Systems Theoretic T&E for Learning-Based Systems

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Research objectives

Pure Research

1. Create a T&E framework for Learning-Based Systems
2. Characterize the change in operational conditions (*ops*) and adversarial actions (*act*)
3. Characterize equation of change in *ops/act* to change in system implementation

Value to Government

1. Characterize assurance trade space of: (increase in) data/model rights on (decrease in) need for testing and (increase in) confidence

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T&E Framework Status

Objective

- Create a T&E framework for Learning-Based Systems

Status

- Work in progress
- Depends on success of other tasks
- This is the ultimate goal

Characterization of external change

Objective

- Characterize the change in operational conditions (*ops*) and adversarial actions (*act)*

Status/Recommended Path

- Use the concept of morphism to characterize change in ops/act
- Characterization of external events relative to each other is inherently included in Wymorian Systems Theory

Characterization of internal change

Objective

- Characterize equation of change in *ops/act* to change in system implementation

Status/Recommended Path

- Given that ops/act (external events) are characterized, the space of systems that are bounded can also be characterized
- Change in the system implementation can be mathematically characterized based on:
    - Hierarchy of system specification
    - Morphisms between systems specified at the same level

Characterize the Value to the Government

Objective

- Characterize assurance trade space of: (increase in) data/model rights on (decrease in) need for testing and (increase in) confidence

Status

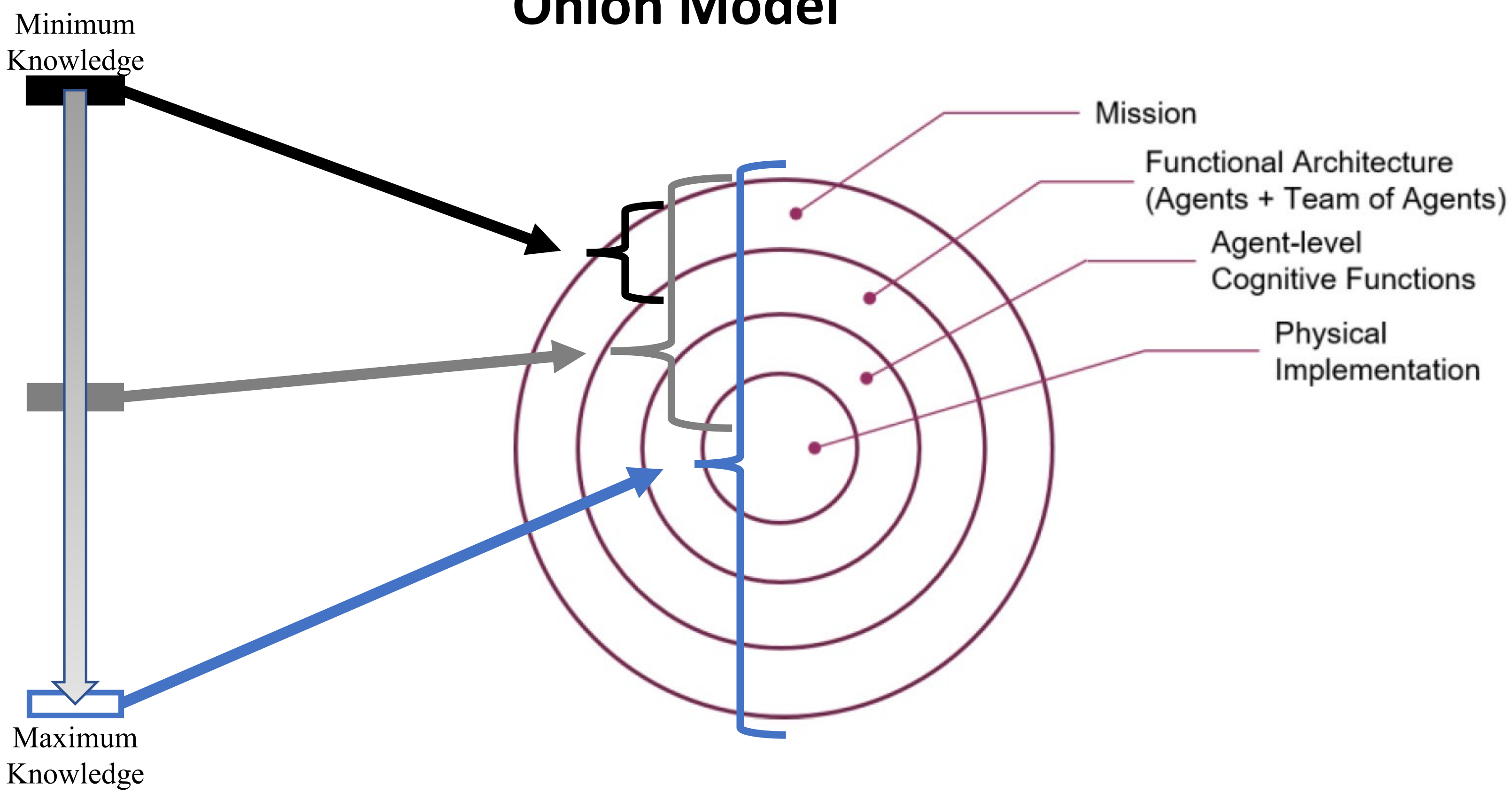
- Developing a Bayesian network and utility-driven method to understand the trade space

