Matching Sensors to Missions using a Knowledge-Based Approach

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Context & motivation

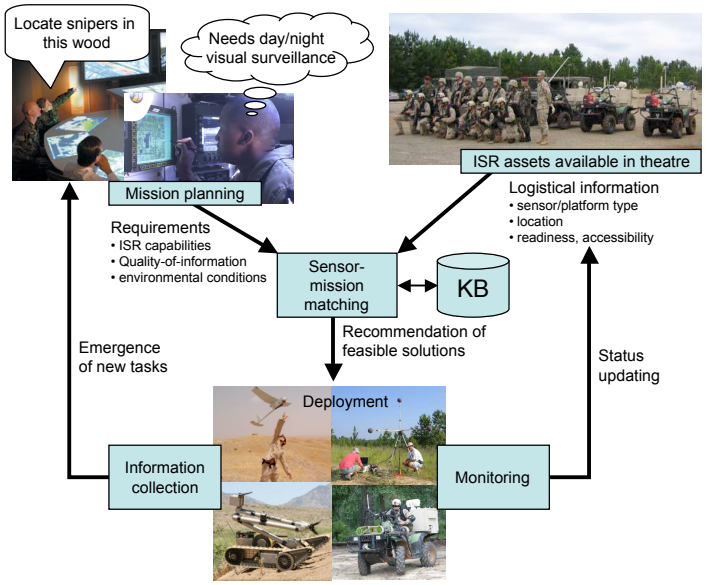
Sensor-mission assignment: allocating a collection of ISR **assets** (sensors and platforms) to one or more **missions** so as to attempt to satisfy the ISR needs of those missions

> "ISR resources are typically in high demand and requirements usually exceed platform capabilities and inventory... The foremost challenge of collection management is to maximize the effectiveness of limited collection resources..."
>
> *Joint and national intelligence support to military operations*, 2004

More difficult in the **coalition** context because the full inventory of ISR assets potentially available is not easy to obtain at-a-glance

Also, the operational environment is highly **dynamic**: ISR requirements change in response to the emerging situation, and the availability of assets needs constant updating

Our big picture



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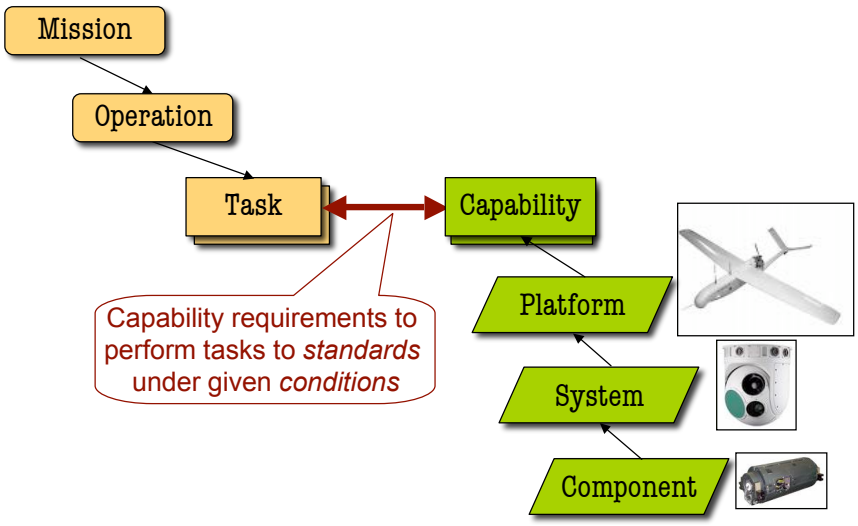
Framework for sensor-mission matching



Military Missions & Means Framework (MMF)

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Ontologies 101

Modern knowledge bases are generally founded on **ontologies**

"A specification of a conceptualization" [Gruber, 1994]

The ontology defines formally the semantics of all of the terms used in the KB's rules, facts, etc

Ontologies address the problem of **knowledge reuse**: if two different KBs use the same ontology, it should be possible to combine their knowledge

An ontology is typically structured as a set of definitions of **concepts** (**classes**) and **relations** between those concepts (**properties**); a fundamental pre-defined property is **subclass** (specialisation)

Ontologies are expressed using some **meta-ontology** language, the most commonly-used of which is the Web Ontology Language (**OWL**)

