VT National Security Institute

Intelligent Systems Division

Using Large Language Models to Accelerate Development of Complex System

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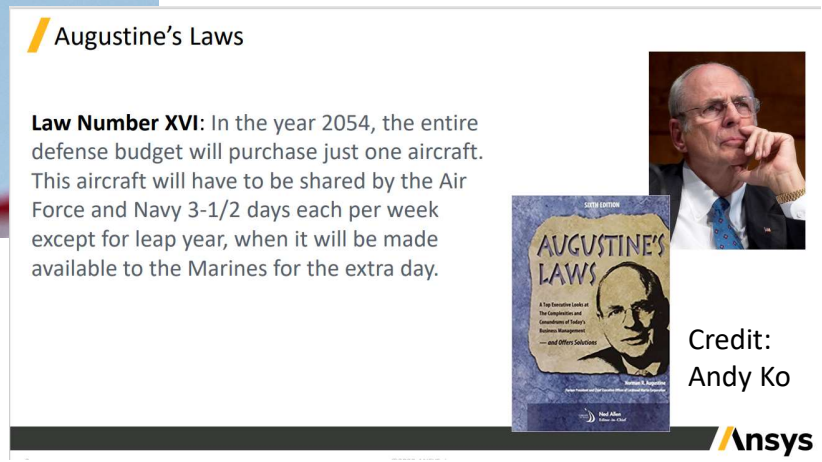
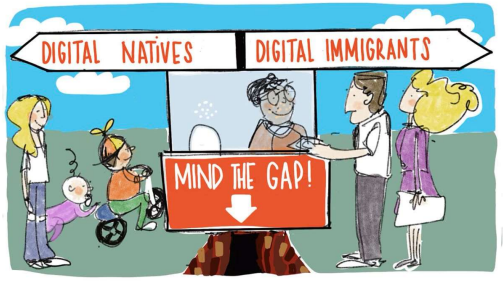
Setting the Stage

- Challenge:

  From empirical evidence and individual experience, **our current approach is not sufficient**

- Example Solution(s):
  - **Digital engineering (DE)**: connecting the right data right to enable effective and efficient decisions and communication
  - **Model-based systems engineering (MBSE)**: the application of DE to enhance systems engineering (SE)





Spectrum of workforce

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Generative Artificial Intelligence (GenAI) & Digital Transformation

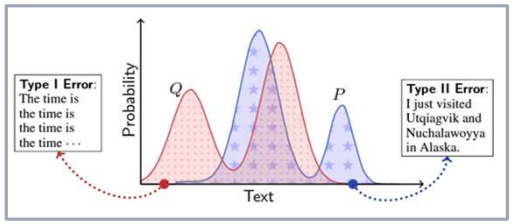
- Challenge:
  - **Adoption** of digital engineering has been **slow**er than expected and the benefits have not yet been realized
- Goal:
  - **Expedite & reimagine** the digital transformation
- Large language models (**LLM**) and the systems modeling language version 2 (**SysMLv2**)
  - Serve as a **workforce bridge** between seasoned generation and incoming digital natives, among other applications
- Thrusts
  1. Text to text
  2. Text/image to SysMLv2 code
  3. SysML image/code to text

