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A PRAGMATIC FOUNDATION FOR DEFINING A RICH SEMANTIC MODEL OF *TRACK*

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INTRODUCTION

Many defense, homeland security, and commercial security objectives require continuous tracking of mobile entities. The systems that perform these functions produce information products called *tracks.* A track associates observations with the mobile entity and typically includes position, velocity, and other similar attributes. Military systems have sophisticated tracking and track fusion processes, but lack uniformity in syntactic and semantic content preventing effective sharing of the information. In other domains of interest, such as seagoing surface ships, dangerous cargo and persons of interest, tracking systems are less mature and have marginal performance. It is now essential that we be able to share information across different tracking systems working in related domains.

In this paper, we describe the Rich Semantic *Track* model [Hayes-Roth 2005] as a foundation for sharing world state information across multiple systems. The model exhibits a belief and evidentiary structure that has not been emphasized in previous track models for broad application. The approach is having a significant impact on design of emerging models, particularly the Maritime Information Exchange Model.

THE PRAGMATICS OF *TRACK*

Tracks are an important element of situation assessment in most command and control systems. Commanders want to track platforms and forces, anticipate their likely motions and potential threats, determine how best to counter threats, and then implement chosen countermeasures efficiently. From these general concerns, we identify the following common pragmatic objectives for a mobile entity M with possible intentions and capabilities to do harm to our interests:

(1) Observe, detect, identify, classify and continuously monitor M.
(2) Locate M.
(3) Infer M's intent.
(4) Determine M's threats $T_{M,D}$ against domain D.
(5) Predict M's future location and behavior.
(6) Alert agent A about M and threats $T_{M,D}$.
(7) Determine countermeasures $CM(T_{M,D})$ to threats $T_{M,D}$.
(8) Inform agent A about countermeasures $CM(T_{M,D})$.

These eight pragmatic objectives define the general and common concerns of military and security agencies with potentially dangerous mobile entities. The whole purpose of sharing information among different sources is to support these common objectives.

Any system of concepts will have its own nuances and best practices for modeling the world effectively. No system is perfect; instead, we wish to initiate use of **evolvable semantics to**

support important pragmatics. Thus, the key capability we need is to <u>do some things well while being able to improve continually</u>. For that reason, almost any reasonable semantic system will be good enough for significant information sharing. The essential quality required is that the system distinguishes states that warrant different inferences and actions.

All assertions in the information space about the state of the world (such as about vessels, cargo, people) are *beliefs*. So, every aspect of the information model of tracks should be considered a "belief" with whatever supporting data any belief can have. Here are the most common structures:

(1) A belief is held to be a **fact**.
(2) A belief is a widely accepted **assumption** that's recognized to be less certain than a fact.
(3) A belief is based on direct credible eye witness report, so it's like **ground truth**.
(4) A belief is based on summarizing and aggregating other beliefs so it's a logical inference or **implication**.
(5) A belief is based on the association and fusion of K observations that support a simplifying inductive inference, interpretation or **abduction**.
(6) A belief is a **composition** (AND) of other beliefs.
(7) A belief is a probable inference or **confirming prediction** from another belief.
(8) A belief is an improbable inference from another belief or a **disconfirming expectation**.
(9) A belief is an analyst **judgment**, intuition, opinion, or concern, based on some other beliefs as well as some inference.
(10) A belief is a pattern-based or rule-based **assessment**, where a set of beliefs about an entity instantiates a pattern template above some threshold level indicating that the pattern's interpretation applies.

Therefore, our approach is to identify a rich semantic model of *tracks* that can express these fundamental belief structures in order to: represent a wide variety of meanings and support a broad array of pragmatic goals; reduce implementation time and cost required to reason about a new type of *track*; simplify the understanding and importation of external sources of track information; help operators describe track attributes they value in performing their tasks; improve our ability to combine multiple sources of track information; provide a stable and evolvable base for best practices supporting information sharing; and improve bandwidth utilization by delivering nothing but valued information at the right time (VIRT) [Hayes-Roth, 2004, 2006].