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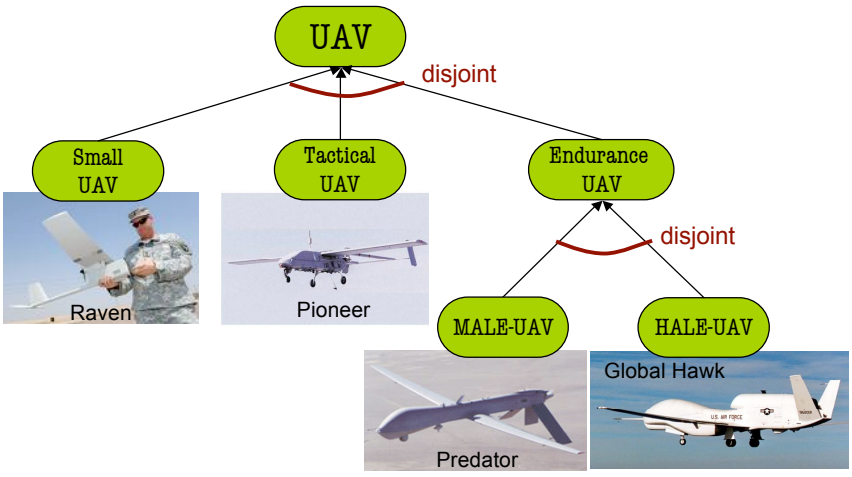
A simple example



e.g. http://uav.wff.nasa.gov/Categories.cfm

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A simple example (continued)

Given a task that requires Wide Area Surveillance

➔This capability is provided by an **Endurance-UAV**

Three UAVs are available:

- Pioneer is-a **Tactical-UAV**
- Predator is-a **MALE-UAV**
- Global Hawk is-a **HALE-UAV**

From the concept definitions we know:

➔Pioneer is not an **Endurance-UAV**

➔Predator & Global Hawk are types of **Endurance-UAV**

So we can use either Predator or Global Hawk

Now, suppose due to weather conditions, an additional capability is to fly "above the weather"

➔Capability provided by **HALE-UAV** (high altitude)

Preferred choice is now Global Hawk

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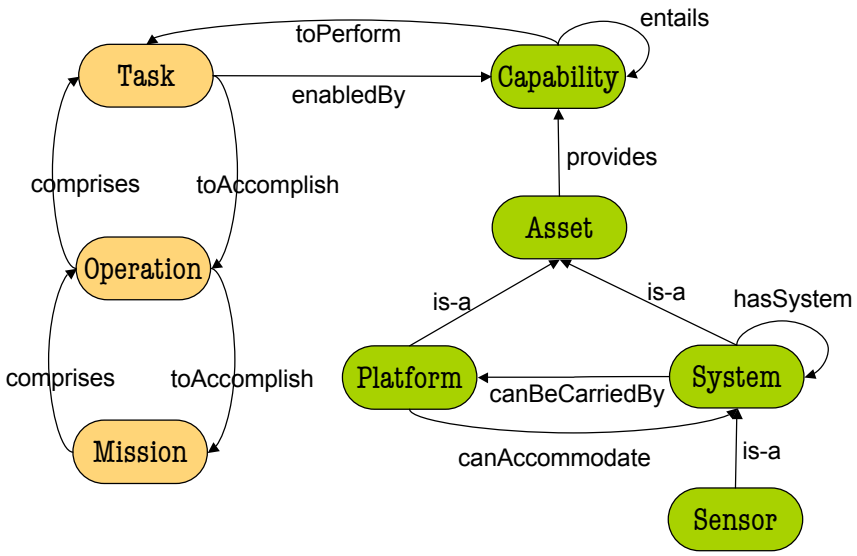
An ontology based on MMF



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Ontologies for the ISR domain

A lot of work already exists in defining ontologies (or schemas) for

- **sensor** & **platform assets**: SensorML, OntoSensor, CIMA, MMI platforms & devices
- mission **tasks**: UJTL, JC3IEDM, CPM

Many of the concepts and relationships in these can be imported into our framework

What is missing is the definitions of various kinds of capability needed to match tasks to assets

There are multiple capability dimensions:

- for **platforms**: mobility, realm (air, land, sea), performance (range, endurance, altitude, speed), mission type (surveillance, reconnaissance, target acquisition), firepower, landing and takeoff, communications, vulnerability
- for **sensors**: phenomena detected (type and spectrum), performance (resolution, sample rate, ...), vulnerability, interferences with other sensors, weather/terrain

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ISR is a multi-ontology space

Platforms

- Platform
  - AerialPlatform
    - Aircarft
    - UAV
      - EnduranceUAV
        - HALE
        - MALE
      - LethalUAV
      - Shipboard
      - SmallUAV
        - MicroUA
        - MiniUA
      - TUAV
      - UCAV
      - UnmannedAirship
        - Aerostat
        - Blimp
  - GroundPlatform
  - SeaPlatform
  - UnderwaterPlatform

Sensors

- Sensor
  - Acoustic
  - Chem-Bio
  - IntegratedSystem
  - IonisingRadiation
  - LDR
  - MetalDetector
  - Optical
    - EO
    - IR
    - TV
  - Radar
  - SIGINTSystem
  - Thermal

Tasks

- Surveillance
  - AirSurveillance
  - BattlefieldSurveillance
  - BorderSurveillance
  - CoastalSurveillance
  - ConstantSurveillance
  - MaritimeSurveillance
  - MissileWarningAndSpace
  - TacticalSurveillance
  - WideAreaSurveillance
- TargetAcquisition
  - TargetClassification
  - TargetDetection
  - TargetIdentification
  - TargetLocation
  - TargetTracking

INT types

- IMINT
  - EO_IR
  - PHOTINT
- MASINT
  - ACINT
  - CBINT
  - DEWINT
  - ELECTRO-OPTINT
  - IRINT
  - NUCINT
  - RADINT
  - RF_EMPINT
  - RINT
- OSINT
- SIGINT
  - COMINT
  - ELINT
  - FISINT
- TECHINT

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Assembling ISR concepts

Class Description: PredatorB

Superclasses
- MALE
- canMountSensor value FLIR
- canMountSensor value LDRF
- canMountSensor value SAR
- canMountSensor value SIGINTSensor
- providesCapability value FirepowerCapability
- endurance value 24.0
- payloadWeight value 3000
- range value 5500
- speed value 400

Inherited anonymous classes
- EnduranceUAV that providesCapability value MediumAltitudeCapability
- providesCapability value ConstantSurveillanceCapability
- UAV that providesCapability value LongEnduranceCapability

Class Description: FLIR

Equivalent classes

Superclasses
- IR
- detects value ThermalEnergy
- hasResolution value FairSensorResolution
- hasSensorCoverage value GoodSensorCoverage
- providesCapability value DayAndNight
- providesCapability value FOPEN
- providesFogPenetration value FairFogPenetration
- providesIdentification value HighQualityIdentification

Inherited anonymous classes
- providesCapability value IMINTCapability
- providesCapability value IRINTCapability

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Sensor-mission matching procedure

Given some task T, with required capabilities C^T:

Recommend a set of **package configurations** (PCs) of types of platforms and sensors, such that:

- for every capability c_i in C^T, there is at least one type of sensor or platform in each recommended PC that provides c_i
- each recommended PC is minimal w.r.t. C^T

A PC could be:

- a single platform+sensor
- arbitrarily complex with many types of platform, each mounting a variety of sensor types

Note that the matching procedure works with sensor and platform **types** - benefits from highly optimised subsumption-based reasoners

(As a pragmatic feature, we allow pre-filtering of asset types based on instance availability)

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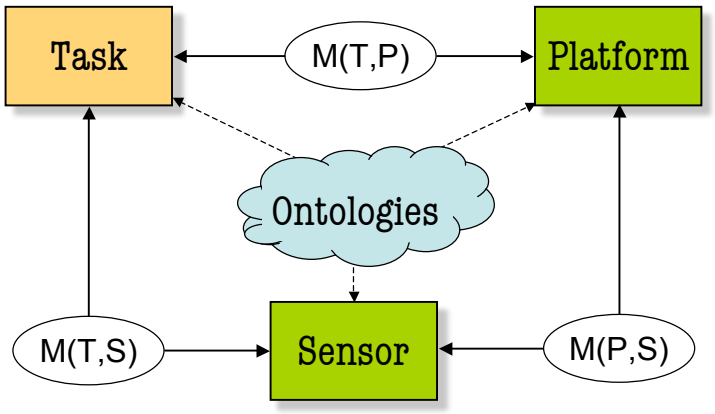
Constraints in matching