Text to text

Human expert

vs

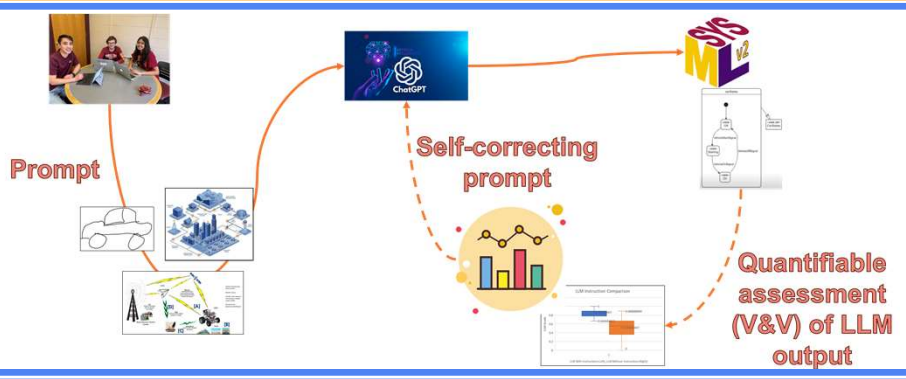
LLM



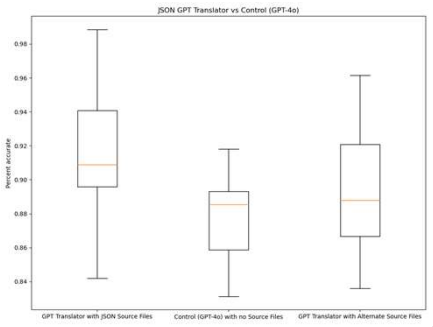
	MAUVE Scores		
Model	Prompt 1	Prompt 2	Prompt 3
GPT-4 (OpenAI)	0.0000	0.0000	0.9137
GPT-3.5 Turbo (OpenAI)	0.0000	0.0001	0.9749
Claude (Anthropic)	0.0000	0.0003	0.9932

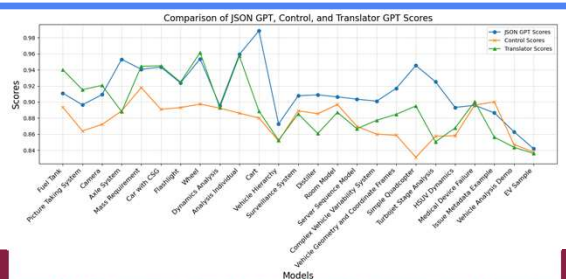
Text/Image to SysMLv2

Notional Prompt with self-correcting V&V of output



SysMLv2 image to text





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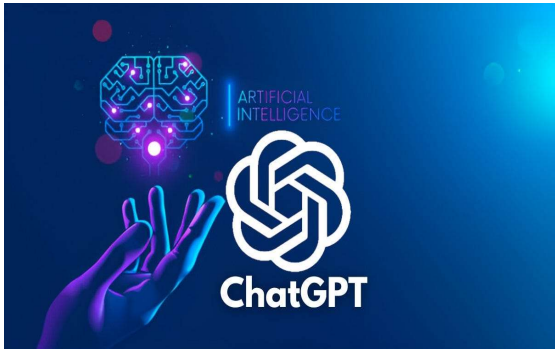
Methodology (Part 1 of 4) – Artifact Generation

LLMs used for Generation:

- ChatGPT – Highly customizable with lots of features to optimize and large number of parameters

Optimizations Performed:

- Fine tuning (SysMLv2 keywords to example diagrams from the SysMLv2 repo) using JSONL format
- Chain-of-Thought Prompting
- Knowledge base (txt files for context)



Gemini

Claude 3

Methodology (Part 2 of 4) – Artifact Analysis

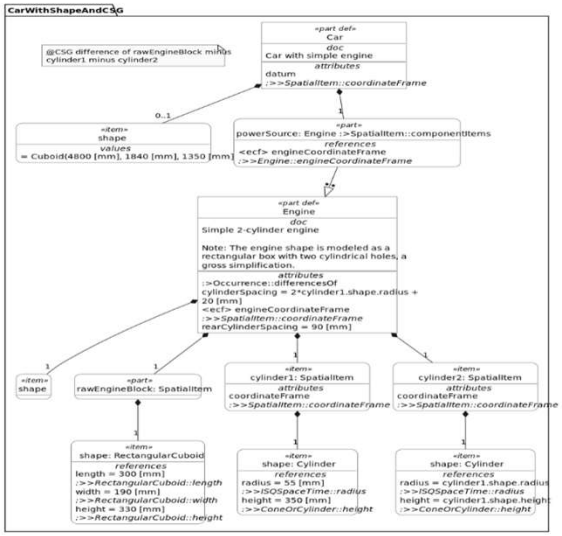
LLMs used for Generation:

- ChatGPT – Highly customizable with lots of features to optimize and large number of parameters
- Claude – Trained on a large number of parameters
- Gemini – Trained on a large number of parameter sand highly customizable

Requested GPT analyze artifacts to provide a textual description of the given system in a manner that is understandable to people who are not subject experts

Optimizations Performed:

- Fine tuning (Providing textual examples to LLM) using JSON format
- Knowledge base (txt or SysML files for context)



Describe this model in plain english and give as much detail about the relationships, attributes, etc. Do this in a paragraph format without using variable and package names. Avoid using SysMLv2 lingo altogether and translate the variable/relationship names into the context of the system description.

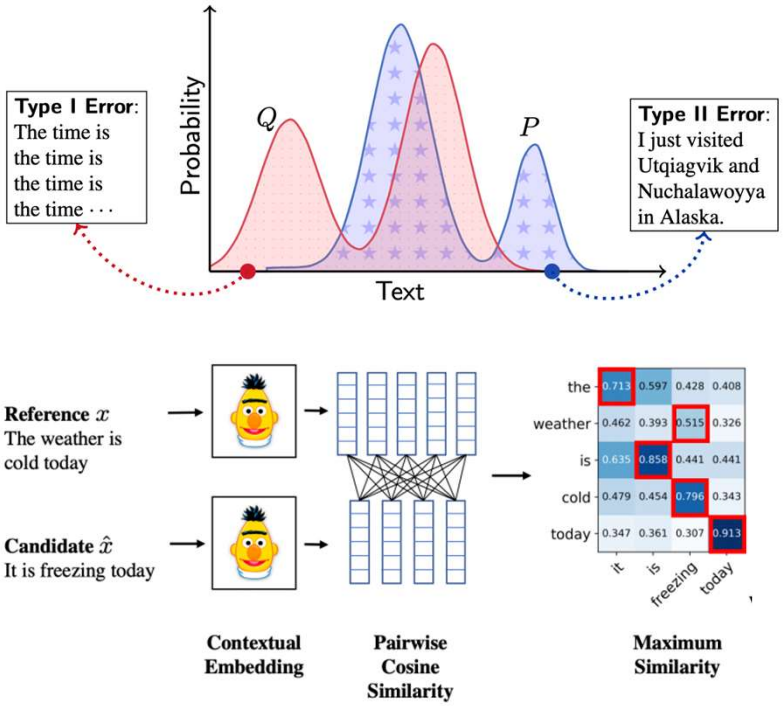
Methodology (Part 3 of 4) – Evaluation Metrics

For Artifact Generation:

- Syntax Score (Provided by Equations on the right)
- Logic Score (Qualitive human score with 3 quantified categories, 0 (insufficient system), 0.25 (partially sufficient system), 0.5 (sufficient system))
- Overall score, α, with syntax weighted double as much as logic

For Artifact Description:

- MAUVE Score
- BertScore
- 2 Sample T-Test



$$Syntax\ Score = 1 - \frac{Number\ of\ Syntax\ Errors}{Number\ of\ Lines\ of\ Code}$$

$$\alpha = \frac{Syntax\ Score\ + Logic\ Score}{1.5}$$

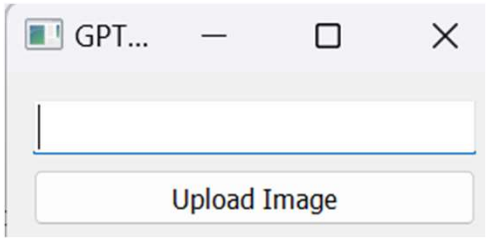
Methodology (Part 4 of 4) – Workflow Automation

For Artifact Generation:

