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Ontological Decision-Making Support for Air Traffic Management

Dr Carlos C. Insaurralde

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- **School Coordinator** for Doctoral Training
- **Principal Investigator** in the Bristol Robotics Laboratory
- **Former Programme Leader** of BEng Robotics
- **Visiting researcher**, US Air Force Research Laboratory
- **Associate Editor** of the IEEE AESS Magazine
- **Member** of the IEEE AESS Avionics Systems Panel
- **Tutorial Instructor** for DASC/ISC
- **Doctor Europaeus**, European University Association

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15 November 2023

Carlos C. Insaurralde, MEng, PgCTLHE, MAst, MPhil, PhD

IEEE Senior Member, HEA Fellow

- US-funded(DoD), UK-funded(MoD) and EU-funded projects
  - US research project in collaboration with the AFRL.
  - UK research projects in collaboration with BAE Systems, Atlas Elektonik, and seabyte.
  - EU research projects in collaboration with Airbus, Eurocopter, Goodrich, Autoflug, ASG, and Secondo Mona.
- Autonomy-based projects
  - Autonomous decision-making support for avionics analytics.
  - Autonomously cross-checked models from multidisciplinary design teams of high-integrity systems.
  - Remote integration of capabilities from autonomous ground vehicles for defence.
  - Automation of distributed aircraft fuel management systems tested in lab and real-scale rigs.
  - Intelligent control architecture for autonomous maritime vehicles.
  - Autonomous reconfiguration of production lines.
- Over 100 publications, including a book, 5 book chapters, and best papers.

Lecture Aims

- Objectives of the Session
  - To **recap** details of the context where **ontologies** are applied.
  - To **explain** an innovative **approach** for **decision-making support** in **ATM**.
  - To **discuss** specific **scenarios** to evaluate the approach's performance.
- Intended Outcomes of Learning
  - To **tell** about **ontologies** as a **technology** for **decision-making support** in **ATM**.
  - To **identify airspace situations** in which the approach can be applied.
  - To **use** the **ontological approach** and the uncertainty method.

Contents

- Introduction
- Background for the approach
- Decision-making support system
- Application examples
- Conclusions and next session topics

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Introduction

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Introduction

- Context
  - The **increasing number of varied information inputs** from communication and navigation requests and the **proliferation of UAVs** are challenging ATM.
  - ATM is getting complex where **decision-making processes** are required to combine **information of a diverse nature** (weather, flights, airports, UAVs, etc.).

- Motivation
  - **Successful use of ontologies in different communities** (medical diagnostics, target assessment, etc.). Avionics can also benefit from ontological approaches.
  - **Emerging interest** from the FAA NextGen and the SESAR system in ontologies.
  - The use of **ontologies enhances** the coordination between physics-based sensing, human-derived communications, and situation reporting.

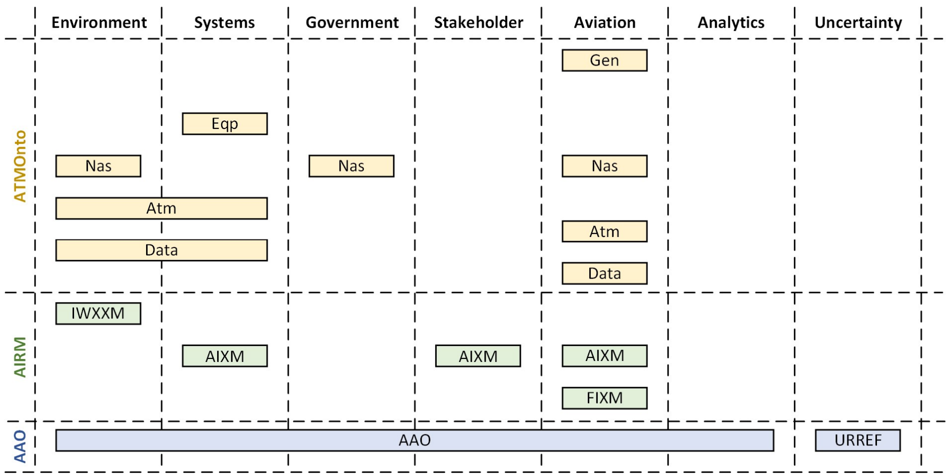
Introduction

- Problem
  - The ATM information complexity demands a **huge workload on pilots and ATCs**.
  - Flight trajectories, safety, and messaging must be prioritized while **cross-checking information** coming from the **different sources**.

- Challenge
  - With a **common avionics ontology**, pilots and ATCs could coordinate to make difficult decisions in the context of data, features, and information uncertainty.

Initiatives to Use Ontologies in Airspace

- NASA ATMOnto
  - is meant to integrate heterogeneous aviation data with a clear propose to be used for aeronautics investigation [1].
- SESAR Ontology Set
  - BEST project proposes an ontological infrastructure for the Single European Sky ATM Research (SESAR) Joint Undertaking [2]-[4].
- **Avionics Analytics Ontology (AAO)**
  - has been developed as a cognitive engine of a Decision Support System (DSS) for avionics analytics for application such as Air Traffic Management (ATM) [5].



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Background

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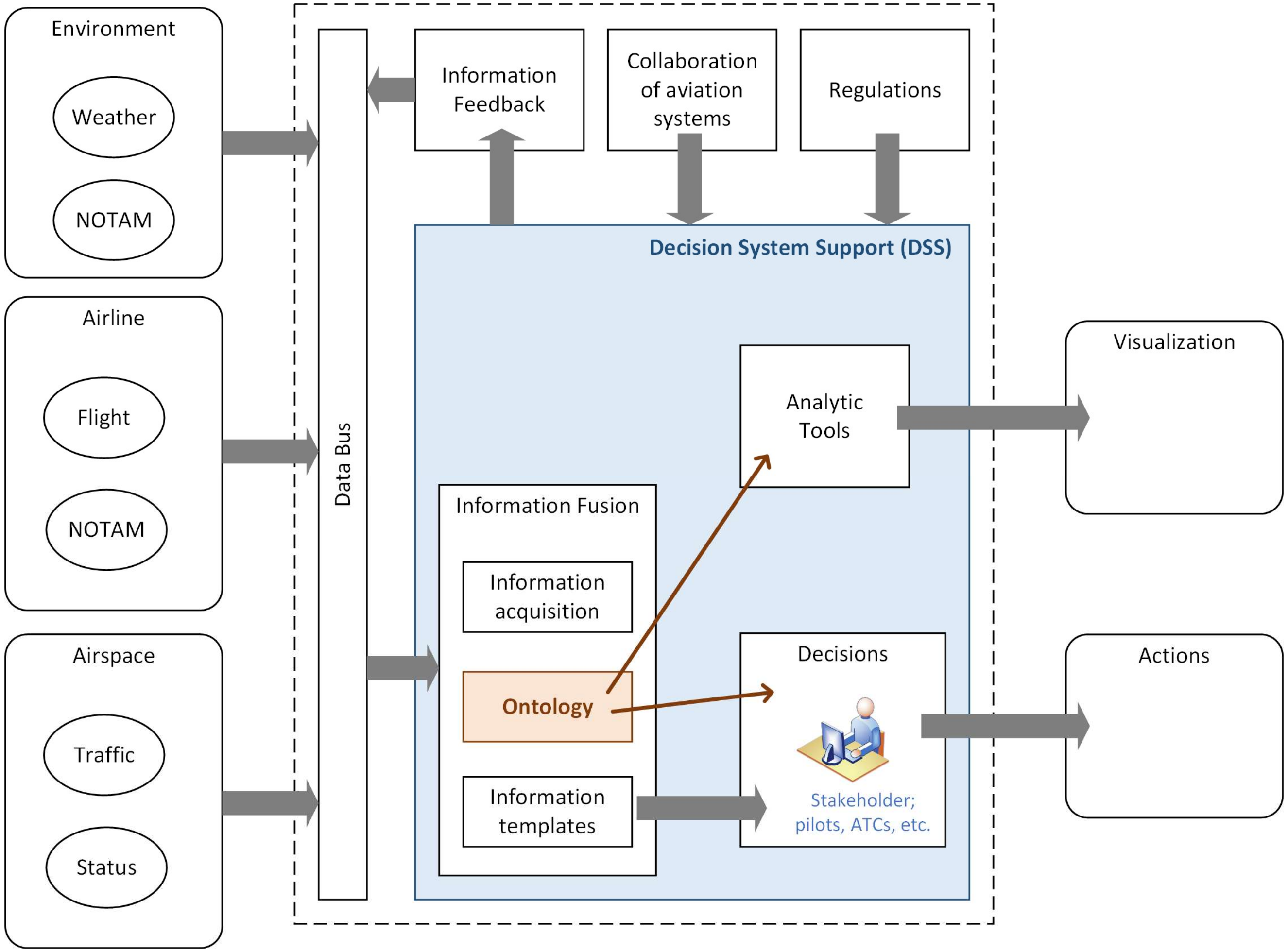
Background

- **Avionics analytics** in **ATM**
- **Mental process** and the role of **cognition**
- Relevance of semantics in **knowledge representation**
- **Ontologies** as a way to **represent knowledge** and support **reasoning**
- **Uncertainty** considerations by means of **Bayesian Networks** (BNs)

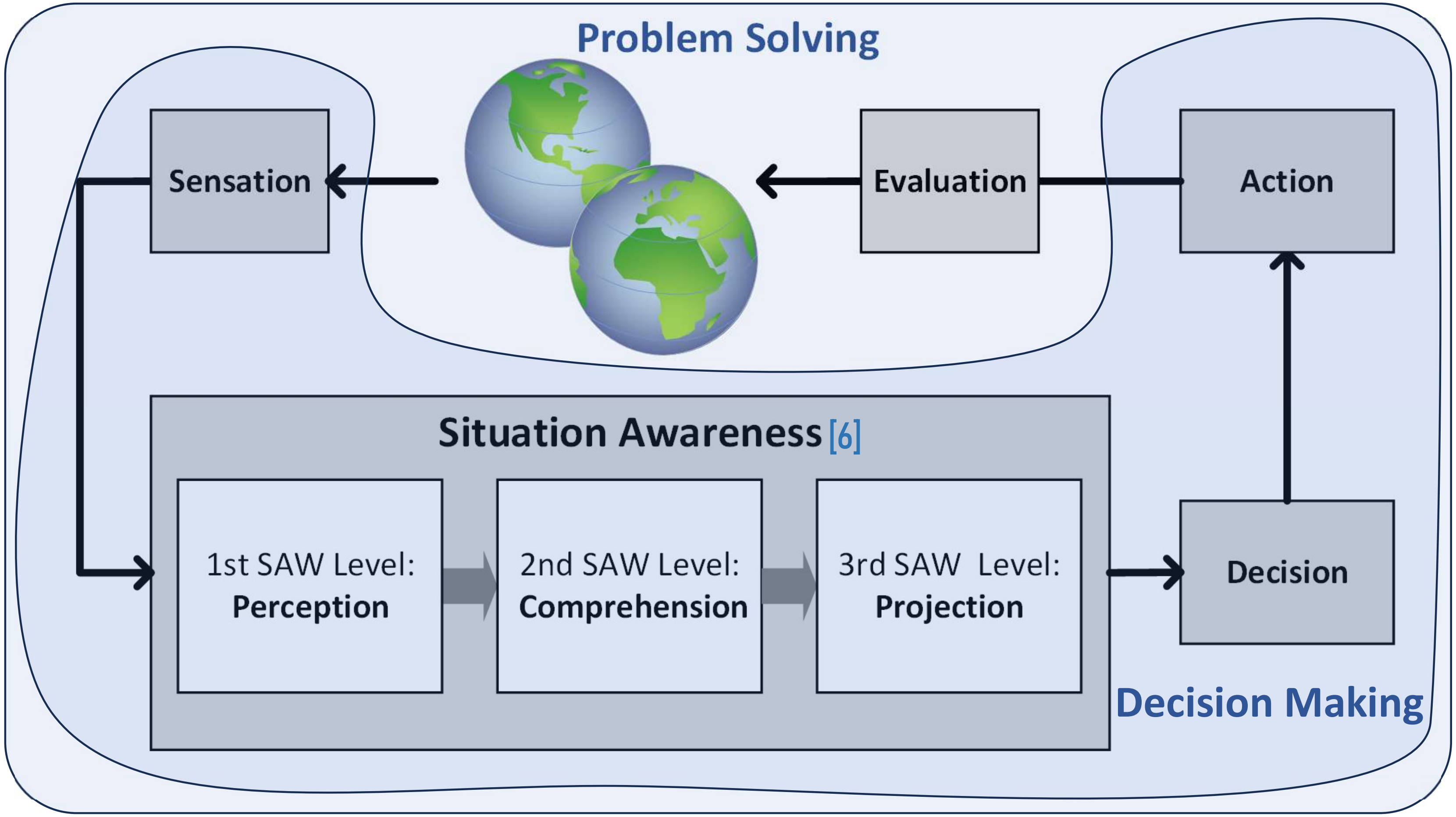
CNS Avionics Analytics

Simplified Architecture for ATM



Analytical Model

From Situation Awareness to Problem Solving



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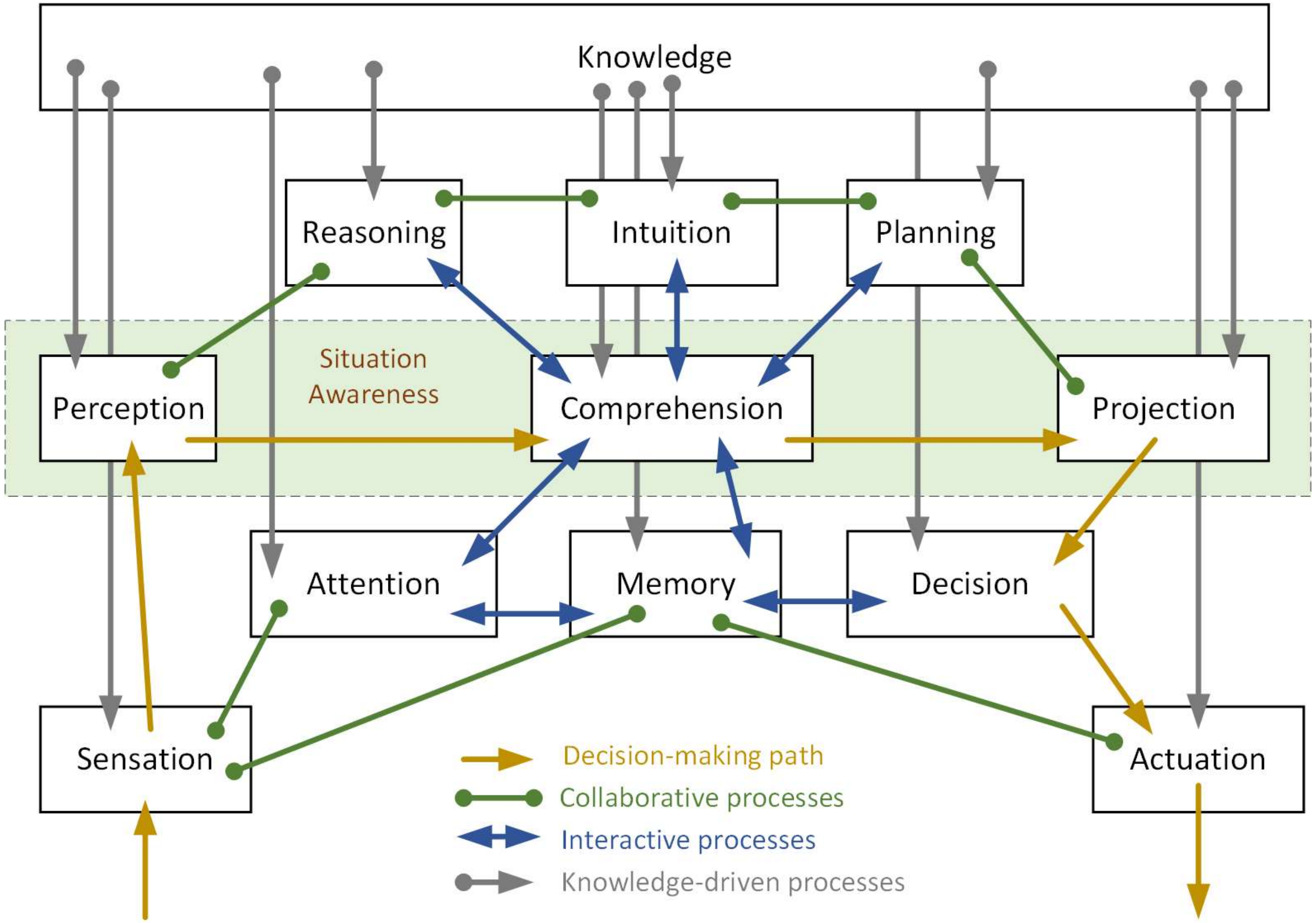
Mental Cognition Process

Cognitive Computing Architecture



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Sematic Data Modelling

Different Types of Relationships between Concepts

- Realization or Classification - *"instance_of"* relations
- Aggregation - *"has_a"* relations
- Generalization/Inheritance - *"is_a"* relations; reciprocal to Specification – *"subtype_of"* relations
- Composition – *"part_of"* relations
- Ability - *"can"* relations
- Property - *"is"* relations
- Concepts are connected by means of four well-defined types of relationship models:
  - One-to-one: a source concept is connected to at most one sink concept and vice versa.
  - One-to-many: a source concept may be connected to one or more sink concepts, but the latter can only be mapped to at most one source concept.
  - Many-to-one: more than one source concept may be linked to one sink concept.
  - Many-to-many: more than one source concept may be linked to more than one sink concept.