Differentiating Levels of Knowledge of a Learning-Based System

System Perspective

- Black Box
- Grey Box
- White Box

Onion Model



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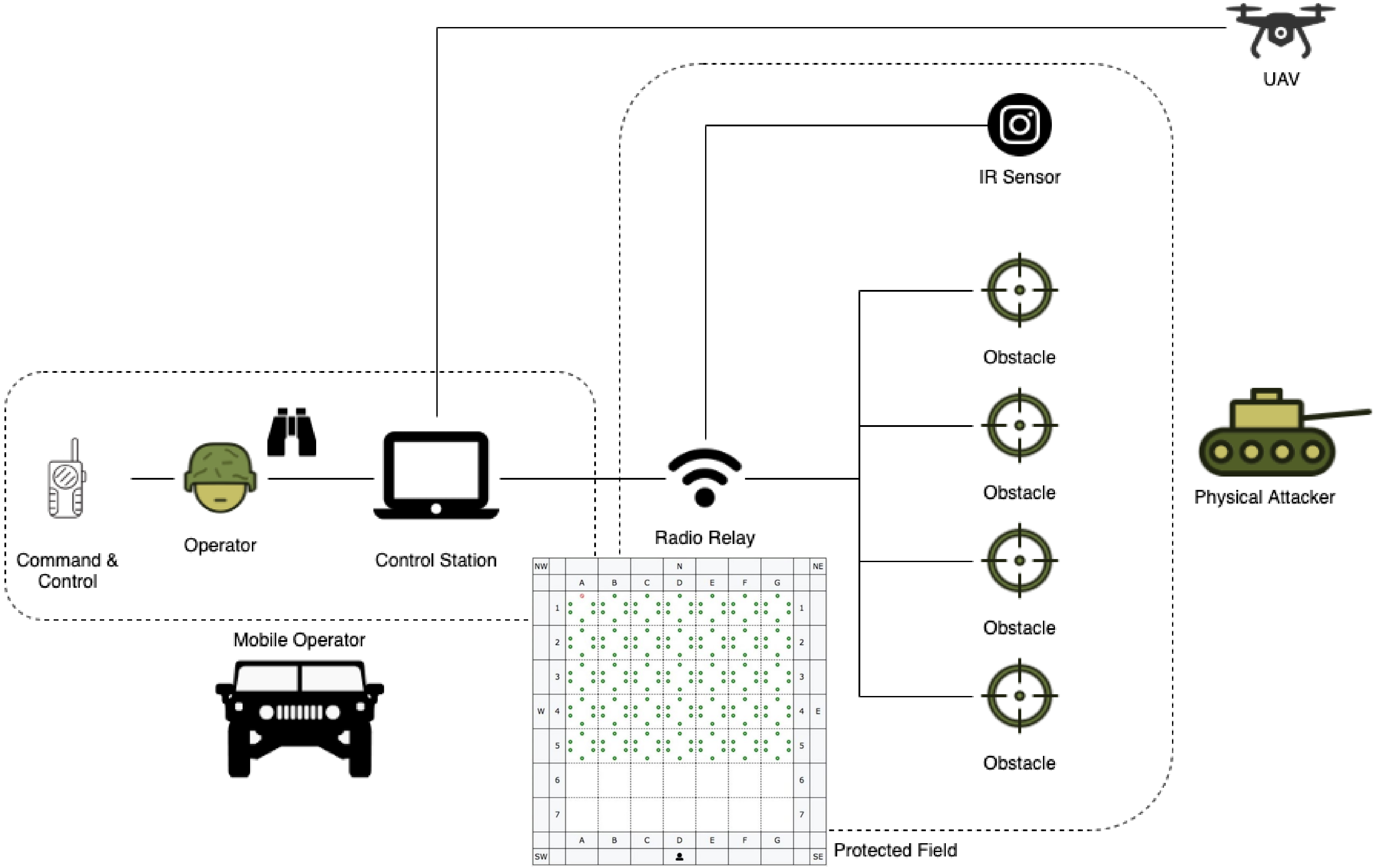
*A general framework is critical for understanding current state of knowledge for learning systems

Moving toward higher complexity: Silverfish architecture

Silverfish description

- Prohibited Area:
  - ~100 acres ≈ .16 sq. miles
- Obstacle Deployment:
  - ~50
  - Aligned to Compass Coordinates (Operator Observation Point)
- Cell Grid:
  - ≈ 300 ft. x 300 ft.
  - 6 Munitions per Cell (Ready/fired state)
- Vehicle Traversal:
  - Max Speed = 10 mph ≈ 15 ft/sec
  - 20 seconds/grid
  - 2.3 min/protected area



