

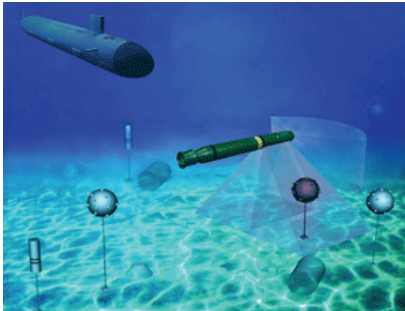
Autonomous Systems Challenges to Test and Evaluation



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The views, opinions, and findings should not
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Growing Demand for Autonomous Systems

- *DoD FY 2009-2034 Unmanned Systems Integrated Roadmap*
 - 311 Joint Capability Area (JCA) “Capability Targets”
 - 138 Systems
 - 41 Performance specifications
 - 17 technologies
 - Uses: Weapons, C4ISR, logistics, transportation, medical care, decision support, and others related to development of unmanned autonomous systems



Current Themes in the Literature

- “There is a common misconception in the testing industry that all unmanned autonomous systems can be tested using methodologies developed to test manned systems”
 - “The main difference lies in the unmanned autonomous system’s role in the decision process”
 - “...there is a need for a methodology that completely tests this decision process **without biasing the system into a default “human” solution.**”
 - Won’t make decisions as humans do
- “Society holds robots to a higher standard and has a lower tolerance for their errors.”
- “Unmanned systems still fall short (from becoming autonomous) in three key areas: **sensing, testing**, and interoperability.”

Dr. Lora G. Weiss

“Autonomous Systems
in the Fog of War”,
IEEE Spectrum,
August 2011

Challenges: T&E of Autonomous Decision Making

- Test Program Design Methodology
- Ensuring Testability
 - Early Engagement in Requirements & System Design
 - Performance Metrics and Standards
 - Use of System Boundaries in the system design

Mike Thompson

“Testing the Intelligence of
Unmanned Autonomous
Systems”

What is Meant by “Autonomous”?

- “Autonomous systems are...capable of performing tasks in the world by themselves, without explicit human control”
- “System that require no human intervention to perform any of its designed activities across all planned ranges of environmental conditions.”
- “Systems that sense, understand and act upon the environment in which they operate.”



- Definitions define “Automated” Systems
- Testing Elevators isn’t the Challenge

“Automated”

Make Prescribed Decisions
In predictable, understood conditions



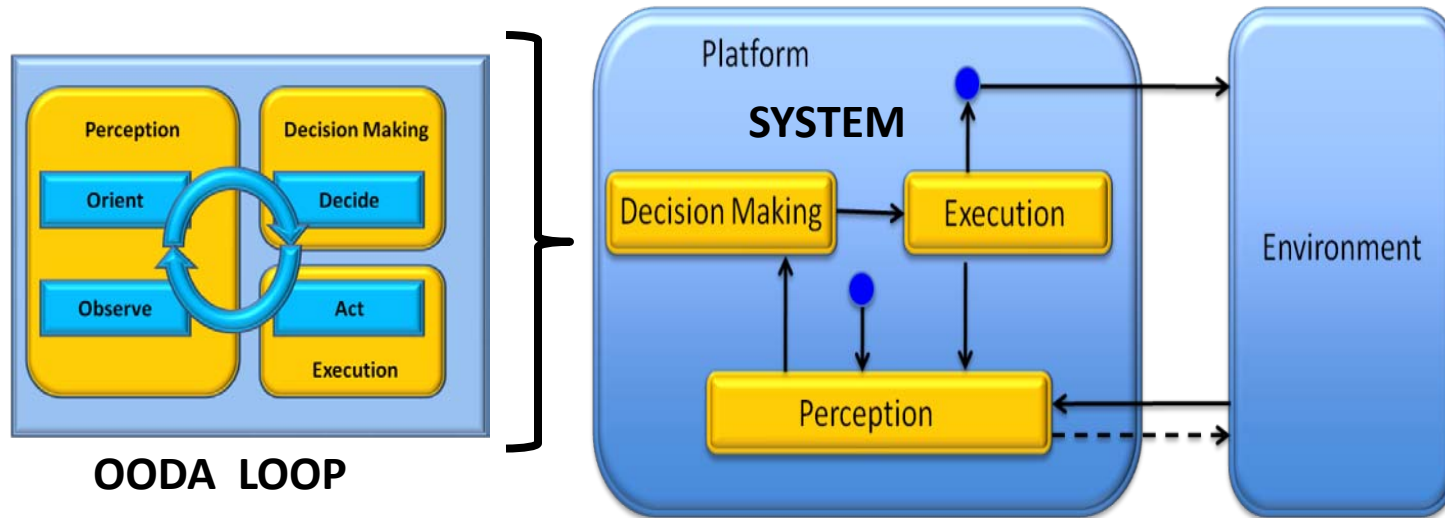
“Autonomous”