Cognitive Computation

Foundations for Knowledge Representation

- **Representation of knowledge** requires the **definition**, **specification**, and **description** of **information elements** and **data structures** as well as their network (**interconnections**).
- Knowledge can formally be represented by means of a mathematical model based on **Description Logic (DL)** [7].
- Table with examples of **DL signatures** for key knowledge elements

Signature	OOP	Example			DL Syntax
Concept	Class	aircraft	airport	runway	C
Role	Property	hasWing	hasRunway	hasStatus	P
Individual	Object (instance of a class)	Boeing_747	IAD (Washington Dulles Int Airport code)		i

Description Language

Formal Knowledge Representation: Concepts and Roles

- Concept expressions based on set operators, for instance:
  - $C_1 \sqcup C_2$ where C_1: ADS-B and C_2: TCAS so it is ADS-B ∪ TCAS or **unionOf**(ADS-B, TCAS).
  - $C_1 \sqcap C_2$ where C_1: aircraft and C_2: unmanned so it is aircraft ∩ unmanned or **intersectionOf**(aircraft, unmanned).
  - $\neg C_1$ where C_1: ImproperSepartation so it is ProperSeparation or **complementOf**(ImproperSepartion).
- Role expressions (between concepts or between individuals), for instance:
  - $\exists P.C$ where P: hasPilot and C: aircraft so it is ∃hasPilot.aircraft or hasClass()
  - $\forall P.C$ where P: hasPilot and C: aircraft so it is ∀hasPilot.aircraft or toClass()
  - $\forall P.\{i\}$ where P: airportOf and i: USA so it is ∀airportOf.{USA} or hasValue()

Description Language

Formal Knowledge Representation: Axioms

- Schema axioms based on set operators, for instance:
  - $C_1 \sqsubseteq C_2$ where C_1: aircraft and C_2: vehicle so it is aircraft $\subseteq$ vehicle or aircraft **subclassOf** vehicle; *"is a"*.
  - $P_1 \equiv P_2^-$ where P_1: unmanned and P_2: manned so it is unmanned $\equiv$ manned or unmanned **DisjointWith** manned
  - $C_1 \equiv C_2 \sqcap C_3$ where C_1: drone, C_2: aircraft, C_3: unmanned and so it is drone $\equiv$ aircraft $\cap$ unmanned or drone **EquivalentTo** aircraft and unmanned
- Data axioms (between concepts or between individuals), for instance:
  - i:C where i: Boeing_747 and C: aircraft so it is Boeing_747:aircraft or Boeing_747 Type aircraft; *"instance of"*.
  - $\langle i_1, i_2 \rangle$:P where i_1: Boeing_747, i_2: Airbus_380, and P: hasAirTraffic

Description Language

Knowledge Representation: Two Main Knowledge Components

- Knowledge Base
  - **TBox** component is a **terminological formalism** (terminology; system description in terms of controlled **vocabularies**). TBox entails inclusion assertions about properties from concepts and roles.
  - **ABox** component is an **assertional formalism** (**assertions** about **individuals**). Abox entails instance assertions such as those for individual objects.
- Formally, the **knowledge base** is

$$\mathcal{K} = \langle \mathcal{T}, \mathcal{A} \rangle$$

where $\mathcal{T}$ is the **TBox** and $\mathcal{A}$ is the **ABox**.

$$\mathcal{T} = \{v_1, v_2, \ldots v_j\}$$

$$\mathcal{A} = \{f_1, f_2, \ldots f_k\}$$

Description Language

Knowledge Representation: TBox and ABox

- Where v_j is the j-th terminological axiom and f_k is the k-th assertional fact with $j,k \in \mathbb{N}$. For instance, for **TBox**

$$v_l: aircraft \sqsubseteq vechile$$

$$v_m: drone \equiv aircraft \sqcap unmanned$$

- For instance, for **ABox**

$$f_p: \langle \mathrm{Boeing\_747}, \mathrm{Airbus\_380} \rangle : \mathrm{hasFixedWing}$$

$$f_r: \mathrm{Boeing\_747}: \mathrm{aircraft}$$

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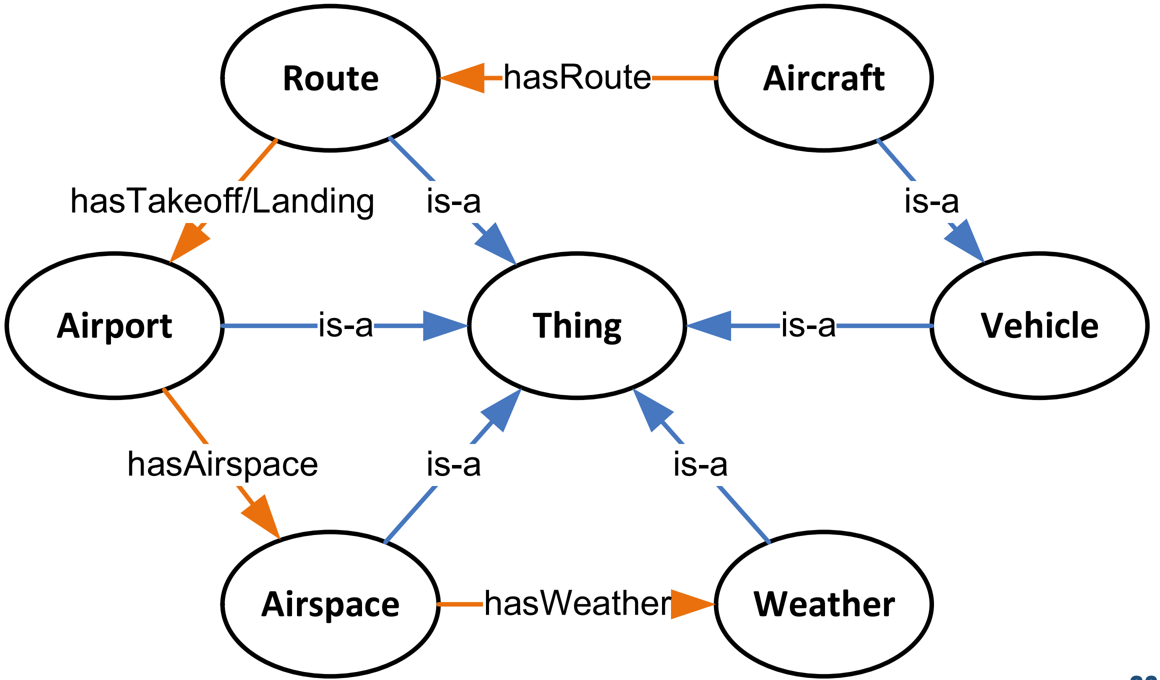
Knowledge Engineering

Ontology Classes and Class Relation

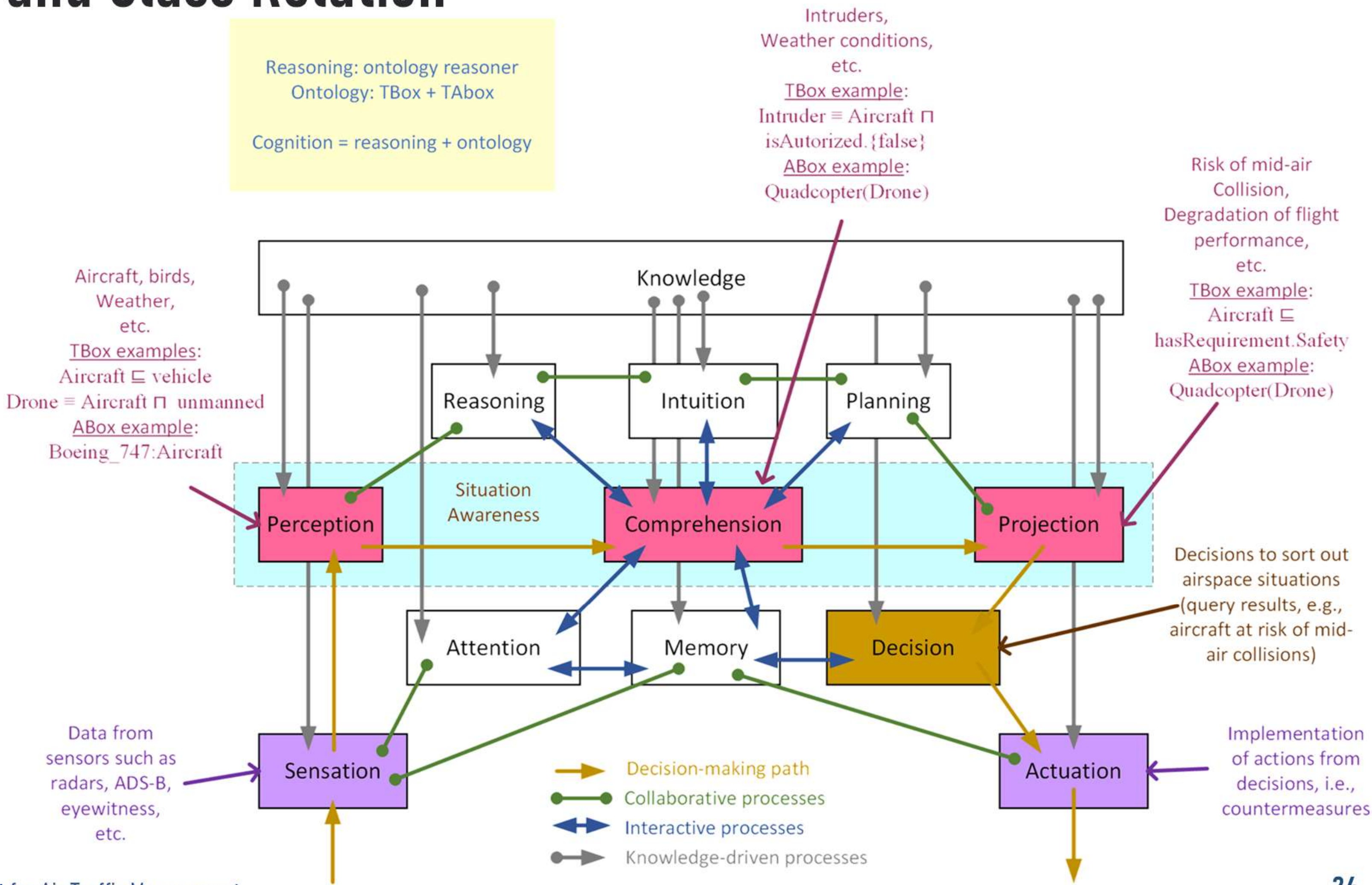
- Ontologies can **represent knowledge** based on the **DL expressions** written in a high-level language (not a mathematical symbol-based language such as DL) easier to deal with by human begins.
- Ontologies make use of **semantic diagrams** to easily realize the connection between concepts.
- Main ontology elements
  - **Classes** (concepts)
  - **Properties** (roles)
  - **Individuals** (objects; instances of classes)
  - **Terminological axioms** (TBox)
  - **Assertional facts** (ABox)



Knowledge Engineering

Ontology Classes and Class Relation

- The **knowledge** base has a **key role** in the SA process.
- The **TBox** component is needed for high-level of sensation and in full for **perception** and **comprehension**.
- The **ABox** component is required for high-level of **perception** in full for **comprehension**, and partially for **projection**.



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Uncertainty Measurement

Analytics and Categorization

- Uncertainty analysis explores the **lack of certain data variables**.
- In the case of the DSS, these variables store data from the in**puts of the DSS**.
- The uncertainty of the variables has an impact on the **decision-making process** of the DSS.
- The DSS considers uncertainty in its **SA-driven decision-making process** by means of
  - Analytical metrics and scientific analysis
  - Categorization and ontological structure

Analytical Metrics and Scientific Analysis

Formalization based on Bayesian Networks

- A **Bayesian Network (BN) B** annotated in a Directed Acyclic Graph (DAG) which represents a **joint probability distribution** over a set of random variables can be defined as follows

$$B = \langle G, \theta \rangle$$

- Where **G** is a DAG with variables $X_1, X_2, \ldots X_n$. Each variable X_i is independent from its parent variables in **G**. **θ** represents a set of parameters of the BN. Such a set entails $P_B(x_i \mid \pi_i) = \theta_{(x_i \mid \pi_i)}$ where x_i is a realization of X_i conditioned on π_i. Then, **B** defines only one distribution for joint probability

$$P_B(X_1, X_2, \ldots, X_n) = \prod_{i=1}^{n} \theta_{x_i \mid \pi_i} = \prod_{i=1}^{n} P_B(x_i \mid \pi_i)$$

Analytical Metrics and Scientific Analysis

Sensors and Aircraft Target

- The **veracity** for the **combined sensors** uses the complement of the product of the non-veracity component of all sensors on **a given aircraft**

$$V_c = 1 - \prod_{s=1}^{n} (1 - V_s)$$

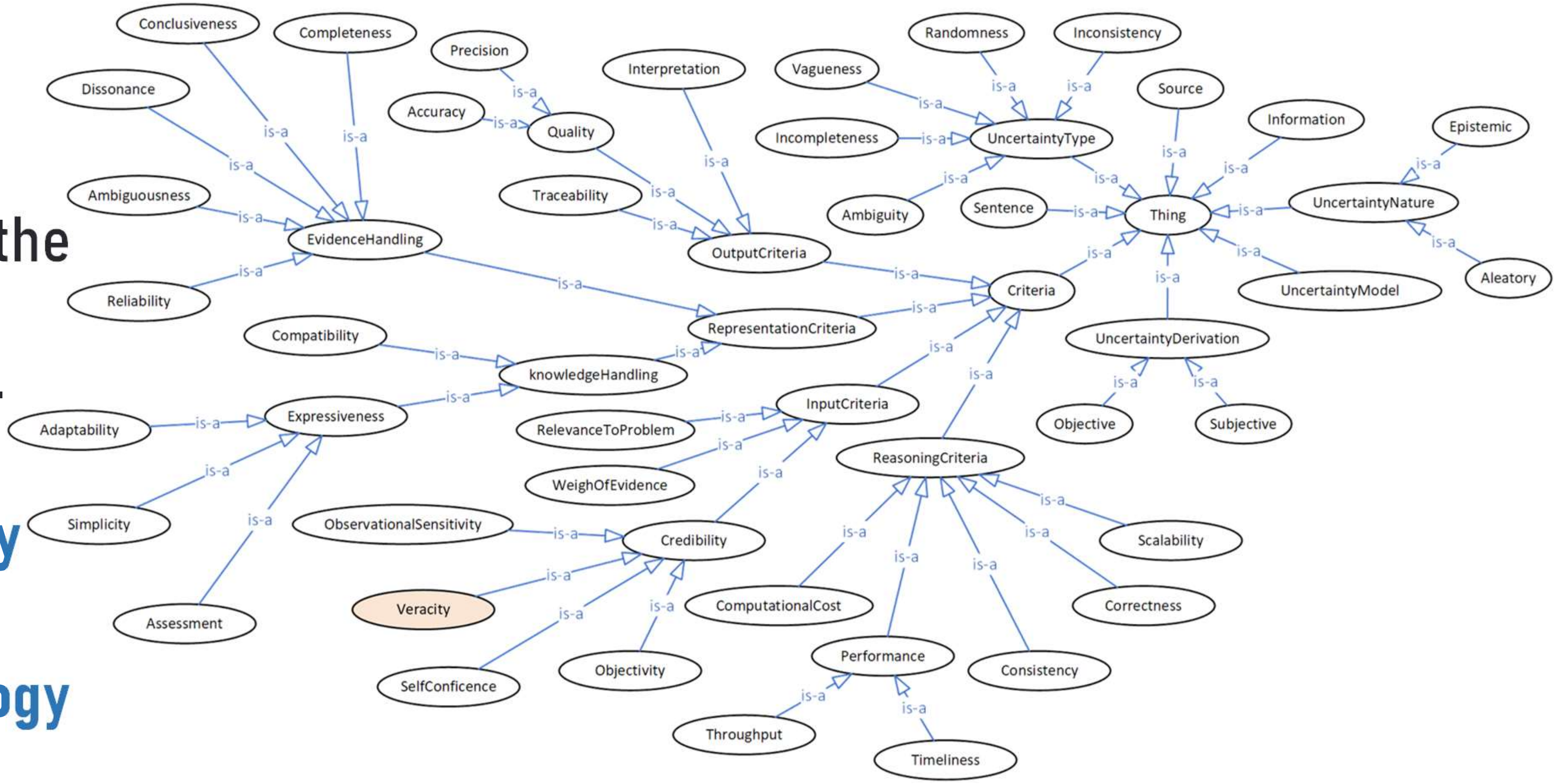
- Where V_c is the combined veracity, **n** is the number of sensors in the platform, and V_s is the veracity of each sensor. The assumption when assessing the **veracity score of a sensor** when answering a query about two subjects (**more than a target per sensor**) is that information on both must be correct.

$$V(s_1, s_2, \ldots s_k) = \prod_{i=1}^{k} V_{\mathrm{i}}$$

Categorization and Ontological Structure

Uncertainty Representation and Reasoning Evaluation Framework (URREF)

- Performance evaluation of the information fusion systems based on the **uncertainty** from **inputs** and **outputs**.
- **Not** tight to any **specific uncertainty analysis method**.
- Realized as **ontology for uncertainties**.



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Decision Support System

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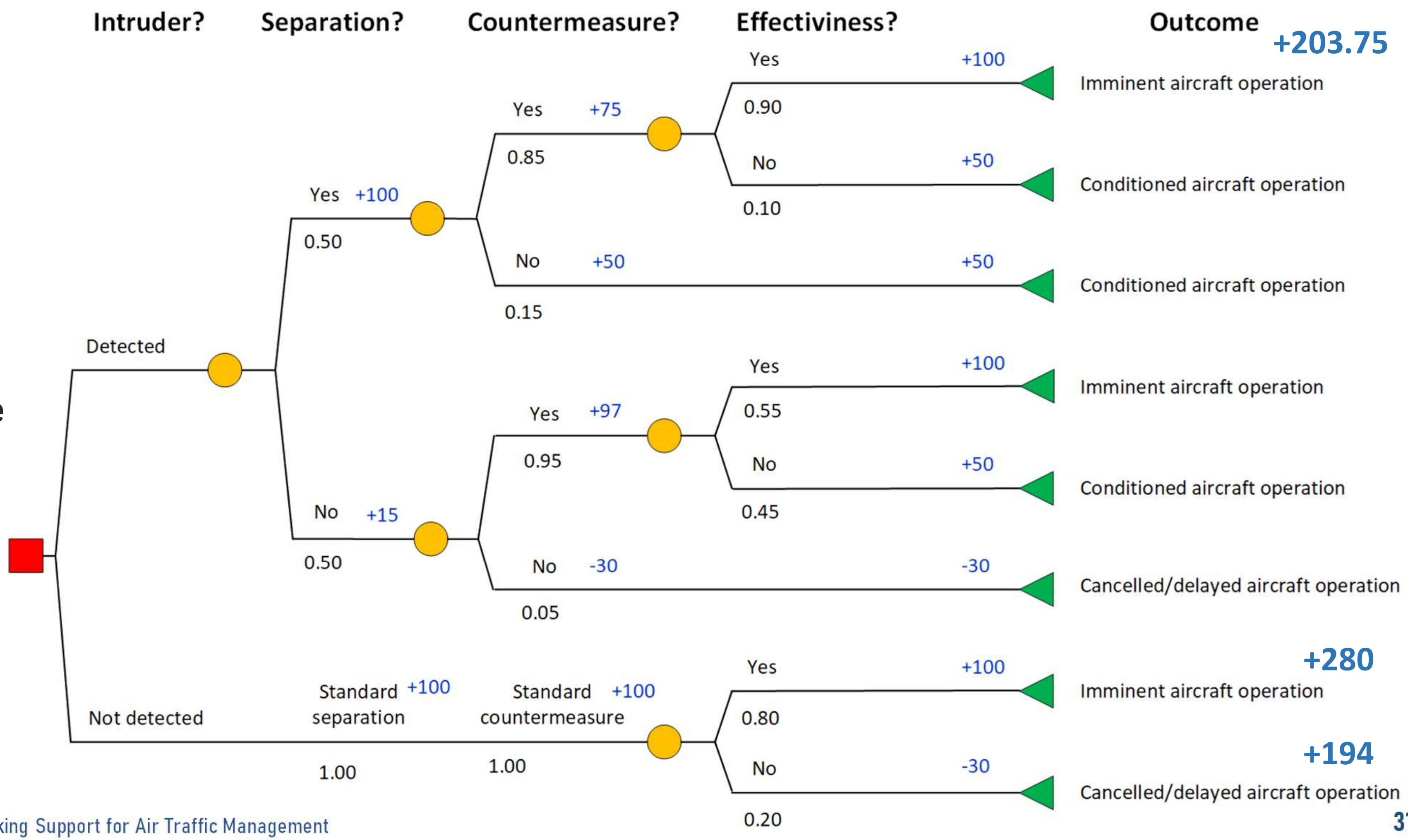
Decision Making Process

Example of Decision Tree for Aircraft Collision Avoidance

- **Expected utility**

$$U_e = \sum_{i=0}^{l} P(x_i)\, u(x_i)$$

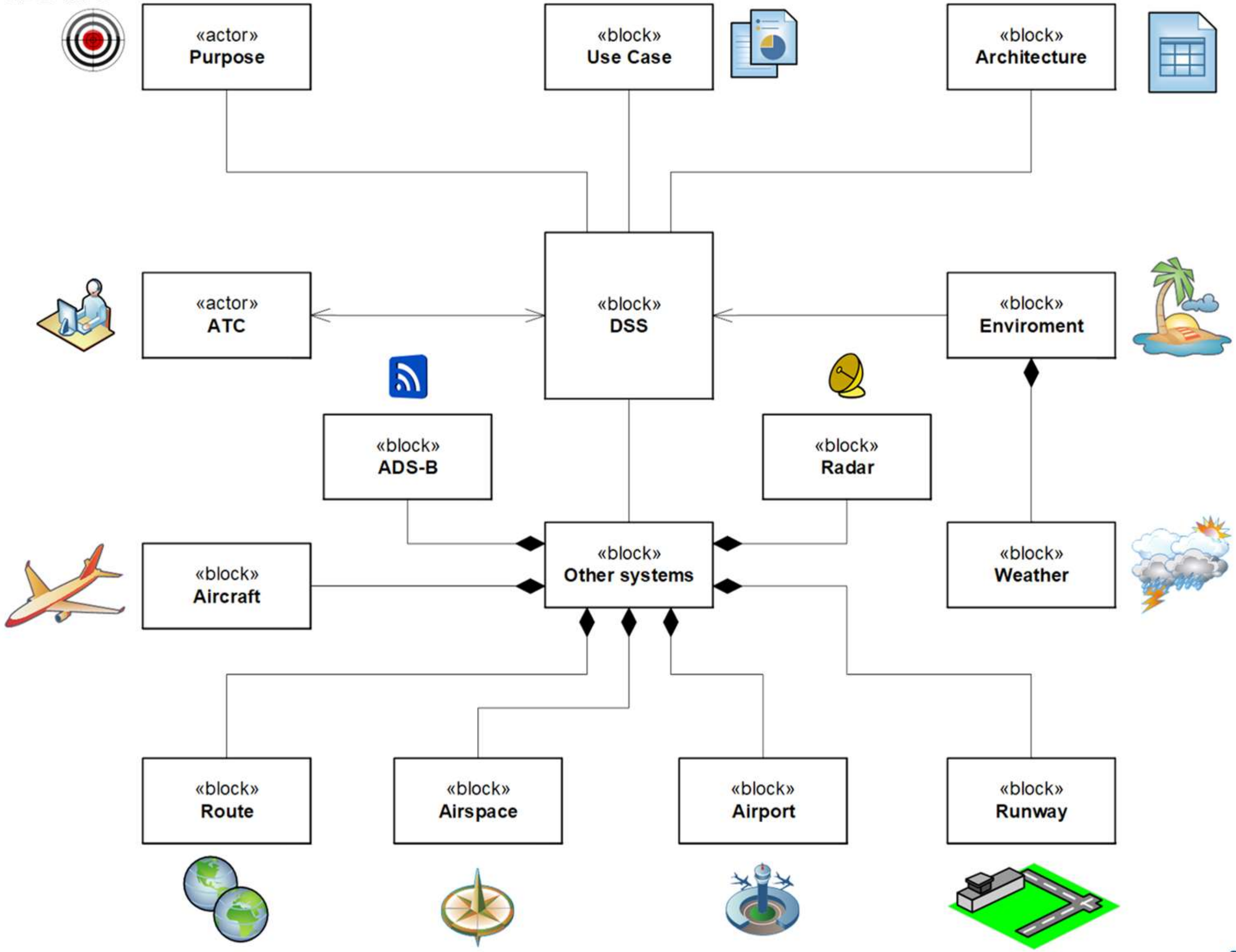
- Where $P(x_i)$ is the probability of the variable x_i (each possible outcome), $u(x_i)$ is the utility of x_i (outcome).



Cognitive Model

Main Concepts and their Relations

- Foundation of the **knowledge for understanding the surroundings** of the operation context of the DSS.
- Investigation of **context concepts and their relations**. The definition of concepts involves all the elements of ATM/UTM operation, e.g., aircraft, airport, radars, weather, and people.
- Relations between concepts are those that connect or **link concepts with each other**, e.g., flights have a route, microburst is a very bad weather condition for flights, and a microburst must be avoided by flights.
- **Concepts and their relations are the building blocks** for the cognitive model as they set the cognitional network to connect related concepts and produce a conclusion regarding an airspace situation.



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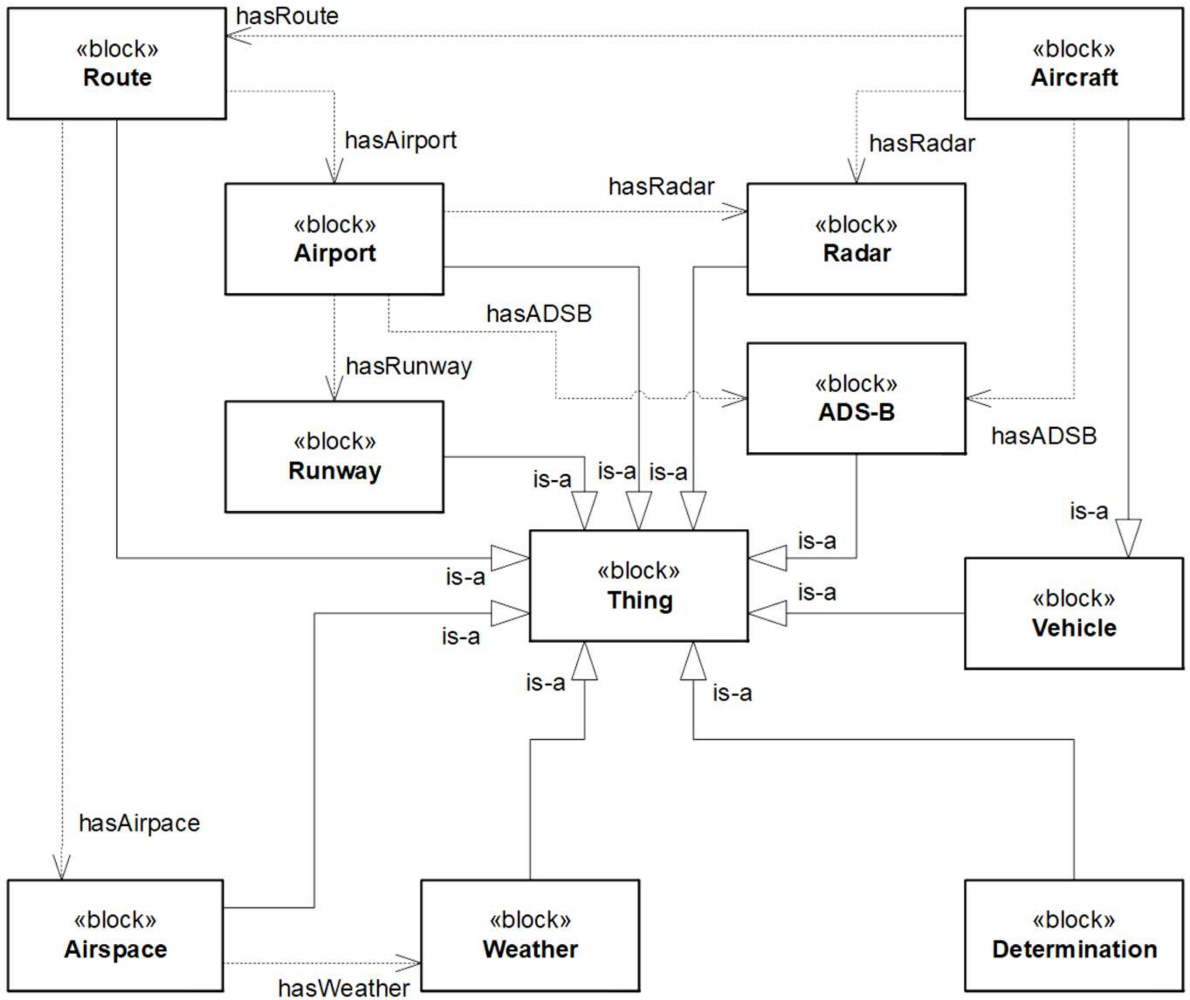
Cognitive Model

Elementary Concepts and their Relation

- The discovery of concepts, relations, and connections between them allows for the **settings of additional constraints** or **requirements for specific logic conditions**, e.g., aircraft have routes, airports have runway, etc.



Airspace Situations

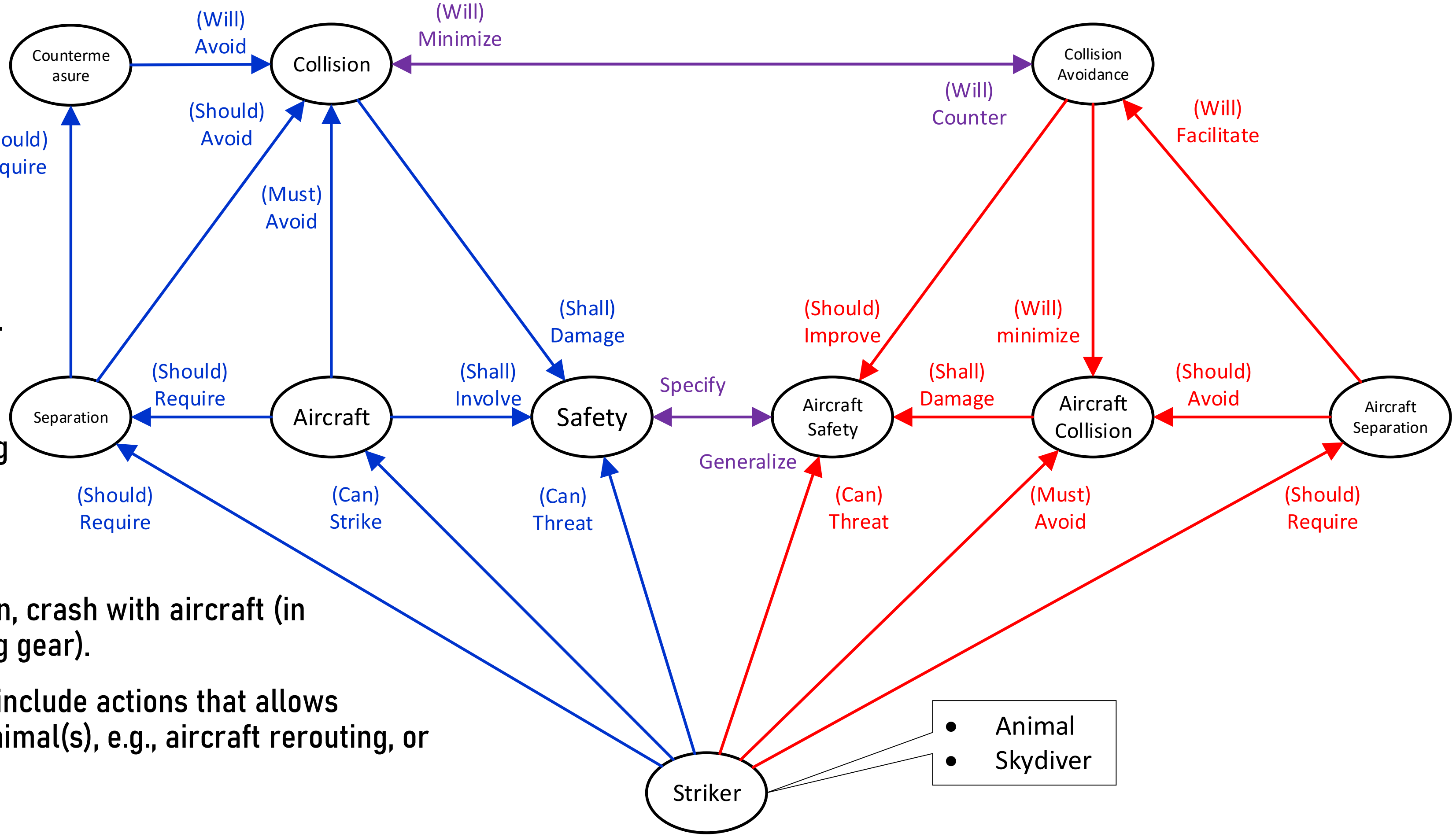
Different Factors Considered for Collision Avoidance

<table>
<tr><th rowspan="2">Aircraft separation (from)</th><th colspan="4">Flight Phases</th></tr>
<tr><th>Taxi-out/in</th><th>Take-off/ Landing</th><th>Climb/ Descent</th><th>Cruise</th></tr>
<tr><td>Animal(s)</td><td>Wildlife Strike (terrestrial animals)</td><td>Wildlife Strike (ground/flying animals)</td><td>Wildlife Strike (flying animals)</td><td>Wildlife Strike (high flying animals)</td></tr>
<tr><td>Vehicle(s)</td><td rowspan="2">Taxiway incursions</td><td rowspan="2">Runway incursions</td><td>UAS intrusions</td><td>Airspace infringement</td></tr>
<tr><td>Person(s)</td><td colspan="2">Skydiver Strike</td></tr>
</table>