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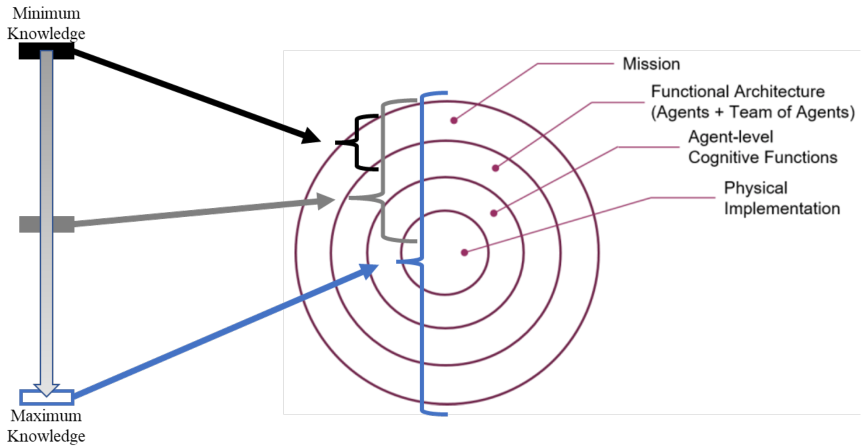
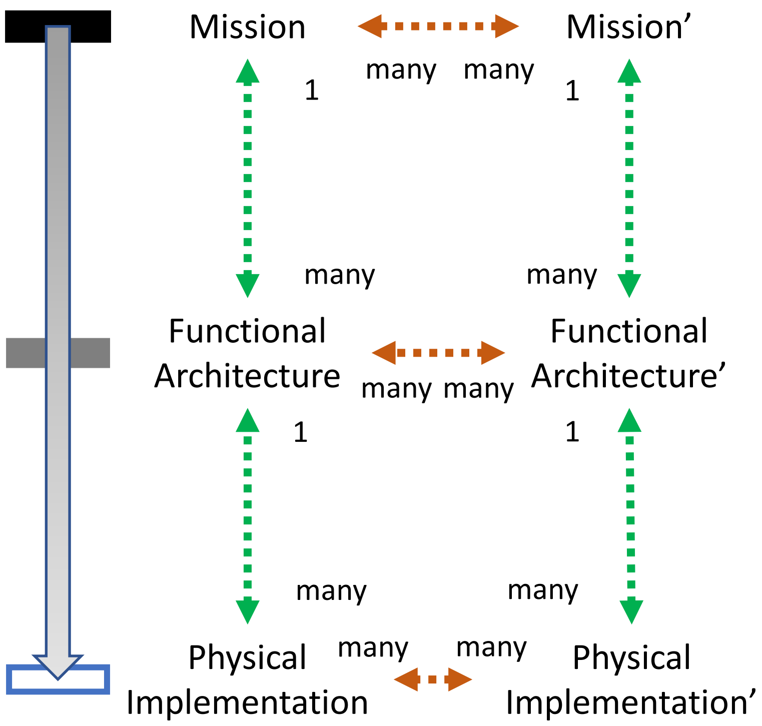
Relating Levels of Knowledge: Systems Theory Perspective



- **Level 1**
  Black Box
- **Level 2**
  Grey Box
- **Level 3**
  White Box



- Each level defines a space that bounds the systems within the lower level (green)
  - Ex: Mission bounds the functional architecture
- Each level has a mathematical relationship that can be mapped to horizontal (orange) changes
  - Ex: Change in mission can be correlated to changes in operational environment and adversarial actions

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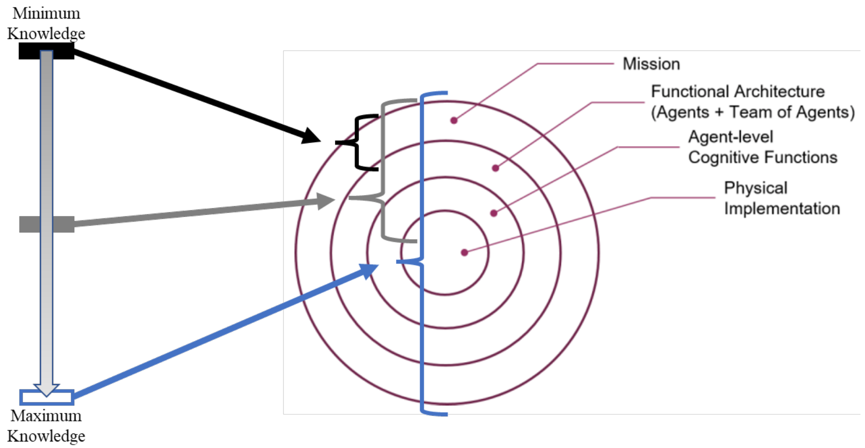
Relating Levels of Knowledge: A Notional Example



