Ship of Theseus Methodology for Creating Living Engineered Systems

Laura Otero Hernandez, PhD Candidate

The George Washington University School of Engineering and Applied Sciences

SE4AI: Evolving Role of Digital Engineering

Theseus, mythical King of Athens, is a divine hero in Greek Mythology, known for slaying the Minotaur. The story goes that Athenians would annually commemorate Theseus by taking a ship named after him to Delos to honor the god Apollo. The Athenians would continue to preserve the ship, taking away old planks as they decay and putting in new and stronger timber, insomuch that this ship became a philosophical example for the logical question of **whether an object is the same object after having its original components replaced over time**, typically one after the other.

Ariadne pointing at the ship of Theseus sailing away in the distance, wall painting, first century bc. © **The Trustees of the British Museum**.

ASIA MINOR

CORCYRA

ΞIAN ΣMPIRΣ

THIS WAY TO

PERSEPOLIS

THE PEL

THIS WAY TO

MAGNA GRAΣCIA
(SOUTH ITALY)

Thesis:

- Integrating existing technologies and concepts (Digital Engineering)
  - Digital Twins
  - MOSA
  - Artificial Intelligence
  - Systems Engineering
- Iterative approach to validate testing and develop methodology
- Embed Systems Engineering in the system

Problems being solved

- Keeping pace with breakthrough technology
- Eliminating or drastically reducing rework
- Incorporating Systems Engineering throughout the lifecycle
- Costs associated with modernization, operations, and replacement

So what?

- Systems Engineering methodology does not currently focus on dynamic refinement of systems
- Takes advantage of AI to inform digital twins and physical twins of a system
- Leap forward in system capabilities
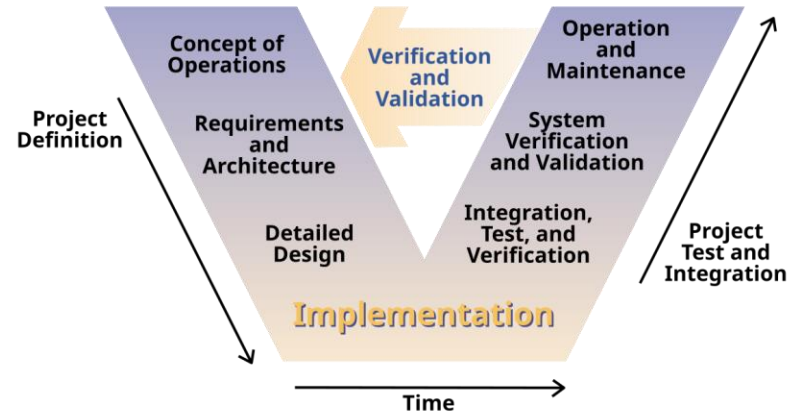
Examples

- Software run-time adaptability
- Flexible hardware platforms like field-programmable gate arrays (FPGAs)
- Reusable hardware such as SpaceX rocket boosters
- Morphing hypersonic engines based on speed

- The ISS's modular and reconfigurable design
- WWII-era U.S. naval warships adapting real-time to enemy tactics
- Automotive variable valve timing for improved performance and efficiency
- Electric vehicles throttling power when batteries overheat or closer to the end of their life

B-52 Bomber of Theseus

Research questions explored

- How can Digital Engineering accelerate technology integration?
- What methodologies exist or are needed to create them?
- Can we design for use cases not yet imagined, or for technologies that do not yet exist?
- How can we define the lifecycle of a digital twin to know when replacement is required?
- What is the essence of a system that qualifies as a *Theseus system*?
- Can we prove that a system can truly self-adapt through replacement?
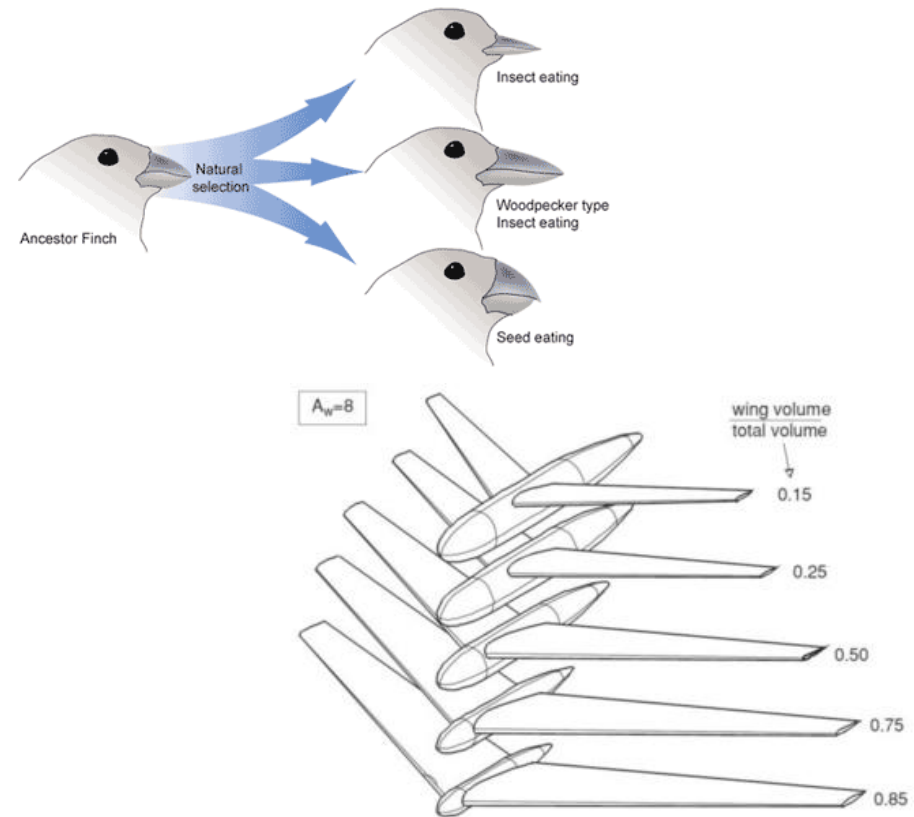
Testing the Hypothesis

- Assumptions:
  - Modular open system architecture (MOSA) was utilized to develop the system in question
  - Digital Twin of the system has been achieved
  - Deployed system has been fielded and is in operation, past the front of the bathtub effect

- Approach:
  - Defining the system and its state-machine diagram
  - Run Failure Mode and Effects Analysis (FMEA)
  - Introduce new stimuli
  - Analysis of system behavior
  - Refining the FMEA and system design

Methodology

- Testing if the system adapts requirements based on changes to behavior
- Feedback loops allows observed behavior to inform the system that it is offset from expected behavior
  - Digital Engineering incorporating AI/ML
- Digital Twins will become a key element to this methodology
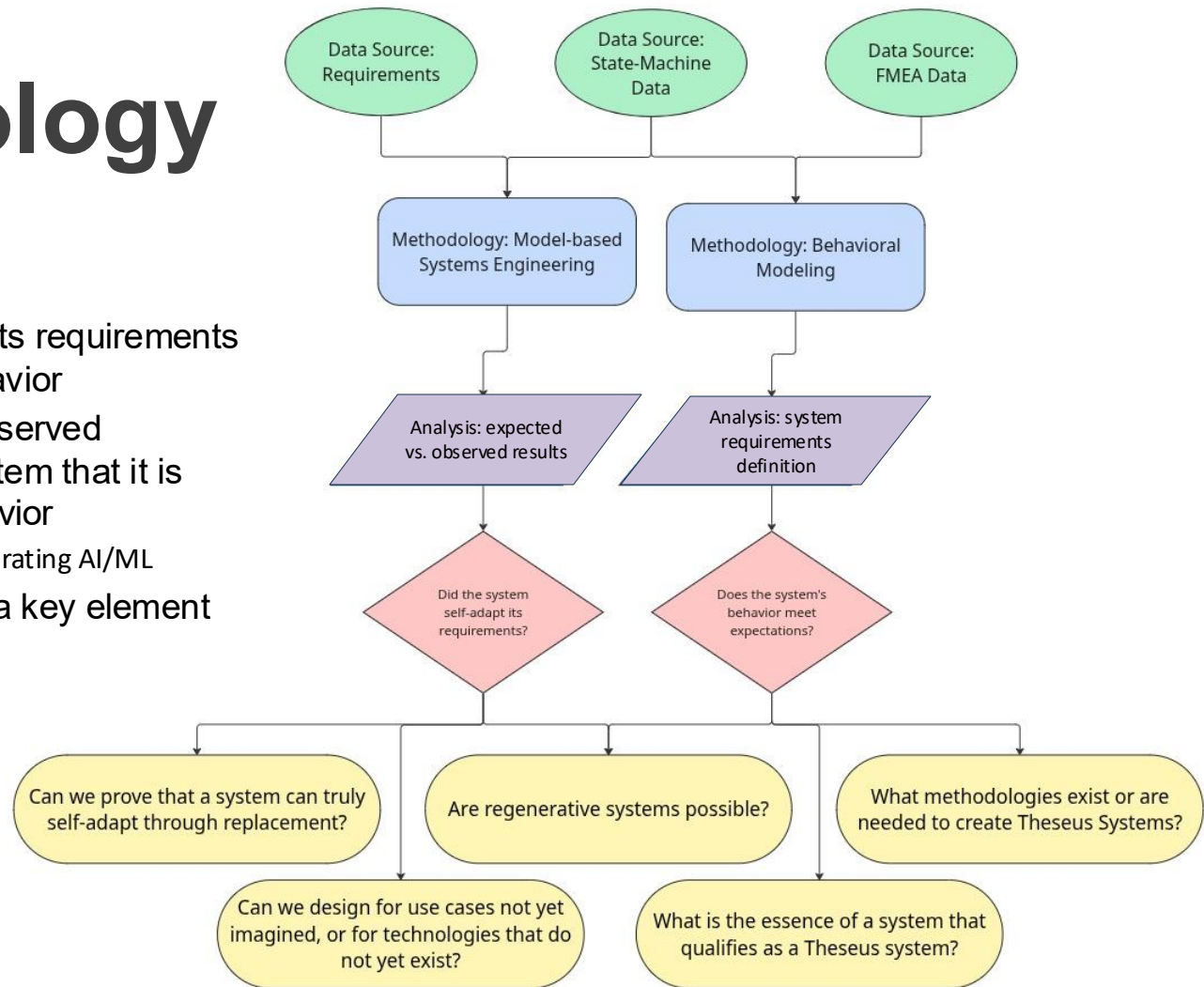
Summary

Ship of Theseus Methodology aims to integrate Digital Twins (behavioral modeling and analysis) with run-time adaptability to prove the possibility of Living Engineered Systems.

Email: Laura.OteroHernandez@gwu.edu