Knowledge Representation and Reasoning for Unmanned Aerial Vehicle Intelligence

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Outline

- Intelligent UAV Systems: technologies and limitations
- Semantic Web Technologies for UAVs
  - Non-standard inference services
- Case studies
  - Context-aware UAV Systems
  - On-board Intelligent Hazard Detection
- Conclusion and future work

UAV Systems

Unmanned Aerial Vehicles (UAV), a.k.a. “drones”

- Ground Control Station (GCS) for remote control of flight and operational parameters, mission planning and sensors monitoring and management
- Autopilot: on-board electronic subsystem autonomously driving the UAV according to received commands from GCS

Traditional applications

- Surveillance
- Search and rescue
- Precision farming

New applications in logistics and smart cities

- Increasing miniaturization and integration of micro-controllers, programmable processing units and sensors
- UAV – Internet of Things – Cloud convergence

Intelligent UAV Systems

Data analysis and decision traditionally implemented in GCS	Embedding Artificial Intelligence (AI) into UAV systems
• Continuous communication between GCS and the UAV → high energy consumption • Communication latency unsuitable for real-time applications	• Enhance perceptive capabilities with autonomous decision-making • UAV swarms as context-aware self-coordinating teams

AI and Machine Learning (ML) algorithms available locally to UAVs

- ↑ Key enabler for real-time use cases
- ↓ ML models often require power-hungry additional hardware
- ↑ UAV systems as trustworthy autonomous agents
- ↓ High-accuracy ML models have limited explainability

Semantic Web Technologies for UAVs

Semantic Web of Everything vision

- Annotate data, objects, phenomenons and events with metadata to make their semantics machine understandable
- Adoption of standard Semantic Web languages for broad interoperability
- Reasoning tasks on pervasive & embedded devices to infer additional knowledge
- Non-standard inference services for on-the-fly query processing
- Logic-based explainability of results
- Tight computational resource and energy constraints

Tiny-ME embedded reasoning engine
[Ruta *et al.*, JWS, 73, 2022]

Web Ontology Language (OWL)

- Modelling complex and structured knowledge
- OWL Knowledge Base (KB) composed by:
  - Terminological Box (TBox, *a.k.a.* ontology): classes and relationships in the knowledge domain
  - Assertion Box (ABox): assertions concerning individuals of a particular problem within the domain

