Towards a Multi-Agent/Multi-Domain World Model

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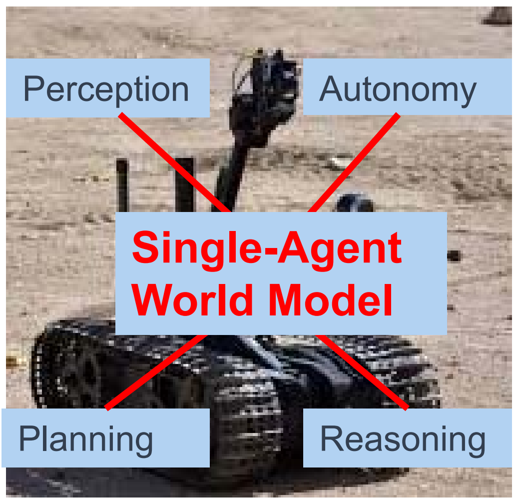
Outline

- 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.

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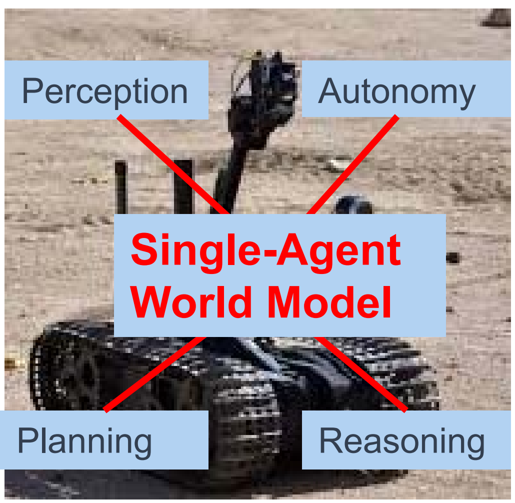
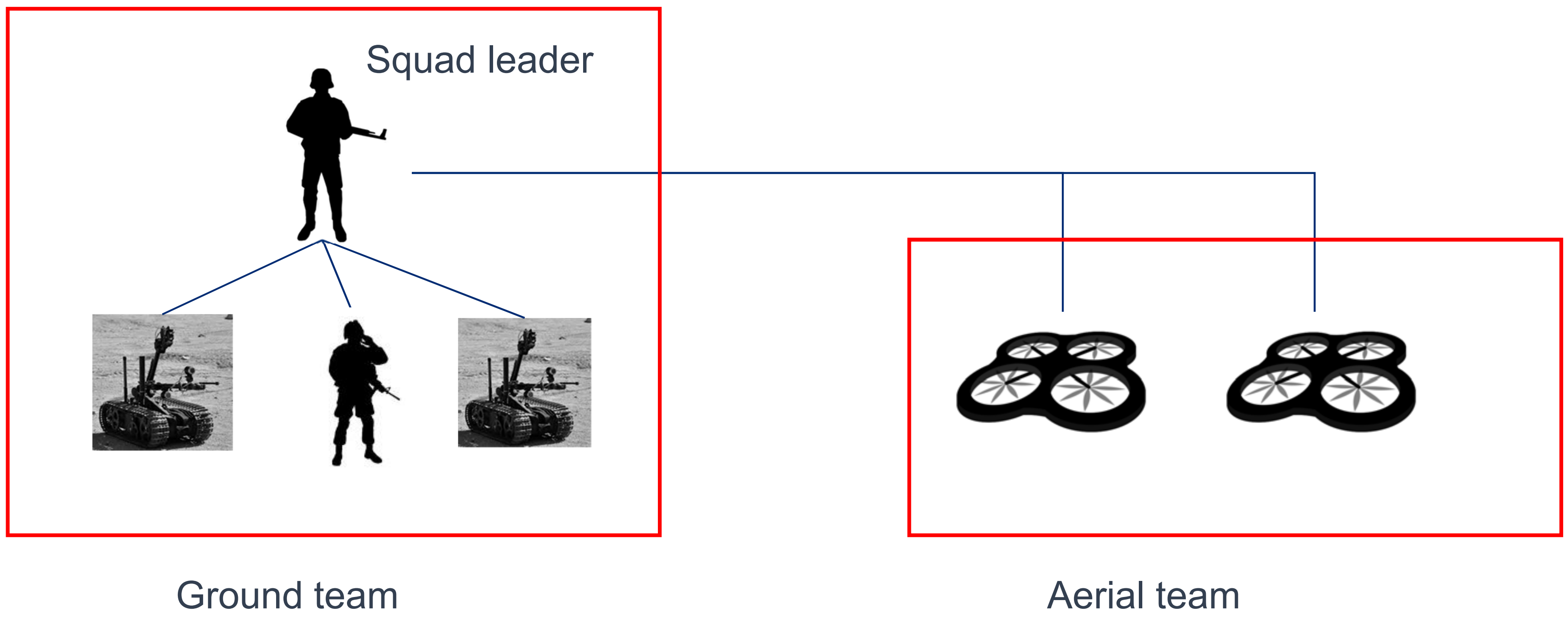


What does “World Model” mean for a Multi-Agent/Multi-Domain system?

