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HUMAN-MACHINE SHARED SITUATIONAL AWARENESS

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ABSTRACT

As unmanned platforms are more and more present in battlefield, alongside humans, in different configurations (from tele-operated to fully autonomous platforms, manned-unmanned teaming, swarming, etc.) and domains (space, air, land, sea, and underwater), it is also necessary for decision-making process to adapt to this new reality. This process will no longer be exclusively human and this requires that humans and machines share a common, meaningful, and timely understanding of the context in which they act and interact, namely a common situational awareness. We will investigate how this objective could be achieved by means of AI-related techniques of inference and reasoning based on ontologies that will enable all levels of information sharing (data, knowledge, and models) among all participants, humans and non-humans. The success of this undertaking shall be reflected by the achievement of a high level of interoperability between heterogeneous entities, within which they will be able to take advantage of each other's best developed abilities.

KEYWORDS: Artificial Intelligence (AI), Common Operational Picture (COP), human-machine, ontology, Situational Awareness (SA)

1. Introduction

The known challenges of high contested or denied combat environments (discontinued communications, sensors jamming, degraded performance as result of different events, etc.) are completed in the case of unmanned systems with an additional challenge: the need to make their own decisions in a manner as close as possible to that of humans. This will be possible only if humans and machines will be able to share a common, meaningful, and timely understanding of the context in which they act and interact, namely a common Situational Awareness (SA).

This paper will investigate how this objective can be achieved by means of AI-related techniques of inference and reasoning based on ontologies. These techniques will be used to improve the current Common Operational Picture (COP) and Situational Awareness (SA) processes by enabling the seamless and meaningful information sharing at all levels (data, knowledge and models) among all participants (machine and humans) in an optimal and realistic way.

In this new perspective, COP will no longer be an image but a unique and authoritative repository of the real-time data, knowledge and models of the operational environment (OE). The ontologies will assure the semantic interoperability achievement between all involved participants, enabling the seamless information exchange among them (COP as a "middleware") and AI-driven generation of the environment elements to populate the perceptual level of

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SA model (Endsley, 1995). This perception will no longer be a passive process, different elements being pulled from the COP, depending on the aspects to which the participant directs his attention.

Furthermore, based on the presented approach, machines are enabled to change their behaviour and even to achieve by themselves higher SA levels (comprehensive and projective) by changing the underlying ontology rather than changing and adapting the software.

2. Common Operational Picture and Situation Awareness Concepts

2.1. Common Operational Picture

The Common Operational Picture (COP) concept appeared in the military environment to support the Joint Operations. Usually, each Service generates and distributes its own picture, the so-called recognized picture, to subordinate structures. Recognized Air Picture (RAP), Recognized Air and Surface Picture (RASP), Recognized Ground Picture (RGP), and Recognized Maritime Picture (RMP) are Service-specific recognized pictures used to plan and carry out their own operations but they are also basis of the COP. From the NATO perspective "Common Operational Picture (COP) capability can be defined as the ability to display on a single screen integrated views of the Recognized Maritime, Air and Ground Pictures, enriched by other tactical data, such as theatre plans, assets, intelligence and logistics information. The purpose of the COP capability is to provide military forces a comprehensive view of the battle space, thereby enhancing situational awareness and the decision-making process across the military command and control spectrum" (Fanti & Beach, 2002). This states that the situational awareness is already achieved and COP just contributes to SA enhancement by sharing information across services and functional areas.

A slightly different perspective, in which COP directly contributes to the SA achievement, is reflected by the following definition: "A single identical display of relevant information shared by more than one command. A common operational picture facilitates collaborative planning and assists all echelons to achieve situational awareness. Also called COP" (DOD Joint Chiefs of Staff (JCS), 2022).

Based on the above considerations but also on other analysis (Steen-Tveit & Munkvold, 2021), we can state that COP represents a means to share information between the participants in a joint operation, but it can also represent the basis for the development of a common Situational Awareness (SA), provided that it meets certain requirements.

2.2. Common Operational Picture Shortcomings and Corresponding Mitigation Solutions

From the perspective of battlefield realities, a single image (COP) can represent a single point of failure in the decision-making process, part of the reasons being identified in Table no. 1. Rather than relying on an image that creates the false feeling that the displayed situation is the real one, military have to think the operational environment in terms of 'situation estimation', focusing on "conditions, circumstances, and influences that affect decisions about the employment of forces and capabilities".