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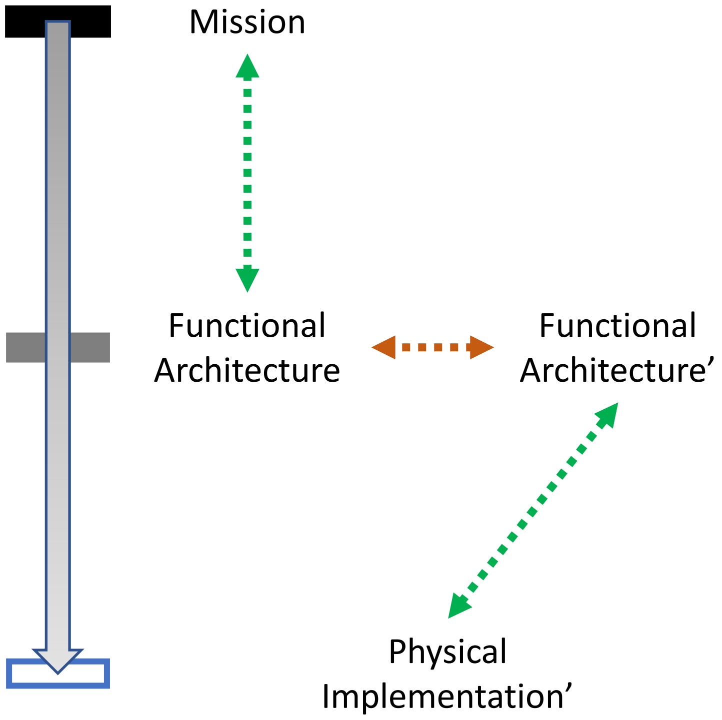
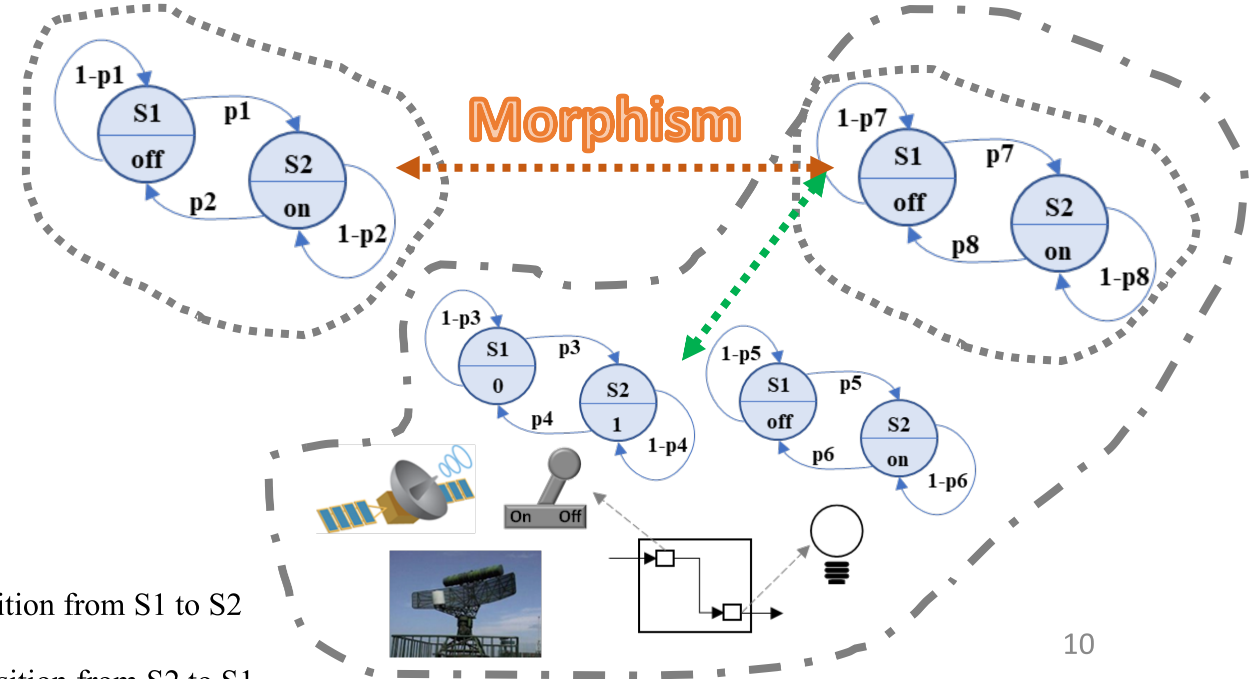


