A Model for Situation and Threat Assessment

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A model is presented for situation and threat assessment, with a goal of advancing the state of the art in representing, recognizing and discovering situations and, in particular, threat situations.

The activity relates to levels 2 and 3 of the familiar JDL data fusion model. Level 2, "Situation Assessment", involves such applications as scene understanding, force structure analysis and many other types of situational analysis. Level 3, "Impact Assessment" includes, besides threat assessment (as level 3 was originally named), course of action analysis and outcome prediction.

Data fusion is the process of estimating or predicting some aspect of the world. Specifically, the data fusion process of Situation Assessment has the job of estimating or predicting situations. A *situation* can be defined very broadly as "any structure part of reality" (Devlin, 1991). In that structural analysis involves an assessment of the element of an entity in their relation to one another, Situation Assessment involves (a) inferring relationships, (b) inferring the states of elements on the basis of estimates of their relationships, and (c) recognizing or classifying situations on the basis of estimates of constituent elements and their relationships. In that the last of these is a recognition/classification problem, we should expect to have some similarity to target recognition and classification; i.e. the matching of data to prior models (a deductive process). As in target recognition/classification, this dependency on prior models presumes a process for generating, evaluating and selecting such models. These are characteristically abductive (i.e. explanatory) and inductive processes.

We take as our starting point the process involved in Scene Understanding as it occurs in machine vision, automatic target recognition (ATR) and remote sensing applications. ATR and machine vision have evolved from straight-forward template matching techniques, in which observed scenes are compared with stored images. Template techniques are obviously constrained by the number of target/context scenes that they can store. Various indexing schemes are used to reduce this burden, by extracting relatively invariant features, but the approach is ultimately restricted to situations in which target signatures are not much affected by contextual factors (occlusion, shadowing, illumination variability, etc.).

Far more robust (although more complex) are model-based techniques, in which candidate scene hypotheses are adaptively generated, evaluated, refined and modified. Such techniques can be augmented by adaptive data collection techniques that anticipate the utility of information in resolving present ambiguities and manage sensors or data mining processes to maximize the value of returned data.

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To extend model-based scene understanding processes for generalized Situation Assessment problem, the technique needs to be able to "think outside the frame", as evidence can come from "anywhere". Furthermore, the process must often deal with a wider range of evidence: understanding of many types of situations involves the use of a wide diversity of information types, relating, e.g. to political, social, informational and psychological aspects of the situation that are not inferable from direct physical signatures alone. Correspondingly, the recognition/classification process must often involve a wider range of entity and aggregate behavior models. This is certainly the case in the many situations of interest that involve estimating and predicting human individual and group behavior.

Therefore it will be necessary to have deductive, abductive and inductive tools that will characterize and recognize situations and constituent relationships. In various applications, relationships of interest can range from logical and semantic ones, to physical, functional, conventional and cognitive relationships. To be sure, most relationships of these types are not Directly Observable; rather, they must be inferred from the characteristics & activities of the related entities.

We are working on defining a formal scheme for representing and reasoning about relationships, situations, impacts, threat, etc. First, it should be noted that a relationships is not simply a multi-target state: a state of the sort of interest in Situation Assessment cannot in general be inferred from a set of single-target states. We will want to combine both direct measurements from "sensors" as all as inferred information – e.g. natural language reports by an analyst, or from HUMINT, document or communications. All such information can be represented in a second-order predicate calculus. We use the formalism of "Infons" introduced by Keith Devlin (1991), but there are equivalent formalisms. Situations s can be defined by means of minimal sets $\mu(s)$ of infons, often with fuzzy membership conditions. Infons and situations can be elements of other infons. This formulation supports Operational Net Assessment: reasoning from multiple perspectives.

Elements of state estimation relevant to threat assessment (and, indeed, to many other types of situation and impact assessment) extend beyond the physical state elements familiar in target tracking and target recognition. Ed Waltz, following Karl Popper, has identified physical, informational and perceptual aspects of state estimation problems. We have used this to develop a taxonomy of discrete and continuous state elements for physical, informational and perceptual aspects, both of entities and of their relationships. Reasoning about informational and perceptual (and, more broadly, psychological) aspects are at the heart of Operational Net Assessment.

We turn to the estimation and prediction *of threats*; or, more generally, of *intentional acts*. Little and Rogova, following the tradition of forensic analysis, have defined threats (i.e. the potential for harmful actions) as a product of the capability, opportunity and intent of agents to carry out such actions (We can generalize this to encompass any intentional act; we can further generalize this to include non-intentional events - harmful or otherwise - by ignoring intent).

The process defined for model-based scene understanding is extended to the general problem of situation and threat assessment. This is done in a very straight-forward manner, by expanding the types of modes for information sources, targets and situations. The functions of model management are also explicitly addressed. A consistent scheme for representing measurements, attributive and relational states and corresponding uncertainties is required throughout the deductive recognition/classification processes and the abductive/inductive model management processes.

The problem of characterizing information sources is present even in systems that have been designed and integrated as a package. Sensor noise statistics and biases can be characterized in calibration and registration;

either by using (a) internal calibration signal sources, (b) known “fiducial” targets in the environment, or (c) the ensemble of information available in a multi-sensor system.

The problem is made more difficult when the performance of information sources cannot be assumed. This is the case in network-centric operations, in which calibration and registration are not easily performed. It is even more the case when the cooperation of information sources cannot be assured; e.g. when sources are agents with varying degrees of autonomy, raising the possibility of private agendas. The same factors can affect the estimation and controllability of assets having some degree of autonomy. Cases extend to the use of non-cooperating agents; e.g. enemy radars that “report” to our ELINT systems who and where they are; generally with no attempt to deceive. Other cases include deception, in such Information Warfare techniques as decoys, deceptive jamming and propaganda. Then there are third-party agents – e.g. commercial news sources, reference texts, and the like – that may or may not be unbiased.

Given the general lack of useful calibration sources or fiducial targets in such cases, fusion system must characterize the reliability & performance of EACH source using the ensemble of information. In other words, the sources available to information systems (and control systems, too) can involve various degrees of noise and bias errors AND various degrees of performance characterization. To extend the network-centric concept, this implies that we can’t assume clear system boundaries: “us” vs “them”: Allegiance is a matter of estimation.

Technical issues in situation and threat assessment include: (a) Data Alignment: Exploiting heterogeneous information types and Normalizing confidence: source characterization, data evaluation; (b) Hypothesis Generation: determining relevant data, generating/selecting candidate scenario hypotheses and representing relationships , situations, etc.; (c) Hypothesis Evaluation: managing uncertainties in data association; (d) Hypothesis Selection: efficient schemes for representing and searching hypotheses.

Engineering issues include principles for partitioning the process into an information exploitation architecture. This includes issues of allocating tasks to humans and to automated processes and attendant presentation and control issues. Particularly difficult engineering issues involve managing models of situations, threats, sources and system resources. Such model management and exploitation will require an otology of situational, mission and system elements and their relationships. The ontology will need to provide criteria for recognizing relationships and situations. It must capture uncertainties in dependencies (e.g. in terms of fuzzy membership).