Scenario – Multi-Agent/Multi-Domain Squad



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

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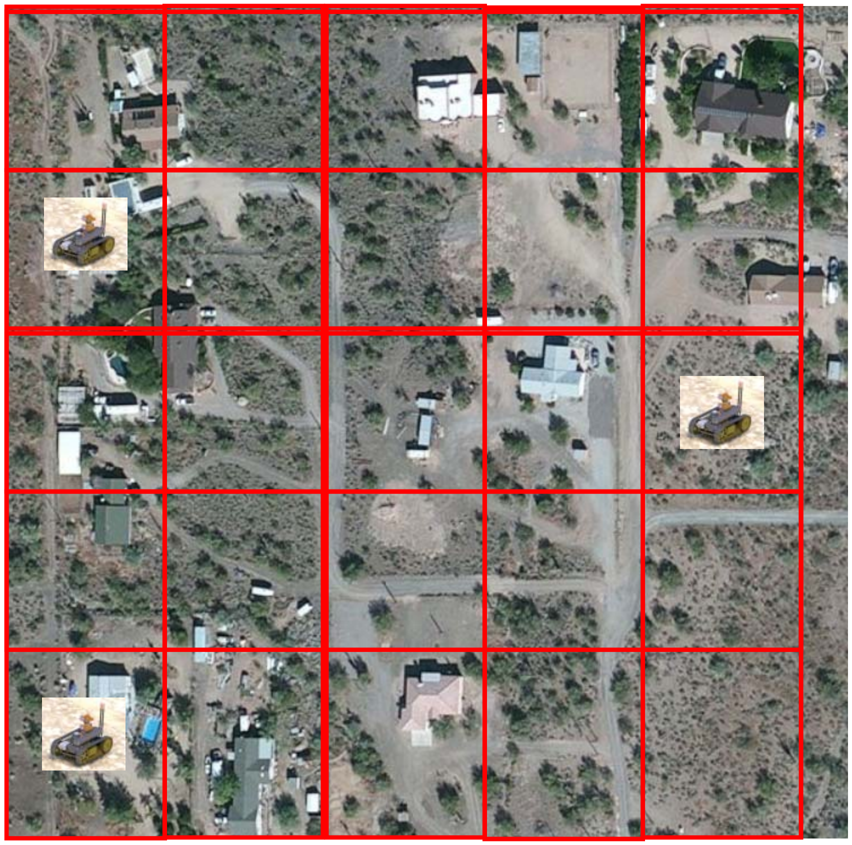

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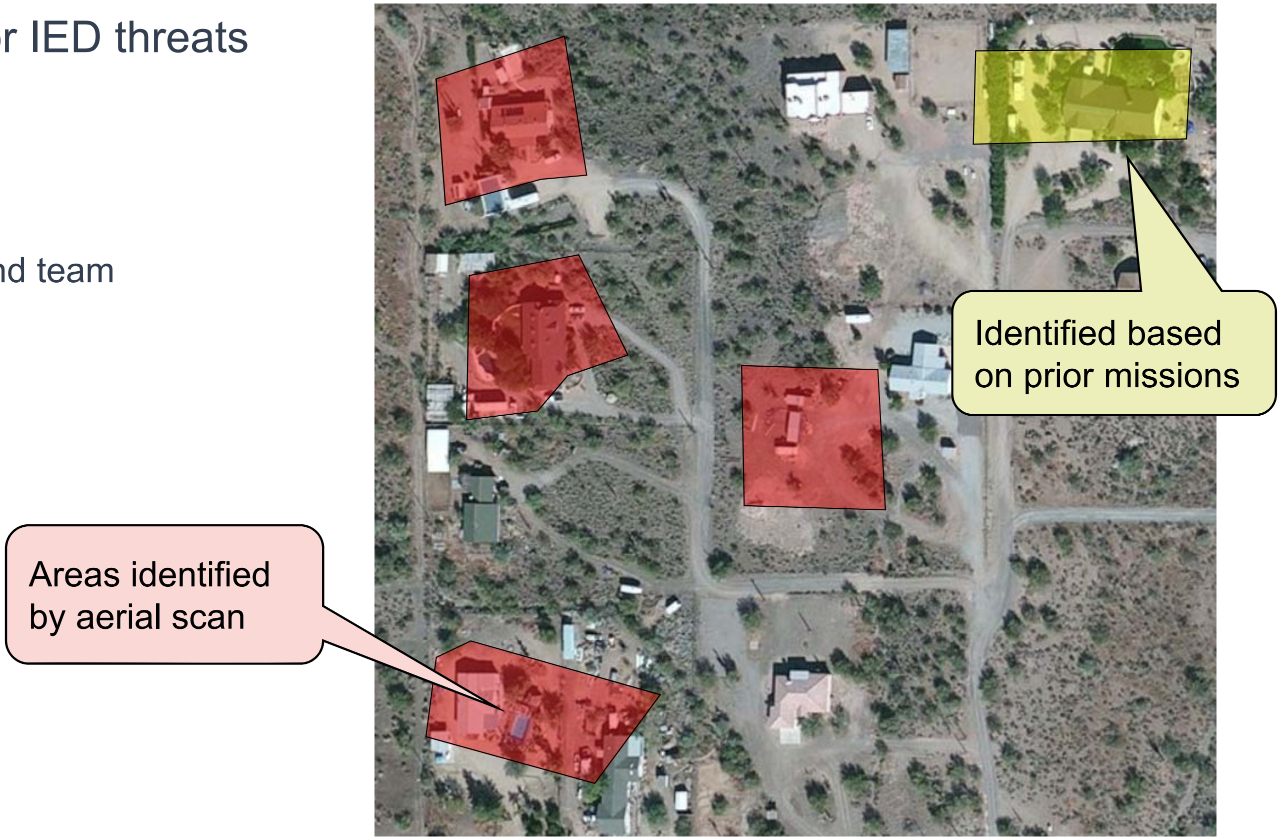

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https://news.usni.org/2015/08/27/advanced-eod-robotic-system-variant-approved-for-emd-phase