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Matching: an example

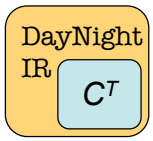
required capabilities

C^T

exact match

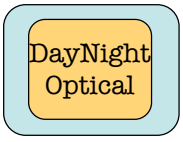
$C^A = C^T$

plugin match



$C^A \rightarrow C^T$

subsumes

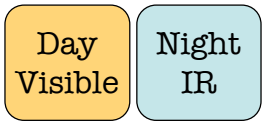


$C^A \leftarrow C^T$

overlaps

$C^A \cap C^T \neq \{\}$

disjoint



$C^A \cap C^T = \{\}$

C^T = task capabilities

C^A = asset capabilities

DayNight → Night
Optical ← IR
Visible ∩ IR = {}
Day ∩ Night = {}

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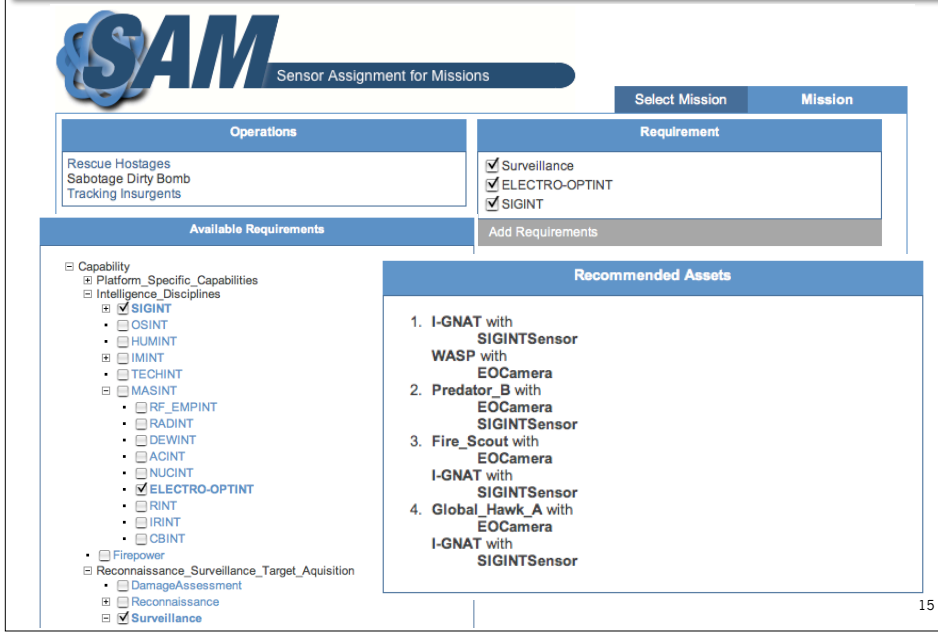
Demonstrating the concept



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Current & future work

Improved handling of ISR requirements

Currently, the capability requirements are far too "how" and not nearly "what" enough:

- move away from "**I need IMINT at location X**"
- to "**is there a Y at location X**"

Developing a KB based on NIIRS (image interpretability rating scale):

- classifies visual, radar, IR, ...
- in terms of detection/identification/distinguishing...
- of various kinds of real-world object

Integration of fusion processes

Package configurations include not only sensors & platforms, but also **algorithms & analysts**...

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Current & future work (continued)

Ranking of recommendations

Currently, our prototype implementation offers only a simple ranking based on cost ("cheapest first")
Some alternatives:

- quality-of-information ("best-first")
- readiness/accessibility of assets ("most available first")
- custom (preference-based)

Resource allocation for deployment

To assign instances of (available) assets, we need to consider resource allocation, where resources are instances of package configurations

Requires consideration of additional constraints on package composition from operational environment

- physical location of in-situ sensors
- logistical data (battery life, damage status, etc)
- ownership

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Summary & questions?

- A new approach to solving the sensor-mission matching problem using a collection of interlinked knowledge bases in the form of ontologies
- Subsumption-based reasoning allows us to define and compute matches between the ISR capabilities required by mission tasks, and those capabilities provided by sensor and platform assets

For more information: **http://www.usukita.org/**

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