Towards a Multi-Agent/Multi-Domain World Model

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Outline

• Our Goal

• Scenario - Multi-Agent/Multi-Domain Squad

• Multi-Agent World Model
  - Definition
  - Requirements

• Our Approach
  - Multi-Agent World Model Demo
  - Standards
Our Goal

Previous work on World Modeling focuses on information integration on a single agent.

Single-Agent World Model

- Repository for storing, providing and sharing information relevant to a system’s operational environment and beliefs.
- Processed sense data.
- Environmental beliefs derived from sense data:
  - Object identification and classification, including threat identification, etc.
- History of behavioral decisions made as a result of sense data and derived beliefs:
  - Path modification for obstacle avoidance, etc.
Our Goal

Previous work on World Modeling focuses on information integration on a single agent.

What does “World Model” mean for a Multi-Agent/Multi-Domain system?
Scenario – Multi-Agent/Multi-Domain Squad

Squad leader

Ground team

Aerial team
Scenario

• Mission: Area reconnaissance for IED threats

• Multi-Domain team needs to
  - Do aerial scan of geographic area
  - Identify suspicious areas
  - In-depth reconnaissance with ground team
  - Identify possible threats
Scenario

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https://upload.wikimedia.org/wikipedia/commons/a/a5/IED_Baghdad_from_munitions.jpg
Scenario – Multi-Domain Squad

Horizontal sharing of information within a squad
Scenario – Multi-Domain Squad

*Vertical* sharing of information with squad leader
Scenario – Multi-Domain Squad

Horizontal sharing of information between squads

Squad 1

Company Command

Squad 2
Scenario – Multi-Domain Squad

Company Command

Vertical sharing of information with company commander

Squad 1

Squad 2
Scenario – Multi-Domain Squad

Remote analysts may need access to the information

Team members can be humans or robots
Multi-Agent World Model

Multi-Agent/Multi-Domain World Model

Facilitates
- Common Operating Picture
- Situational Awareness across System of systems
- Command and control

Enables
- Semantic data interchange among heterogeneous robot and human teams
Multi-Agent World Model - Requirements

• **Shared**
  - Within and across systems
  - Vertical and horizontal
  - Timely and relevant (right information, right place, right time)

• **Scalable**
  - Across many heterogeneous agents
  - With differing capacities (network, compute, storage)

• **Extensible**
  - New kinds of missions and tasking
  - New kinds of domains (e.g., amphibious robots)

• **Interoperable**
  - Interoperability of data across lifetime of systems
  - Across multiple vendors

• **Resilient**
  - Unreliable networks and topologies
  - Node failures
  - Unexpected tasking (on-the-fly teaming)
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World representation is **meaningful** across:
- Heterogeneous robots
- Human operators
- Aggregated data repositories
- Reasoning engines

Focus on **semantic data** rather than raw sensor data & specific algorithms
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Data is available
- Across system topologies
- Across node capabilities

Efficient use of network bandwidth
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Data definitions are **dynamic** (add new types of data on the fly, e.g., vehicles, weapons)

Data is **self-describing**
- Facilitate aggregation across composite sources, querying
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Requires **standards**
- Data formats
- Semantics (ontology)
  - Things in the world
  - Relationships between them
  - Types of missions
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- Robust
- Persistent
- Available
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Multi-Agent World Model Demo - Motivation

- Work through a scenario
- Motivate design for standard
- Proof of concept
  - Viability of approach (key part of a world model is need to accommodate legacy systems)
Multi-Agent World Model Demo

In Theater

Commander

- Turtlebot Operator
- Traxxas Operator
- Analyst (remote)

Recon robot

Mapping robot

Mission:
- Map a building using Mapping robot
- Examine potential threats using Recon robot
- Assess threats with help from Analyst
Multi-Agent World Model Demo

In Theater

Mission requires:
- Sharing data

• Discovery-based peer-to-peer data synchronization
• Invisible to World Model clients