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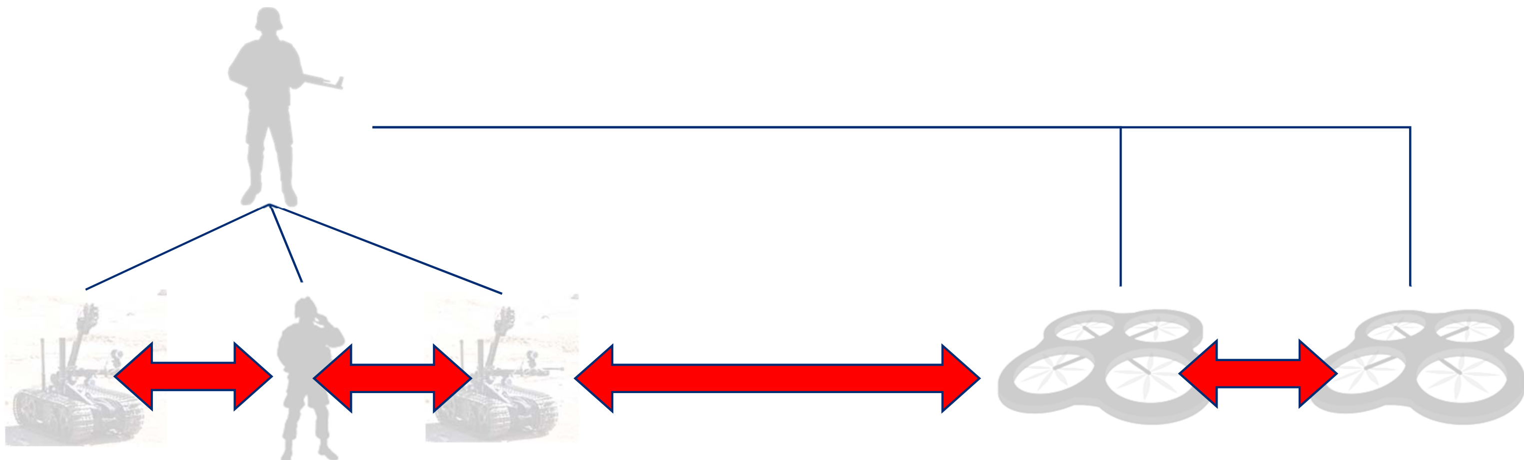
  - **Identify possible threats**

https://upload.wikimedia.org/wikipedia/commons/a/a5/IED_Baghdad_from_munitions.jpg

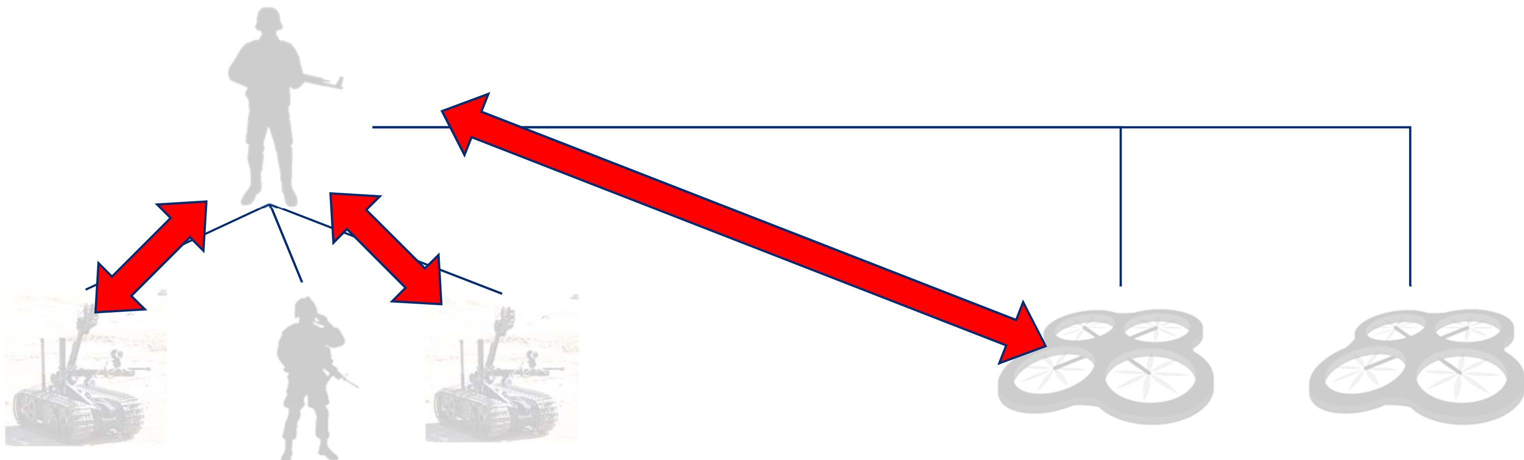
Scenario – Multi-Domain Squad

Horizontal sharing of information within a squad



Scenario – Multi-Domain Squad

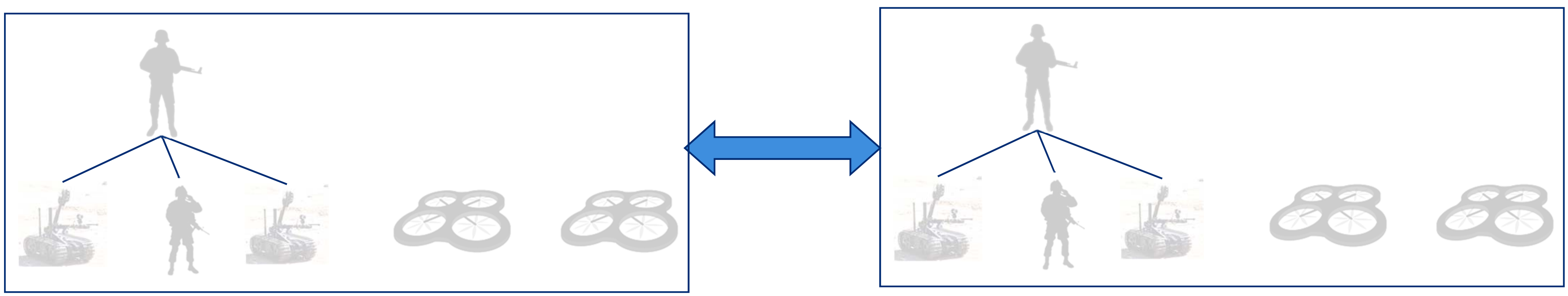
Vertical sharing of information with squad leader