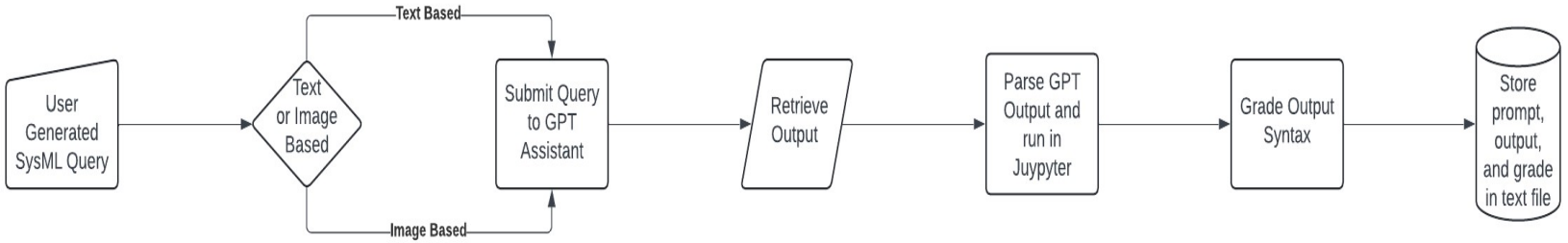
- Syntax Score (Provided by Equations on the right)
- Logic Score (Qualitive human score with 3 quantified categories, 0 (insufficient system), 0.25 (partially sufficient system), 0.5 (sufficient system))
- Overall score, α, with syntax weighted double as much as logic

For Artifact Description:

- MAUVE Score
- BertScore
- 2 Sample T-Test




```
----- TEST Run2 -----
Prompt: Generate SysMLv2 code that models a four-wheeled car in motion.
Code: package 'VehicleDefinition' {

        import ScalarValues::*;

        part def Vehicle {
                part def Transmission;
                part def CarAxle {
                        port leftAxleMounting;
                        port rightAxleMounting;
                }

                part def Wheel;

                // Specific vehicle contents
                part theCar :> Vehicle {

                        // Parts
                        part theTrans :>
                                theCar.Transmission;

                        // Completions
                        part rightFrontWheel : Wheel in
                                theCar.AxleMount.rightAxleMounting;
                }

        }

}

Errors: stderr ERROR:no viable alternative at input 'in' (1.sysml line : 22 column : 33)
ERROR:no viable alternative at input '.' (1.sysml line : 23 column : 11)
ERROR:no viable alternative at input '.' (1.sysml line : 23 column : 21)

Syntax Score: 89.0%
Image File:
```



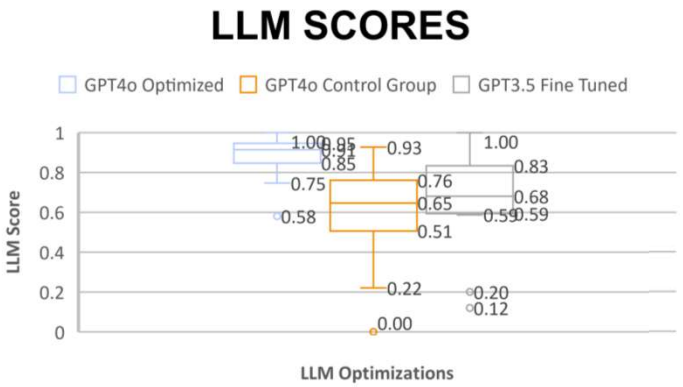
Results (Part 1 of 2) – LLM Artifact Generation

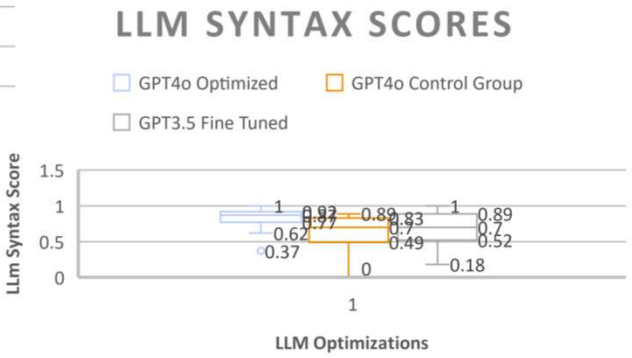
Statistics:

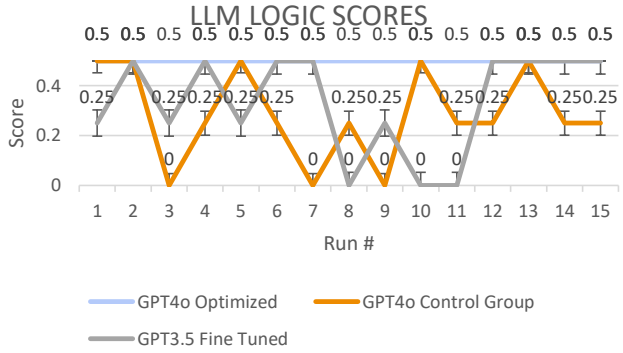
- 15 given text-based prompt querying for systems designed for a defense-specific audience
- Output syntax, logic, and overall score graded for each tested instance of GPT (GPT 4o optimized, GPT 4o control, and GPT3.5 fine tuned)

Results:

- The instance of GPT 4o given context, chain-of-thought prompting instructions, and a log of errors it historically made performed best
- GPT 3.5 when fine tuned performed second best
- The control instance of GPT 4o performed worst in all grading categories







Results (Part 2 of 2) – LLM Artifact Analysis

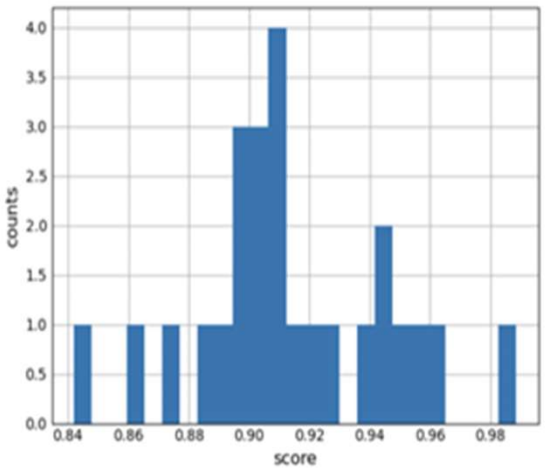
Statistics:

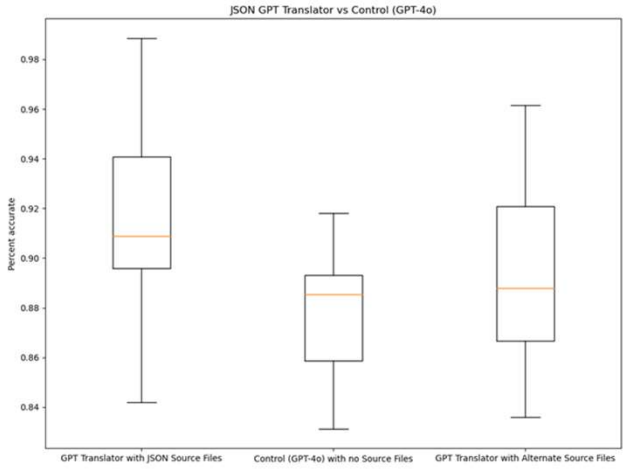
- 25 given text-based prompt querying for example system descriptions from the SysMLv2 repository
- Provided MAUVE and BertScore two sample t-test results

Results:

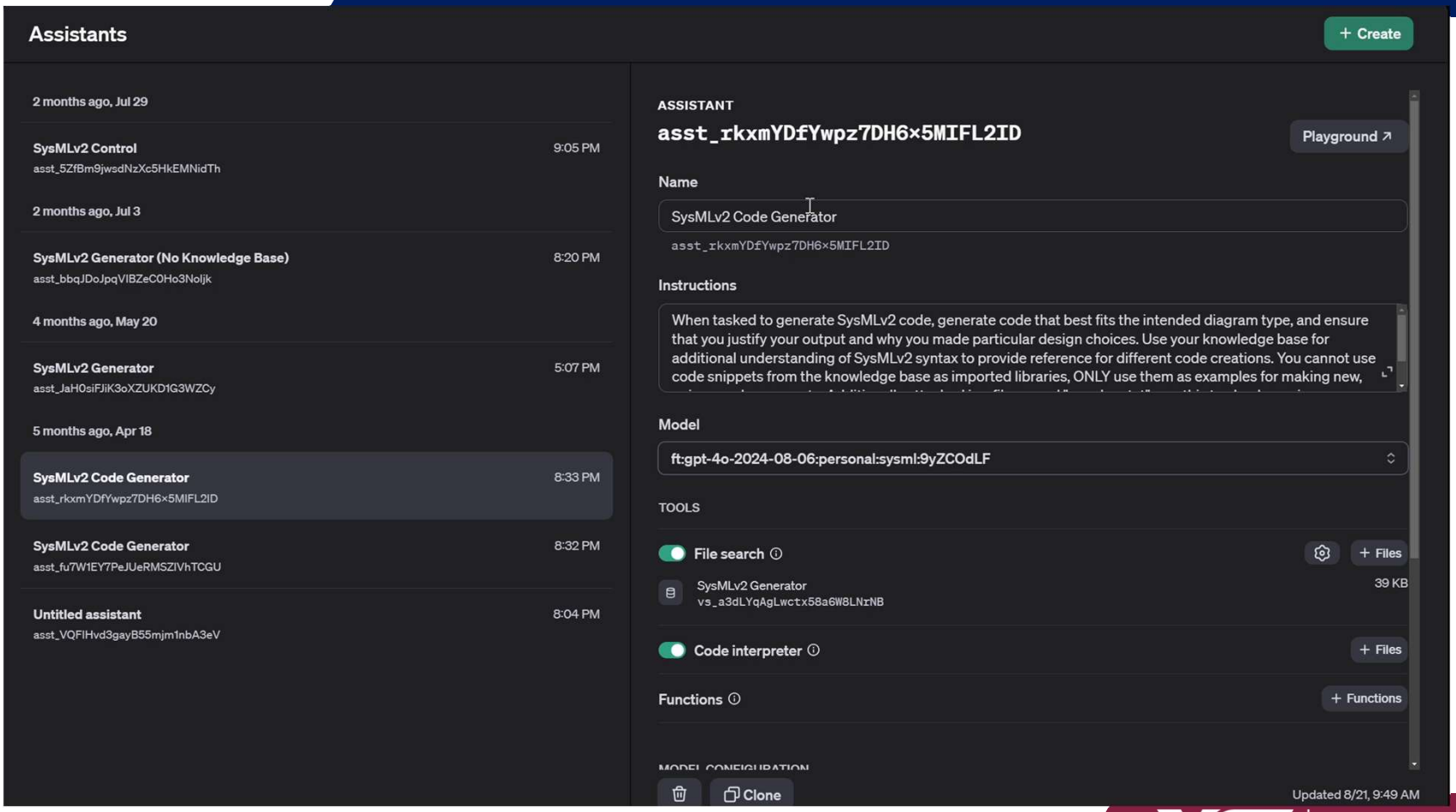
- Mean score of fine tuned GPT translator showed a statistically significant difference in that of the control group for the BertScore
- MAUVE showed indeterminate results

```
In [10]:
1 import torch
2 print(f"The JSON GPT on average was: {100 * torch.mean(F1):.2f} % accurate to the correct description.")

The JSON GPT on average was: 91.37 % accurate to the correct description.

In [11]:
1 import matplotlib.pyplot as plt

In [12]:
1 plt.hist(F1, bins=25)
2 plt.xlabel("score")
3 plt.ylabel("counts")
4 plt.show()
```





DEMO Video



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What's on the Horizon?

