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DoD Autonomy Roadmap

Autonomy Community of Interest

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Briefing Outline & Flow

- **Overview of the Autonomy CoI**
  - CoI Purpose & Organization
  - Investment Profile
  - Technical Taxonomy
- **Key Challenge Areas**
  - Goals and Hard Problems
- **Overarching Autonomy Message & Wrap-up**
  - Notable Recent Achievements
  - Autonomy CoI Way Forward

Autonomy Community of Interest (CoI)

Purpose: **The Autonomy CoI's purpose is to advance autonomous systems by assessing Science & Technology investments, gaps, and opportunities, and initiating critical enabling technology development.**

The Autonomy CoI provides a framework for DoD scientists, engineers, and acquisition personnel to:

- **Engage in multi-agency coordination and collaboration**
- **Report on the "state-of-health"**
- **Identify emerging research opportunities**
- **Measure progress**

Autonomy CoI Steering Group:

Autonomy CoI
Technology Portfolio

Autonomy is the computational capability for intelligent behavior that can perform complex missions in challenging environments with greatly reduced need for human intervention, while promoting effective man-machine interaction.

What's driving Autonomy S&T?

- Manpower efficiencies (reduce human footprint and personnel cost)
- Rapid response and 24/7 presence (timely, persistent, enduring)
- Harsh and unpredictable environments (day, night, bad weather, rubble, barriers)
- New mission requirements (increasing competence enables new capabilities)
- Advanced medical applications (critical response, end-to-end critical care)
- Logistical support (reduce logistics burden: hold, transport, carry, watch)

Technology Taxonomy (Tier 1 – Key Challenges Areas)

Machine Perception, Reasoning and Intelligence

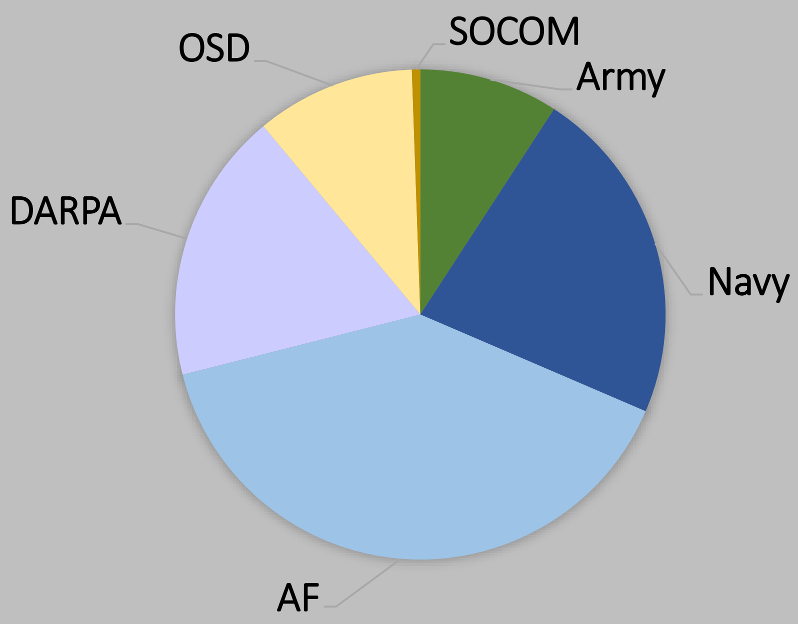
Human/Autonomous System Interaction and Collaboration