Participants have to work on an operational picture corresponding to the Level of War (LoW) where they are involved. The information needed by these forces must relate to their specific problem set. They have to identify and refine sources for operationally relevant information (Grattan, 2021):

- Tactical level, METT-TC stands for Mission, Enemy, Terrain and weather, Troops and capabilities, Time, and Civil considerations.

– Operational level, PMESII-PeT is used to account for Political, Military, Economic, Social, Information, Infrastructure, Physical environment, and Time factors.
– Strategic level, DIME-FiL analyzes Diplomatic, Information, Military, Economic, Financial, and Law Enforcement considerations as elements of national power.

Table no. 1

Current COP shortcomings and corresponding mitigation solutions

Shortcoming	*Reason*	*Potential mitigation solution*
Groupthink (Grattan, 2021)	The same information is used to deal with different military problems	The information needs to address each participant problem, set at the corresponding Level of War
Target Fixation (Grattan, 2021)	Information is received only from a defined set of sources	Increase the type of information related to a particular situation
Diminished ability of the user to perceive the relevant elements (Luokkala, 2016)	Information overload	Context-Aware Common Operational Picture (CACOP) based on ontologies (Luokkala, 2016)
Simultaneously wrong decisions at several levels (Grattan, 2021)	Actively manipulated information by the enemy	Use of as many information sources as possible, of different types. Identify the deception patterns
Difficulty to identify adequate Courses of Action in the support of decision-making process (Grattan, 2021)	Insufficient information diversity	Use of as many sources as possible, of different types. Intensive use of historical data for prediction process
Information loss during COP generation and poor information integration	COP is generated by combining the Service-specific Recognized Pictures, that are built to meet specific Service requirements	COP generation directly from the primary information sources, currently used to build recognized pictures, based on requirements established at joint level
Weak end-user interaction with COP	Services maintain their authority over the generation and maintenance of recognized pictures; filtering capabilities are set-up for relatively large categories of information	Enabling the system active response to user feedback and/or requirements, including through the use of AI techniques and methods

2.3. Situational Awareness

Significant efforts have been made to define the construct of (shared) situational awareness (SA) and its relation to human decision making and performance (Endsley, 1995; Nofi, 2000; Luokkala, 2016). For the purposes of this work, we will use the definition given by Endsley (1987; 1988): "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." A very similar definition can also be found in Nofi (2000) where the result of SA (defined as "the result of a dynamic process of perceiving and comprehending the events in one's environment, leading to reasonable projections as to possible ways that environment may change, and permitting predictions as to what the outcomes will be in terms of performing one's mission") is the dynamic mental model of one's environment, a state of knowledge. However, this state is achieved, acquired and maintained by separate processes, referred to as situation assessment.

The hierarchical phases and primary components described in the aforementioned definition are detailed in the form of a model,

as presented in Figure no. 1. Situation awareness is achieved in three steps:

- Level 1 SA: Perception of the Elements in the Environment – perceives the status, attributes, and dynamics of relevant elements in the environment. In this paper we are assuming that Level 1 SA is actually COP.
- Level 2 SA: Comprehension of the Current Situation – is based on a synthesis of disjointed Level 1 elements and seeks to include an understanding of the significance of those elements in light of pertinent operator goals. An important aspect refers to patterns forming, by putting together Level 1 elements with the other elements (gestalt), based on which the decision maker (DM) forms a holistic picture of the environment, comprehending the significance of objects and events. This perspective can be exploited by non-humans actors.
- Level 3 SA: Projection of Future Status – is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation (both Level 1 and Level 2 SA).