Scenario – Multi-Domain Squad

Company Command

Horizontal sharing of information between squads

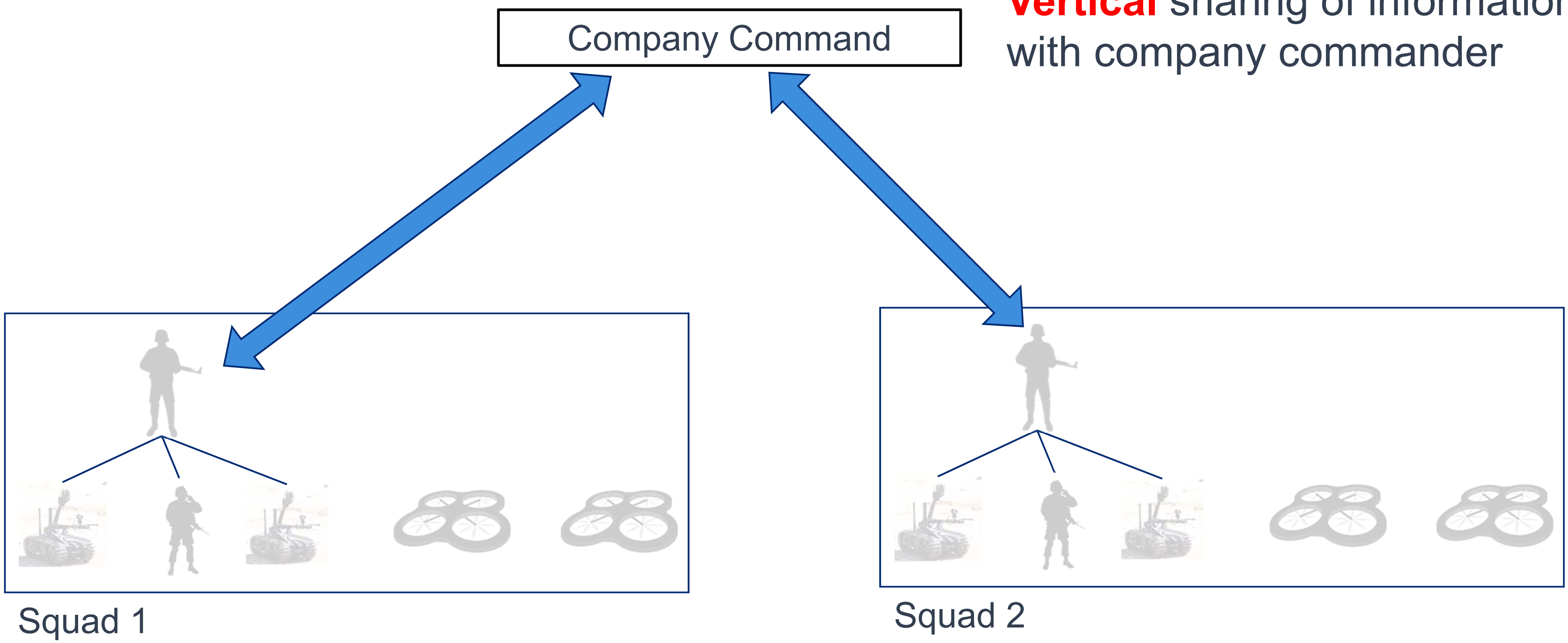


Squad 1

Squad 2

Scenario – Multi-Domain Squad

Vertical sharing of information with company commander



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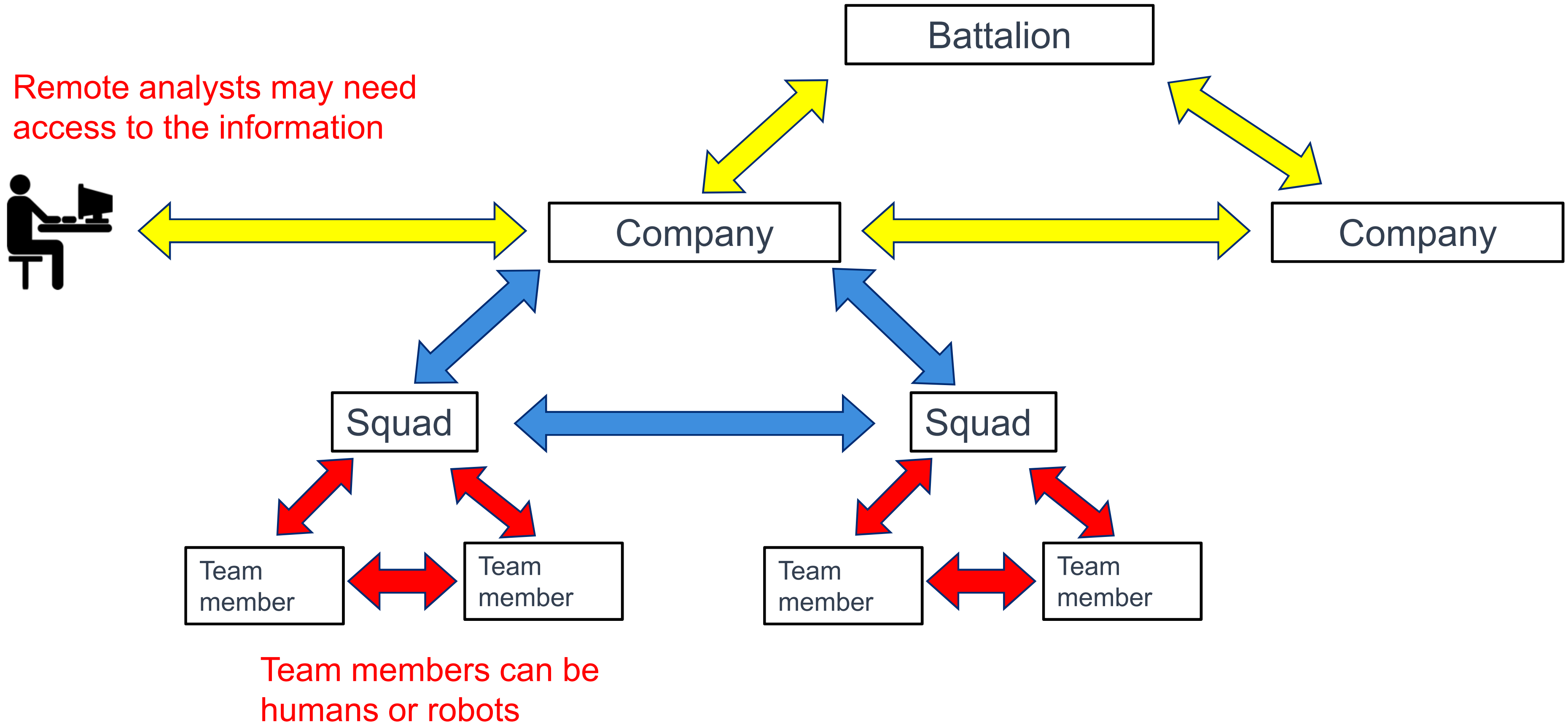


Multi-Agent World Model

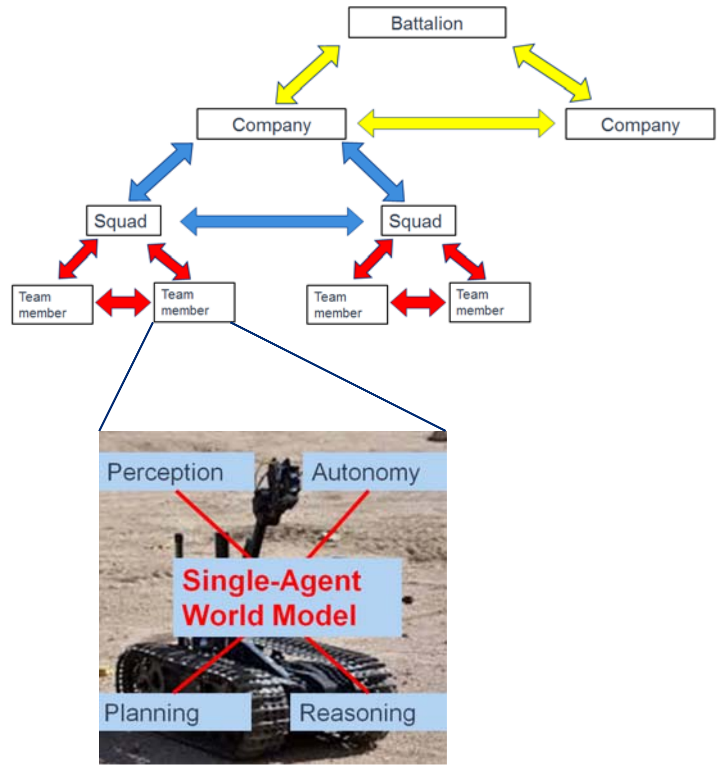
Multi-Agent/Multi-Domain World Model

Facilitates

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

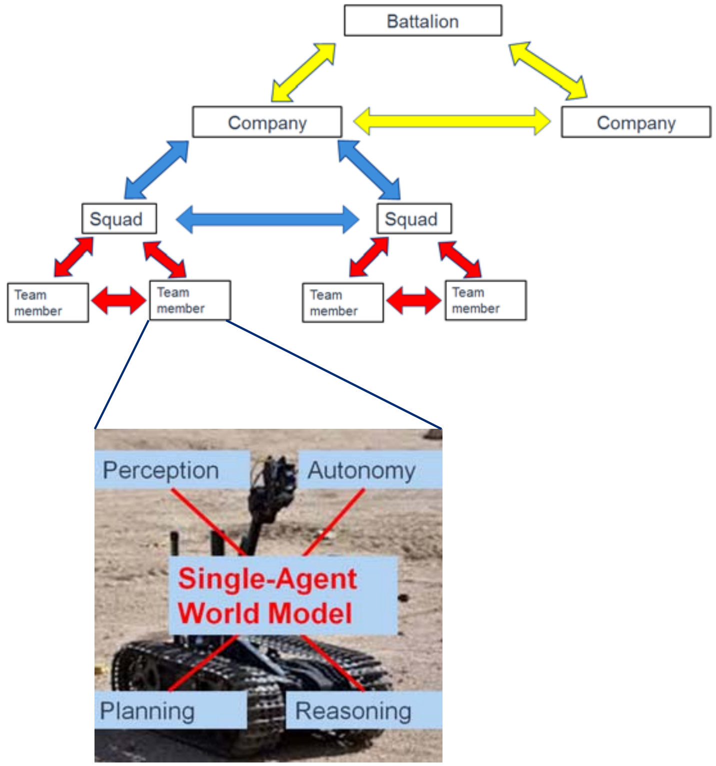
Enables

- 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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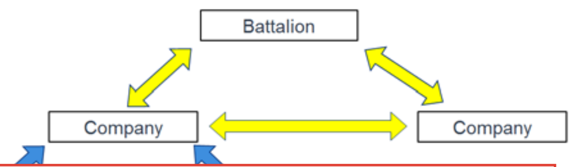

Data is available
- Across system topologies
- Across node capabilities

Efficient use of network bandwidth

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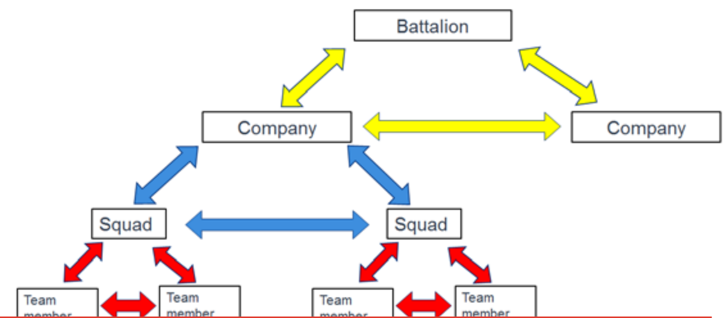
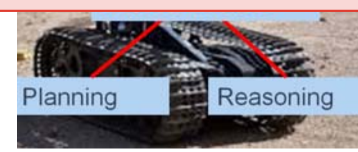


Data definitions are **dynamic** (add new types of data on the fly, e.g., vehicles, weapons)

Data is **self-describing**

- Facilitate aggregation across composite sources, querying



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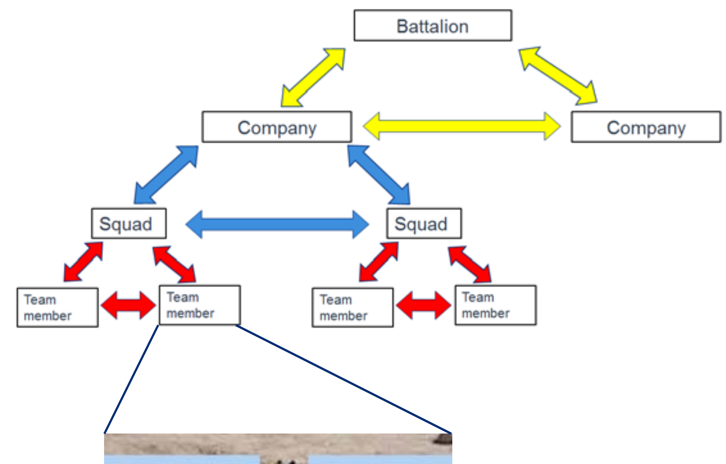

Requires **standards**
- Data formats
- Semantics (ontology)
  - Things in the world
  - Relationships between them
  - Types of missions

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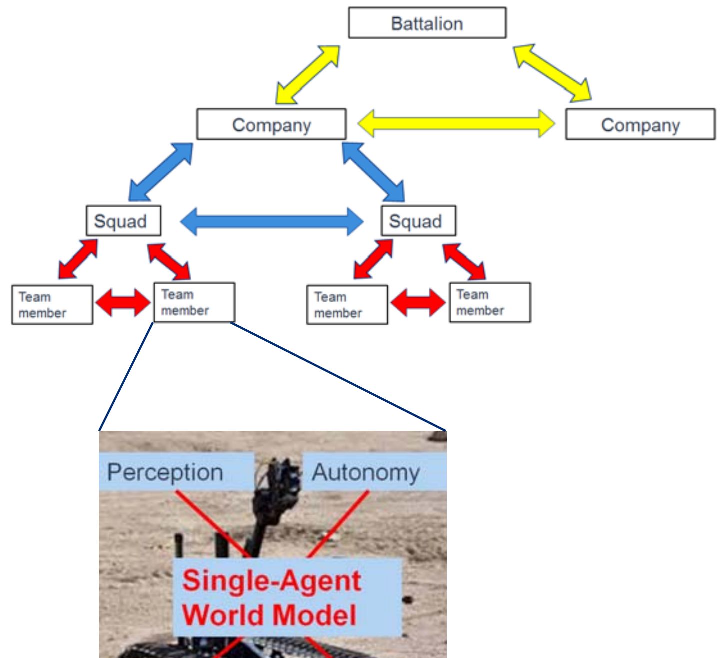

- Robust
- Persistent
- Available

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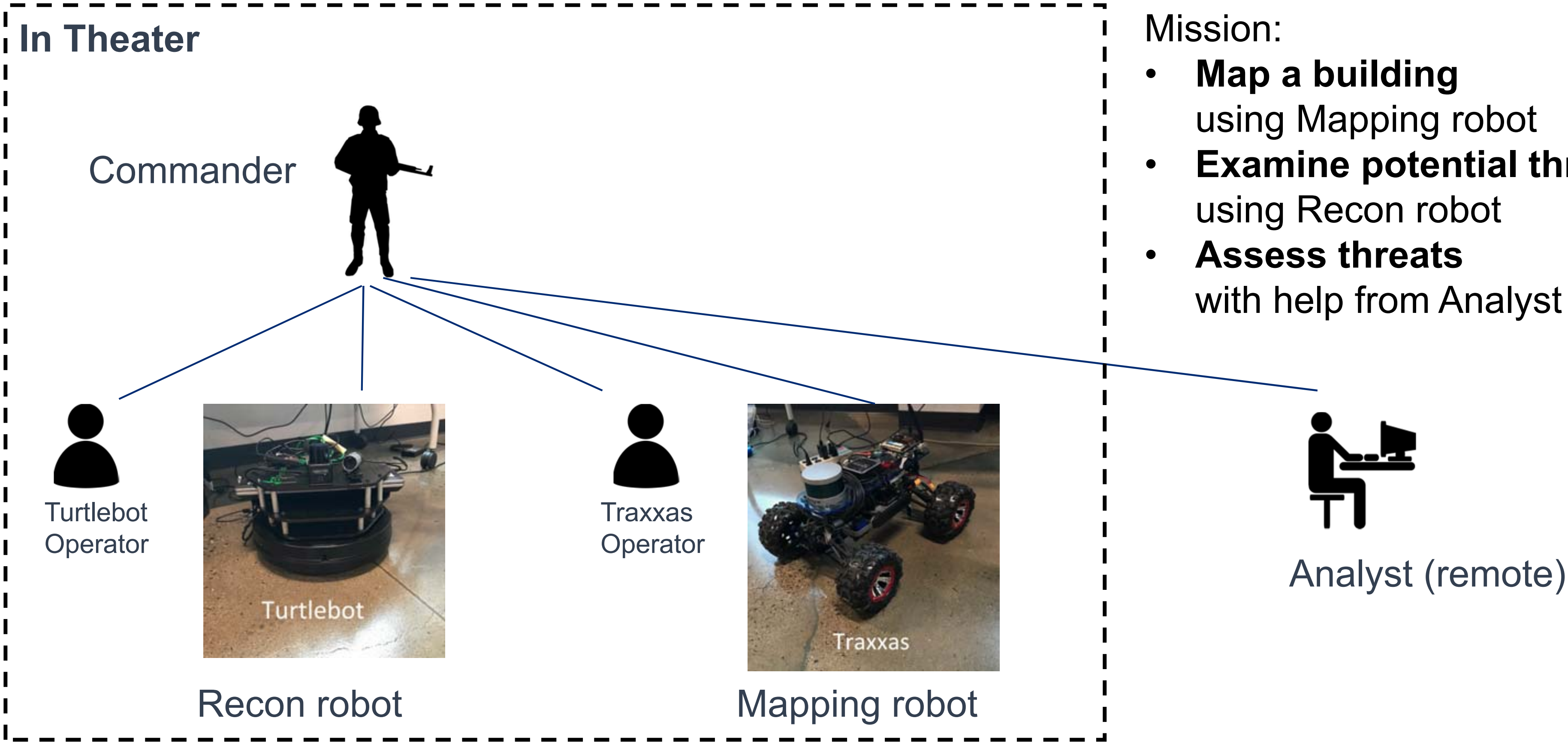
Multi-Agent World Model Demo - Motivation

- 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)

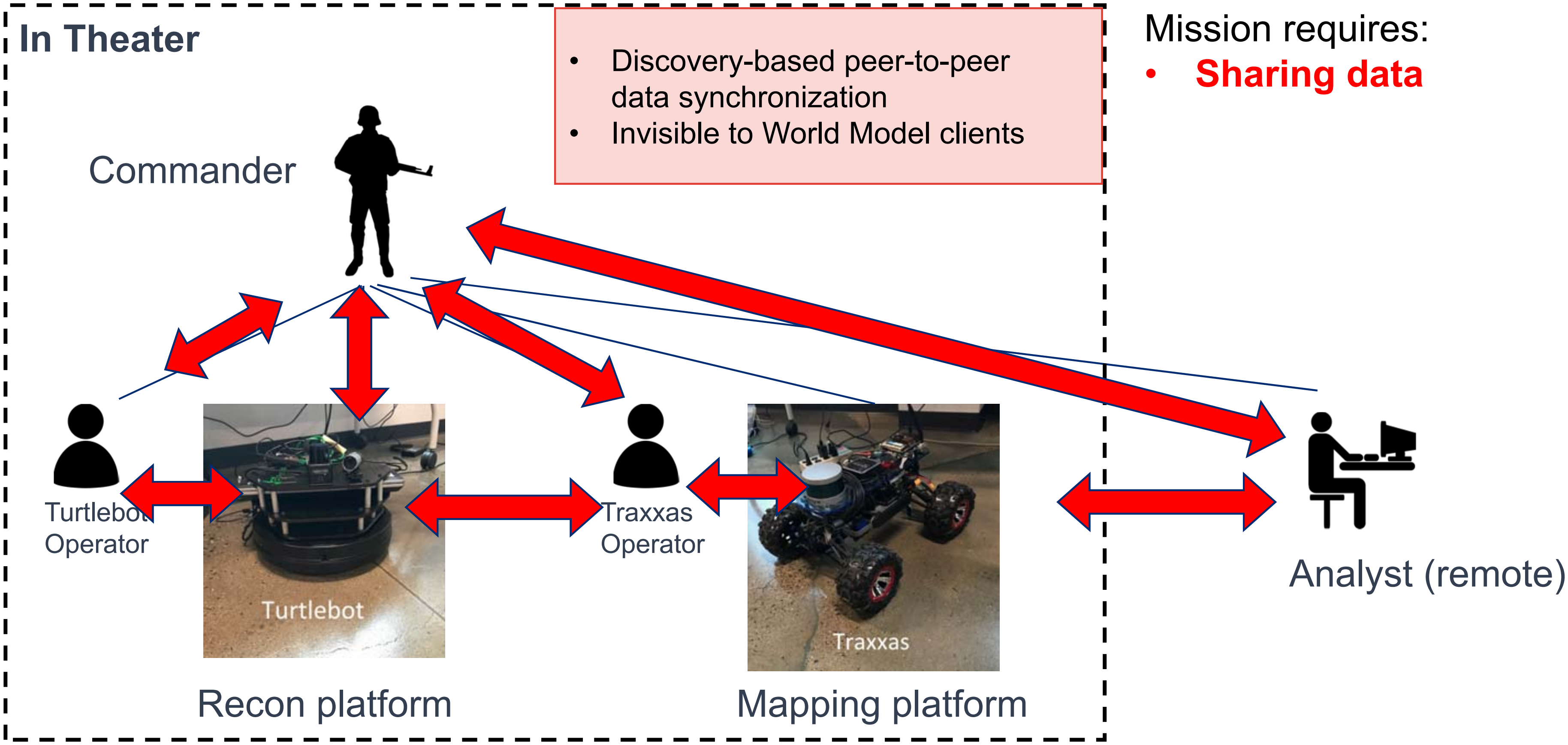
Multi-Agent World Model Demo



Mission:

- **Map a building**
  using Mapping robot
- **Examine potential threats**
  using Recon robot
- **Assess threats**
  with help from Analyst