Scalable Teaming of Autonomous Systems

Test, Evaluation Validation and Verification

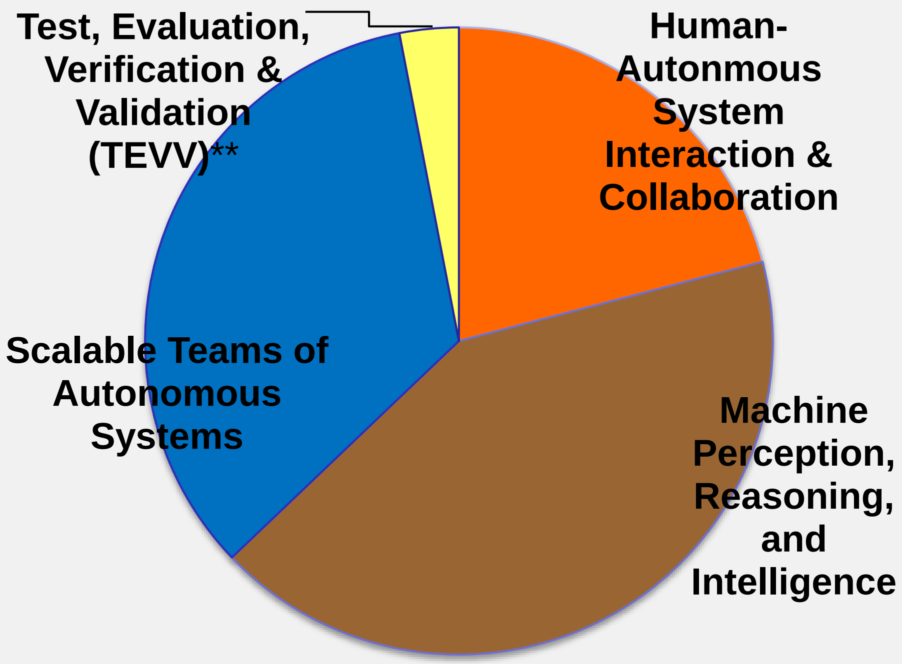
Autonomy CoI Funding Breakdowns

FY 2018 PRIMARY + ANCILLARY DATA



Approx. FY18: $520M

BREAK-OUT OF SERVICE INVESTMENTS



Dedicated TEVV research efforts continues to be area of low investments

** Some TEVV research is captured in programs binned against other areas

Tier 1 Technical Challenge Area's Descriptions and Goals

Machine Perception, Reasoning and Intelligence (MPRI): *The underlying perceptual, reasoning, and learning capabilities to greatly reduce the need for human interventions, while enabling effective teaming with the warfighter*.

Goals:

- Common representations/architectures
- Learning and Reasoning
- Understanding the Situation/Environment
- Robust capabilities/decision-making

Human/Autonomous System Interaction and Collaboration (HASIC): *Effective human-machine collaboration, enabled by trust and shared understanding, and supported by natural interaction, communication and learning.*

Goals:

- Calibrated trust and transparency
- Common understanding and shared perception
- Human-agent interaction
- Collaboration
- Interactive learning

Scalable Teaming of Autonomous Systems (STAS): *Shared mission intent &execution (decentralized and collaborative) incorporating both homogeneous and heterogeneous groups.*

Goals:

- Mission-level task allocation/assignment
- Robust self-organization, adaptation, and collaboration
- Space (air, land, water) management operations
- Sensing/synthetic perception

Test, Evaluation, Validation, and Verification (TEVV): *From algorithms to scalable teams of multiple agents – Developing new T&E, V&V technologies needed to enable the fielding of assured autonomous systems*.

Goals:

- Methods, metrics, & tools assisting requirements development and analysis
- Evidence-based design and implementation
- Cumulative evidence through R&D, & operational testing
- Run-time behavior prediction and recovery
- Assurance arguments for autonomous systems

Human/Autonomous System Interaction and Collaboration (HASIC)

Goals

Calibrated Trust and Transparency

- Understanding of and confidence in the others' actions.

Common understanding and shared perceptions

- Information in a form easily understandable by both human and autonomous teammates.

Human-agent interaction

- Fluid and natural interactions and communication using various modalities.

Collaboration

- Flexible levels of autonomy, graceful hand-offs of authority.

Interactive learning

- Acquiring new information and skills as a team.

Technology Challenges

Transparency-enabled approaches to autonomy

- Complex AI decision process summarization.

Improved methods for sharing of authority

- Dynamically changing levels of interaction/collaboration.
- Improving methods for determining, and transitioning to different agents having authority.