UAV Context Awareness

UAV systems can be made **situation-aware** and **self-adapting**, monitoring

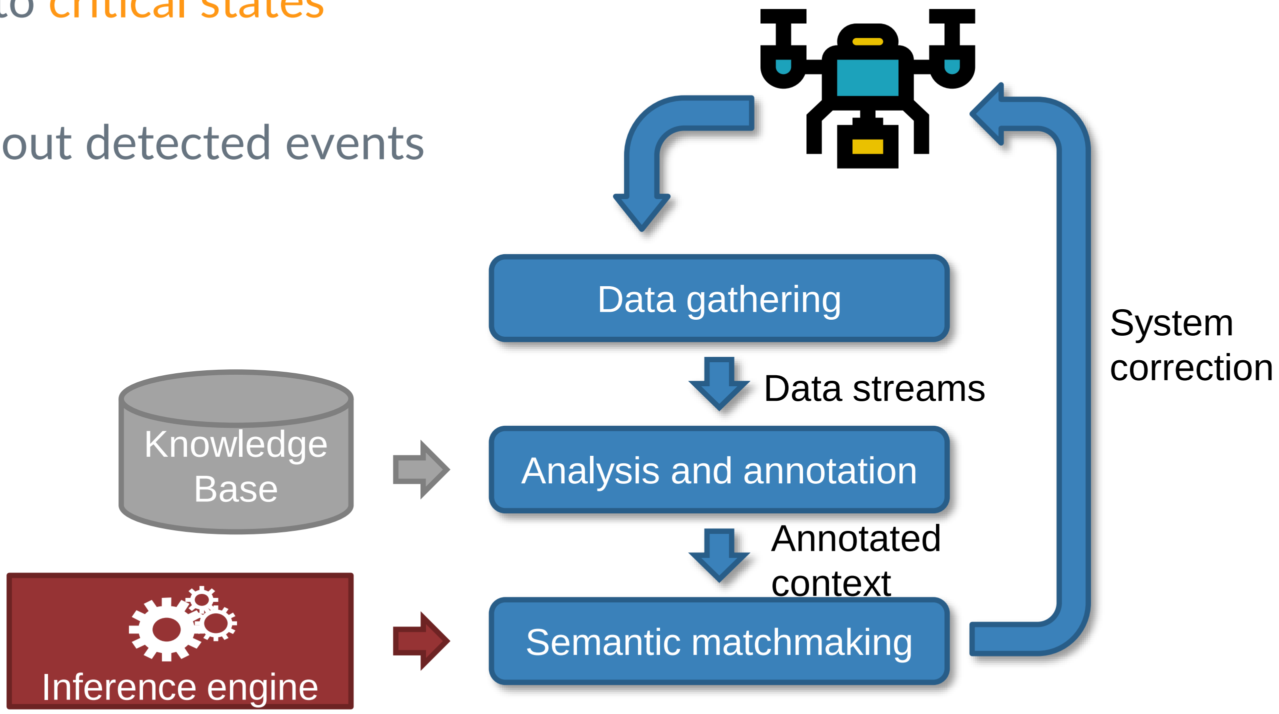
- Their internal state (kinematics, processing resource usage, previous results, …)
- Sensory and environment contextual features (wind speed/direction, lighting, camera settings, …)

On-board reasoning enables **real-time autonomous context management**

- Determine the proximity of the current situation to critical states
- Dynamically adapt to avoid the critical state
- Improve operational efficiency and confidence about detected events