Make Emergent & Adaptive Decisions
In unpredictable ways
In unpredictable conditions

The Distinction is in the Decision Making Algorithms

Decision Making Systems

A “Functions” Oriented Description

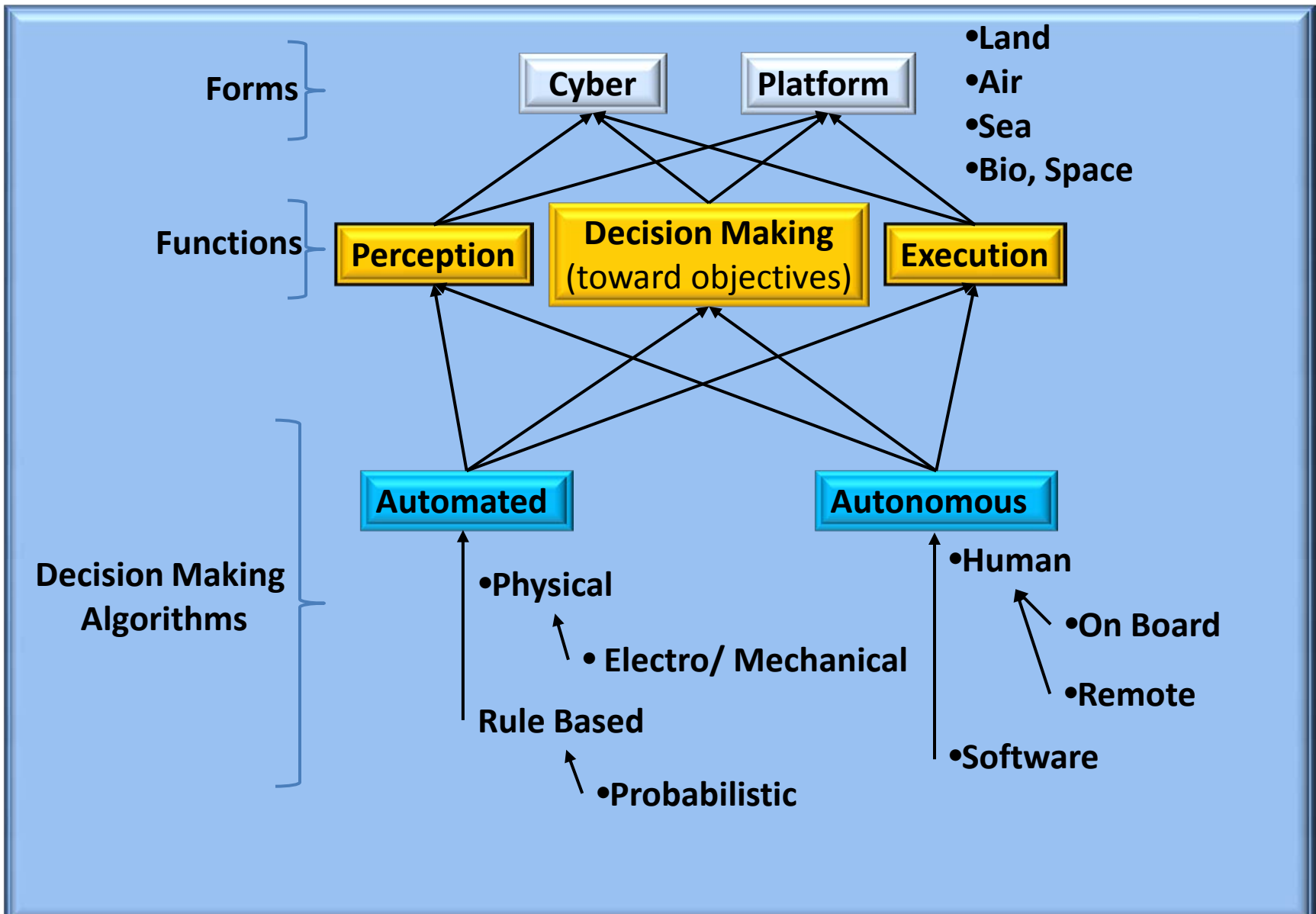


Three Core Functions:

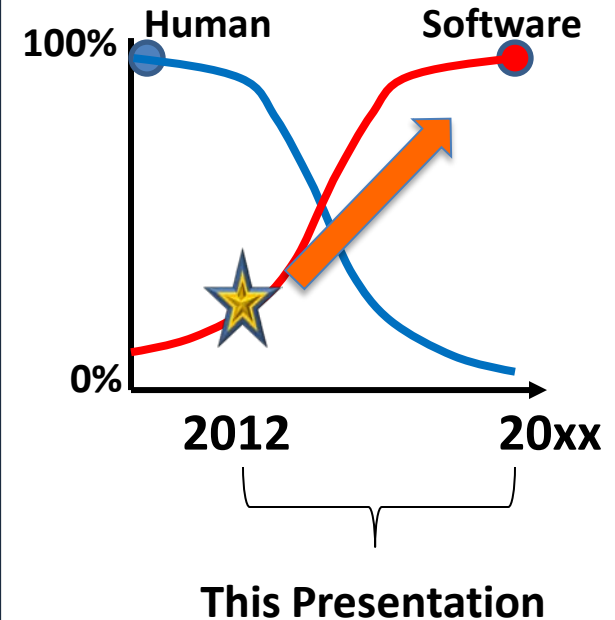
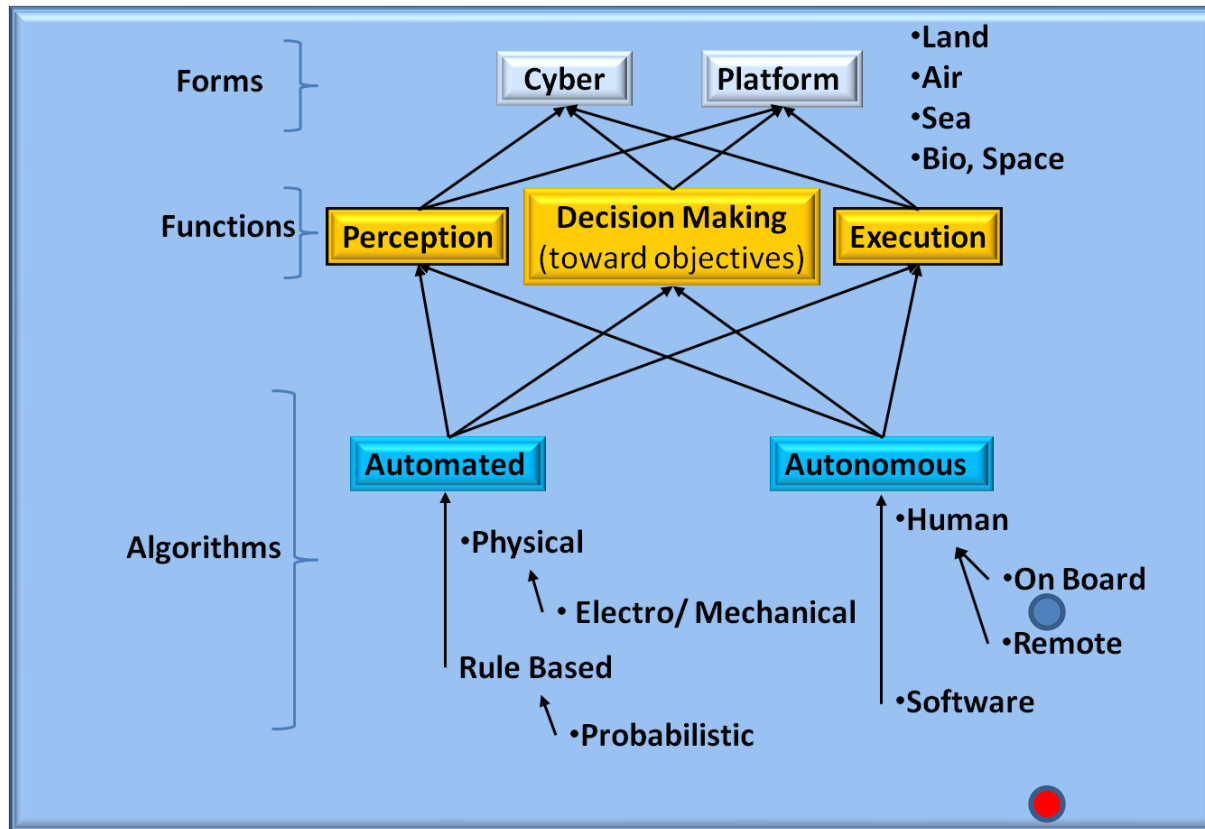
- **Perception:** Observing (sensing) characteristics of the environment and forming an Understanding (orientation)
- **Decision Making:** Prescribing actions toward satisfying objectives
 - Mission Objectives (what to accomplish)
 - Behavioral Objectives (how, and how not, to accomplish)
- **Execution:** Implementing prescribed actions