Cognitively-compatible behavior

- Human-compatible situational awareness.
- Robustness to incomplete, uncertain, and inaccurate information.

Context-aware interaction

- Awareness of "commander's intent".

Dynamic bi-directional information flow; dialogue with AI

- Prediction of human teammate needs/performance.
- Explanation of AI or human decisions to teammates.

Ad hoc collaboration

- Between "untrained" human teammates and "uncalibrated" autonomous system.
- Changing interactions with team maturity.

Machine Perception Reasoning & Intelligence (MPRI)

Goals

Common Representations/Architectures

- Think & fight as team: systems must reason about situation & orders for rapid collaboration
- Communicate critical estimates for decision-making (explain situation, propose actions with rationale)

Learning and Reasoning

- Development of methods for entities to evolve behaviors over time based on a complex and ever-changing knowledge base of the battle space.

Understanding the Situation/Environment

- Understand threats: systems must rapidly learn to recognize concealed, camouflaged, and deceptive obstacles, behaviors & threats, adaptively.
- Intelligent exploration and coordination across entities within the environment to minimize uncertainty.

Robust Capabilities

- Fundamentally explore system paradigms to ensure behavioral stability in the face of increasing complexity and uncertainty.

Technology Challenges

Common Representations/Architectures

- Representations that support perception and intelligent behavior.
- Computational models for representing knowledge of the mission space, rationale, and machine agent capabilities.

Learning and Reasoning

- Learning in complex data environments.
- Learning context, adaptive recognition and scene understanding.

Understanding the Situation/Environment

- Processing of sensor data, to information, to actionable understanding presented to the warfighter and the system.
- Integrate small teams of humans & artificially-intelligent agents to provide improved decision-making with less data & in less time.
- Autonomously adjudicate between behaviors, e.g. task priorities.

Robust Capabilities

- Learning for robust control: enabling systems to incorporate decision makers in an action, in both planned and unpredictable scenarios.

Scalable Teaming of Autonomous Systems (STAS)

Goals

Mission-level task allocation/assignment:

- Collaborative and distributed ensembles easily tasked/re-tasked, under uncertainty & partial info.
- Responsive to mission-level changes in operator-directed intent.

Robust self-organization, adaptation, and collaboration:

- Dynamic adaption, ability to self-organize and dynamically restructure
- Agent-to-agent collaboration.
- Robustness to dynamic changes in contested environments with denied infrastructure

Space management operations:

- Operation over diverse spatial areas, flexibly to adapt with distributed intelligence to update, within-mission boundaries, incorporating scalability and timelines for mission success.

Sensing/synthetic perception:

- Distributed perception, learning, and sharing via a variety of sensing modalities.
- Ability to overcome individual platform limitations.
- Integrate human and intelligent system perceptions.

Technology Challenges

Task allocation/assignment

- Scalable, self-organizing organization appropriate to mission tasking.
- Task allocation/assignment, planning, coordination and control for heterogeneous systems.

Self-organization, adaptation, and collaboration:

- Robust to limited communications
- Appropriate coordination and relationships between individual unit intelligence, team, and coalitions.
- Balancing multiple competing and conflicting performance metrics, and individual platform vs. group objectives.
- Local and global adaptation in mission, organization, roles and behaviors within commander-directed intent.

Space management

- Permitting operation in close proximity to other manned and unmanned systems.
- Dispersed operation over large, crowded areas.

Sensing/synthetic perception

- Information and data fusion from many heterogeneous sources under intermittent communications and bandwidth constraints, including varying levels of information-sharing.

Test and Evaluation, Validation and Verification (TEVV)

Goals

Methods, Metrics, and Tools Assisting in Requirements Development and Analysis:

- Precise, structured standards to automate requirement evaluation for testability, traceability, and consistency.

Evidence-Based Design and Implementation:

- Assurance of appropriate decisions with traceable evidence at every level to reduce the T&E burden.

Cumulative Evidence through Research, Development, and Operational Testing:

- Progressive sequential modeling, simulation, test, and evaluation to record, aggregate, leverage, and reuse M&S/T&E results throughout engineering lifecycle.