Cognitive Model

Example for Wildlife Strikes

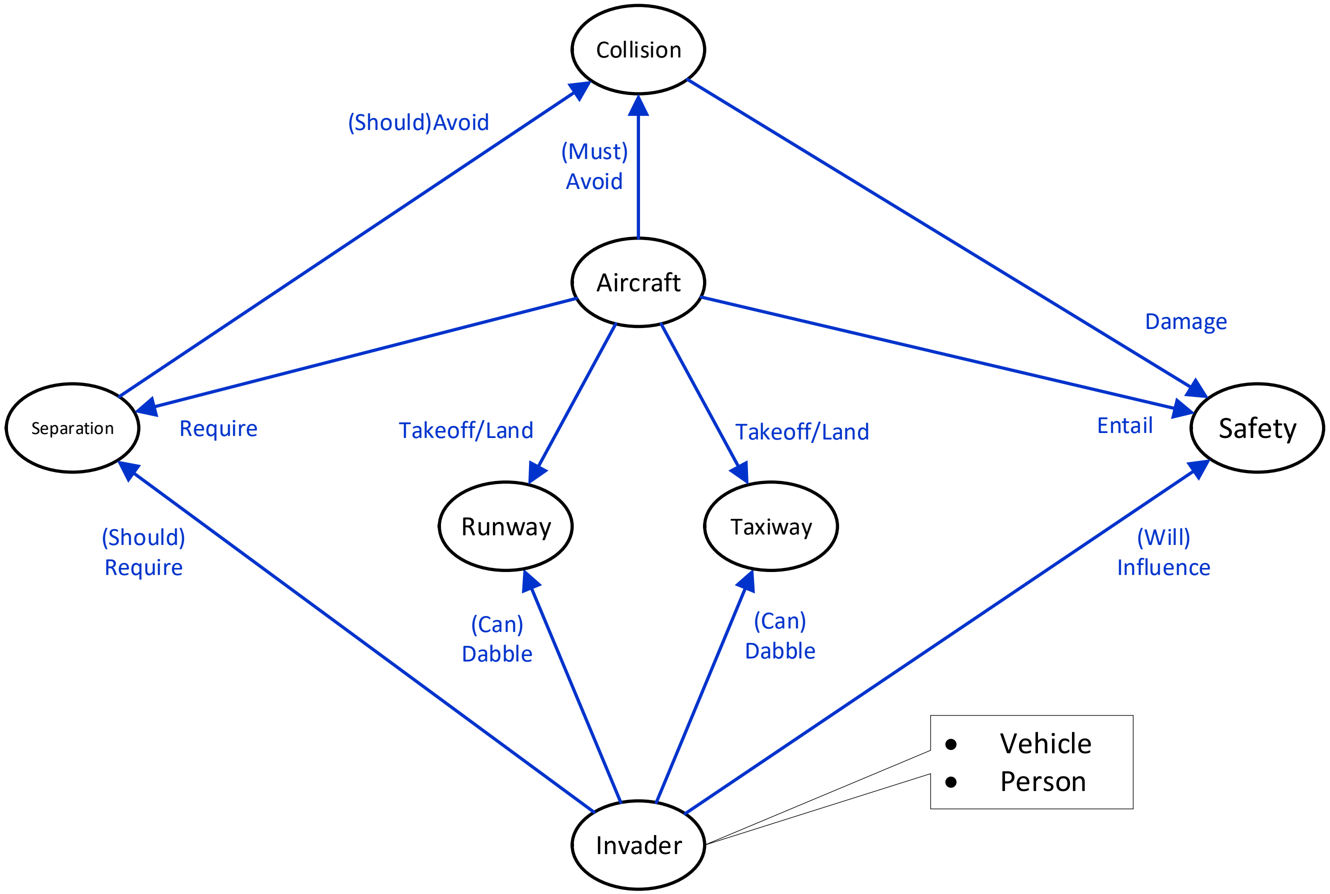
- **Factor**: Wildlife strike
- **Cause**: Animals (either terrestrial or flying ones) wandering or flying nearby runways, flying nearby airports, and even at very high altitude.
- **Flight phases**: Any flight phase (i.e. taxi-out, take-off, climb, cruise, descent, landing, and taxi-in).
- **Detection**: Sighting (including using binoculars) for low altitudes. Specialized LSRs for detection of large flocking birds.
- **Goal**: Avoidance of engine ingestion, crash with aircraft (in particular, windshields and landing gear).
- **Action**: Decision outcomes should include actions that allows aircraft to avoid collision within animal(s), e.g., aircraft rerouting, or diverting as needed.



Cognitive Model

Example for Taxiway and Runway Incursions

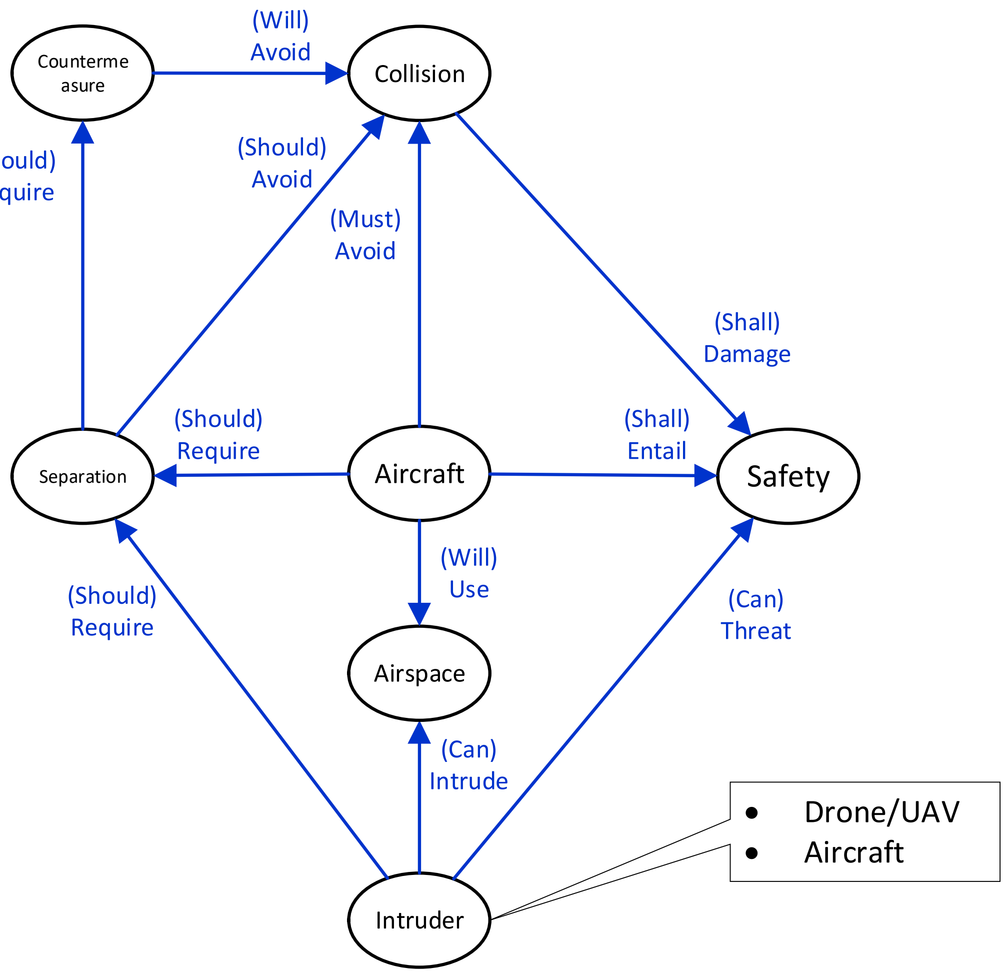
- **Factor**: Runway/taxiway incursions
- **Cause**: Incursion of vehicles or persons in runways. ATCs are usually aware of these situations.
- **Flight phases**: Taxi-out, take-off, landing, and taxi-in.
- **Detection**: ATCs are informed by means of requests from vehicles/persons.
- **Goal**: Avoidance of contention problem.
- **Action**: Authorization when runway/taxiway is available for incursions.



Cognitive Model

Example for UAS Intrusions

- **Factor**: Airspace intrusion
- **Cause**: UAVs or drones flying nearby aircraft and airspace infringement
- **Flight phases**: Any flight phase (i.e. taxi-out, take-off, climb, cruise, descent, landing, and taxi-in).
- **Detection**: Drone detection system, PSR, SSR, ADS-B, TCAS
- **Goal**: Airborne collision avoidance
- **Action**: Aircraft manoeuvring to avoid other aircraft

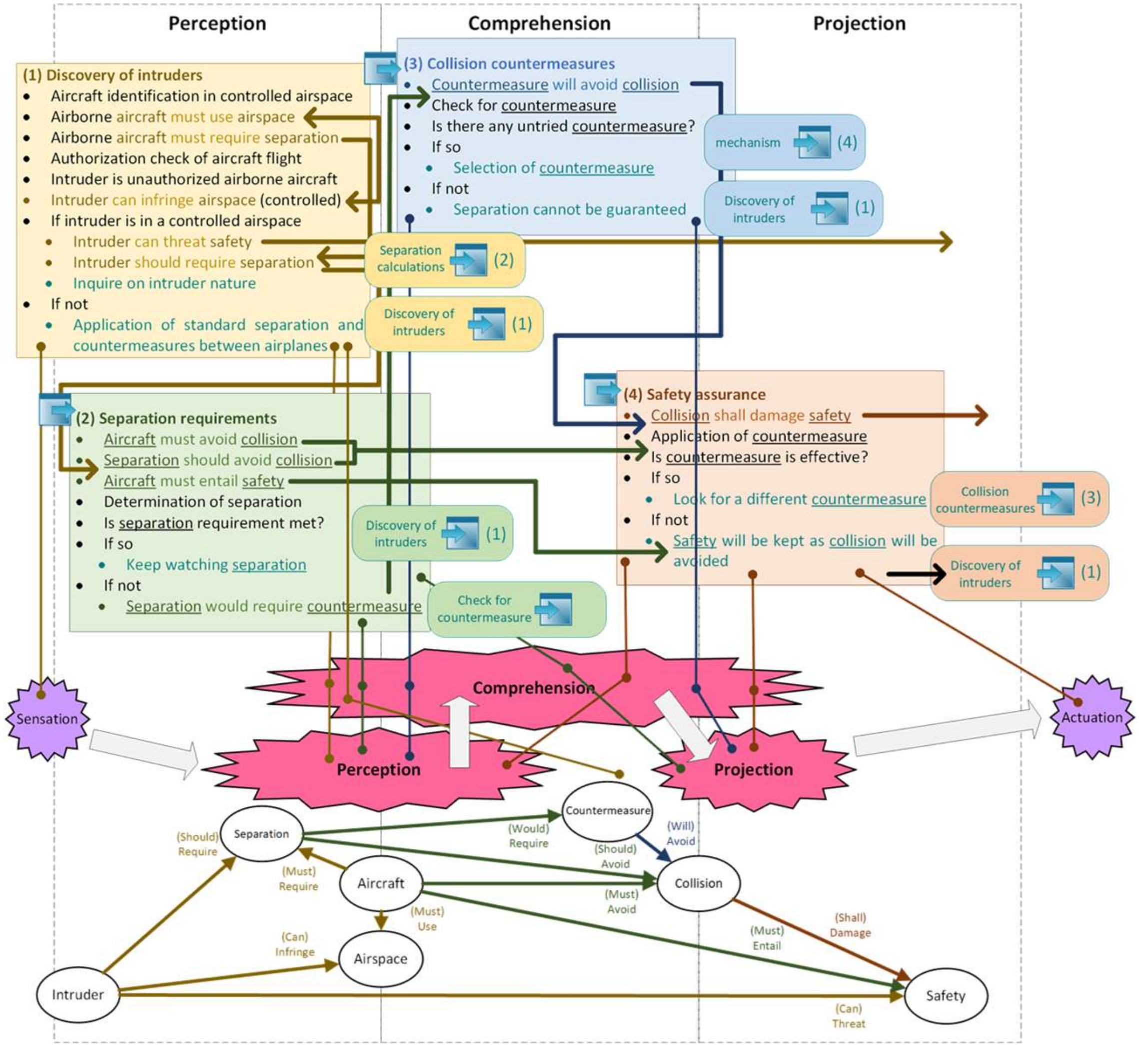


Cross-Impact Analysis

Cognitive Model for Potential Intruders

❖ **Logical reasoning** through the cognitive model to be aware of safety hazards due to aerial intruders

1) Discovery of intruders
2) Separation requirements
3) Collision countermeasures
4) Safety assurance



Knowledge Representation

TBox Axioms for Cognitive Model (Potential Intruders)

Step	Cognitive Model Sentence	Description Logic Syntax
Discovery of Intruders	Separation is-a requirement	$Separation \sqsubseteq Requirement$
	Aircraft is-a vehicle and has requirement of separation	$Aircraft \sqsubseteq Vechile \sqcap \exists hasRequirement.Separation$
	Airplane is-a aircraft	$Airplane \sqsubseteq Aircraft$
	Quadcopter is-a helicopter is-a rotorcraft is-a aircraft	$Quadcopter \sqsubseteq Helicopter \sqsubseteq Rotorcraft \sqsubseteq Aircraft$
	Airspace is-a environment	$Airspace \sqsubseteq Environment$
	Intruder is equivalent to aircraft that (and) is not authorized to fly	$Intruder \equiv Aircraft \sqcap \exists isAuthorized.\{false\}$
	Intruder is-a aircraft that (and) can-infringe airspace	$Intruder \sqsubseteq Aircraft \sqcap \exists canInfringe.Airspace$
	Safety is-a status	$Safety \sqsubseteq Status$
	Intruder is-a aircraft that (and) can-threat safety	$Intruder \sqsubseteq Aircraft \sqcap \exists canThreat.safety$
	Aircraft has requirement of separation	$Aircraft \sqsubseteq \exists hasRequirement.Separation$
	isAirTrafficOf is not hasAirTraffic	$isAirTrafficOf \equiv hasAirTraffic^{-}$
	isUnmanned is not IsManned	$isUnmmanned \equiv isManned^{-}$
Separation requirements	Aircraft has constraint of no collision	$Aircraft \sqsubseteq \exists hasConstraint.\neg Collision$
	Separation can-avoid collision	$Separation \sqsubseteq \exists canAvoid.Collision$
	Aircraft has entailment of safety	$Aircraft \sqsubseteq \exists hasEntailment.Safety$
	Separation has countermeasure of avoidance	$Separation \sqsubseteq \exists hasCountermeasure.Avoidance$
Collision countermeasures	Separation can-avoid collision	$Separation \sqsubseteq \exists canAvoid.Collision$
	Intruder has-mechanism countermeasure	$Intruder \sqsubseteq \exists hasMechanism.Countermeasure$
	ProperSeparation is-a Separation	$ProperSeparation \sqsubseteq Separation$
	ImproperSeparation is-a Separation	$ImproperSeparation \sqsubseteq Separation$
	ProperSeparation is not ImproperSeparation	$ProperSeparation \equiv \neg Improperparation$
Safety assurance	Collision can-damage safety	$Collision \sqsubseteq \exists canDamage.safety$

Knowledge Representation

ABox Axioms for Cognitive Model (Potential Intruders)

Step	Cognitive Model Sentence	Description Logic Syntax
Discovery of Intruders	Drone is-a quadcopter	$Quadcopter(Drone)$
	Drone is unmanned	$\langle Drone, true\rangle: isUnmanned$
	Drone is not authorized to fly	$\langle Drone, false\rangle: isAuthorized$
	Drone is airborne	$\langle Drone, true\rangle: isAirborne$
	Drone has contactable pilot	$\langle Drone, true\rangle: hasContactablePilot$
	Drone is detected by PSR1	$\langle Drone, PSR1\rangle: isDetectedBy$
	Drone is detected by SSR1	$\langle Drone, SSR1\rangle: isDetectedBy$
	Drone is detected by ADS-B1	$\langle Drone, ADS-B1\rangle: isDetectedBy$
	Drone has airspace Airspace1	$\langle Drone, Airspace1\rangle: hasAirpsace$
	Airspace1 is controlled	$\langle Airspace1, true\rangle: isControlled$
	Airplane has airspace Airspace1	$\langle Airplane, Airspace1\rangle: hasAirspace$
Separation requirements	Airplane1 has Separation DroneSeparation	$\langle Airplane1, AirplaneSeparation\rangle: hasSeparation$
	Drone has Separation DroneSeparation	$\langle Drone, DroneSeparation\rangle: hasSeparation$
	Drone has Distance DroneDistance*	$\langle Drone, DroneDistance\rangle: hasDistance$
Collision countermeasures	PilotContact is-a countermeasure	$Countermeasure(PilotContact)$
	PilotContact is untried	$\langle PilotContact, true\rangle: isUntried$
	PilotContact is applied	$\langle PilotContact, true\rangle: isApplied$
	Drone has countermeasure PilotContact	$\langle Drone, PilotContact\rangle: hasCountermeasure$
Safety assurance	Mid-air collision is-a collision	$Collision(MidAirCollision)$
	PilotContact is applied	$\langle PilotContact, true\rangle: isApplied$
	AirplaneSafety is-a safety	$Safety(AirplaneSafety)$
	AirplaneSafety is damaged	$\langle AirplaneSafety, true\rangle: isDamaged$

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Application Examples

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Progressive Prototyping

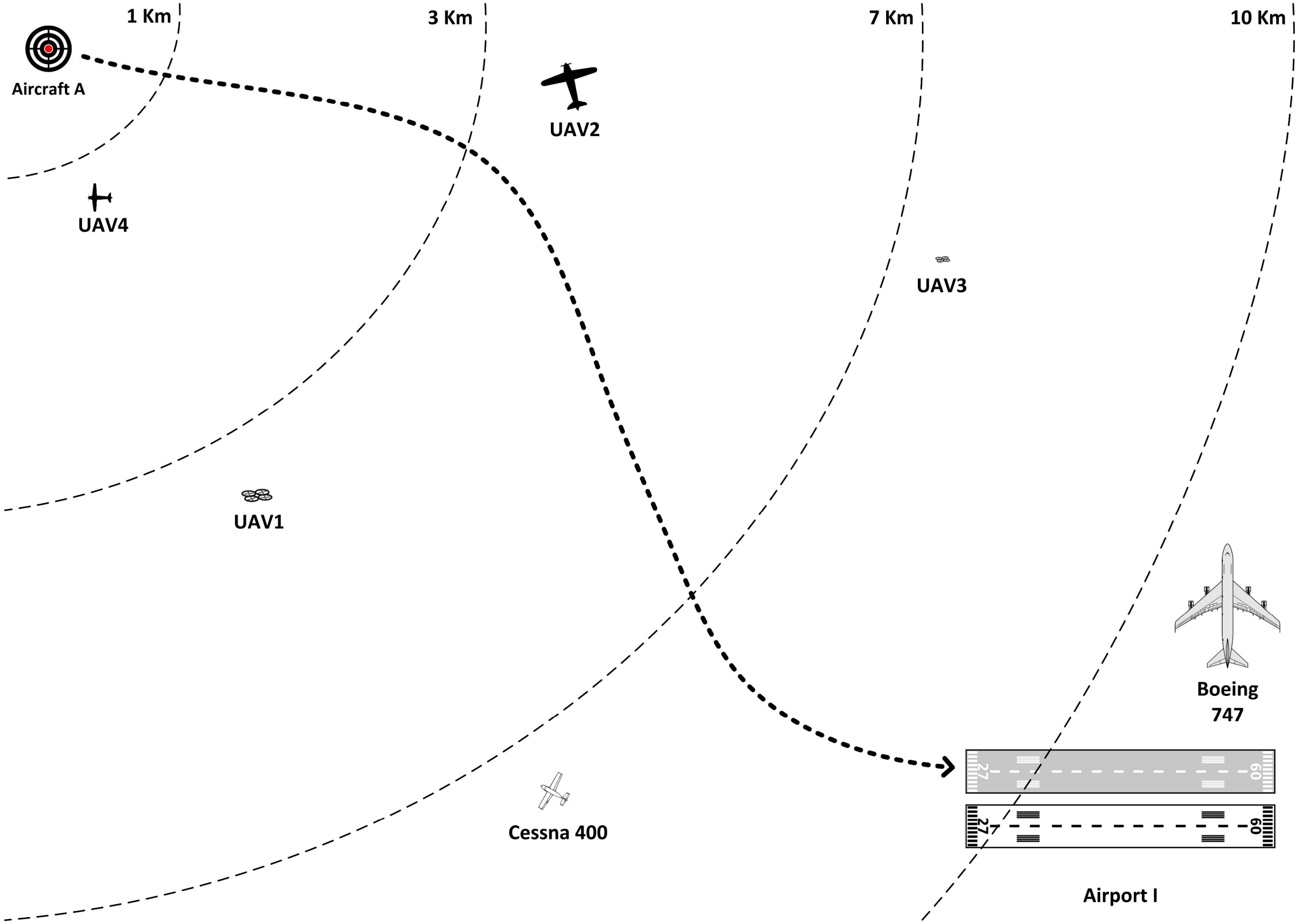
From Ontology Tool to Physical Prototypes

- Proof of concept using the Protégé tool [8]
  - Aircraft proximity [5]
  - Weather conditions [5]
  - Moral autonomy [9]
- Analytical calculation of uncertainty
  - Airplane take-off (take-off rolling) [10]
- Preliminary trials with physical prototype
  - Airplane take-off (taxied for take-off roll)

Proof of Concept Using the Protégé Tool

Aircraft Proximity

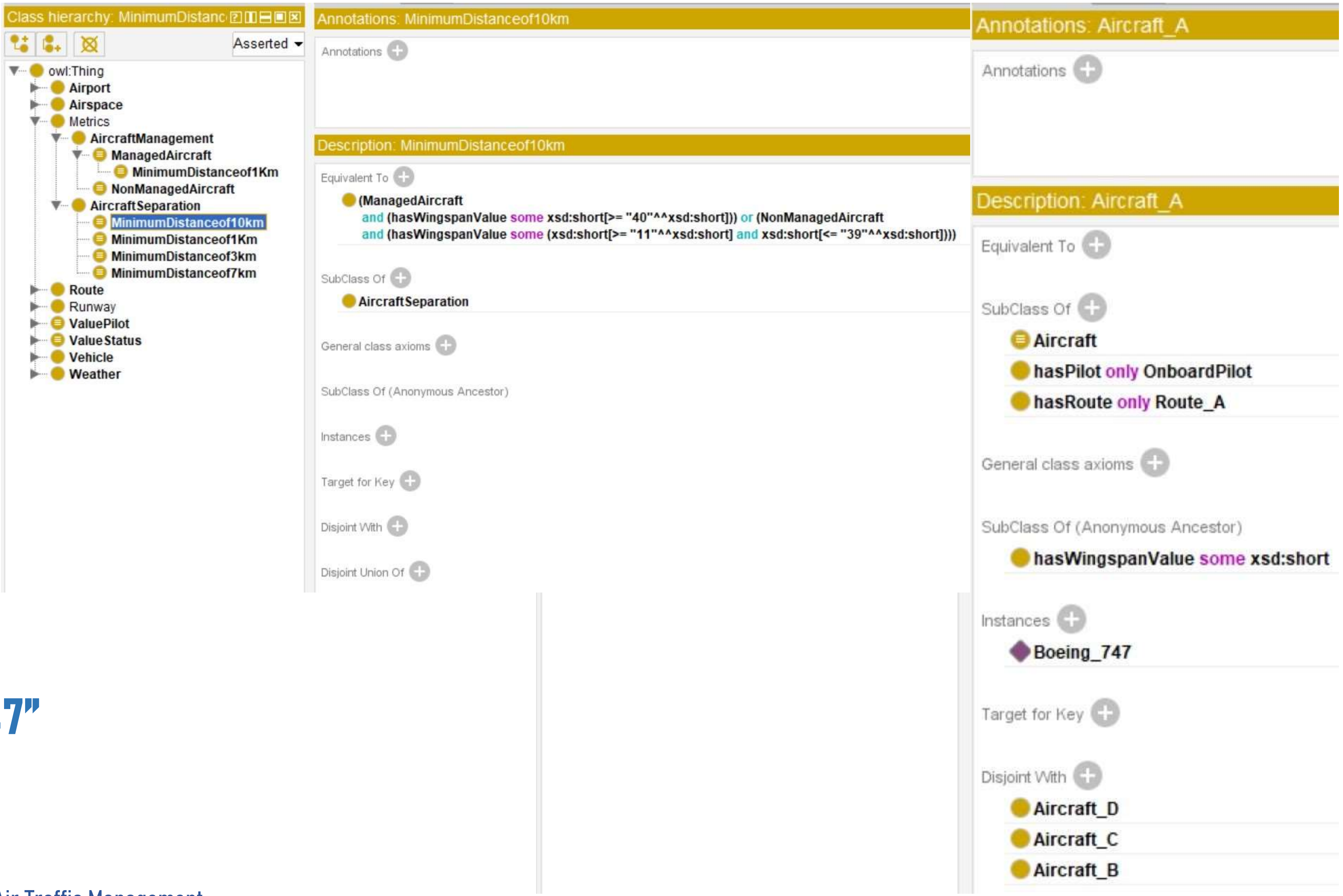
- **Aircraft A** is approaching **airport I**.
- **Aircraft A** is in the proximity of a large airplane (e.g., **Boeing 747**), a small airplane (e.g., **Cessna 400**).
- There are also four **UAVs** (**two remotely-piloted UAVs** and **two autonomous UAVs**).
- **Aircraft A** plans to land at an airport where **weather conditions are good**.
- All the aircraft are within the **same controlled airspace class**.



Aircraft Proximity

Protégé Class Tree of Asserted AAO Classes

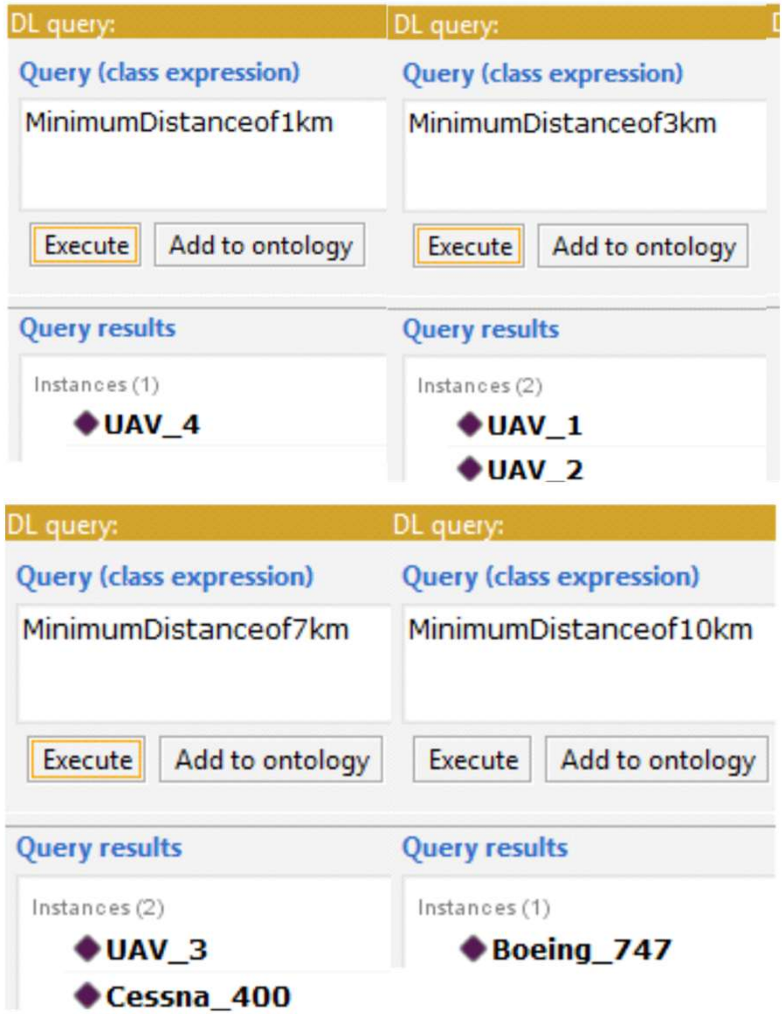
- Airports
- Airspaces
- Metrics
  - Aircraft Management
  - Aircraft Separation
- Routes
- Runways
- Aircraft
  - Individual **"Boeing_747"** is an instance of class **"Aircraft_A"**



Aircraft Proximity

Queries to Check Minimum Distances (Separation)

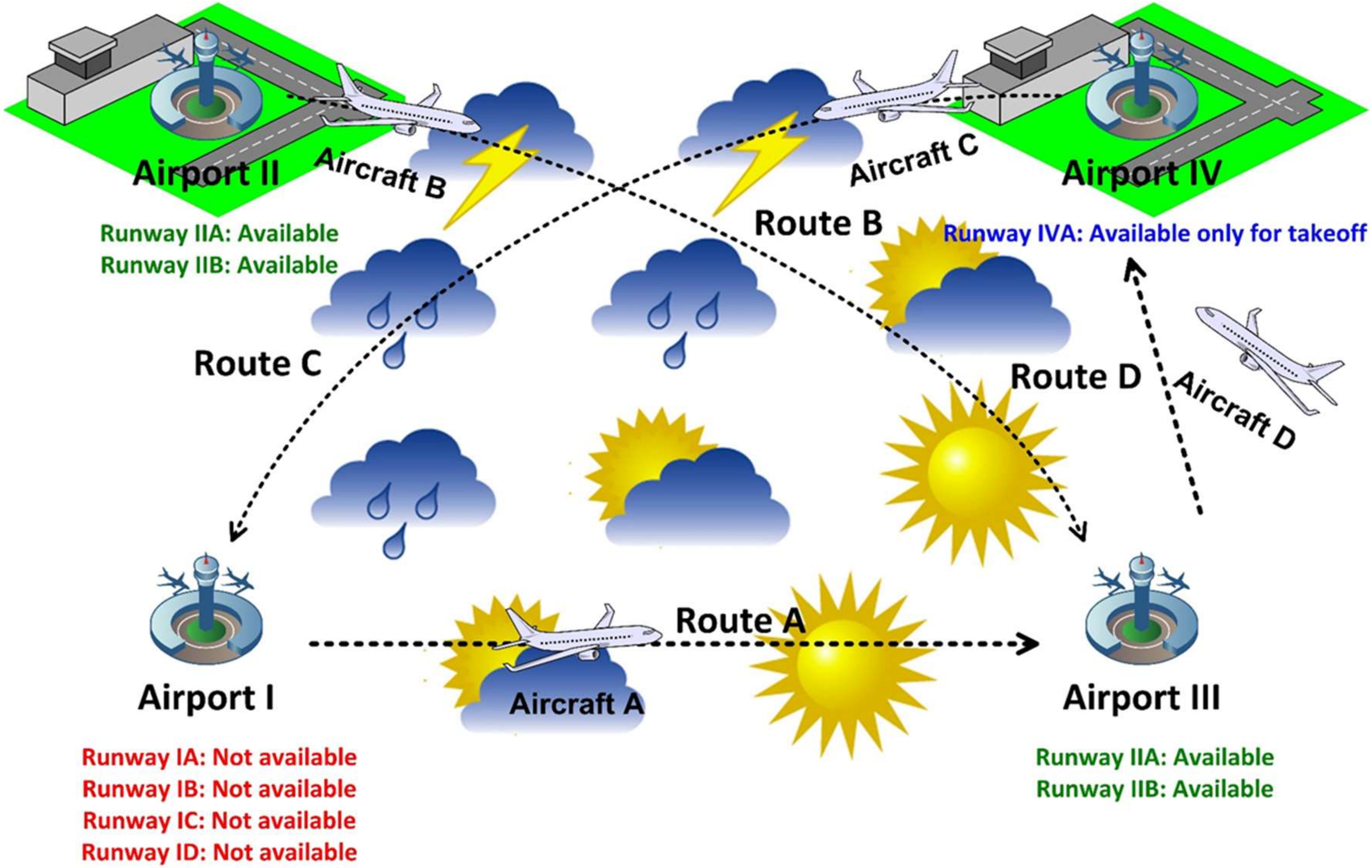
- The **AAO suggests** that all the aircraft should be separated to different distances.
  - A **Boeing 747** (due to its size and on-board pilots) **requires 10 km**.
  - **UAV1** & **UAV2** can have a distance of **3 km**.
  - **UAV2** should keep a distance of **7 km** but it could be approached up to **3 km** since it has a remote pilot.
  - The **Cessna 400** and **UAV 3** require **7 km** of minimum distance, even though the **UAV 3** is small, but it is autonomous.
  - The **UAV 4** is larger than the **UAV 3** (no pilot), but it has a contactable remote pilot to deal with its waypoints.



Proof of Concept Using the Protégé Tool

Weather Conditions

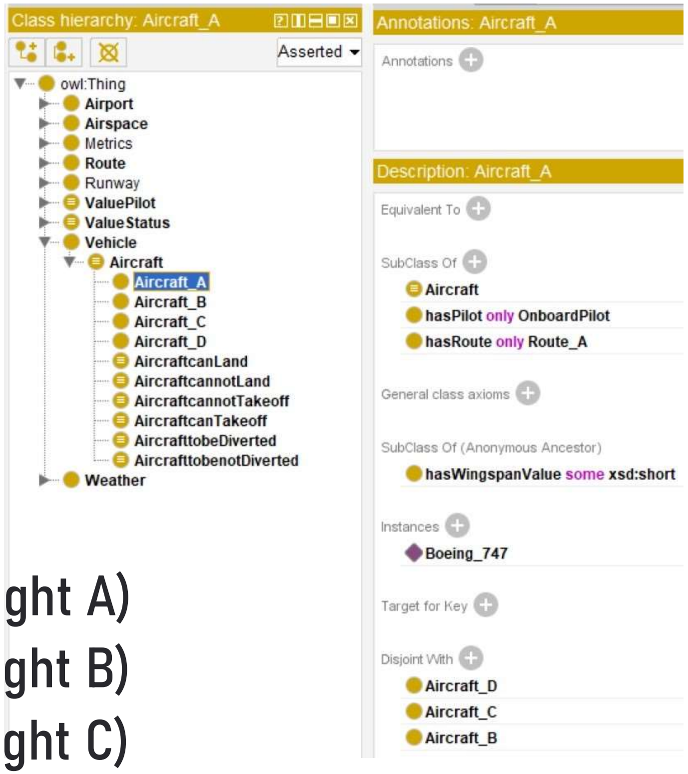
- **Flight A** takes off from Airport I and plans to land in Airport III.
- **Flight B** takes off from Airport II and plans to land in Airport III.
- **Flight C** takes off from Airport IV and plans to land in Airport I.
- **Flight D** takes off from Airport III and plans to land in Airport IV.
- **Weather conditions are very bad** in the airspace **en route** to **Airport I** & **Airport III** (Aircraft B & C) from Airport B & C.

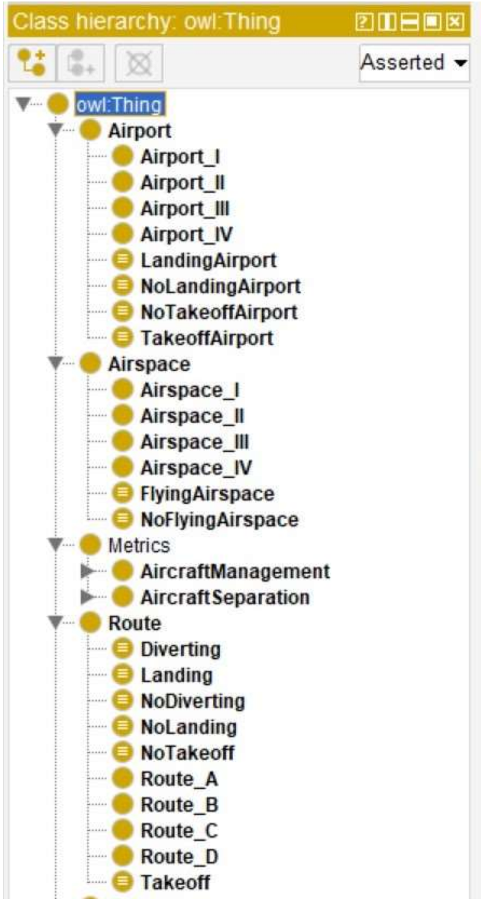


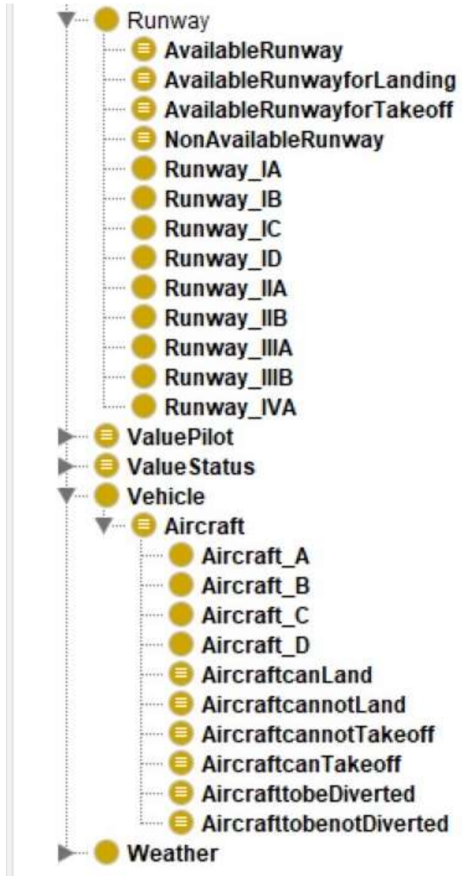
Weather Conditions

Protégé Class Tree of Asserted AAO Classes

- Airports
- Airspaces
- Routes
- Runways
- Aircraft
  - Aircraft_A (Flight A)
  - Aircraft_B (Flight B)
  - Aircraft_C (Flight C)
  - Aircraft_D (Flight D)



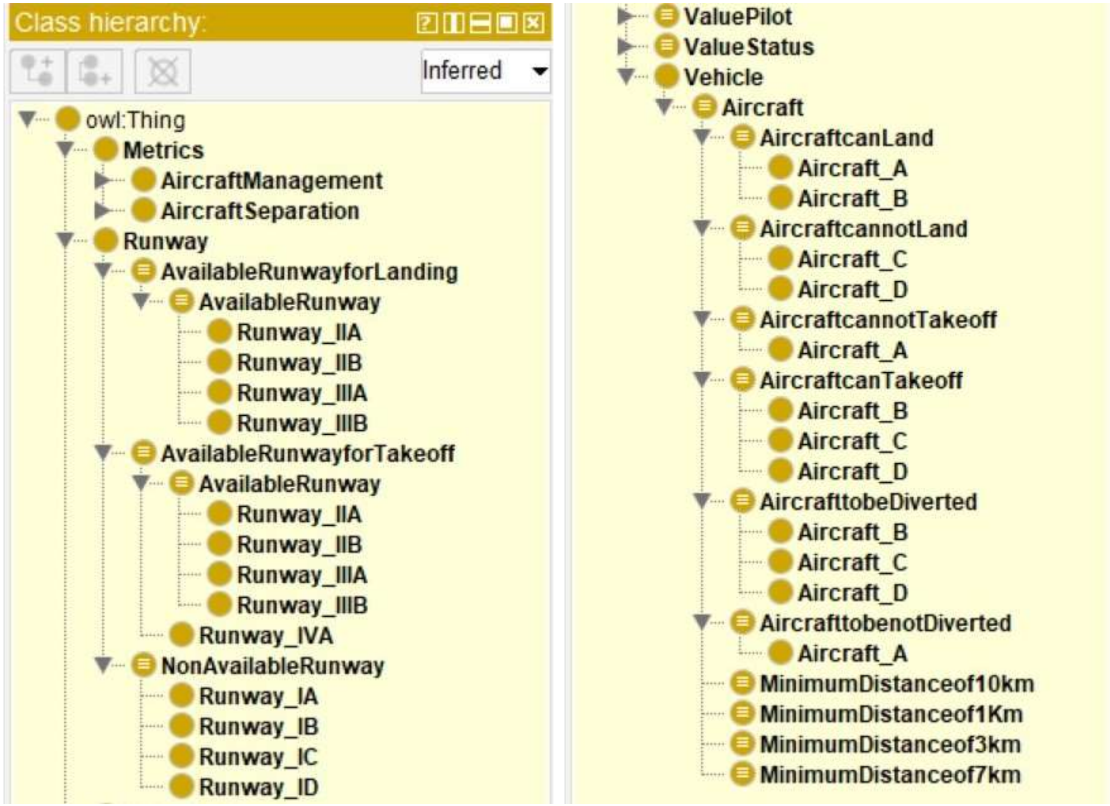




Weather Conditions

Protégé Class Tree of Inferred AAO Classes

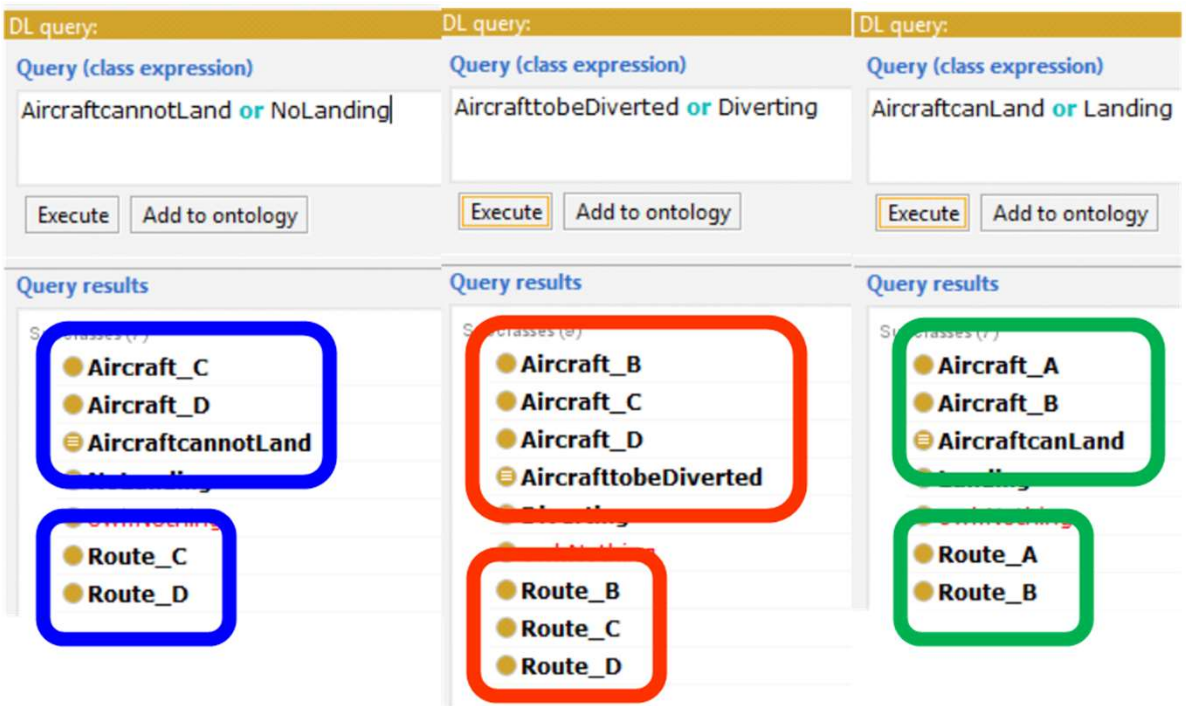
- Class **inference** comes from the **execution of the reasoner**.
- **Runways available** for take-off and landing
  - Runway IIA, IIB, IIIA, & IIIB
- **Runways** that are **not available** (take-off and landing)
  - Runway IA, IB, IC, ID
- Also, **inference for aircraft** as to flight operations, i.e., can land, can take off, flight diversion, etc.



Weather Conditions

AAO Queries Results for Flight Operations

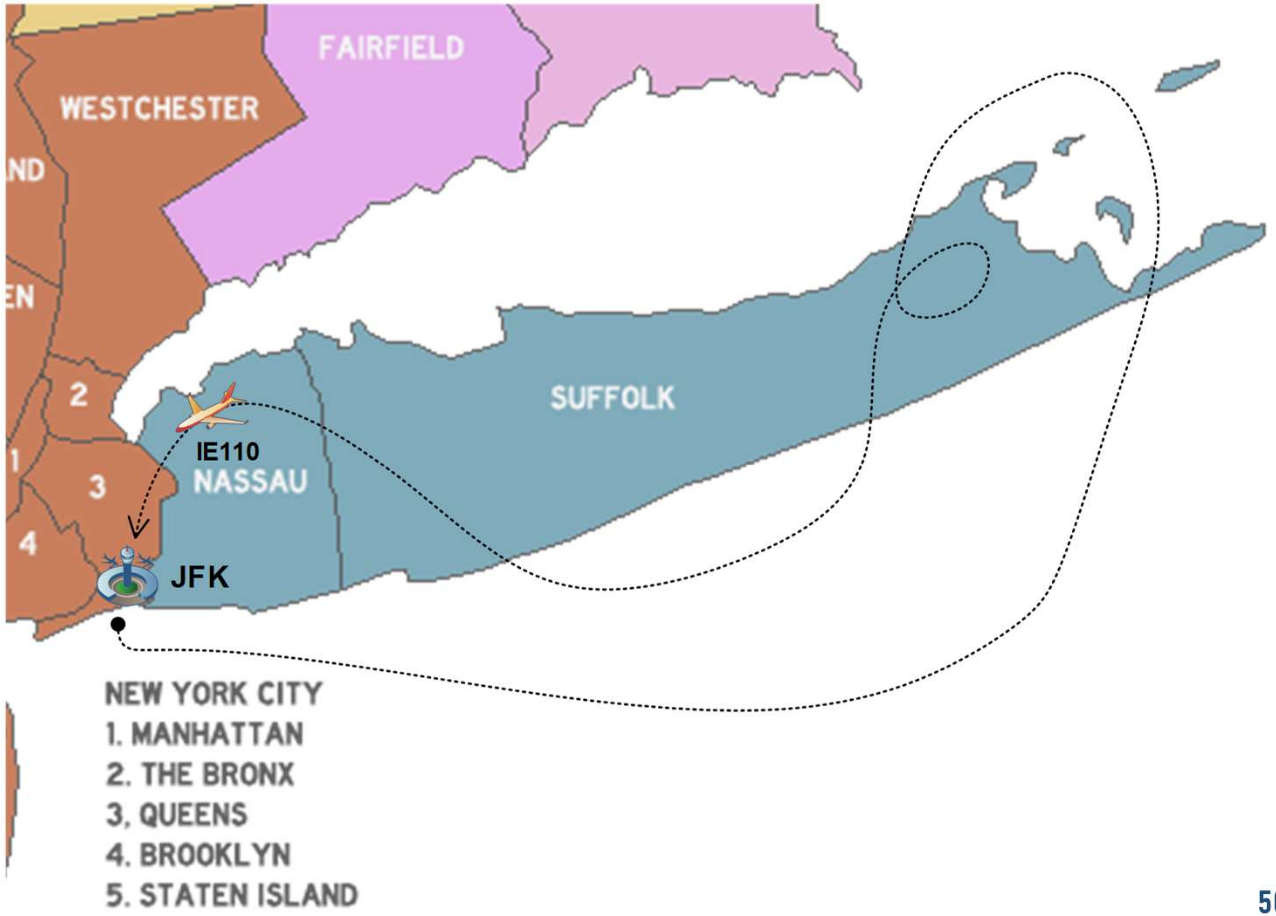
- **Aircraft C** and **D** (Flight C and D) will **not be able to land** as planned in route C and D
- **Aircraft B**, **C**, and **D** (Flight B, C, and D) should be **advised to change routes** as planned (Route B, C, and D)
- **Aircraft A** and **B** (Flight A and B) will be **able to land** as planned in route A and B)



Proof of Concept Using the Protégé Tool

Moral Autonomy

- **Real flight data** from Flight Radar 24 [11].
  - JFK airport to SNN
  - IE110 Flight (Boeing 757-200)
  - 28 Sep 2015
- Airplane emergency landing [9]
  - **Hydraulic system failure**
  - Airplane had climbed 16,000 feet



Moral Autonomy

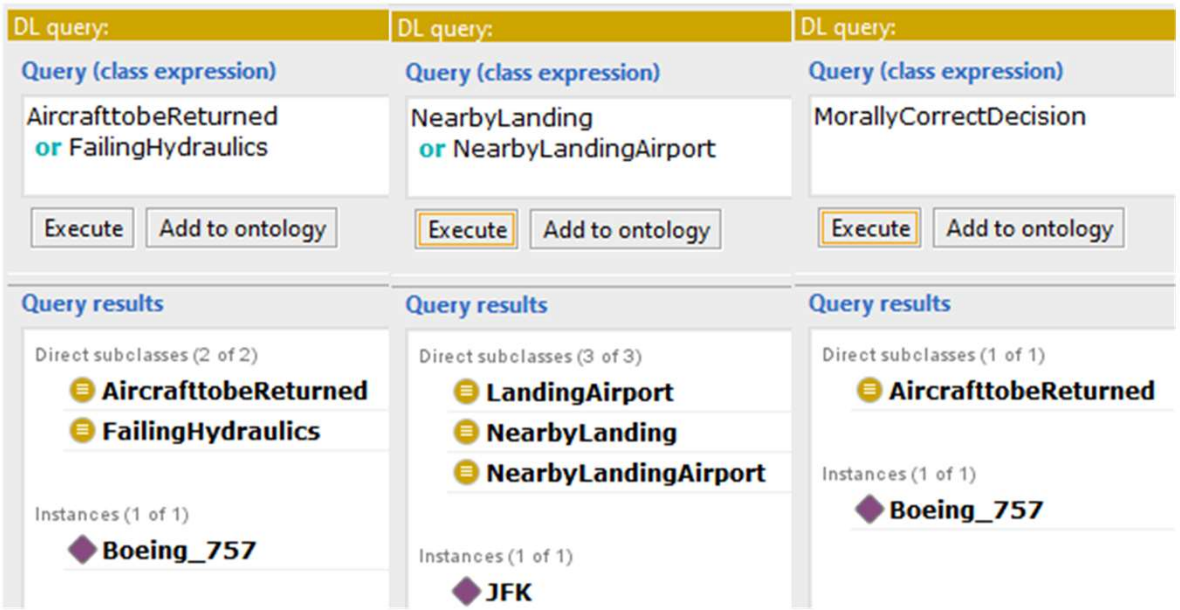
Examples of Semantic Statements

Semantic statement	AAO Axiom
Landing passenger aircraft with faulty hydraulic system is good and right.	AircrafttobeReturned **equivalent to** (Aircraft hasPeople **some** crew **or** passenger) **and** (Aircraft hasRoute **only** NearbyLanding) **and** (Aircraft hasSystem **only** FailingHydraulics) Route hasNearbyAirport **only** DepartureAirport Hydraulics hasFailure **some** catastrophic AircrafttobeReturned hasMorals **some** Good **and** hasEthics **some** Right MorallyCorrect **equivalent to** Morals **and** Ethics Morals **equivalent to** Good **or** Better **or** Best **or** Bad **or** Worse **or** Worst Ethics **equivalent to** Right **or** Wrong
Preservation of human life is morally correct	HumanLifePreservation hasMorals **only** Good **and** hasEthics **only** Right
Defueling passenger aircraft with faulty hydraulic system is the better and righter (more correct) to do over an area without population.	Defueling **equivalent to** (Aircraft hasPeople **some** crew **or** passenger) **and** (Aircraft hasLandcape **only** nopopulation) **and** (Aircraft hasSystem **only** FailingHydraulics)
Unauthorized airspace incursions by AUV(s), e.g., wingspan less than 2 m and less than 500 m separation to aircraft, are not right nor good.	RiskofCollison **equivalent to** (NonManagedAircraft **and** (hasSeparation **some** xsd:short[<= "500"^^xsd:short]) **and** (hasWingspanValue **some** xsd:short[<= "2"^^xsd:short])) UnauthorizedAirspaceIncurssions **subclass of** hasMorals **some** Bad hasEthics **only** Wrong

Moral Autonomy

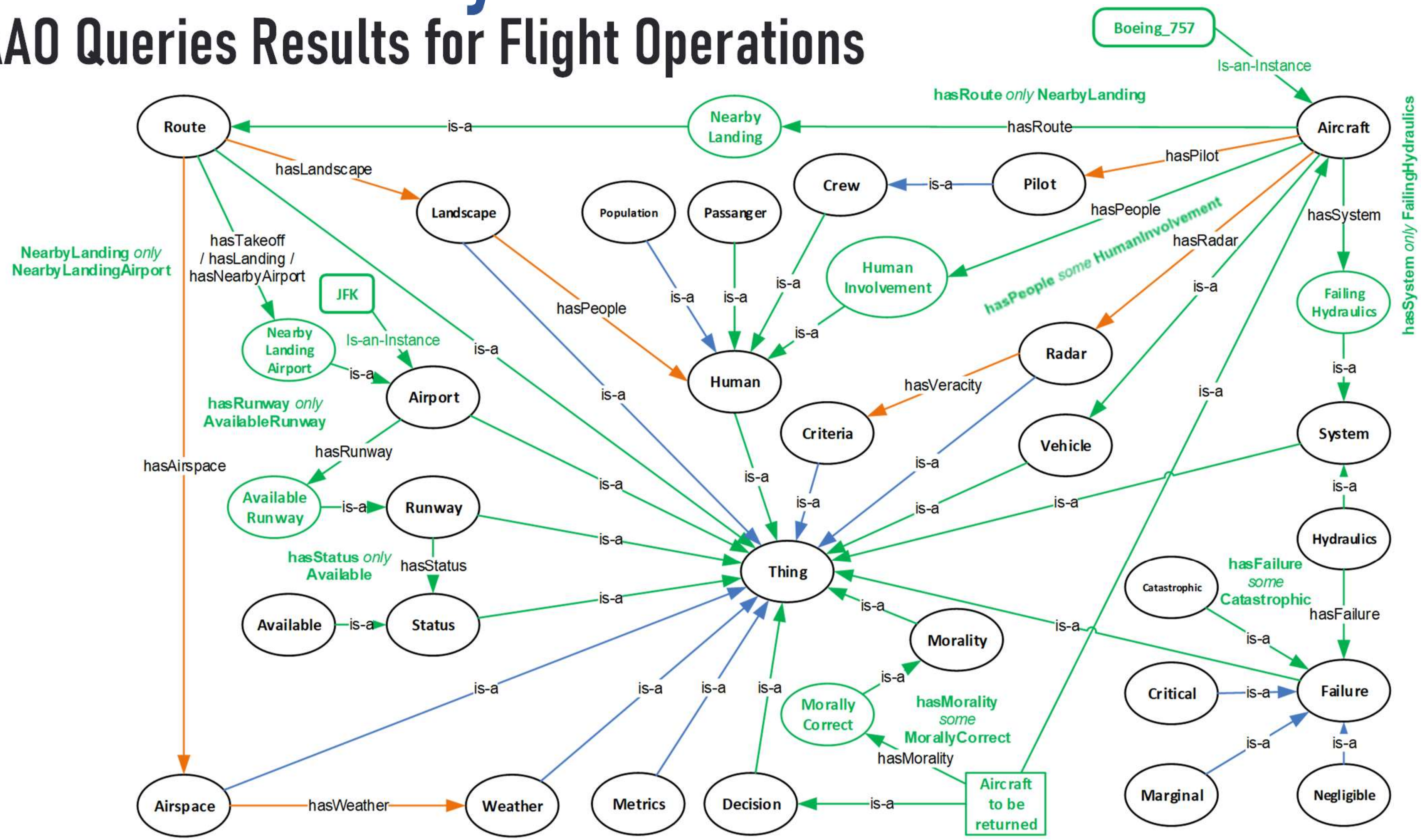
AAO Queries Results for Flight Operations

- the aircraft in **trouble** due to **failure in hydraulics** is a **Boeing 757** (Flight IE110)
- the **closet airport for landing** (in emergency) is actually the one from which the aircraft departed (**JFK**)
- the **decision** to make Flight IE110 return to JFK is **correct** from a **moral viewpoint**



Moral Autonomy

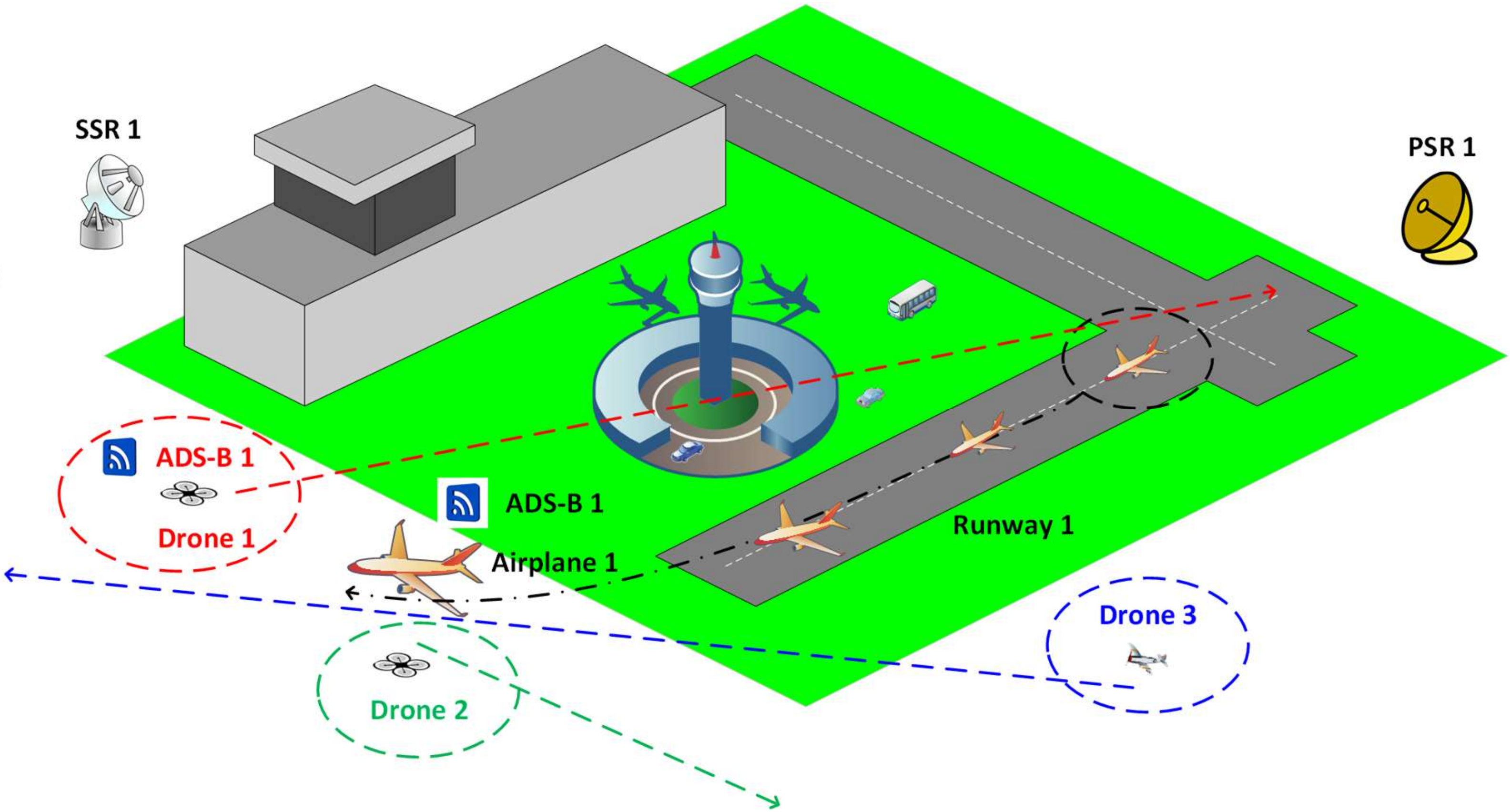
AAO Queries Results for Flight Operations



Analytical Calculation of Uncertainty

Airplane Take-off

- **Airplane 1** is a Boeing 787
- **Drone 1** is an airport's inspection UAV (no pilot)
- **Drone 2** is a recreational quadcopter (contactable remote pilot)
- **Drone 3** is an unmanned airplane (no remote pilot).



Airplane Take-off

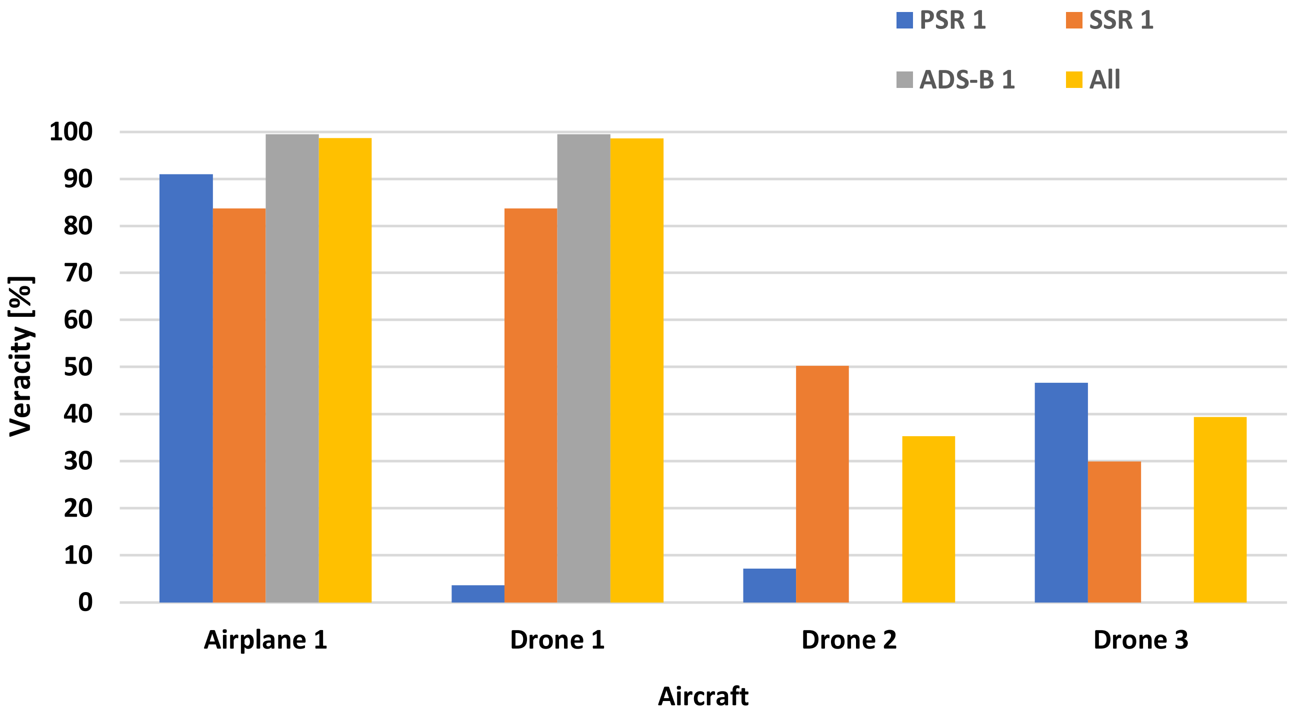
Take-off Scenario Details

		Surveillance Systems			Pilot	Wingspan / wheelbase [m]
		PSR 1	SSR 1	ADS-B 1		
Accuracy		Low	Medium	High	N/A	N/A
Sensitivity		Medium	high	Very high	N/A	N/A
Distance	Airplane 1	Very close	Close	Very close	Contactable onboard	60
	Drone 1	Very far	Close	Very close	Non-contactable remote	1.9
	Drone 2	Far	Near	Not equipped	Contactable remote	1.6
	Drone 3	Near	Far	Not equipped	Non-contactable remote	1.1

Airplane Take-off

Veracity (%) for Aircraft Localization in the Application Scenario

	Aircraft			
	Airplane 1	Drone 1	Drone 2	Drone 3
PSR 1	91.0	3.6	7.2	46.6
SSR 1	83.7	83.7	50.3	29.9
ADS-B 1	99.5	99.5	N/A	N/A
All	**98.62**	**98.55**	**35.27**	**39.38**



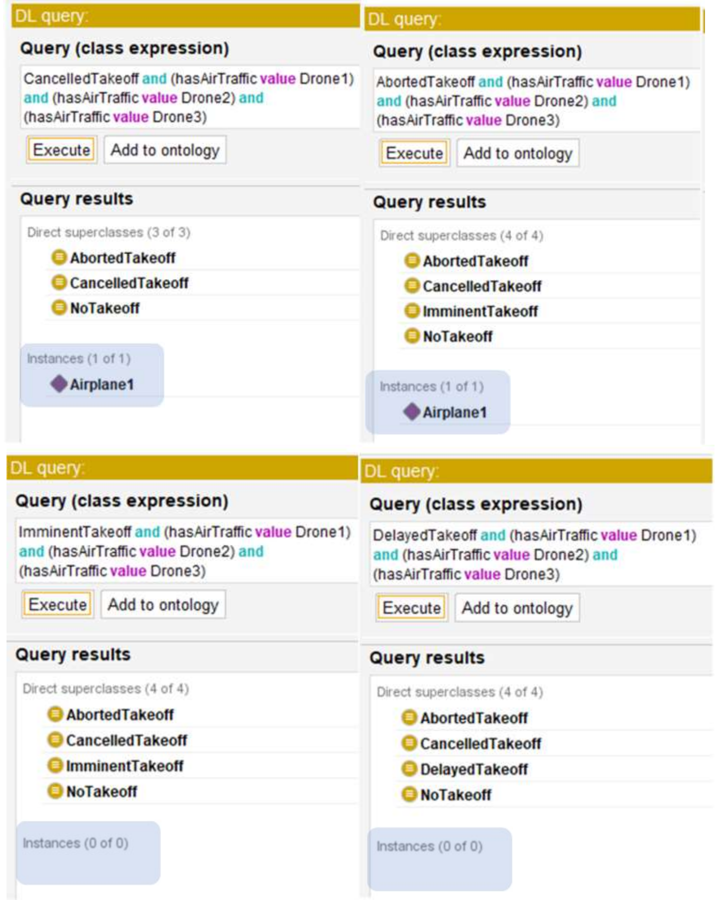
Combined veracity for all sensors (PSR1, SSR1, and ADS-B):

$$V_c = 1 - \prod_{s=1}^{n} (1 - V_s)$$

Airplane Take-off

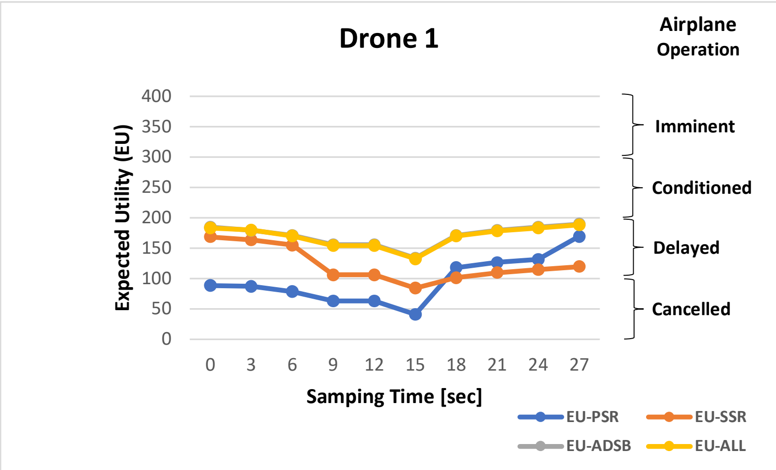
Queries for Decision Making

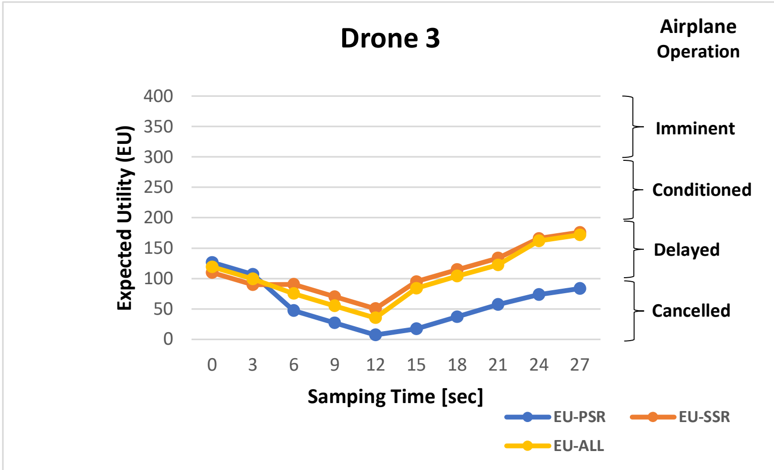
Query/Class		Intruder	Main Class Equivalence	Secondary Class Equivalence
Airplane does not take off	Cancelled take-off	Yes	CancelledTakeoffEquivalentTohasAirTrafficsomeIUsUcAirspace	IUsUcAirspaceEquivalentTo Intruder andImproperSeparationand (isAirTrafficOfsome Aircraft) and (hasCountermeasurevalueNoCountermeasure)
	Aborted take-off		Same axiom than the one for cancelled take off. (initially, no intruder or intruder with separation then intruder without separation)	
Airplane takes off	Imminent take off	Yes	ImminentTakeoffEquivalentTohasAirTrafficsomeISUcAirspaceorISCAirspace	IUsUcAirspaceEquivalentTo Intruder andProperSeparationand (isAirTrafficOfsome Aircraft) and (hasCountermeasurevalueNoCountermeasure)
				ISCAirspaceEquivalentTo Intruder andProperSeparationand (isAirTrafficOfsome Aircraft) and (hasCountermeasurevaluePilotContact)
		No	ImminentTakeoffEquivalentTohasAirTrafficsomeUnISUcAirspaceorUnISCAirspace	UnIUSUcAirspaceEquivalentTo (not Intruder) andProperSeparationand (isAirTrafficOfsome Aircraft) and (hasCountermeasurevalueNoCountermeasure)
				UnISCAirspaceEquivalentTo (not Intruder) andProperSeparationand (isAirTrafficOfsome Aircraft) and (hasCountermeasurevaluePilotContact)
	Delayed take-off	Yes*	ImminentTakeoffEquivalentTohasAirTrafficsomeIUsCAirspace	IUsCAirspaceEquivalentTo Intruder andProperSeparationand (isAirTrafficOfsome Aircraft) and (hasCountermeasurevaluePilotContact)