Commander

Turtlebot Operator

Turtlebot

Recon platform

Turtlebot Operator

Mapping platform

Traxxas Operator

Traxxas

Analyst (remote)
Multi-Agent World Model Demo

In Theater

Commander

Turtlebot Operator

Turtlebot

Recon platform

Traxxas Operator

Traxxas

Mapping platform

Mission requires:

• Sharing data
• Resilience

• Physical congested wireless (WiFi)
• Unpredictable system availability
Multi-Agent World Model Demo

In Theater

Commander

Linux GUI

Mission requires:
• Sharing data
• Resilience
• Interoperability

• OS and transport-agnostic
• JAUS↔ROS adapters

Turtlebot Operator

Recon platform

JAUS

ROS

Windows GUI

Analyst (remote)

Traxxas Operator

Mapping platform

JAUS

ROS

Traxxas
Multi-Agent World Model Demo

1. Recon robot uses map generated by Mapping robot
2. Recon robot visits POI designated by commander, takes snapshots
3. Commander asks remote analyst for assessment
4. Analyst gives response
Multi-Agent World Model Demo – Lessons Learned

• Viability of standards-compliant facade
  - Integrated existing ROS-based system into a system of systems through a standards-compliant (JAUS) layer
  - Backwards compatibility with legacy systems

• Value of open interface
  - Ability to run on multiple systems (Win, Linux),
  - Support for using multiple transports (DDS, ROS, JAUS)

• Importance of testing with physical networking configuration
  - Exercised data distribution and scaling in face of realistic delays and network congestion
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Standards Activity - Previous

• Joint Architecture for Unmanned Systems (JAUS)
  - Reference Architecture 3.3 (2007)
    ▪ World Model Vector Knowledge Store
    ▪ Geometric focus rather than flexible metadata
    ▪ Limited cross-platform data-sharing mechanism
  - Environment and World Model Task Group (2013)
    ▪ Effort discontinued

• RCTA Common World Model (2013)
  - Focus on data sharing within a platform, not between platforms
  - APL assessment: Disadvantages of RCTA model outweighed advantages (2014)
    ▪ Restrictive, fixed set of metadata
    ▪ Hardcoded self information
Standards Activity – Current Approach
Working with SAE AS-4 JAUS Committee

• Treat “World Model” as a collection of capabilities (services)
• A Multi-Agent application may
  - Mix-and-match these capabilities
  - Have a different mixture of capabilities on each node
• Identify a factoring of services that maintains a good separation of concerns. E.g.:
  - Autonomy
  - Data fusion
  - Information sharing and synchronization
  - Transport considerations
• Work on standards for foundational pieces
  - Data storage, transport, synchronization

Current Status
• Initial proposal to SAE AS-4 Committee in October 2016
• Informal task force established to refine proposal
• Used the proposed standards in our World Model Demo
Standards Activity – Lessons Learned

• DON’T
  - Start with detailed ontology definitions
  - Rely on static data definitions
  - Try to boil the ocean (single-shot comprehensive solution)

• DO
  - Consider **system-of-systems** from the start
  - Consider **distributed data** from the start
    - Network topologies, discovery, data transfer, replication, …
    - Hard to retrofit multi-system scenario into single-system architecture
  - Design for **extensibility as core principle** ("design the syntax, not the sentences")
    - Self-describing data definitions and ontology
    - Extensible ontology, sensors, algorithms, mission types, capabilities
  - Design for **backward compatibility**
    - Adapters for legacy systems and architectures (or for COTS architectures)
# Towards a Multi-Agent/Multi-Domain World Model

## Requirements

**Shared**
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- Vertically and horizontally
- Timely and relevant

**Scalable**
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## Lessons for the Future

| Consider system-of-systems from the start |
| Consider distributed data from the start |
| Design for extensibility as a core principle |
| Value of open interfaces |
| Design for backward compatibility |
| Viability of standards-compliant façades |
| Testing with physical multi-agent configurations |