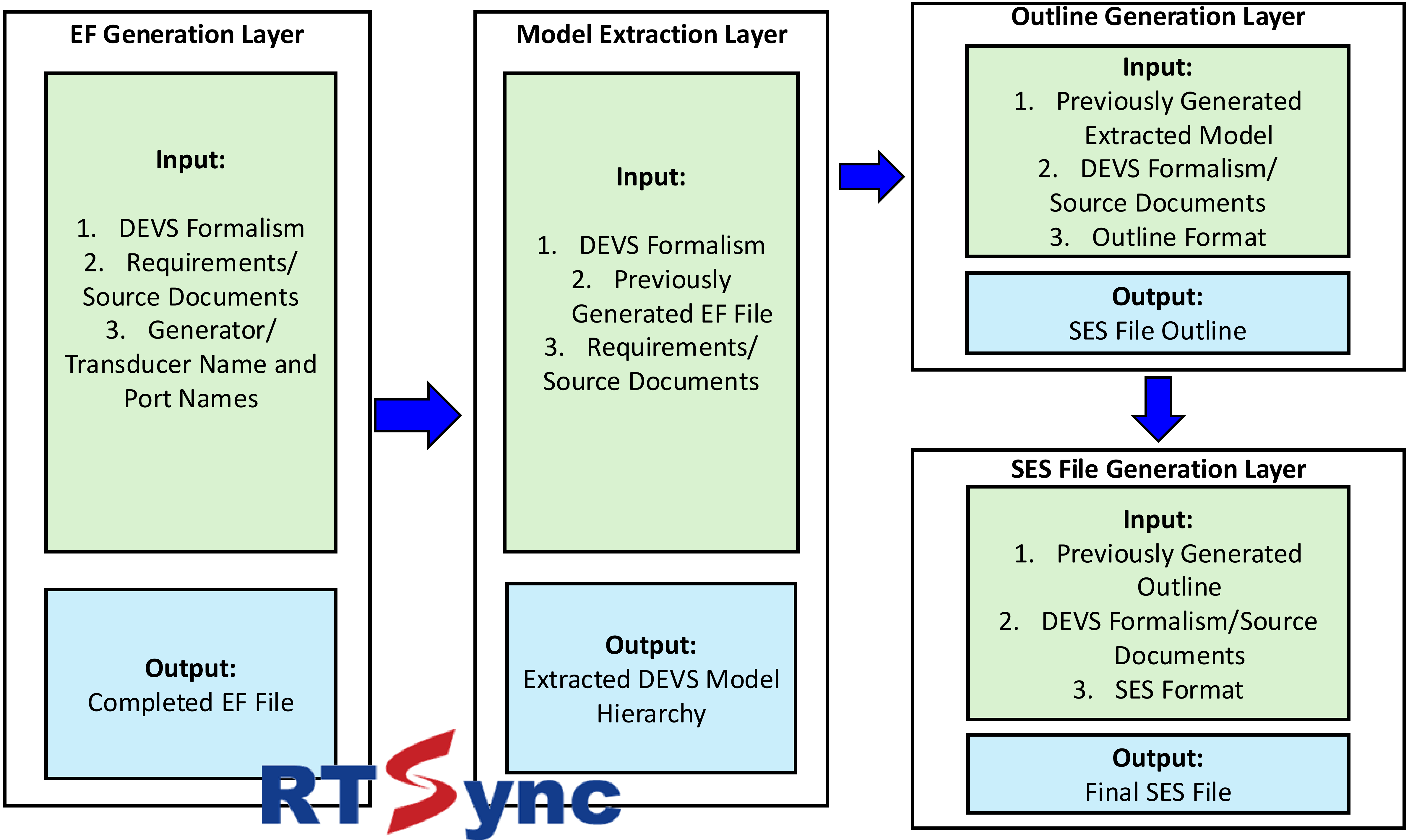
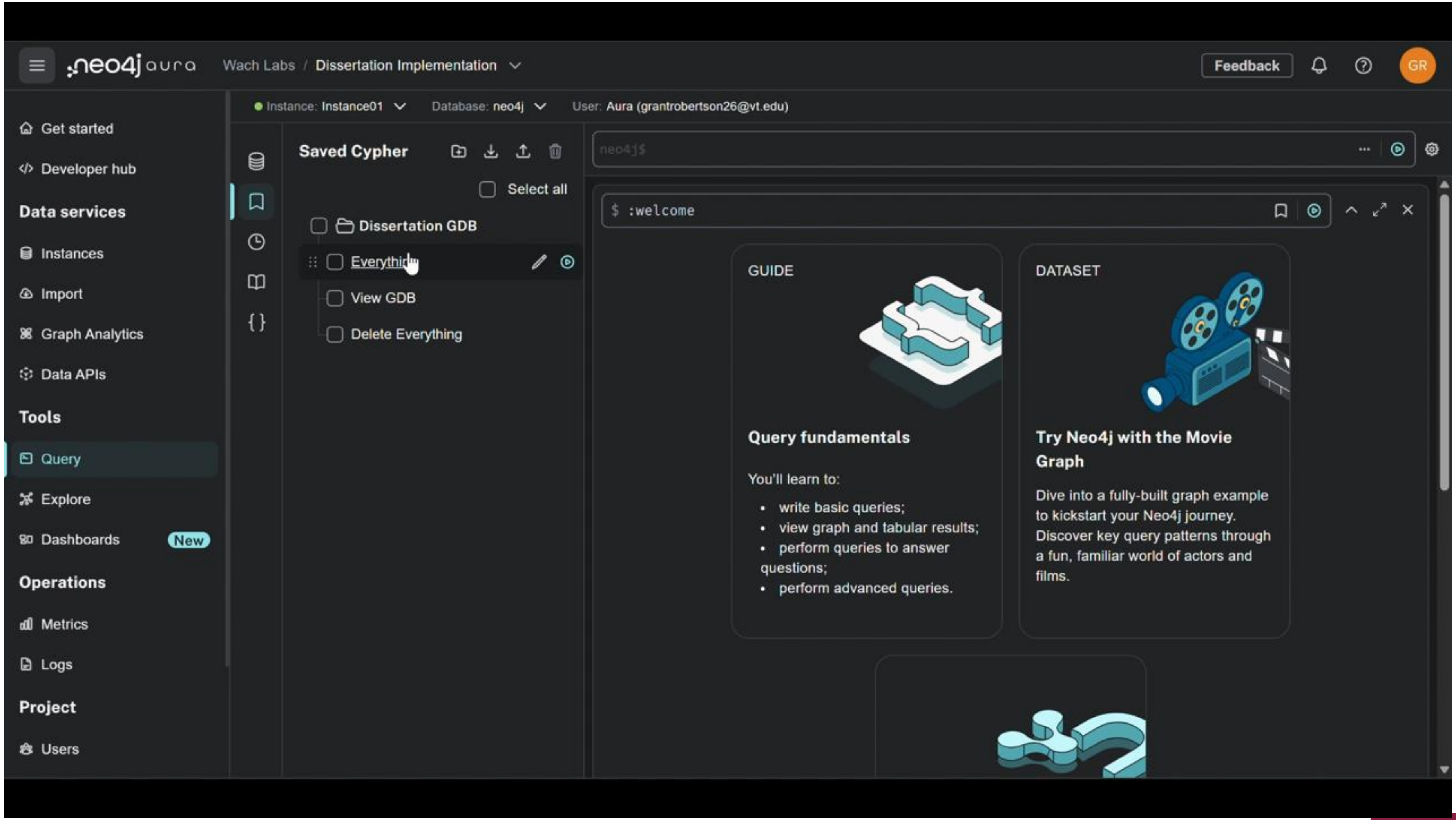