A System Ontology

Forms, Functions and Decision Making Algorithms



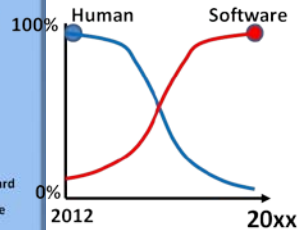
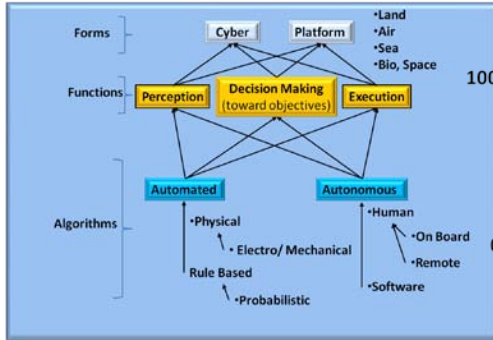
The Evolving “Share” of Autonomous Decision Making



Human Autonomous Algorithms: Current Role

- Make decisions that software cannot yet make
 - **Being overcome by technology**
- Enforce “human” standards on decisions made by non-human decision making
 - **Limiting potential effectiveness**

Autonomous Software Decision Making Algorithms



Human Autonomous Algorithms:

- Make decisions that software cannot yet make
- Enforce “human” standards on decisions made by non-human decision makers

Software Autonomous Algorithms:

- Make decisions in unpredictable ways
 - Adaptable decision making process (complex adaptive algorithms)
 - Evolve to “best” achieve objectives under constantly evolving conditions
 - Conditions and the “sequence” of conditions are unpredictable
 - Example: genetic algorithms in agent based simulations
- Require Metrics and Standards for:
 - The system to achieve objectives
 - The system to behave appropriately

T&E of Autonomous Systems

Characteristics, Metrics and Standards

Characteristics, Metrics and Standards for:

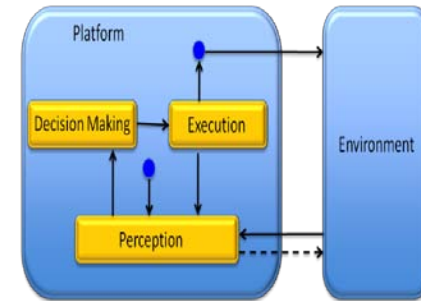
- **Observing:** Sensor design & performance
- **Orientating:** Situation understanding
- **Decision Making:** Solutions for achieving the objective conditions
 - **Conditions for Mission Objectives**
 - **Conditions for Appropriate behavior (toward others and self)**

• Challenges for System Designers (and T&E):

- Establishing which Characteristics to observe
 - Environmental characteristics germane to the system's objectives
 - Includes characteristics of objectives, of threats, of location, of neutrals, of the of the system itself, of many other germane entities
- Establishing Metrics for each characteristic
 - "What essentially describes (measures) the characteristics?"
 - Tilt or height of a wall, GPS coordinates, motion of a human
- Establishing Standards for the Metrics
 - How "collapsed" (short or leaning) does a wall need to be to be "destroyed" :
 - To stimulate action (coordinates of "here" VS of the "destination")
 - To know when to STOP or not take action

Autonomous System Testability

- Perception Function
- Decision Making Function
 - Decision making toward achieving objectives
- Execution Function



A T&E Question:

Q: Is an inadequate system performance toward its objectives due to:

- Erroneous Perception of the environment? or
- Erroneous Decision Making from a valid Perception of the environment? Or
- The system's inability to execute prescribed decisions?

Ensuring Testability Implies:

- A System Design discipline establishing **“System Boundaries”** between the Perception Function, the Decision Making Function and the Execution Function
- A **Severability** of T&E :
 - T&E of Perception from the T&E of Decision Making
 - Have **“ground truth”** for T&E of Perception, none for Decision Making
 - T&E of Decision Making from the T&E of Execution
 - Don't have time to test Decision Making via Execution

Autonomous System T&E Challenges

1. Perception Function (observe and orient)

•T&E tasks: Inform a confidence in the Perception Function by:

- Stimulating sensors

- Evaluating:

 - Sensor performance

 - Derived “orientations” / understanding

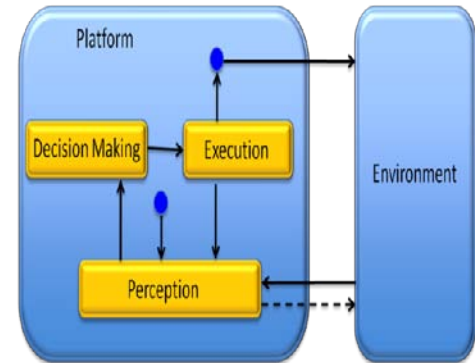
 - By comparison to “ground truth”

•T&E Challenges (**Semi-Tough**)

- Physics and facilities to adequately stimulate sensors (“Challenge” facilities)

 - Appropriately presenting characteristics for the sensors to measure

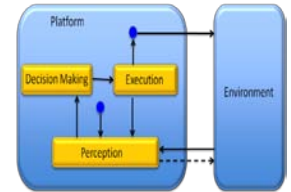
 - Including background interactions



Autonomous System T&E Challenges

2. Decision Making Function (prescribe actions toward objectives)

- **T&E Tasks:** Inform a confidence in the performance of autonomous decision making software



- T&E of complex adaptive algorithms

- Algorithms that constantly evolve their decision making process to produce “best solutions” based on an constantly evolving perception

- Perception based on unpredictable and constantly evolving content and sequence of conditions.