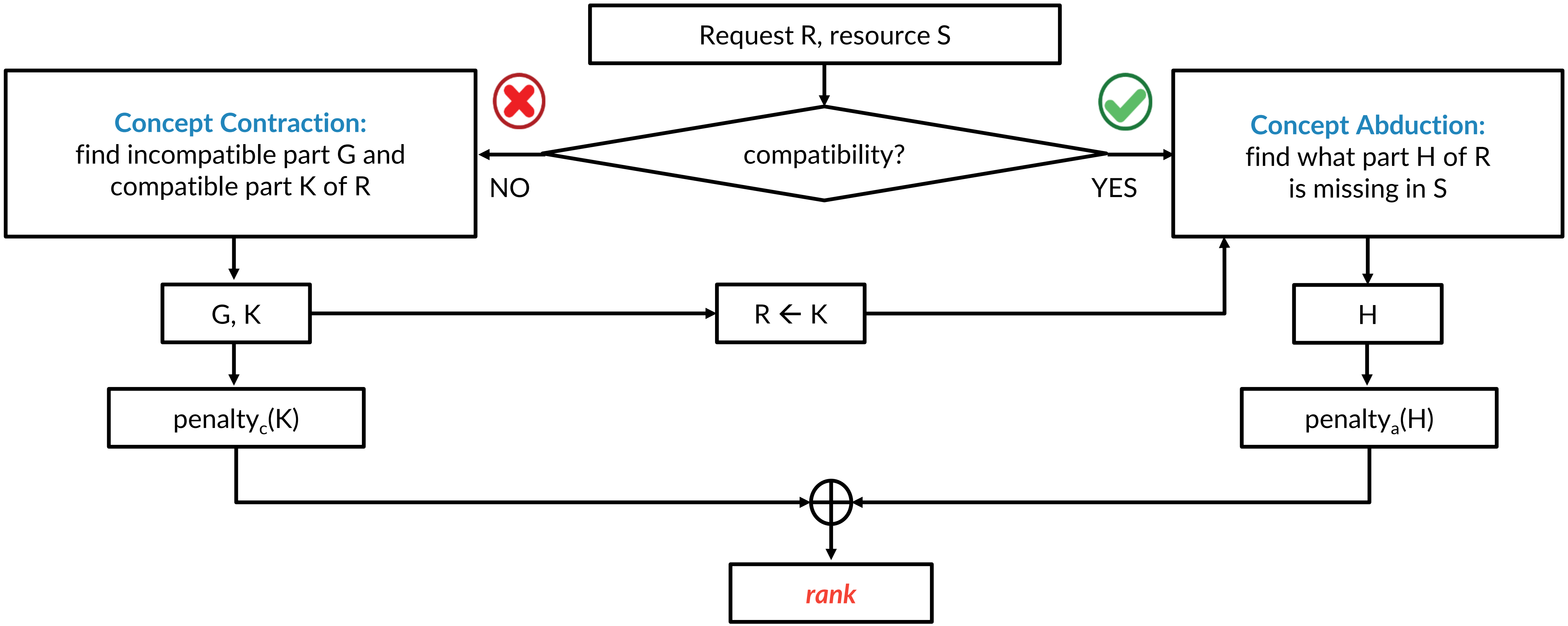
Information modeling

- General description of internal and external features in terms of an ontology model
- Set of pre-defined individuals describing critical scenarios
- Annotation of the current state as a new individual



Semantic Matchmaking

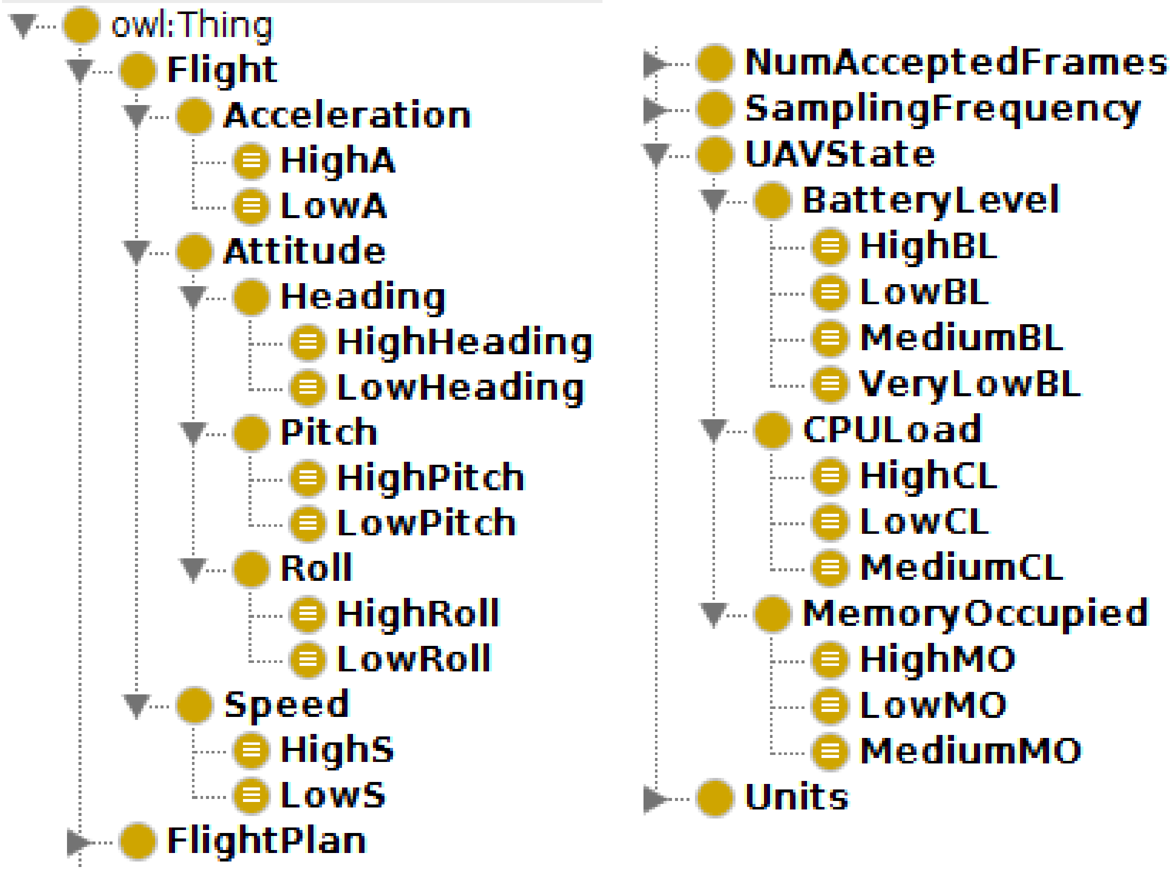
Semantic Matchmaking exploits *Concept Contraction* and *Concept Abduction* non-standard inference services