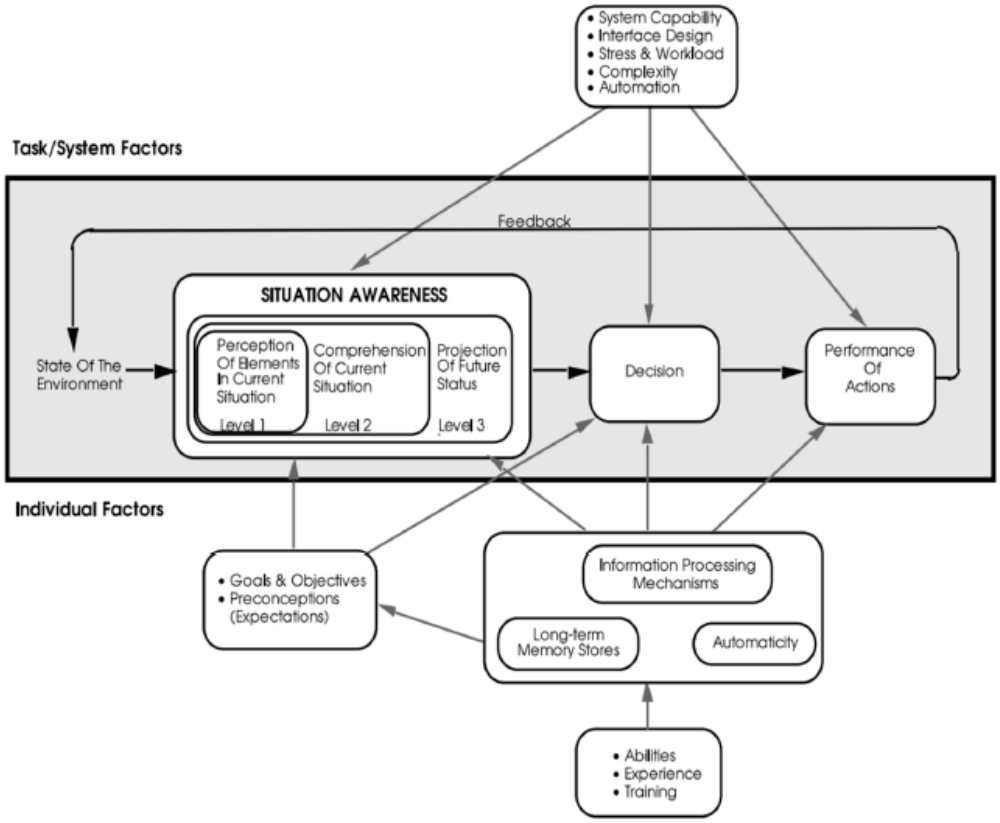


Figure no. 1: *Model of situation awareness in dynamic decision making*
(Source: Endsley, 1995)

We can conclude that SA requires knowing the relationships among the sensed objects within the region of interest that are relevant to current operation, as they evolve over time. A significant part of this process occurs in the mind of participants, this characteristic being so far exclusively human. Once the autonomous robots come into play on the battlefield, bringing with them a plethora of sensors and computational resources, the situation becomes more complex, pushing to the

limits humans' ability to maintain SA. Furthermore, humans have to share the SA with machines in a consistent manner.

2.4. A New Approach Proposal for the Situational Awareness Assessment

A conflict presents individuals and forces with problems specific to their role and missions. Information represents a critical resource that supports the intelligence cycle and decision-making process at the strategic, operational, and tactical levels of war. The consistence of the relevant information across the entire operations spectrum (common operational picture) is one of the fundamental requirements to be successful on the battlefield. However, this aspect is at least as important as the way in which a participant perceives the situation from its point of view (situational awareness), taking into account the increasing involvement of machines on the battlefield.

The Situational Awareness is achieved, acquired and maintained by the process referred to as situation assessment. Even if the base of this process is Common Operational Picture, there is a gap between the two concepts. The current Command and Control (C2) system producing COP, no longer directly supports the achievement of situational awareness from the Level 2 SA upwards, for this purpose being used tools loosely coupled with them, and humans representing the central element of the process.

The following assertions are proposed to represent the starting point of our undertaking:

- Common Operational Picture (COP) represents a real-time, multi-level, and distributed storage, processing and networking construct, designed to act as a virtual unique and authoritative source for generation of the consistent participant Situational Awareness (SA).
- Situational Awareness (SA) is a synthetic and participant-oriented operational image, generated from interactions of humans and/or machines with COP system, in accordance with the participant specific requirements.

The elements of the current situation (Level 1 SA) shall be generated and maintained based on the events triggered by the participants [R1] (these enumerated abbreviations will be used in the following sections to refer to the corresponding requirements), using the information provided by different kind of sources (remote sensing, environmental sensors, databases), presented in any form (signal, data, knowledge, and models) [R2]. The access to all these resources will be performed by means of a unique virtual interface that will also delimitate the COP system [R3]. The aspects related to the network infrastructure and security aspects are not in the scope of this work. Information shall be processed, stored and retrieved by the agents in the system, both humans and machines, in a distributed and multi-level manner [R4]. COP information shall be directly used by the machines in a flexible manner [R5].

3. AI-Driven Situational Awareness Assessment Approach

A high-level conceptual model of the AI-driven SA assessment, based on previously stated assertions and requirements is presented in Figure no. 2.

A wide range of AI methods can be used to support the required processes, suitable for each level, from inductive up to deductive methods. Among inductive reasoning methods, we mention traditional machine learning – Logistic Regression (LR), Support Vector Machine (SVM), Naive-Bayes (NB) or deep learning – Convolution Neural Network (CNN), Long Short Term Memory (LSTM), Gated Recurrent Unit (GRU). The deductive

methods are represented by the knowledge-rule systems. But the seamless collaboration at all levels, in an efficient manner, will only be achieved when all the system's components have the same understanding of the goals, concepts and relationships. Ontologies represent the most appropriate tool for this purpose (Sharman, Kishore, & Ramesh, 2004).

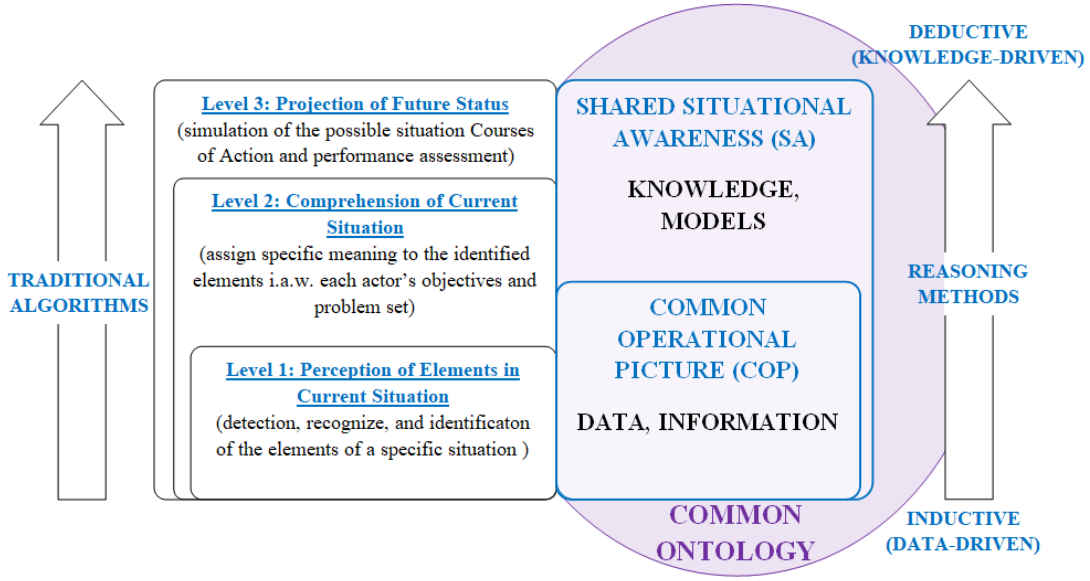


Figure no. 2: *AI-driven Situational Awareness Assessment Concept*

An ontology is a formal description of knowledge as a set of concepts within a domain and the relationships between them (Ontotext, 2022; Earley, 2015). The ontology components are presented in Figure no. 3 and a detailed formal description of them can be found in Sharman, Kishore & Ramesh (2004).

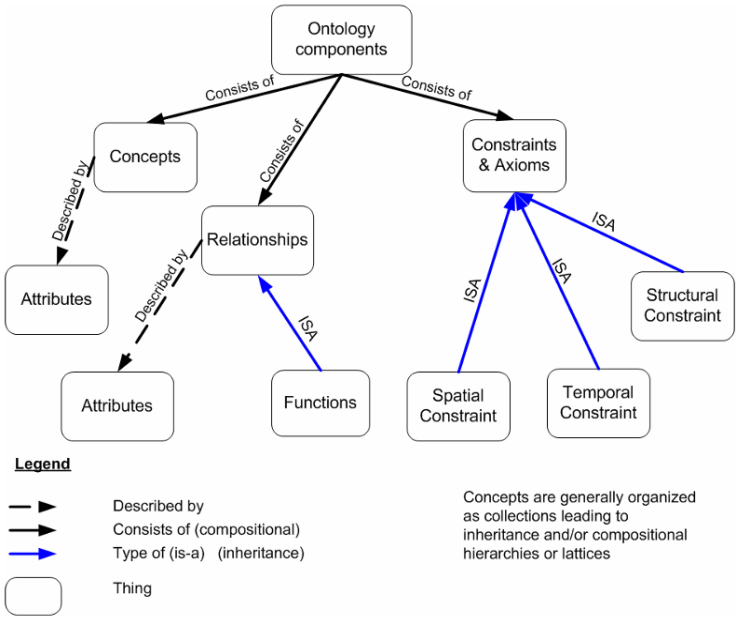


Figure no. 3: *Components of an Ontology*
(Source: Sharman, Kishore & Ramesh, 2004)

Usually, in order to achive the objectives of a project, a single ontology is not enough, being necessary to select a set of ontologies of different types (top-level, domanin, and application) as shpwn in Figure no. 4. Such a set, empowered with the ability to learn, will constitute the central element of our framework.

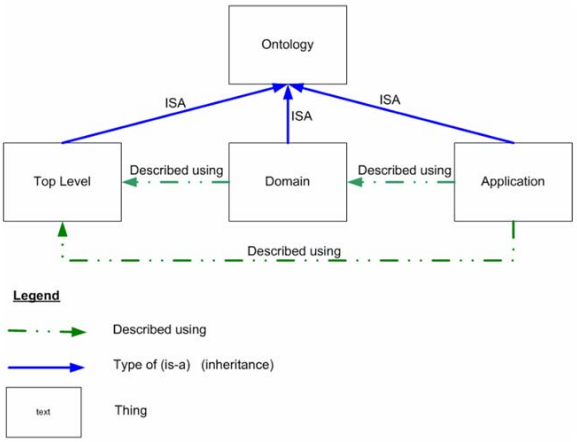


Figure no. 4: *Ontology Types*
(Source: Sharman, Kishore & Ramesh, 2004)

Based on the identified requirements, we are proposing a structure of ontologies serving the shared Situational Awareness achievement, together with a suitable bunch of the candidate ontologies, to meet the requirements [R1] to [R5].

The central element of this construct will be ontology able to model the inherent structure of the SA domain, independently, as much as possible, on the particular tasks. For the selection of particular ontologies, the evaluation framework for Situational Awareness upper ontologies has been used, as presented in Baumgartner & Retschitzegger (2006). This refers to three dimensions:

- Top-level concepts, derived from common top-level ontologies and especially from Standard Upper Merged Ontology – SUMO (Niles & Pease, 2001). The following concepts have been identified in this category: „Situation", „Event", „Relation and role", „Attribute", and „Object".
- Situational Awareness specific concepts, based on situation theory and JDL Data Fusion Model (Llinas, Bowman & Rogova, 2004). The following concepts have been identified in this category: „Space and Time", „Thematic Roles", „Situation Types", and „Situation as Objects".
- Modeling Characteristics of Upper Ontologies.

The SUMO has been selected as top-level ontology because it forms, together with its domain ontologies, the largest formal public ontology in existence today. They are being used for research and applications in search, linguistics and reasoning. SUMO is the only formal ontology that has been mapped to all of the WordNet lexicon. SUMO is free and owned by the IEEE. The ontologies that extend SUMO are available under GNU General Public License (Pease, 2021). The role of this ontology is to provide a description of everything at a very abstract level.

Only two ontologies have been identified as being appropriate for our purpose: Situation Awareness Assistant (SAWA) and Sensor observation, Sample, Actuator (SOSA). The role of this type of ontology is to provide integrate heterogeneous information about the perceived objects, identify the relevant situations in a domain independent manner, and share knowledge about situations among intelligent agents across domains

and different levels of abstraction. SAWA seems to be more appropriate for our purposes, being designed for military purposes from the beginning.

The combined top-level concepts of SUMO and SAWA ontologies are illustrated in Figure no. 5, under the form of an UML class diagram, demonstrating that a logical construct underlying a common shared situational awareness for intelligent agents, humans and machines, is feasible.

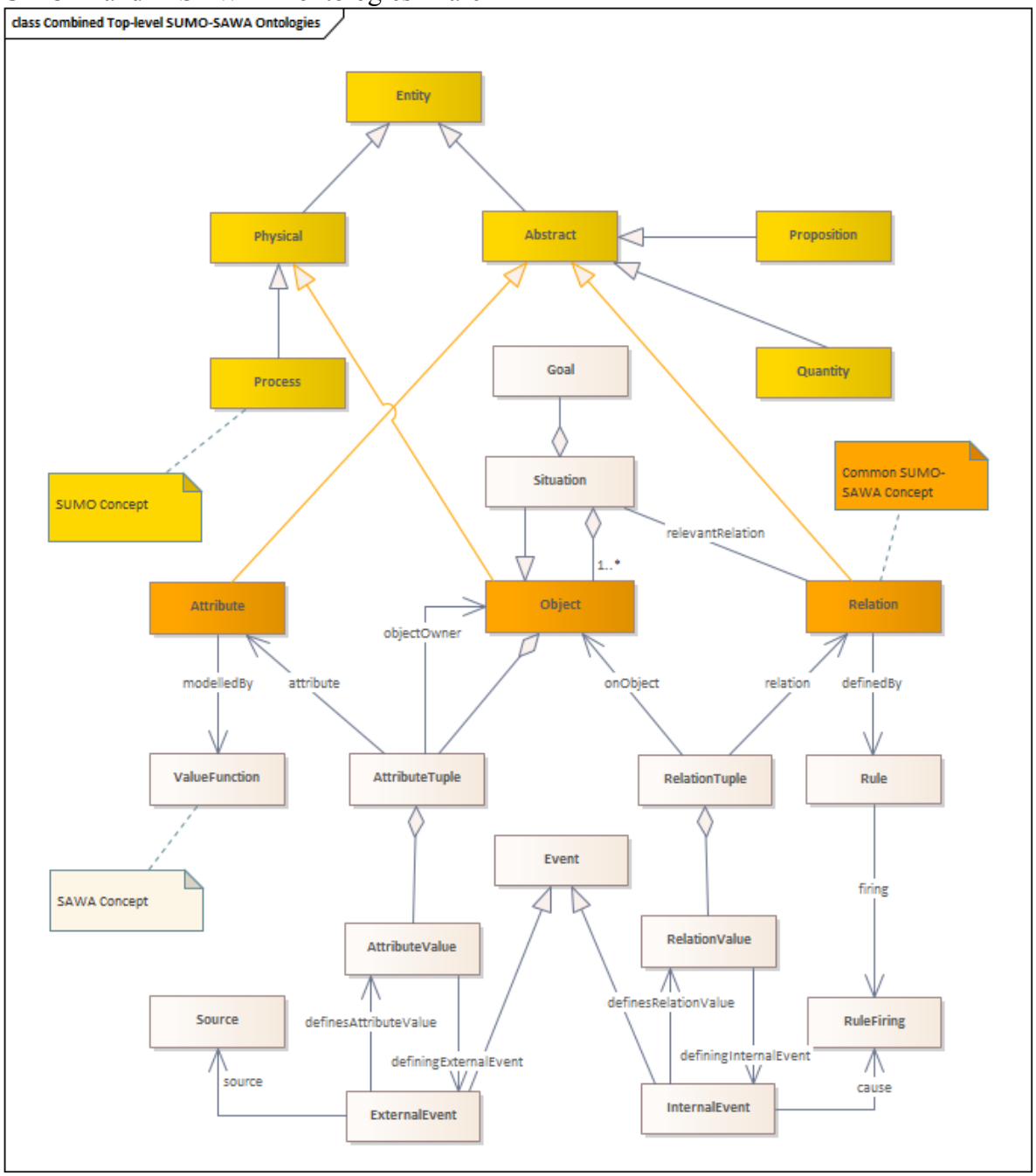


Figure no. 5: *Combined top-level concepts of SUMO and SAWA ontologies*

4. Conclusions

The AI-related techniques of inference and reasoning based on ontologies represent a feasible logical construct to achieve a shared situational awareness between humans and machines by enabling the seamless and meaningful information sharing at all levels.

There were identified suitable top-level and situational awareness upper ontologies (SUMO, SOSA, SAWA, etc.) to support our assumptions but no specific ontologies for air, ground, maritime, and underwater situational awareness have been found. Furthermore, more work has to be performed in order to represent the knowledge under the form of actionable intelligence that could be used directly by the machines for actively participating to the situational awareness assessment.

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