EF Generation Layer
Input:
1. DEVS Formalism
2. Requirements/ Source Documents
3. Generator/ Transducer Name and Port Names
Output:
Completed EF File
Model Extraction Layer
Input:
1. DEVS Formalism
2. Previously Generated EF File
3. Requirements/ Source Documents
Output:
Extracted DEVS Model Hierarchy
Outline Generation Layer
Input:
1. Previously Generated Extracted Model
2. DEVS Formalism/ Source Documents
3. Outline Format
Output:
SES File Outline
SES File Generation Layer
Input:
1. Previously Generated Outline
2. DEVS Formalism/Source Documents
3. SES Format
Output:
Final SES File
RTSync

DEMO Video 1: Graph Database (Neo4j)

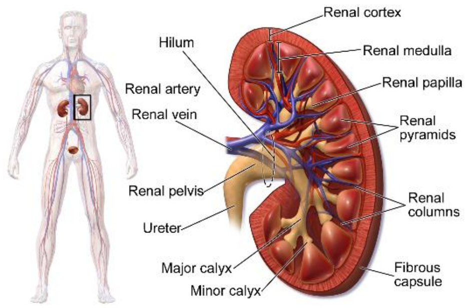


Enables **enhanced data analysis** and increased rigor **data structures, based on ontological** foundations

Kudos to **Grant Robertson**, Summer volunteer Industrial & Systems Engineering rising senior, expected graduation May 2026

Who is Paul? (or Professor Paul or Doc Wach)

BS in Biomedical Engineering 2009



Kidney Anatomy

MS in Mechanical Engineering 2013

PhD in Industrial and Systems Engineering 2022

Research Faculty in Intelligent Systems Division 2023-present

Virginia Tech – National Security Institute (NSI)

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