Run-time Behavior Prediction and Recovery:

- Real time monitoring, just-in-time prediction, and mitigation of undesired decisions and behaviors.

Assurance Arguments for Autonomous Systems:

- Reusable assurance case-based on previously evidenced “building blocks”.

Technology Challenges

Requirements that are mathematically expressible, analyzable, and automatically traceable to different levels of autonomous system design.

- Dynamic requirements generation & feedback, Design time and run time transparency

Methods and tools enabling the compositional verification of the progressive design process.

- Trust / transparency in design, “Correct by construction” synthesis

Systems that are “licensed” to perform functions after requirements satisfied.

- Transparency Learning Algorithms,
- Pedigree-Based Licensure

System constrained by set of allowable, predictable, and recoverable behaviors, shifting analysis/test burden to more deterministic run-time assurance mechanism.

- Run time analysis prediction,
- Transparency models for past performance and future behaviors.

Argument based notations, structures and semantics of arguments, implicitly tied to requirements

Autonomy CoI S&T Priorities with Notable Recent Achievements

- **Effective human-machine collaboration to enhance overall team performance, increase safety for human partners, and offset brittleness**
  - Successful test of IMPACT system (C2 platform) with live small UAVs cooperatively with air, ground, sea virtual autonomous systems (TTCP partners)
- **Versatile standards for autonomy modeling, design, and interfaces**
  - Autonomous Aerial Cargo/Utility System helicopter operated without a pilot during exercises; included Marines loading the helicopter with supplies, then using the application to clear it for autonomous takeoff and flight
- **Learning in complex data environments; resource-constrained AI processing at the point-of-need**
  - DoD Researchers were Winners of the Large-Scale Movie Description Challenge at the 2017 International Conference on Computer Vision in Venice, Italy, October 22-29, 2017
  - Demonstrated discovery of multi-INT ordinal and temporal patterns and anomalies using Bayesian and Causal models transitioned to customer
- **Powerful new capabilities for testing and evaluating autonomy**
  - DoD–led Workshop on Verification of Autonomous Systems, ICRA 2018
  - Multidisciplinary University Research Initiative on Unifying Stochastic, Discrete, and Continuous Dynamics in Mathematically Rigorous Verification Frameworks for Intelligent and Autonomous Systems
- **Continuous, real-time V&V of autonomy as it adapts in the field**

Autonomy CoI Way-Ahead

- **Continue to Increase Cross-COI engagement**
  - ASBREM Autonomous Medical Evacuation (AME) Workshop
  - Counter IED FOCUS Program
  - Human Systems, C4I, Sensors & Processing, Power and Energy, Air Platforms, Ground and Sea Platforms
- **Investigate Workshops:**
  - Cross-DoD workshop to review service plans for data and algorithms, to look for coordination opportunities
  - "Architecture" Workshop
- **Industry Outreach**
  - Planning for CY18 non-traditional/startup engagement in Boston
  - The Autonomy CoI looking for industry suggestions on ways to improve collaborations and share gaps, technical challenges, and technical directions

Questions

Back Up

Current Autonomy CoI Program Success: Allied IMPACT

TTCP The Technical Cooperation Program

Autonomy Strategic Challenge

Our mission is to enhance, demonstrate and evaluate the military utility of autonomous systems for future littoral operations.

Objectives	Annual Progress
Determine the potential **military utility** of autonomy technologies.	Military endorsed ASC "use-case" applications. AIM system evaluated by FVEYS military experts at two trials.
Advance and demonstrate **human-autonomy teaming** through simulation and live trials.	First four-eyes test of "AIM" system with multiple allied co-developed software parts.
Improve **interoperability** of emerging FVEYS autonomous systems.	Successful test of IMPACT system with live small UAVs cooperatively with air, ground, sea virtual autonomous systems.
Harness **industry developments** for FVEYS military requirements.	Engaged industry and identified a range of UAV, UGV, USV, UUV platforms and systems.

AIM=Allied IMPACT
IMPACT=US Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies