# Multi-Domain Sensing Autonomy and Future Directions in Radar

*for*

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*Integrity ★ Service ★ Excellence*

# Outline

**Objectives: Provide an overview of AFRL Sensing Autonomy goals, technical challenges, and research directions.**

- Motivation

- Vision & Goals

- Notional Mission Perspective

- Technical Challenges & Barriers

- Research Thrusts & Experimentation

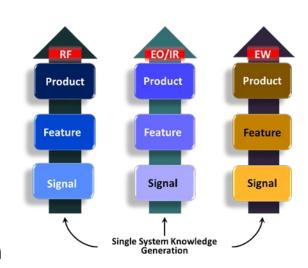- Future Directions in Radar

- Summary

# Motivation
## The Need for Change

- **Adversary timelines are outpacing our ability to adapt and respond**

    – **Approach to knowledge generation is linear, manual, slow and not scalable**

    – **Only a small percentage of sensor data is used to generate knowledge**

    – **Currently USAF is good at generating knowledge using predefined meaning and specific tasks in a linear fashion**

- **Knowledge generation tends be stove-piped within a single domain, INT**

- **Agility and flexibility lacking**



Single System Knowledge Generation

# Sensing Autonomy Vision

*Autonomy Vision: Timely, flexible knowledge creation to allow speed of decisions & effects that will collapse the adversary's OODA Loop.*

*Moving from a platform-focused to a mission effects-focused networked, distributed, flexible architecture*

*How do we network military capability so that we can ... achieve a decision speed that our adversaries can never match? – **General Goldfein, CSAF, Future of War Conference March 2017***

# Autonomy Defined

- **A capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, "self-governing." USD(AT&L), 2012**

- **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. DoD Autonomy COI, Defense Innovation Marketplace, 2017**

- **Systems which have a set of intelligence-based capabilities that allow it to respond to situations that were not programmed or anticipated in the design; self government and self directed behavior with the human's proxy for decisions. USAF Autonomy Science and Technology Strategy, 2013**

- **Autonomous Systems (AS) must possess: AFRL Autonomy FAQs, 2017**
  - **Peer Flexibility: AS can change roles; e.g. subordinate, peer, supervisor**
  - **Task Flexibility: AS can change tasks (sensing/assessing/acting)**
  - **Cognitive Flexibility: AS can learn new behaviors/models over time**

  **\*\*Each contains the idea of *change***

**An autonomous system must contain *all* three flexibilities!**

# AFRL Autonomy Initiative
## Attributes & Features

| Autonomy in Motion (AiM) | Autonomy Capability Team 3 (ACT 3) | Autonomy at Rest (A@R) |
|---|---|---|

**Cyber**

**Space**

**Air**

Imagery Signals    Detections Tracks

Radio    Microwave    Infrared    Visible

**Social Media**

**Objects Patterns Behaviors Intent COAs**

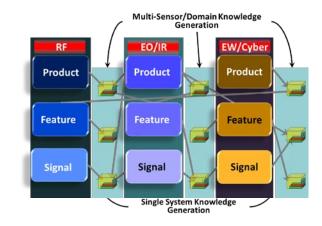**Algorithms**    **data**    **Compute Options**    **People**

# Attributes of Sensing Autonomy

- **Goal of autonomy is to generate knowledge applicable across numerous tasks to break linearity**
  - Understand the **multi-domain mission environment** as a single integrated battlespace; applies at all levels of instantiations
  - Tighter integration across ISR, Strike & EW functions/missions
  - Utilize multi-domain knowledge (in vastly greater quantities and varieties) for **faster decisions and actions/effects**

- **Evolution of knowledge generation requires**
  - Robust representation
  - Dynamic information flow and control
  - Flexible relationships between humans and machines
  - Scalable combination of **cognitive, peer, and task flexibilities**
  - Execute **mission effects** and **assess** them in a timely manner



Multi-Sensor/Domain Knowledge Generation

RF | EO/IR | EW/Cyber
Product | Product | Product
Feature | Feature | Feature
Signal | Signal | Signal

Single System Knowledge Generation

*Goal: Accelerate Our Knowledge of the Contested, Denied Environment to be inside the Adversary Decision Loop*

# Sensing Autonomy Impacts all Op Levels

## Strategic

**Focus:** autonomous, multi-source predictive analytics for ISR indications and warning

## Operational

**Focus:** distributed and adaptive sensing in CDO air-to-ground targeting environments

## Tactical

**Focus:** autonomous electronic warfare for platform protection and SEAD operations



- Pre-Day 0 ISR *Persistence*
- Find/Fix/Track/Intent
- IPoE ⟷ MDC2 ⟷ O-Plans
- "Keep 'em on the rail"
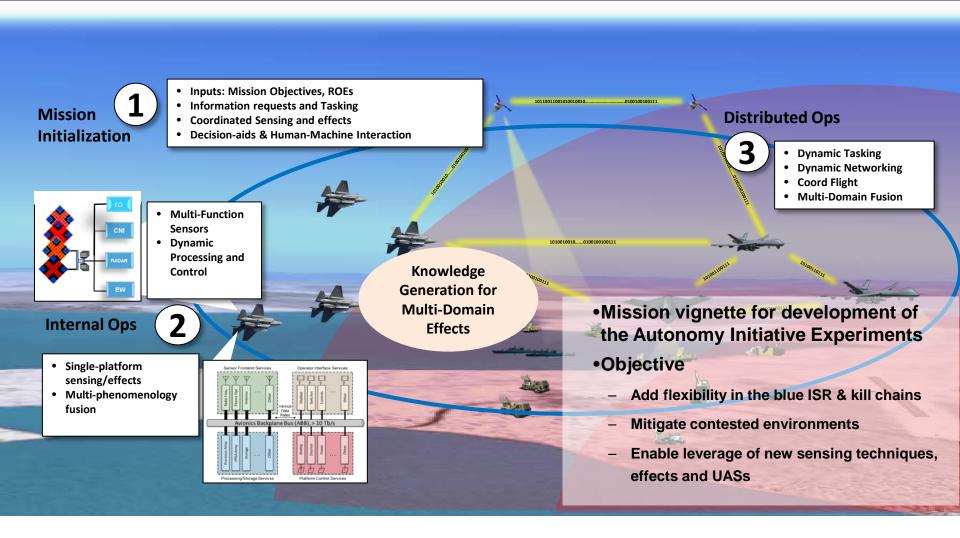
- System of System Mission Planning
- Manage Spectrum Dominance
- Distributed mission execution payloads

- Execute Mission Plan
- Tactical ISR/CAP/OCA/DCA
- Pos ID/Targeting/Engage/Assess
- Comms with other TACAIR agents

# Sensing Autonomy OV-1



**Mission Initialization**

**(1)**
- Inputs: Mission Objectives, ROEs
- Information requests and Tasking
- Coordinated Sensing and effects
- Decision-aids & Human-Machine Interaction

- Multi-Function Sensors
- Dynamic Processing and Control

**Internal Ops**

**(2)**
- Single-platform sensing/effects
- Multi-phenomenology fusion

**Knowledge Generation for Multi-Domain Effects**

**Distributed Ops**

**(3)**
- Dynamic Tasking
- Dynamic Networking
- Coord Flight
- Multi-Domain Fusion

- **Mission vignette for development of the Autonomy Initiative Experiments**
- **Objective**
  - Add flexibility in the blue ISR & kill chains
  - Mitigate contested environments
  - Enable leverage of new sensing techniques, effects and UASs

# Sensing Autonomy Research Vectors

- **Sensor resource management**
- **Multi-sensor/platform sensing & effects**
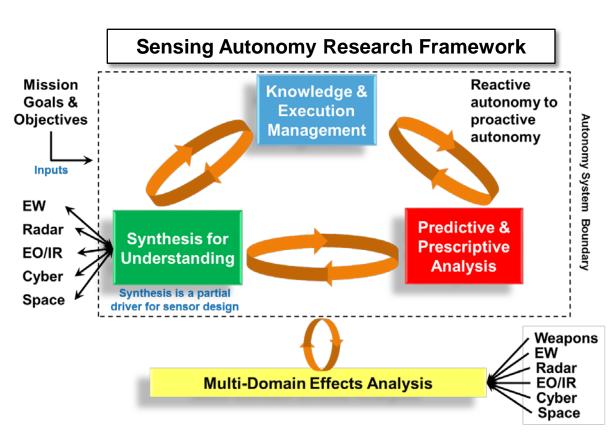- **Multi-INT/domain sensing**
- **Cognitive EW**
- **Combat ID (ATR)**
- **Distributed processing**
- **Avionics cyber protections**
- **Constructive to mission-level sensing and effects MS&A**



**Sensing Autonomy Research Framework**

Mission Goals & Objectives → Inputs

EW, Radar, EO/IR, Cyber, Space → Synthesis for Understanding

Synthesis is a partial driver for sensor design

Knowledge & Execution Management

Reactive autonomy to proactive autonomy

Autonomy System Boundary

Predictive & Prescriptive Analysis

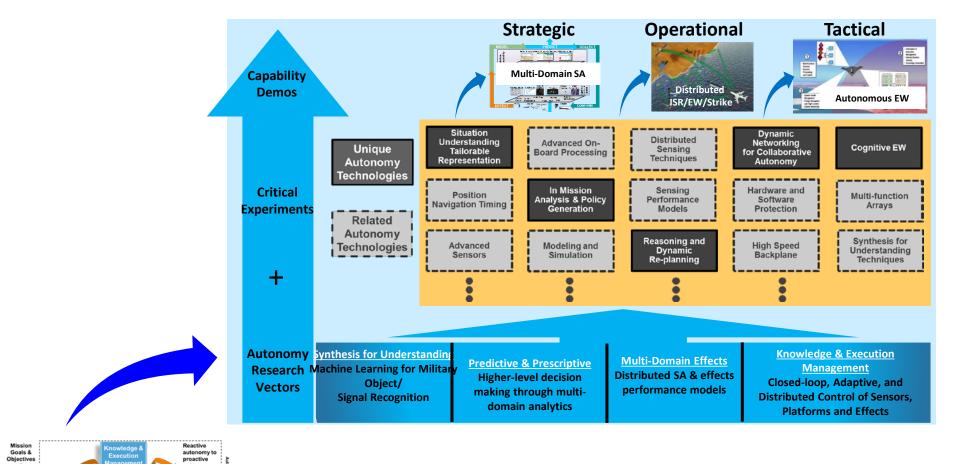Multi-Domain Effects Analysis ← Weapons, EW, Radar, EO/IR, Cyber, Space

Note: "Sensing" includes the physical sensor through the processing required to generate the knowledge and understanding for a given task

# Autonomy Technologies and Critical Experiments



**Capability Demos**

**Strategic** — Multi-Domain SA

**Operational** — Distributed ISR/EW/Strike

**Tactical** — Autonomous EW

**Critical Experiments**

+

Unique Autonomy Technologies

Related Autonomy Technologies

| | | | | |
|---|---|---|---|---|
| Situation Understanding Tailorable Representation | Advanced On-Board Processing | Distributed Sensing Techniques | Dynamic Networking for Collaborative Autonomy | Cognitive EW |
| Position Navigation Timing | In Mission Analysis & Policy Generation | Sensing Performance Models | Hardware and Software Protection | Multi-function Arrays |
| Advanced Sensors | Modeling and Simulation | Reasoning and Dynamic Re-planning | High Speed Backplane | Synthesis for Understanding Techniques |

**Autonomy Research Vectors**

**Synthesis for Understanding**
Machine Learning for Military Object/ Signal Recognition

**Predictive & Prescriptive**
Higher-level decision making through multi-domain analytics

**Multi-Domain Effects**
Distributed SA & effects performance models

**Knowledge & Execution Management**
Closed-loop, Adaptive, and Distributed Control of Sensors, Platforms and Effects

# Sensing Autonomy Experiments

```
→  [ Understand the        ]  →  [ Reason Over the       ]  →  [ Distributed System  ]
   [ Environment           ]     [ Environment & Own     ]     [ Re-Planning         ]
                                 [ State                 ]
```

- **Turn data into information and knowledge to support real-time, automated military operations**

- **Achieve high confidence over complexity of military operating conditions**

- **Incorporate learning for unknown objects and signals**

- **Flexibly leverage multiple heterogeneous, distributed knowledge sources to enable high confidence, context dependent decision-making**

- **Adaptively reason over current knowledge across multiple scales to optimize sensing resources and military effects in adversarial environments**

- **Autonomously manage internal and distributed sensor resources, platforms, communications, and effects for optimal aggregate performance**

- **Perform real-time adaptation for dynamic targets and environments**

# Collaborative Autonomy and Flexibility

- **Observed signal's meaning varies for different agents**
- **The meanings are shared among agents**
- **Effect is chosen based on mission goals**
- **Knowledge structure supports relationship and context representation between agents**

1. **Observed IADS Signal Meaning**
   - **Threat → EW agent & Cyber agent**
   - **Coherent source → Targeting agent**
2. **Desired Effects**
   - **EW & Cyber agent → Countermeasure**
   - **Targeting agent → multi-static targeting of other adversary objects**
   - **Both effects required for mission**
3. **Reasoning**
   - **Agents share meaning of signal**

4. **Effect Chosen**
   - **Cyber technique selected**
   - **Deny info to IADS**
   - **Signal used as source for targeting**