Notional Mission

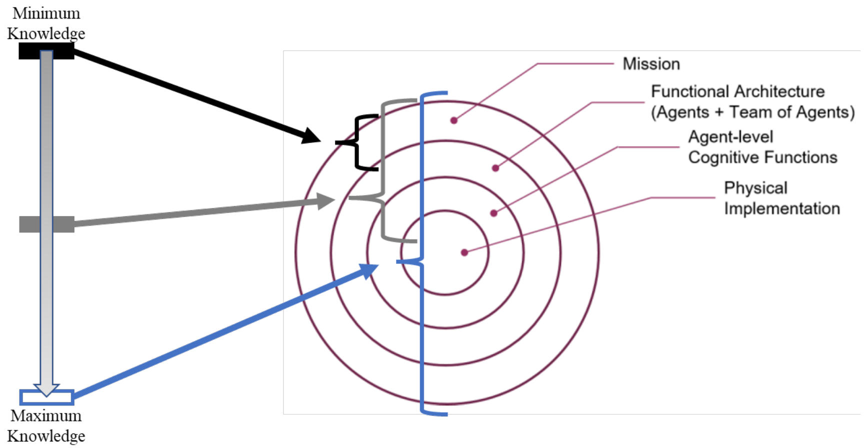
1. The system needs to turn on the light when Object X is detected
2. The system needs to be off when Object X is not detected



P_odd: probability of transition from S1 to S2

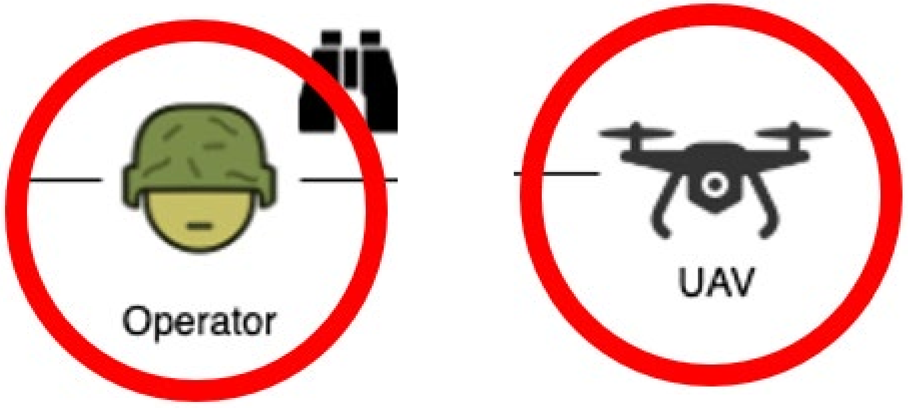
P_even: probability of transition from S2 to S1

Relating Levels of Knowledge: In the context of Silverfish



Silverfish description

- Mission
  - Activate the obstacles, given detection of a physical attacker
- Functional Architecture
  - Know specification desired behavior of the System of Systems **as whole**
- Limited knowledge of the Physical Implementation
  - Know that a drone provides the physical attacker detection mechanism through visual surveillance
  - Know that the activation is provided by the human operator



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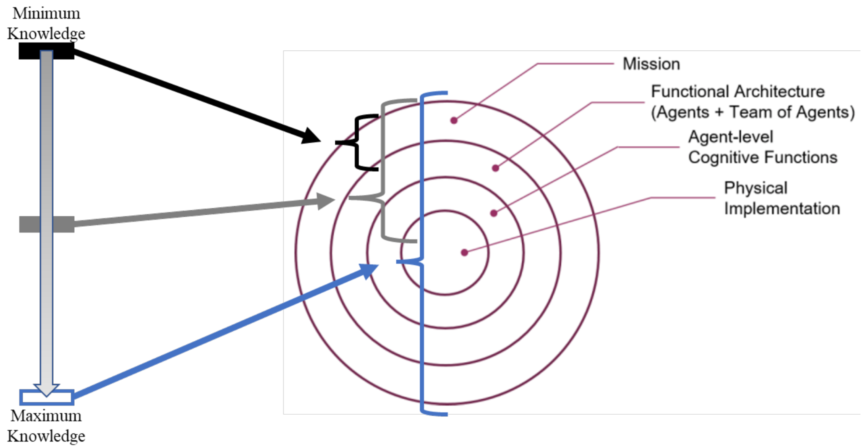

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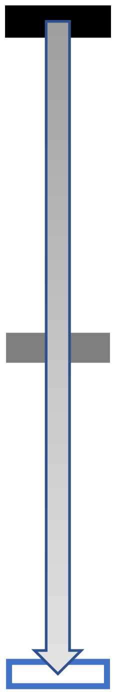
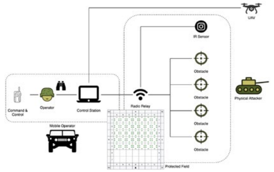
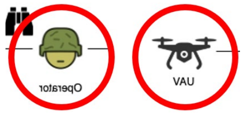


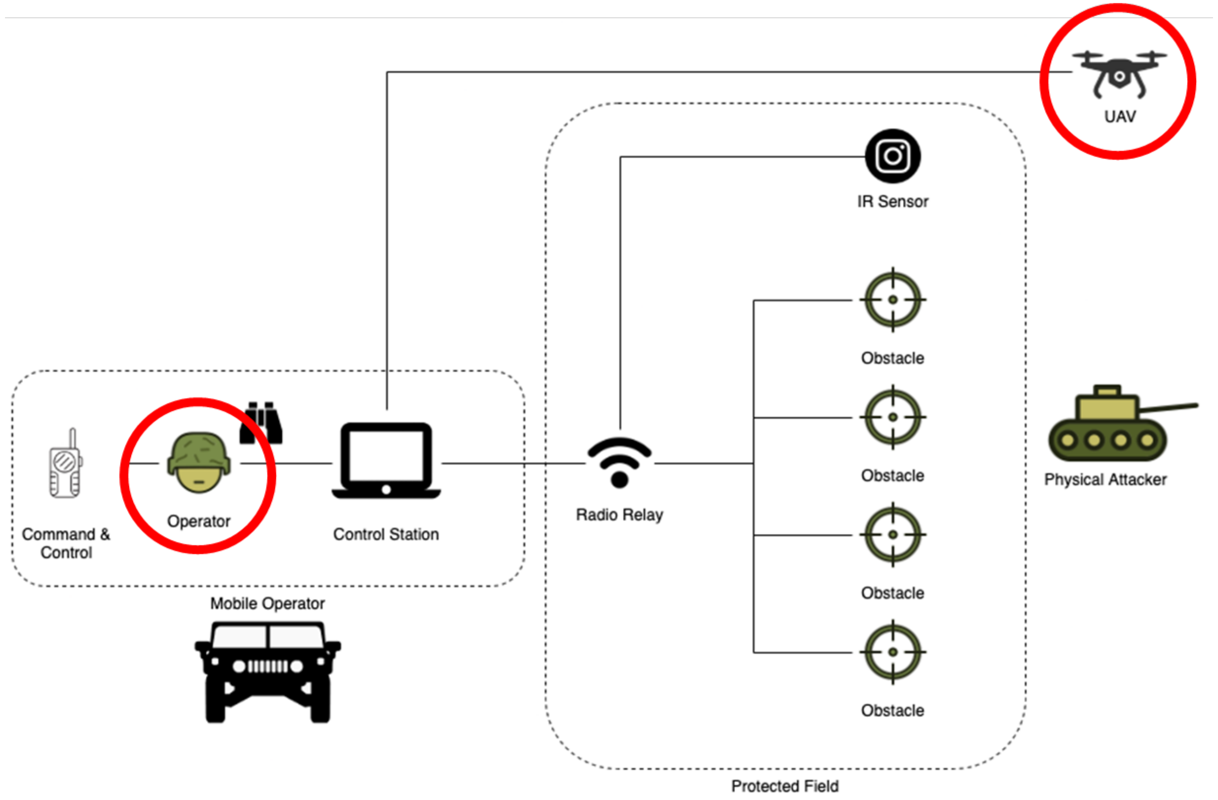
Mission ↔ Mission’

Functional Architecture ↔ Functional Architecture’

Physical Implementation ↔ Physical Implementation’





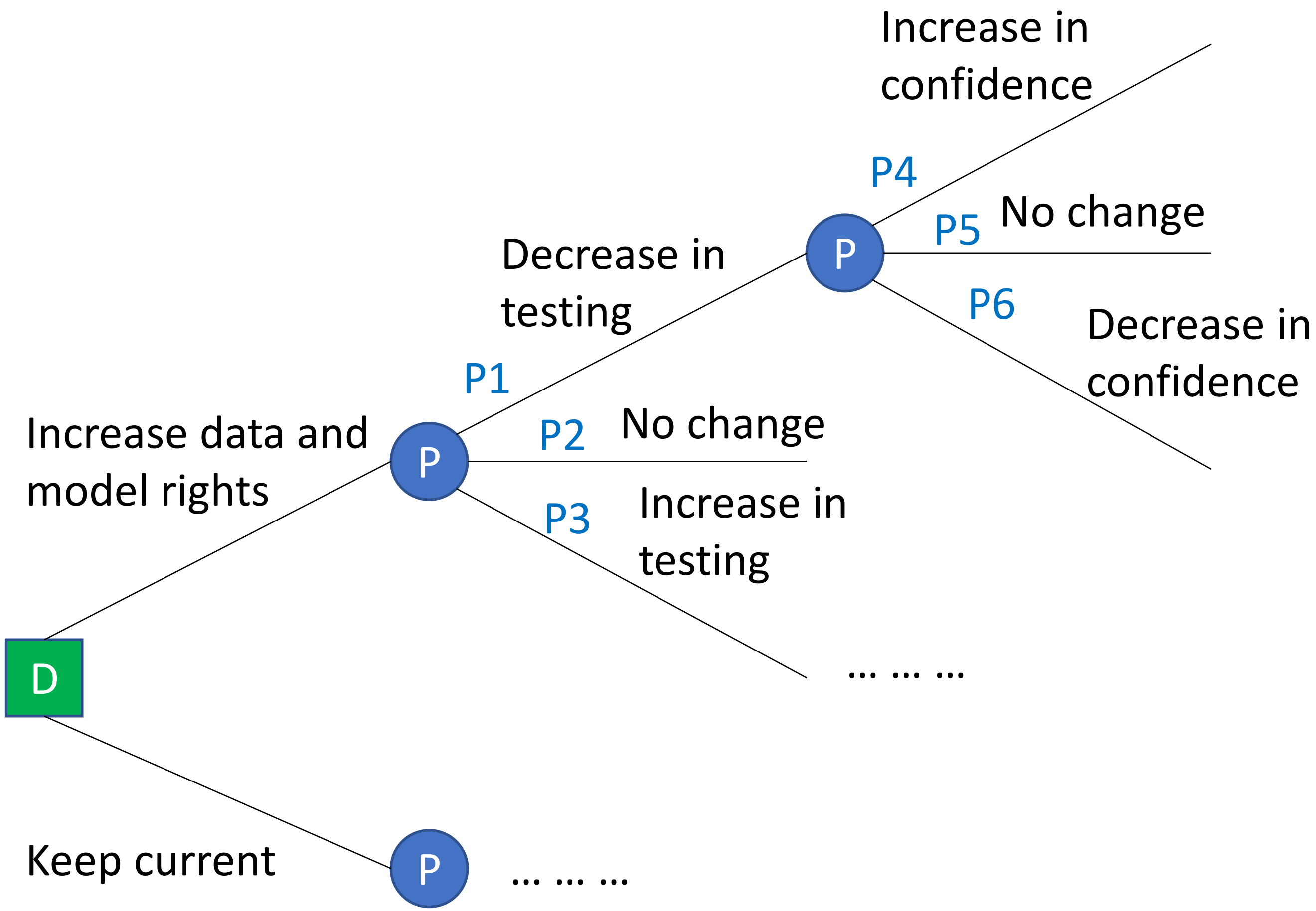


*Ideally we have full understanding. Limited understanding of the physical implementation impacts our understanding of fulfillment of functionality and mission objectives

D Decision

P Probability

Characterizing Value to the Government



Upper Level Decision Network

- Decision:
  - Characterize assurance trade space of: (increase in) data/model rights on (decrease in) need for testing and (increase in) confidence
- Fed by more complex Bayesian Networks
- Utility can be added ($/time)
- Can perform risk/uncertainty analysis

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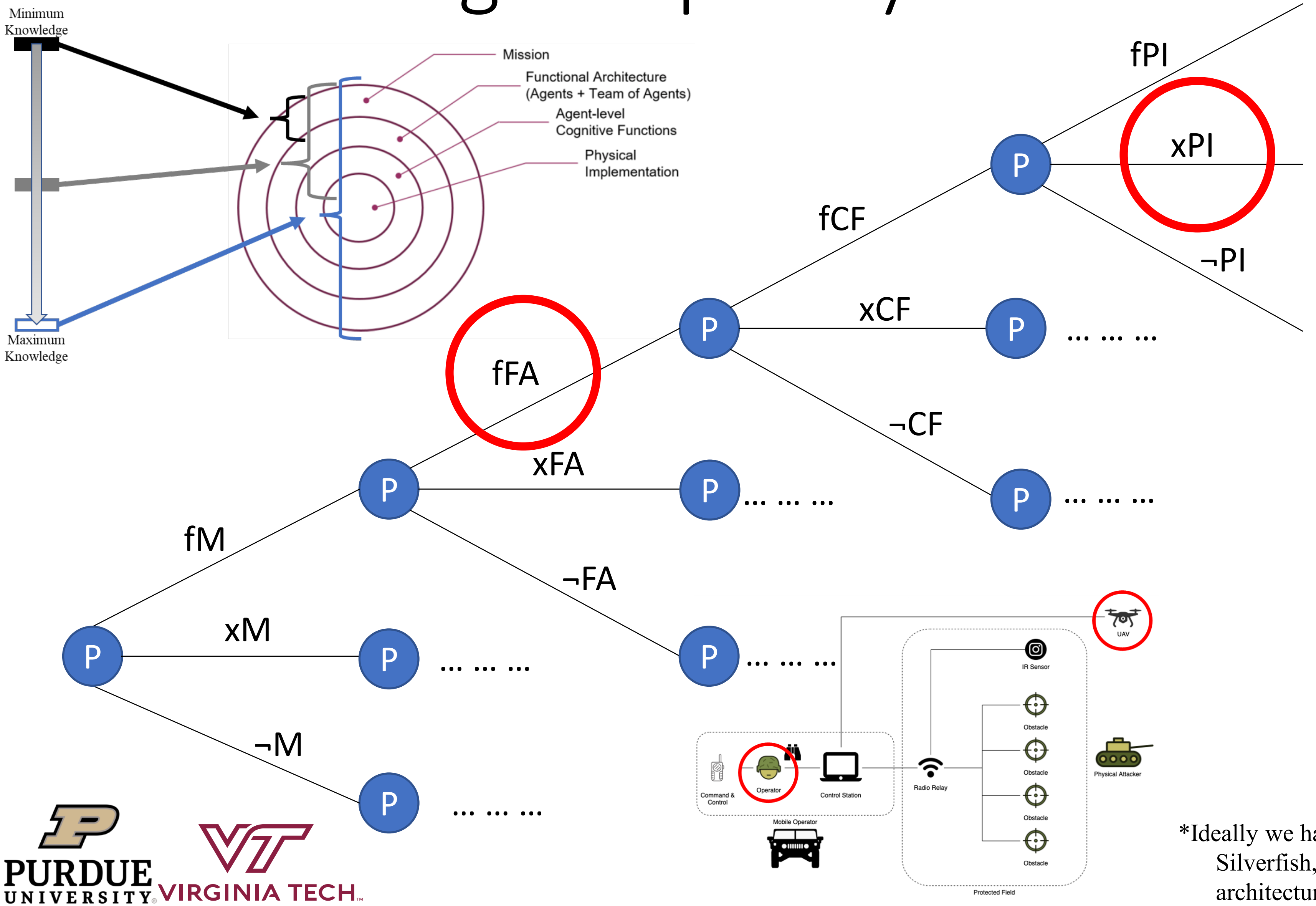
Increasing complexity of the network