Trajectory

- ❑ Application domain(s)
  - ➢ Mission engineering, predictive maintenance, secure energy, secure cyber resilient engineering (SCRE), smart cities
- ❑ Capability growth
  - ➢ Beyond SysML (CAD, etc.)
  - ➢ LLM vs SLM
  - ➢ Team of agents
  - ➢ Relational versus graph database
  - ➢ **Scaling**
    - ✓ CUBE (NSI GPU cluster)
    - ❖ CREATE (NSI cyber range)
  - ➢ Systems Theoretic Advisor

Scaling to CUBE environment

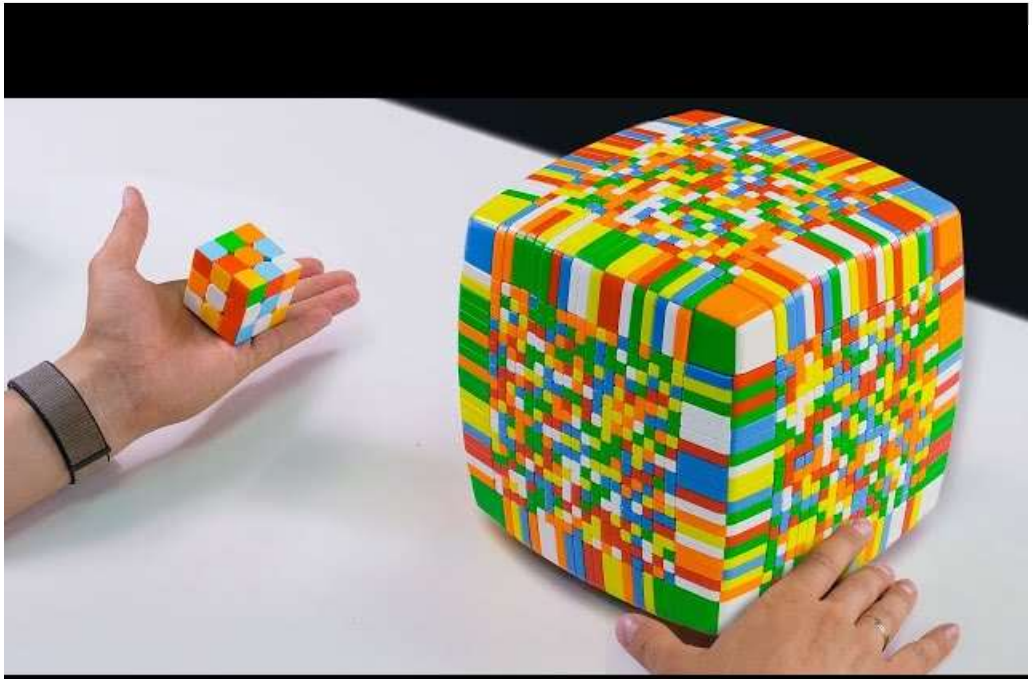
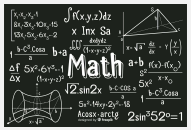


Image source credit

*CUBE = …
**CREATE = Cyber Research Environment and Threat Evaluation

Mathematical Underpinning to Digital Transformation (e.g., Digital T&E)

- Challenge:
  - Model-based systems engineering (**MBSE**) is qualitative (i.e., **lacking mathematical underpinning**)
- Goal:

