A first cut of the military QoI attribute space and hypothesis structure for abductive reasoning

David J. Thornley, Mark P. Harvey, *Imperial College London*

Abstract—**The concept of quality of information (QoI) provides a focus for developing and evaluating information gathering and situational awareness (SA) assessment methods. Effective prima facie estimates of accuracy, latency and trustworthiness are essential elements in the assessment of an information product delivered to, for example, a decision maker charged with timely and accurate identification of targets. QoI must support reasoning under conditions of uncertainty and conflict, which is a motivation for the application of abductive reasoning. This type of reasoning evokes hypotheses for ground truth that include the characteristics of the subject matter, contexts, producers and channels of information products. For our purposes, hypotheses are to be tested using a model related in intent to the enterprise QoI space of Wang et al, but which must take into consideration a significantly richer set of uncertainties resulting from the complexity and range of military activities that may require concurrent evaluation. This paper and accompanying poster begin to define that space.**

Index Terms—**Narrative, Abductive reasoning, QoI**

I. Introduction

The NATO Code of Best Practice on Assessment of Command and Control [1] recognizes that operations other than war require sophisticated belief support theory, since an opponent or an internally conflicted potential ally may construct as complex a deceptive structure as their technical, social and political talents enable. Deducing or inferring the structure and state of an organization not under our control requires quantitative, counter-intuitive reasoning. This task motivates computational support of abductive reasoning.

We consider that the output of any sensor networks and other intelligence sources constitute a number of narratives, and relate this to abductive reasoning (*e.g.* Heuer's analysis of competing hypotheses [2]). This reveals QoI attributes that relate not only to the physical domain (*e.g.* accuracy, latency), but also the information (*e.g.* relevance, security, specificity) and cognitive domains (*e.g.* anger, irony, surprise). Our accompanying poster [3] details the attributes; here, we describe how hypotheses for potential causality link the domains, and that the attributes describe confidence in alternative states within a hypothesized causality model.

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II. Background

The Network and Information Sciences International Technology Alliance (ITA) has chosen the concept of QoI to be a focus for the development and characterization of intelligence capabilities. QoI within a sensor network has been defined pragmatically as desirable metadata accompanying an information product [4]. We focus here on the stochastic modeling approach of Mission Abstraction, Requirements and Structure (MARS) [5,6] that began by working back from command requirements to the physical layer, to then build predictive models for information quality and utility estimation. Having demonstrated synthesis of mission-specific QoI measures of presence assertion [7], and quantification of the quality and utility of a decision-making sequence [8], we now expand the stochastic QoI attribute space to provide concrete computational support for unified abductive reasoning for sensing, information and cognition assessment.

III. Narrative, SA and abduction

Our task is to reconstruct from information products a more or less coherent narrative for the behavior of actors on the spectrum between friend and foe. Furthermore, in situations involving duplicity, a *surface narrative* may be presented for our consumption from which one would need to derive alternative hypotheses as to possible *deeper narratives* (see Figure 1). Delving down toward truth requires investigation of questionable sources or conclusions, relying on imaginative but disciplined quantitative inference. Quantitative evaluation of trust is a strong priority, but no complete solution has been identified. Abductive reasoning allows us to enumerate and structure to all the factors that impact on the trustworthiness of an information product or source, and crucially provides a mechanism for estimating the likelihoods of each.

SA is developed using those parts of the relevant narrative that, according to the current hypothesized connectivity and causality, we presume to be trustworthy. As well as supporting the discovery of the mapping between information product contents and reality, exploring different structures can reveal an opposing force's command or social structure [9].

As well as fusing externally generated, dynamic estimates of trust provided in QoI metadata [4] as a part of a recursive trust mechanism, using abductive reasoning enables us to address trust questions raised by internal inconsistencies in the narrative. For example, a magician fans the cards while you take one: if the intent were *simply* for you to take a card, then he might have handed the deck to you for inspection and selection. If an intent is communicated, but we observe an act that was unnecessary, or do not see an act that would be likely in corresponding circumstances, this warrants suspicion and hypothesis of reasons and mechanisms.

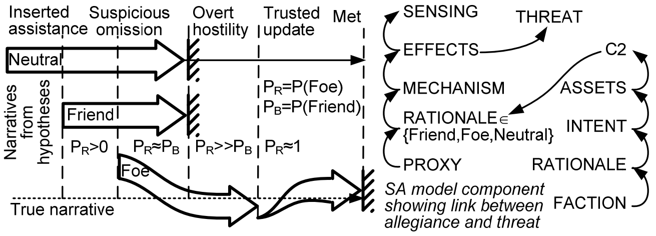

Figure 1. An example sequence of hypothesis spawning and pruning, and a simple SA causality model fragment. An initial assumption of neutrality of an entity is augmented with an alternative hypothesis of friendliness because of an apparent demonstration of loyalty. A hypothesis of opposition is added to account for a potentially damaging omission that would be considered unlikely were the entity friendly. An overtly malevolent act then contradicts other hypotheses. A fragment of the dependency structures is shown.

Our SA models comprise a graph of nodes and edges. Nodes enumerate the potential states of an element of the mission, which might be the posture of an actor associated with a physical effect (see Figure 1). The edges, or more strictly the ensemble of incoming edges to a given node, give the functional transformation from the states of the source nodes to an update (replacement) or upgrade (fusion) to the estimated distribution over states at that node.

IV. QoI ATTRIBUTES

The space of QoI attributes we propose in the accompanying poster [2] is not yet resolved to a strictly complete treatment of opportunities to assess information and SA: instead, it is an exposition of modeling and assessment elements we can describe that are necessary for guiding fusion, inspecting the narrative, prioritizing investigation, taking decisions and balancing investment. We express QoI attributes in our research as probability distributions. For example, the QoI of a detection report is a probability that it is correct conditioned on any relevant contextual and inherent factors. This probability decays with time – certainly if no further reasoning or fusion is performed in relation to it – because the target is not under our control [7]. Utility and value as distinct from quality are considered in our companion paper [10].

QoI functions are found by surveying the response of a system to point phenomena to give distributions over report contents. Formulating an accuracy QoI function generally requires substitution of ground truth with an estimated prior distribution (*e.g.* uniform if no bias is known). This is generally intractable as a closed analytic form, but can be estimated numerically [11]. Heuristic models of human cognition quality can also be calibrated [12].

General definition of QoI has been a significant challenge, and has been the subject of military and non-military studies (*e.g.* [13,14]). By narrowing our focus to command satisfaction and performance prediction, we find that QoI relates to probability distributions over possible states of a system as estimated in an information or intelligence product.

V. CONCLUSIONS

We have indicated probability distributions across states in a dependency structure relate to the necessary reasoning and prediction in mission operation and modeling. These correspond to *stochastic QoI* of information products and elements of situational awareness that are commissioned, generated, distributed and interpreted. We have also sketched out a space of QoI attributes in the accompanying poster [2] relating to a wide range of assessments, from delay and error in location, through trustworthiness and psychological state, to balance of investment questions. They map to probability distributions across potential ground truths for which we hypothesize causal structures. Measurements provide estimates of elements of the physical and information domains, timed stochastic modeling provides estimates of the future behaviours of a system that we must prepare to respond to (by disseminating information, deploying equipment and personnel), and the hypothesis graph structure supports inference of remaining unmeasured state probabilities using, for example, Bayesian Net methods [15].

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