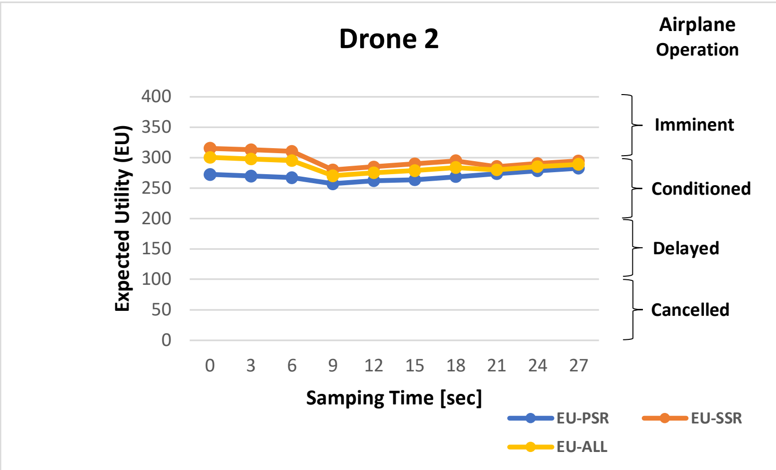


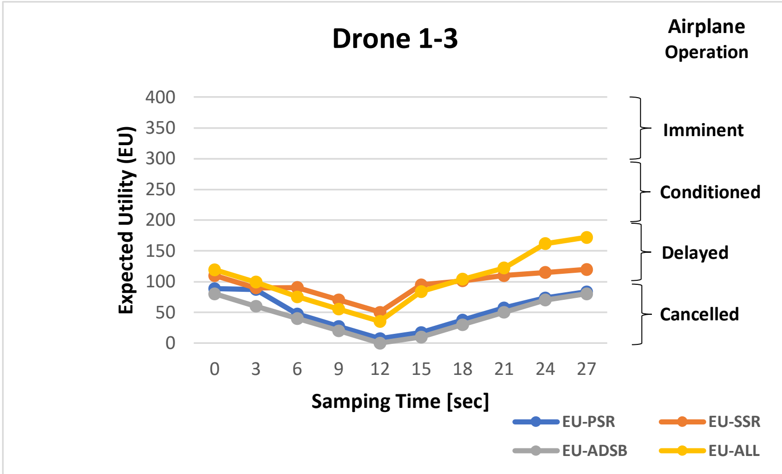
Airplane Take-off

Expected Utilities for the Take-off Decision of Airplane 1



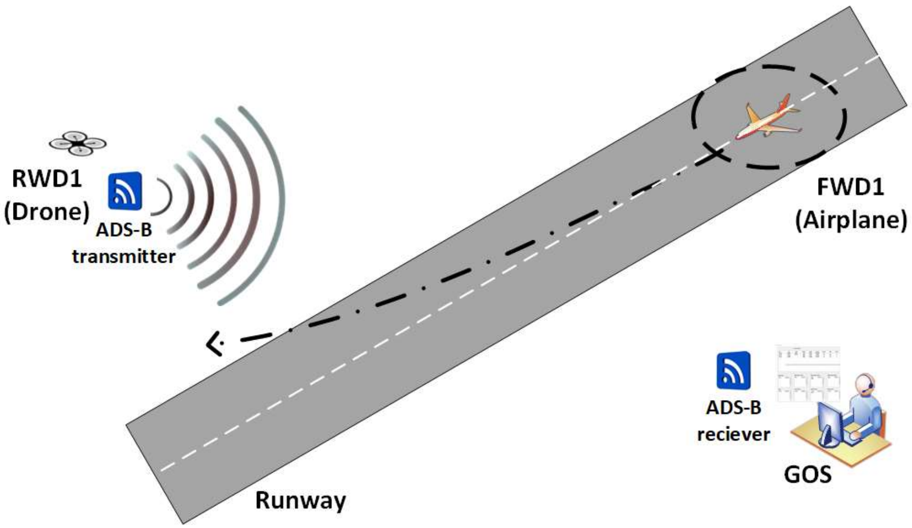


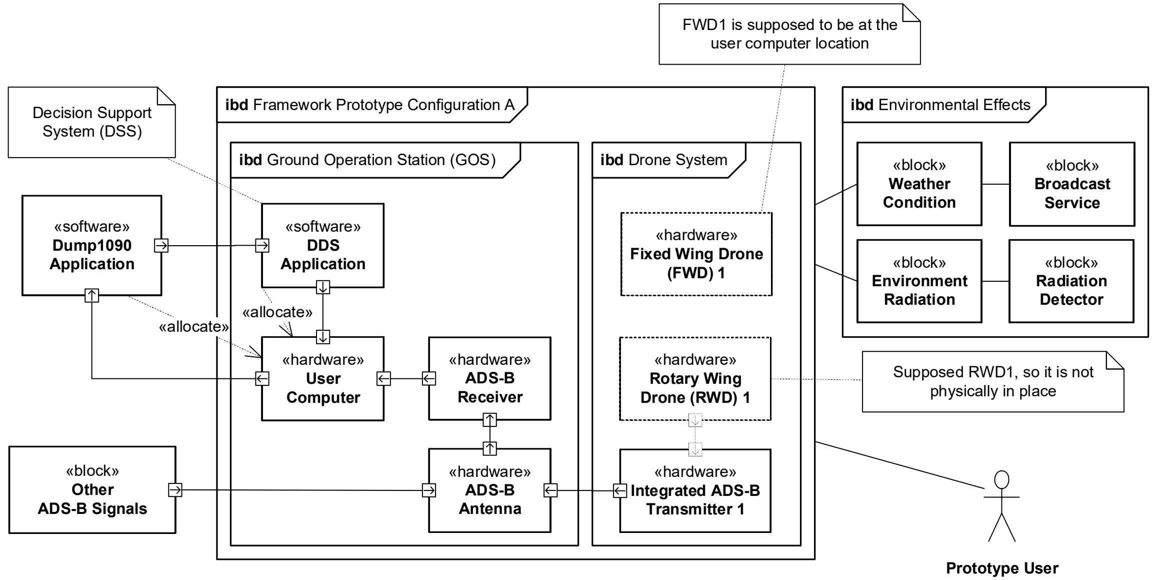




Preliminary Trials with Physical Prototype

Airplane Take-off (Taxied for Take-off Roll)





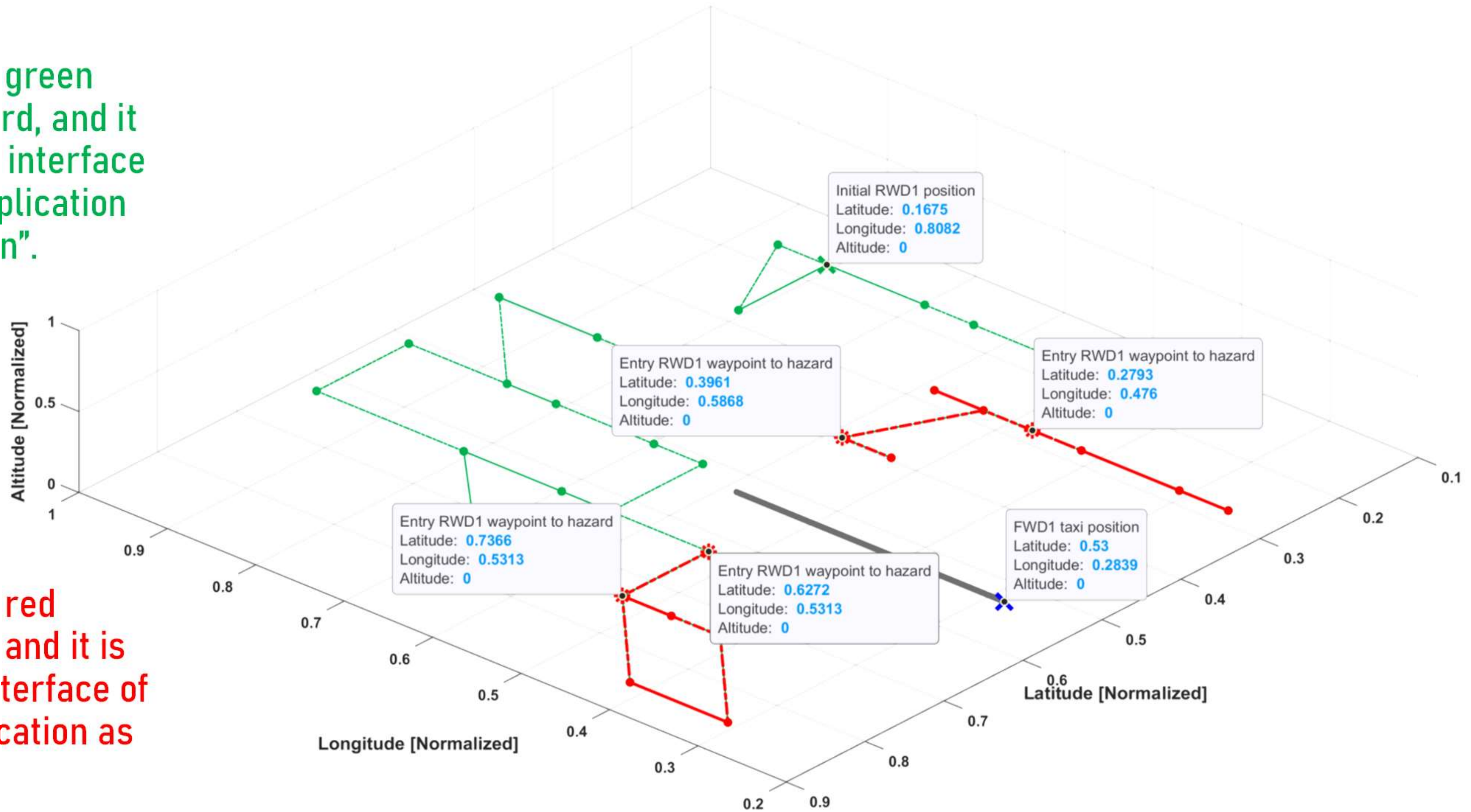
Airplane Take-off (Taxied for Take-off Roll)

Readings from ADS-B Devices

- The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as "Flight Safety Caution".

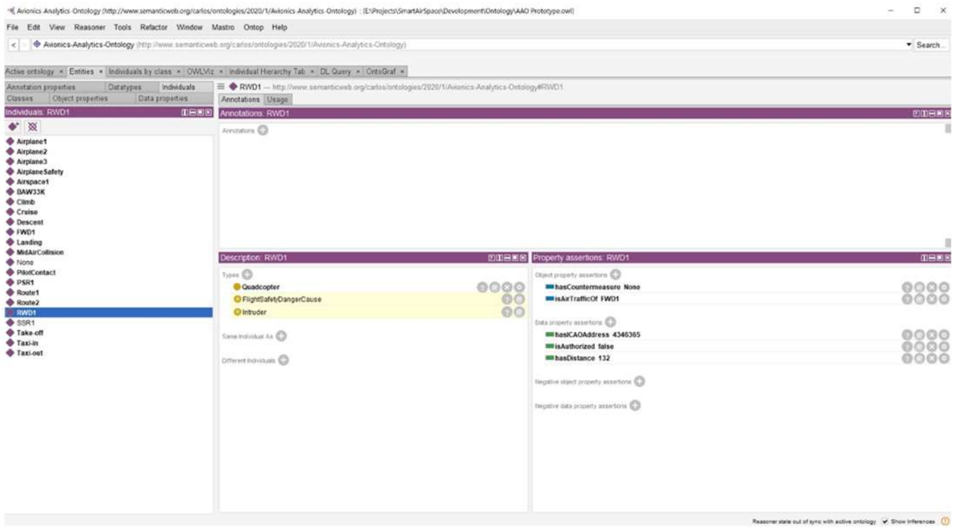
- FWD1 is taxied ready for take-off roll (blue cross).

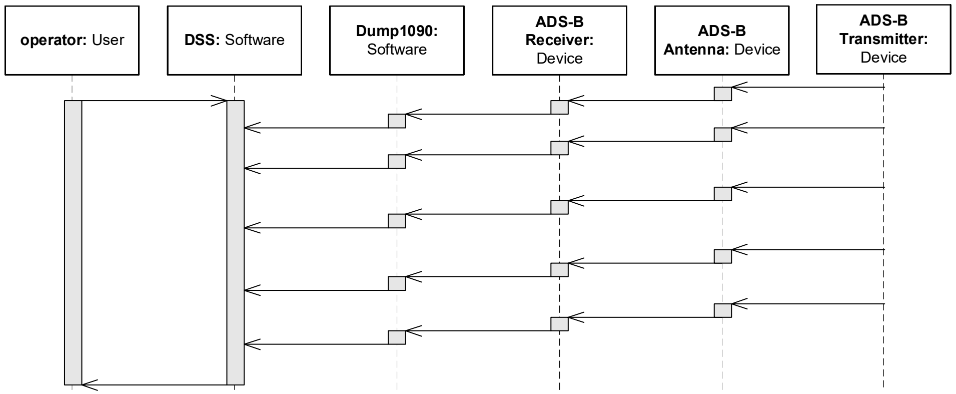
- The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as "Flight Safety Danger".

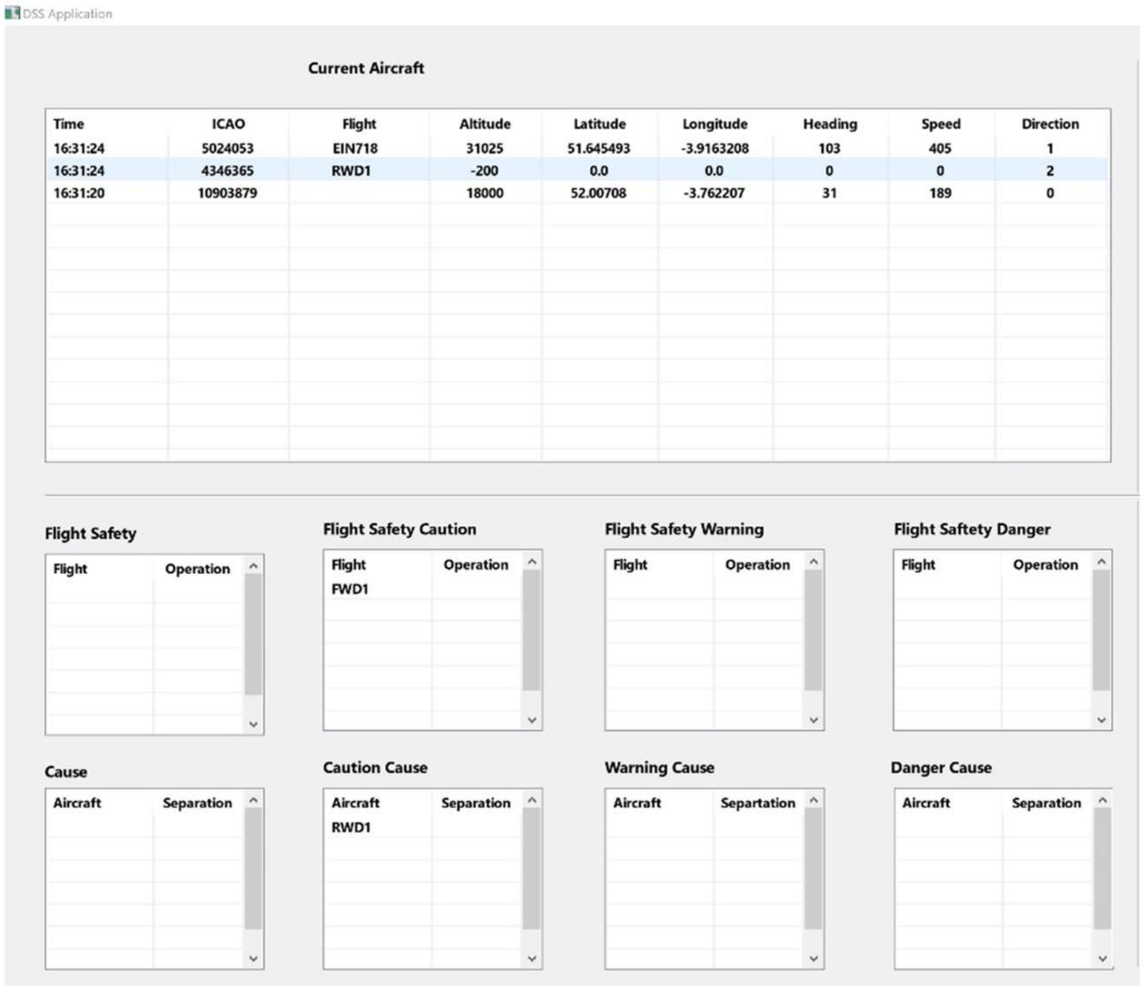


Airplane Take-off (Taxied for Take-off Roll)

DSS Software Application







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Ontological Decision-Making Support for Air Traffic Management

Conclusions

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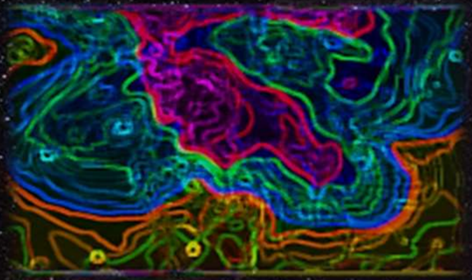
Conclusions

- Lecture remarks
  - **ATM** is become **complex** more and more
  - Some **ontology**-based initiatives exist for **aviation**, but not to support **ATM**
  - Ontologies are an **attractive** approach to support ATM **decision making**
  - **Ontologies** can be formalized by means of **Description Logic** (DL)
  - Simple but useful **examples** show the potential of ontologies
  - The **proof of concepts** range from **computer tool** to **physical prototypes**
- Next related lecture topics
  - Results from **downscaled-scenario** trials using a physical prototype
  - Discussion on **advantages** and **disadvantages** when **using ontologies** in **ATM**



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Questions and Answers

Avionics Systems Panel

If you wish to discuss possible collaborations with the AESS Avionics Systems Panel (ASP) please send an email to: roberto.sabatini@ieee.org

You can find additional information about the ASP at: https://ieee-aess.org/tech-ops/avionics-systems-panel-asp

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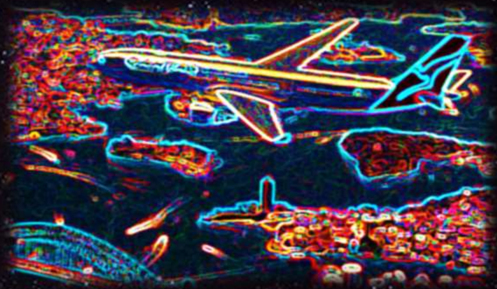

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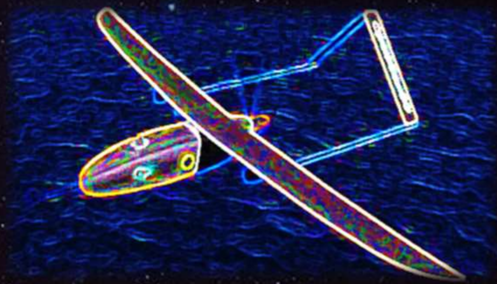

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