Multi-Agent World Model Demo

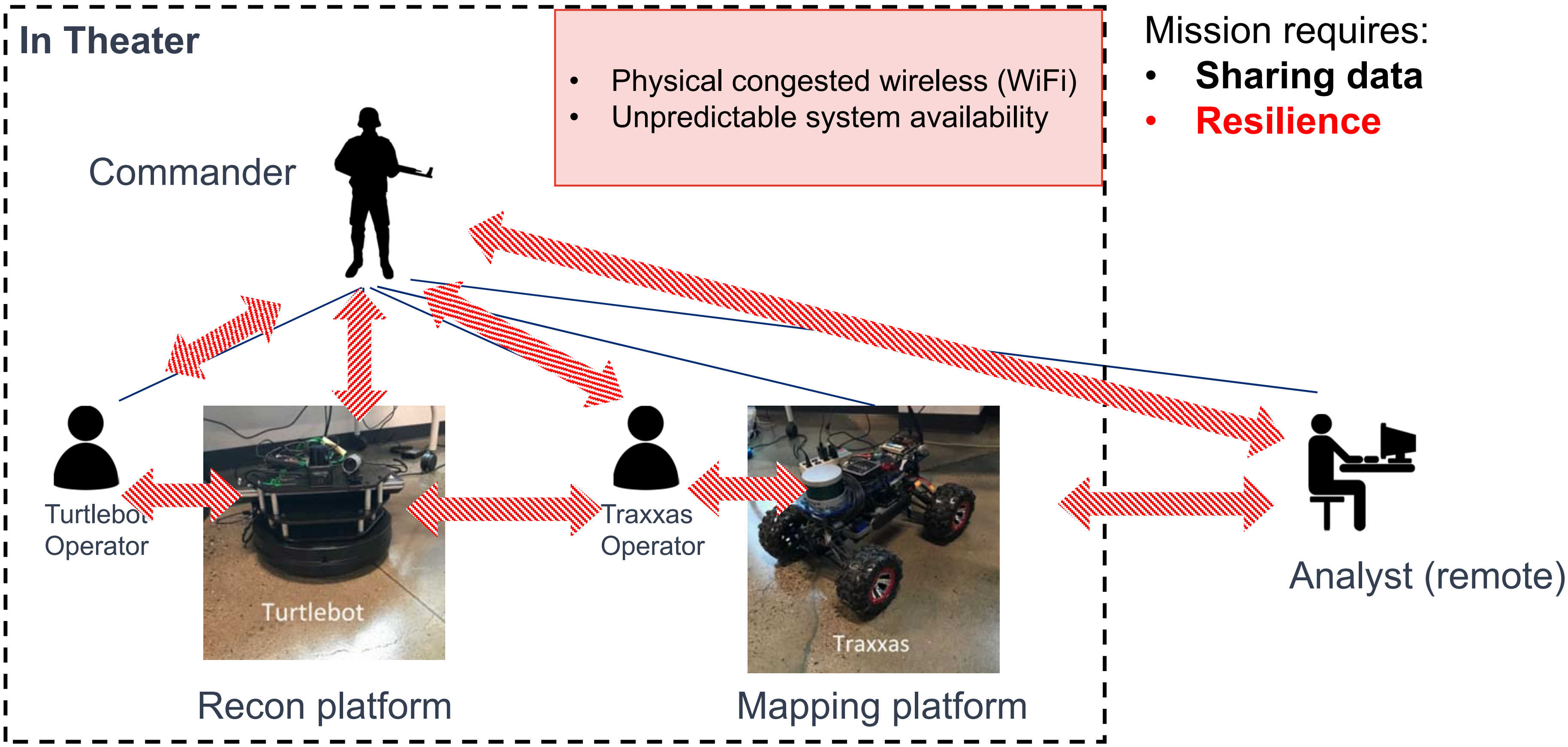


- Discovery-based peer-to-peer data synchronization
- Invisible to World Model clients

Mission requires:

- **Sharing data**

Multi-Agent World Model Demo



Mission requires:
- **Sharing data**
- **Resilience**

Multi-Agent World Model Demo

In Theater

- OS and transport-agnostic
- JAUS↔ROS adapters

Commander **Linux GUI**

Turtlebot Operator

JAUS

ROS

Recon platform

Traxxas Operator

JAUS

ROS

Mapping platform

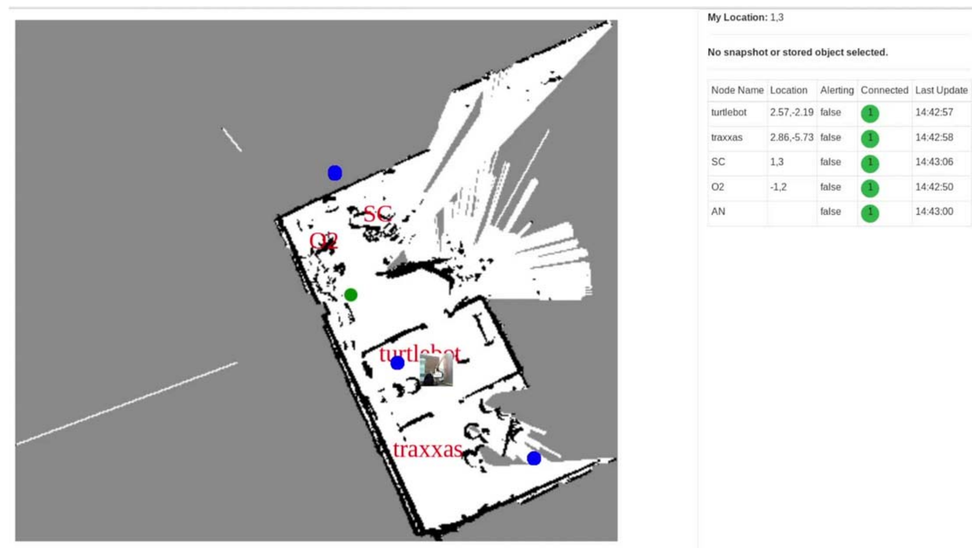
Windows GUI

Analyst (remote)

Mission requires:

- **Sharing data**
- **Resilience**
- **Interoperability**

Multi-Agent World Model Demo



❶ Recon robot uses map generated by Mapping robot

❷ Recon robot visits POI designated by commander, takes snapshots

❸ Commander asks remote analyst for assessment

❹ 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)

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- Timely and relevant

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Extensible
- New kinds of missions and tasking
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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

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