P Probability



**Example network used to feed characterization of value to the government

M – Knowledge of Mission

f… – Full knowledge
x… – Partial knowledge
¬… – Zero knowledge

FA – Knowledge of Functional Architecture
CF – Knowledge of Cognitive function
PI – Knowledge of physical implementation

*Ideally we have full understanding. In the case of the example of Silverfish, we are starting with full knowledge of the functional architecture and partial knowledge of the physical implementation.

Next Steps

Plans by December

- Create physical implementation of the decision making-agent and UAV-based perception agent
  - Purdue part of the team
- Isolate the human-agent and UAV elements from the MBSE model in GENESYS
  - VT part of the team
- Initial Bayesian construct

Future Steps

- Development mathematical models and advance the T&E framework
- *Seeking* government and industry *partners*

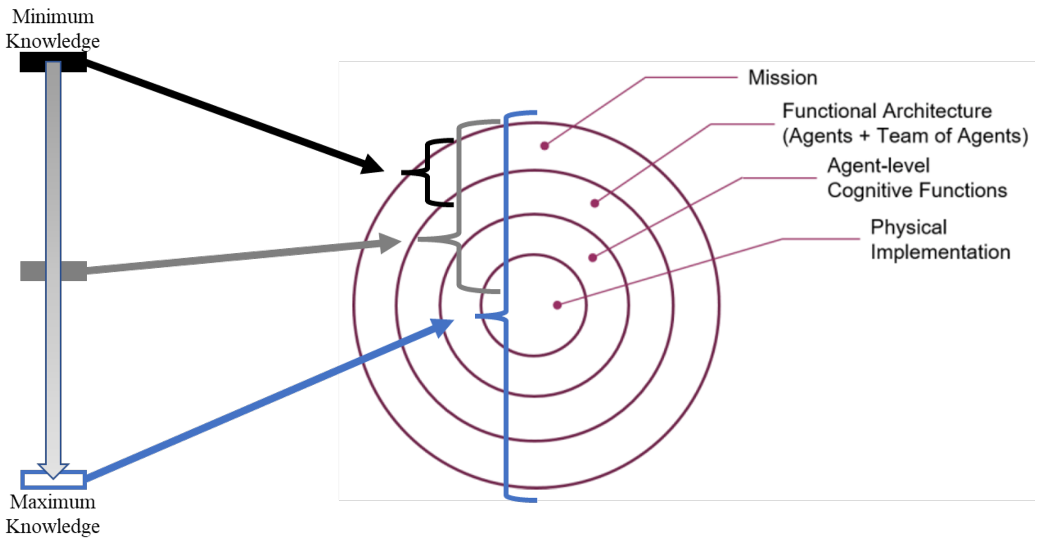
Expectations: Prospective Partners

Decision support to prove value to the Government

- If we have probabilities:
  - Gives us initial look at suggested value to government
- If we have utility value (time/$)
  - Likely to change the recommended decision
  - Enables uncertainty analysis of decision/recommendation to the government
- Case dependence
  - Decision may be case dependent
  - Global recommendation may be different
- Combinations of full, partial, zero system knowledge
  - Used to prove effectiveness of T&E framework
  - Degree to which the morphism holds determines the evaluation of the system

What we will provide to partners

- A (recommended) tool to:
  - Model the mission and systems (onion knowledge)
  - Measure morphisms
  - Model decision makers' preferences using utility
  - Model decision makers' state of knowledge
    - Bayesian network used to:
      - Collect data/probabilities
      - Likely to be in the format of an Excel file



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Thank you

Questions?

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