**Sensor Payloads**

- Targeting Agent
- Electronic Attack Agent
- Cyber Agent

**Agents physically reside across one or more platforms**
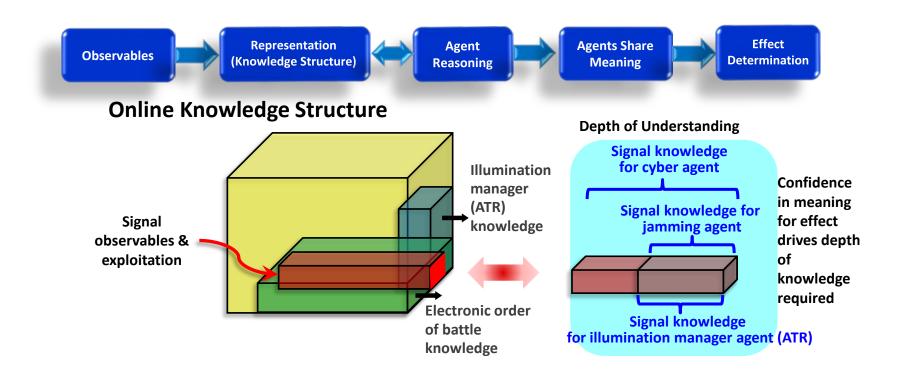
# Knowledge Representation & Reasoning

Observables → Representation (Knowledge Structure) ⟷ Agent Reasoning → Agents Share Meaning → Effect Determination

## Online Knowledge Structure



Signal observables & exploitation

Illumination manager (ATR) knowledge

Electronic order of battle knowledge

Depth of Understanding

Signal knowledge for cyber agent

Signal knowledge for jamming agent

Signal knowledge for illumination manager agent (ATR)

Confidence in meaning for effect drives depth of knowledge required

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# Autonomy in Motion Sensing
## Functional Block Diagram



Search areas informed by IPOE
**Observe**

Locate & ID CMTs and/or support equipment
**Orient**

Determine current status and activities
**Decide**

Strike support
**Act**

Battle damage assessment
**Feedback**

Aircrew Interface

Reasoner

Re-plan ID & Location Tasks

Control Sensor Mode & Platform Location

Refine Distributed ID, Location &Targeting

Initialize /cue Effects

Mission Planning

Distributed System Initialization

CMT/Support System ID & Location (Contingency)

On-line Knowledge Representation

- **Capability of radar systems must evolve to function as one of several agents within an autonomous sensing construct:**
  - **Agile wrt spectrum, modes, signal and data processing algorithms**
    - **Radar Modes (imaging, tracking), waveforms, dwell, revisit, DoFs**
    - **Coordination with other sensors/platform agents (i.e., negotiate bistatic/multistatic operation parameters, geometry)**
      - **Configure sensor agents to generate required knowledge**
      - **Geometry/sensor placement, platform velocity**
    - **Passive Operation (survivability, bistatic/multistatic, EW/SIGINT functions)**
    - **Resolution, revisit for ISR vs. strike functions**
- **Interaction required with multiple heterogeneous agents (other sensors, platforms performing other tasks) to provide context (i.e., POL)**
  - **Data exchange, timing**

# Future Directions in Radar
## Flexibility (Cognitive, Task, Peer)

- **Real-Time onboard processing with performance monitoring**
  - **Inform task effectiveness**

- **Reasoning & Cognitive Flexibility:**
  - **Cognitive radar has been active research area for several years**
  - **Methods for reasoning across desired performance metrics to choose appropriate radar parameters**
  - **Cognitive radar flexibilities must extend beyond just the radar:**
    - **Performance models of other sensors in the battlespace**
    - **Reason over radar observations to inform other sensors**
    - **Predictive analytics and COA development (i.e. what should the radar do?**

- **Peer Flexibility to _accept_ cueing and tasking from multiple agents; <u>direct</u> tasks to other agents**

# Summary

- **Numerous military challenges can be overcome by autonomy**
  - **Sensing autonomy is a particularly attractive application area**
    - **AiM and A@R suggest multiple opportunities from sensor/radar resource management to signal & data exploitation**
  - **Rapid generation of battlespace understanding and application of effects is the key**
  - **Multi-domain (i.e., air, space and cyber) as an integrated battlespace**

- **Future military radar must function as an agent within an autonomous construct fully employing three flexibilities:**
  - **Task, Peer, Cognitive**

- **Research investment and experimentation underway at AFRL to develop and demonstrate autonomous systems, including sensors and sensing systems**

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