- **T&E Challenges: (Tough)**

- Informing a confidence in an algorithm’s decision making performance

- **Testing algorithms across a vast scope of content and sequences of “conditions”**

- Requiring new, advanced computer based test methods

- **Developing a new, scientifically rigorous foundation for designing T&E programs**

- Design of Experiments (DOE) on steroids

- Effective T&E of unpredictable processes and emergent behaviors

- **Collaboration early with designers to ensure decision algorithm testability**

- Defining testable characteristics, metrics and establishing standards

- Demands (professional/ moral/ legal) for ensuring adequate T&E to avoid unacceptable consequences from system behavior

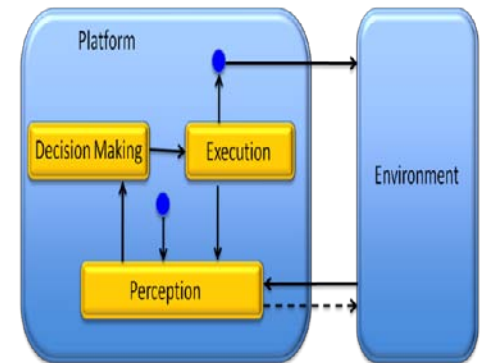
- Establishing Certifications for Autonomous System T&E methods and practitioners

- T&E of Decision Making Algorithms in a system context

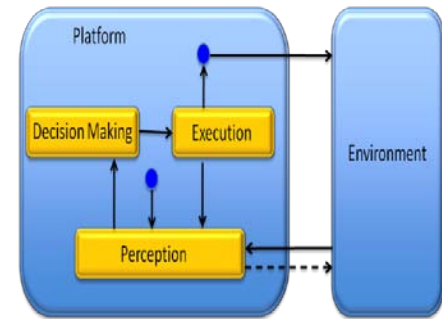
Autonomous System T&E Challenges

3. Execution Function (implements prescribed decisions)

- **T&E Tasks:** Inform a confidence in the system's performance of prescribed actions
 - T&E of classic system functions
 - Animation, protection, power, reliability
 - Performance of system controls
 - electro-hydraulic-mechanics
 - Autopilots, servos, etc
- **T&E Challenges: (Not so Much)**
 - Physical System Performance
 - Speed, Carrying Capacity, Energy Demand, Mobility, Fatigue, Vulnerability, etc
 - Traditional performance metrics
 - Traditional T&E methods



Required: A Scientifically Rigorous Foundation for Planning T&E of Autonomous Systems



- To Ensure Testability of unmanned autonomous system's
 - **Incorporating decision making performance in the system design**
 - To provide system based Characteristics, Metrics and Standards for use as Conditions and Standards for T&E of a system's Decision Making performance
- **To provide a scientifically rigorous basis for designing adequate T&E Programs**
 - Define number and conditions of tests required to establish "confidence".
 - Comprised of an amalgam of:
 - **Control Theory**
 - For the system design to produce Characteristics, Metrics and Standards for the Decision Making functions ... enabling testability
 - **Complexity Science**
 - To address Unpredictability, Emergent Behavior, Fitness Landscapes & Attractors in the system design and in design of the T&E program
 - **Design of Experiments (DOE)**
 - To prescribe the number and conditions of specific Tests to be performed to support a confidence in the system's behavior



T&E of Autonomous Systems

Summary



- **Traditional Systems T&E will not be Sufficient for T&E of Autonomous System.**
 - Must now inform a confidence in “emergent”, rather than “prescribed”, performance
 - Resulting from adaptive decision making processes being driven by unpredictable conditions
 - Satisfying “mission accomplishment” as well as “acceptable behavioral” objectives
- **To ensure Testability: (what to measure to establish performance)**
 - **Requires a new System Design discipline and an early collaboration with T&E**
 - Establishing System Boundaries between Perception, Decision Making and Execution Functions
 - Incorporating decision algorithm performance in system control design
 - Producing Characteristics, Metrics and Standards for effective decision making
- **To ensure adequate Testing (to inform confidence in the measured performance)**
 - **Requires a new, scientifically rigorous foundation for planning T&E programs for autonomous systems, Merging:**
 - Control Theory
 - Complexity Science
 - Design of Experiments

