Situation Awareness: Issues and Challenges

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1 Basic Situation Awareness Concepts

To explain what I mean by "situation awareness" I often use the example of watching the games like American football or baseball. Since I have never learned the rules and the strategies of these games, when watching them on TV, although I can clearly see where each player is and where the ball is, I still have no idea of what is going on. Clearly, in this case I cannot claim that I am aware of the situation.

The term "situation awareness" has been often interpreted in a somewhat simplistic way as merely the knowledge of all the objects in a specific area, and possibly their kinematic states. It is clear, however, that the meaning of this term implies more than that. For instance, in [1], awareness is explained as "AWARE implies vigilance in observing or alertness in drawing inferences from what one experiences." In other words, a subject is aware if the subject not only observes (experiences) the objects but also is capable of drawing conclusions from these observations.

The next question is about the meaning of being aware of a specific situation. The word "situation" is defined in [1] as: "1 a : the way in which something is placed in relation to its surroundings." So the essence of situation awareness is the knowledge of all the objects that are relevant to the subject and the knowledge of the relations that the subject is in with respect to these objects. In other words, awareness means knowing not only objects but also relations.

The notions of "awareness" and "situation" are not totally independent in the sense that they both have one common aspect, the aspect of "relation". In mathematics, a relation is a subset of the Cartesian product of a number of sets. For instance, the Cartesian product $A \times B$ of two sets A and B is the set of all ordered pairs $< a, b >$, i.e., $A \times B = \{< a, b >, a \in A, b \in B\}$. A relation R is then a subset of the Cartesian product, $R \subset A \times B$.

In logic, relations are treated as interpretations of predicates. While a predicate is a syntactic concept, a relation is a semantic counterpart of the predicate. Awareness requires the capability of drawing conclusions, where the process of drawing conclusions is also called inferencing or reasoning. In logic, reasoning is a process of applying inference rules to either the axioms of a given theory or to previously drawn conclusions (theorems) with the intent of deriving new theorems. The axioms and the theorems are expressed in terms of predicates. Since, as we pointed out earlier, the predicates are interpreted as relations, the inference process derives true statements about relations.

Logical reasoning viewed as the application of inference rules is a good model for the automation of the reasoning process. Once premises and axioms are declared and a conjecture is posted, the process of proving that a conjecture is true (i.e., that it is a theorem) can be viewed as a search in which inference rules are matched against the axioms and already derived conclusions until a newly derived conclusion is equal to the conjecture. Mathematical reasoning, on the other hand, relies more on the ingenuity of the human to derive proofs. In mathematical reasoning models, i.e., sets, functions and relations, play a more explicit role than they do in logical reasoning. In other words, mathematical reasoning can be viewed as a process of manipulating the semantic objects rather than the syntactic objects.

The purpose of this discussion was to stress the fact that while situation awareness clearly requires an inference capability, the inference process itself can be carried out using either a mathematical or a logical framework. As we mentioned above, the two frameworks are duals of each other and we wanted to make this fact explicit. The advantage of a logical framework is the flexibility that it provides, i.e., one has only declare axioms and premises and the reasoning process will proceed automatically. This approach is also termed as declarative programming. Automation is more difficult using traditional programming languages, but the advantage is that more complex theorems can be proven at a lower computational cost. This approach is termed procedural programming.

In addition to reasoning about relations, situation awareness involves one more aspect that has to do with the use of the concept of situation in real life. While a situation can be defined as a set of relations with other objects, both the objects and the relations change with both time and location. For instance, I am in different situations when I am driving home and when I am hiking in the mountains. To make use of situation awareness one must be able to recognize situations, assess their impact on one's goals, memorize situations, associate various properties with particular situations, communicate descriptions of situations to others. This leads to the requirement that situations be treated as objects, similarly like physical objects or conceptual objects.

The issue of situations as objects has been studied in logic. Here we refer only to the work of Barwise [2], but many others had contributed to the formalization of this term. Here is a quote from Barwise: "One of the starting points for situation semantics was the promotion of real situations from second class citizens to first class citizens. By a situation, then, we mean a part of reality that can be comprehended as a whole in its own right - one that interacts with other things. By interacting with other things we mean that they have properties or relate to other things."

The objects may be complex, incorporating both other objects as well as their properties and relations among the objects. It can even include other situations. In our work, we have developed an ontology for situation awareness - we call it Core SAW Ontology [3]. This ontology is available on our web site in the OWL representation. The discussion of this ontology can be found in [4]. We encourage the fusion community to use it as a starting point for developing more complex ontologies. This ontology is extendible to accommodate more complex domain ontologies. The use of the same ontology promotes interoperability among different systems.

2 Challenges

Situations as Objects: Situation awareness in Level 2 fusion is considered to be a computer-based process that can recognize and manipulate situations. The computer is also assumed to be responsible for making decisions depending on the situation. This is different from human-oriented situation awareness, where the human needs to be aware and then use this awareness for decision making. This kind of a requirement for a computer system creates many challenges that need to be addressed by the developers of such computer systems.

Relation Derivation Algorithms: How can a program determine whether a particular relation holds or not? For instance, in order to determine that two numbers, say 2 and 5, are in the "$\leq$" relation we need to have a procedure to make such a conclusion. Either we remember this as an atomic fact, or we apply a rule to establish such a fact. For instance, we may remember the ordering of all single-digit numbers and then compare the number of digits in a number. If one of the numbers has more digits and the first digit is not a "0", then it is larger than the other one. Obviously, this is not a complete rule, but it should be clear how such a rule could be specified. In general, for each relation a rule is needed to derive its validity. For any domain, a set of rules needs to be developed.

Relevance of Relations: The next question is which of the relations should be derived or monitored? Consider, for instance, that there are 100 objects in the area. Even if we consider only binary relations, the number of possible binary relations is equal to $2^{10,000}$. This is because the cardinality of the Cartesian product in this case is 100×100 and then there are as many relations as there are subsets of such a set. Typically, only a subset of these relations would be relevant. The challenge then is to develop methods for determining which of the possibly many relations are really relevant and thus should be monitored.

Complexity of Derivation Algorithms: In the previous section we mentioned two approaches to the derivation of relations - declarative (or logical) and procedural (or mathematical). Using the declarative approach it is relatively easy to specify all the facts that the derivation algorithm should consider. The derivation algorithms are (conceptually) simple search algorithms. However, such a search is exponentially complex. The challenge then is to find algorithms that can "understand" their own limitations and can assess their own abilities given the resources. On the other hand, the procedural approach would require the specification of domain-specific derivation procedures during the design of a situation awareness system. The burden then is on the designer to develop a relatively complete set of such procedures.

Certainty of Derived Relations Independently of which approach to relation derivation is chosen the issue of uncertainty of derived decisions is a great challenge. It is highly unlikely that the designer of a situation awareness system will provide a complete coverage of all relations that will potentially be needed by the user of such a system. Incorporating the computation of uncertainty of decisions adds to the complexity of this task. The logic-based solution is not a simple case, either. Although many attempts to combine, for instance, Bayesian reasoning with logical reasoning have been documented, this task is still a great challenge that needs to be addressed.

References

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[3] SAW Core Ontology. http://vistology.com/onts/onts.html.

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