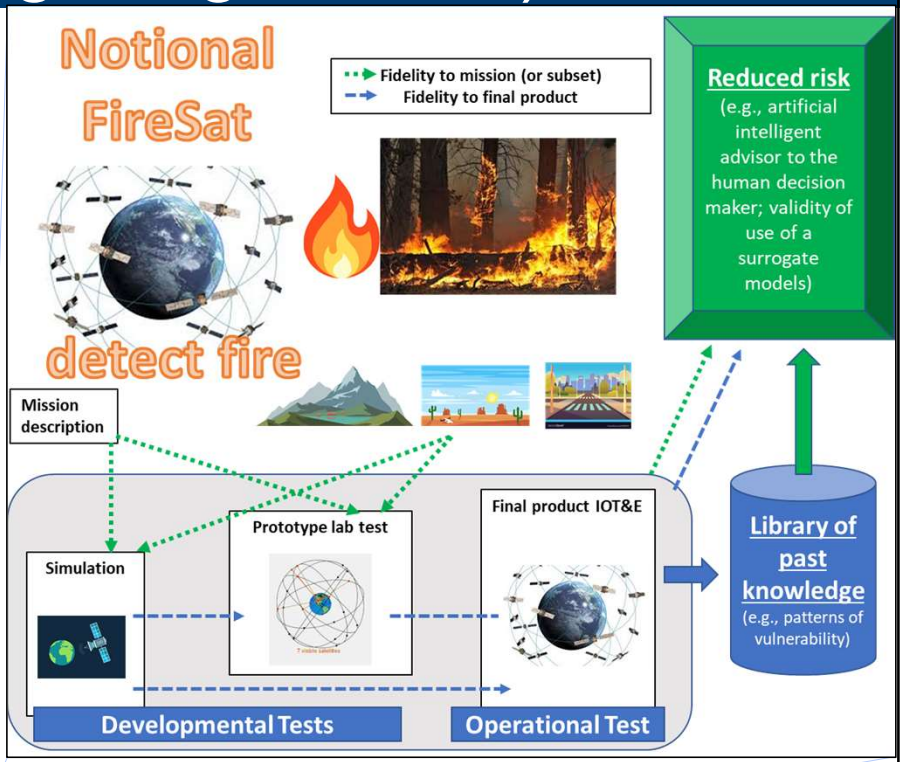


  - Develop methods and tools for Tier 3 of T&E
    - See article titled Positioning Test and Evaluation for the Digital Paradigm
- **Systems Theoretic Advisor**
  - Minimum viable product (MVP) developed by NSI funding completed in Aug 2024

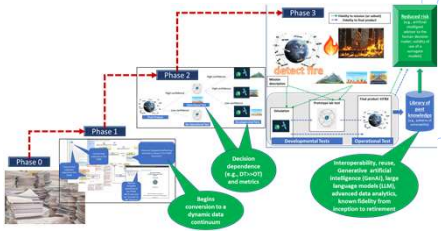
Harmonizes the data and models through mathematical underpinning

Sends that data to the machine learning (e.g., **LLM**) and computational backend to be processed

Collects that data and creates a visual of the solution to the query



Tier 3 of Digital T&E



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Closing the Stage

"It is not necessary to change."

"Survival is not mandatory." - Deming

Current thrusts

1. System theoretic assistant
2. Text-2-text (Measured)
3. **Text-2-SysML**
4. **SysML-2-text**

Accepting nominations for naming of co-pilots

General
Leslie Groves
Director, Manhattan Project

Image from: Wikipedia

Introducing…

Image from: iStock

Questions?

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Back-up

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We meet the pressing needs of the defense and intelligence communities by developing their future workforce and advancing interdisciplinary research, technology, and policy.

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Technical Divisions

Spectrum Dominance

- Assured and secure communications
- Advanced C4ISR and counter-C4ISR
- Quantum and heterogeneous computing
- RF machine learning
- Open Gen wireless innovation

Mission Systems

- Resilient, autonomous missions
- Remote & in-situ sensing
- Space situational awareness
- Marine autonomy and robotics
- Energetic materials

Intelligent Systems

- Data science, ML, AI
- Cyber security & complex systems
- Validation and test & evaluation
- Deep learning for sensor processing
- Data fusion and sensemaking

Facilities

Digital Test & Evaluation (T&E)

- Challenge:
  - To maintain and surpass the pace of the threat, new methods and tools are needed
- Goal:
  - Advance digital transformation of T&E
- Thrusts
  1. Model-Based Test & Evaluation Master Plan (MBTEMP)
  2. Integrated Decision Support Key (IDSK)
  3. Uncertainty propagation through the digital T&E pipeline
  4. Digital twin, connected and curated data
- Work in progress
  - Defined phases to measure progress
  - Creating methods and exemplars
  - Planning for mission assist