UAV Context Awareness: case study

Ontology for UAV crowd detection with nadiral camera and frame-based image analysis

Classes describe the levels of the parameters managed by the UAV



Current and critical scenarios described with semantic expressions based on the ontology classes

```
Current: (HighRoll) and (LowPitch) and (LowA)
         and (LowS) and (LowHeading) and
         (MediumBL) and (HighCL) and (HighMO)
```

The current scenario is compared with every critical scenario in the Knowledge Base, *e.g.*:

```
Crit1: (Roll) and (Pitch) and (Heading) and
       (Acceleration) and (BatteryLevel) and
       (Speed) and (HighCL) and (HighMO)
```

Semantic Matchmaking detects a critical match threshold due to *high CPU load* and *high occupied memory* contextual features

Processing of the next frame is **skipped**

On-board Hazard Detection

Real-time identification of environmental risk levels and handling

Information modeling

- UAV on-board sensors and actuators
- Detectable substances and their dangerous levels
- Critical atmosphere conditions for the considered substances

Periodic task

- Collect values from on-board sensors and annotate them
- Exploit the Tiny-ME reasoning engine to build a class expression for the current scenario
- Semantic matchmaking between the newly created individual and risk conditions in the KB

Reference platform

- 3DR Iris Plus UAV
- Pixhawk 1 embedded flight controller
  32-bit STM32F427 Cortex® M4 core, 168 MHz/256 KB RAM/2 MB Flash
- Apache NuttX OS

On-board Hazard Detection

Detection of flammable and explosive substances according to *Directive 2014/34/UE*

The current atmospheric condition is expressed through a semantic expression

```
MediumConcentration_Methane and
HighOxygenConcentration_Methane and
LowVentilation_Methane
```

It is compared with every individual describing critical atmospheric conditions

```
Explosive_Methane ≡
HighConcentration_Methane and
HighOxygenConcentration_Methane and
LowVentilation_Methane
```

```
Flammable_Methane ≡
MediumConcentration_Methane and
HighOxygenConcentration_Methane and
LowVentilation_Methane
```

Semantic Matchmaking detects *Flammable_Methane* as the nearest individual

- A flammable atmospheric condition is detected
- An **alert** related to the methane substance is raised

Conclusion & future work

- Integration of Knowledge Representation and Reasoning in Unmanned Aerial Vehicles
  - Miniaturization of electronic components allows advanced autonomous applications in UAV systems
  - Semantic Web of Everything approaches and tools can grant better efficiency and explainability w.r.t. conventional Machine Learning techniques
  - Case studies concerning context-awareness and advanced hazard detection

- Future work
  - Systematic performance evaluation on relevant UAV platforms
  - Expanding the scale and scope of applications
  - Knowledge-based information fusion within UAV swarms and with vehicular networks and urban infrastructures

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SCAN ME