THE SEMANTICS OF *TRACK*

The choice of engineered semantics rests on pragmatics – describing what differences in behavior must be supported. Given a set of pragmatic objectives, the inference process considered earlier relies upon conceptual categories. A semantic hub or "core" should make all of the conceptual distinctions required to support those categories and related pragmatics. The rich semantic *Track* model, therefore, should reflect aspects of state that most users of track information require for addressing expected pragmatic concerns. As we employ such a model to mediate sharing among systems, we will inevitably discover additional concerns not yet adequately addressed in the current model. This will drive an iterative, evolutionary series of improvements to the community's evolving model of *Track*.

We have created a mostly-hierarchical conceptual scheme (Figure 2) working backwards from pragmatic objectives to required concepts to supporting distinguished data values. The ability to adapt this standard hierarchy rapidly to exploit a new source would be the operational test of value. This suggests both what types of products we need and also what types of methods will enable us to adapt these products to new situations. The *Track* model allows us to describe our beliefs about a mobile entity and its past, present and predicted future states. In addition, we are able to justify inferences that we make as part of the tracking process.

Track
- Beliefs
  - Identity
  - Characteristics
  - Dynamic State at Time T
  - History of States (past "track")
  - Predicted States (future "track")
- Meta-Information
  - Evidence
  - Inferences
  - Error and uncertainty estimates
  - Temporal qualifications
  - Spatial qualifications

Figure 2. The top-level conceptual hierarchy for *Track*[1].

This fragment of a conceptual hierarchy describes the most general, or topmost, element called *Track*. The concept *Track* contains two principal component concepts, called Beliefs and Meta-Information, respectively. Components of Meta-Information may apply to each element of Beliefs. That is, when we use the conceptual hierarchy to create actual beliefs that are instances of *Track* Beliefs, we may find it useful to qualify every belief by using the sub-concepts of Meta-Information. In this sense, Meta-Information plays dual roles of meta-data (data about data) or reification (statements about statements). Moreover, Meta-Information can apply to combined Beliefs, as in providing rationale for bringing the Beliefs together.

RESEARCH AND DEVELOPMENT AGENDA TO ACHIEVE POTENTIAL BENEFITS OF THE SEMANTIC MODEL OF *TRACK*

To advance the agenda on track-related systems, we need to accomplish several intermediate objectives:

- Select a community of interest that recognizes the importance of this task.
- Enumerate and prioritize information sharing scenarios.
- Determine a high-value near-term subset of the hub semantics.
- Identify viewer/editors that operators will employ in these sharing scenarios.
- Determine translator requirements to support the scenario.
- Implement an initial semantic hub and related translators to/from interoperating systems..
- Test the environment, and identify high priority requirements for improvements to the hub and translators.
- Identify operators for whom VIRT capabilities have highest value.
- Determine best methods to gain knowledge of operator's context and identify valuable information.

[1] Successively indented topics represent specializations or subcategories under the topic they descend from.

- Implement query methods and notification methods to operationalize valued information at the right time.
- Iterate, through earlier steps, to implement continuous improvement.
- Place responsibility for this continuous improvement process in the hands of an appropriate agent or team.

This R&D agenda provides an incremental approach that can provide immediate benefits and can quickly exploit learning to gain additional benefits. These concepts are already influencing new track model designs. The approach has informed development of the Joint Track Management data model and is strongly integrated into the Comprehensive Maritime Awareness (CMA JCTD) Maritime Information Exchange Model (MIEM). In the MIEM, all objects and their constituent elements support a rich metadata structure (information sources, pedigree, time-varying nature, threat/vulnerability, confidence, annotation, etc.) to enable clear expression of value added information.

CONCLUSIONS

Many defense, homeland security, and commercial security objectives require continuous tracking of mobile entities. We wish to share information among different tracking systems working in similar domains. To combine information from different sources, we will need a flexible framework that can tolerate and exploit data products from different systems, although these systems employ different representations and embody different assumptions. Our approach is to create a rich semantic model of tracks that can support a wide variety of objectives related to information sharing. The semantic model is developed to play the role of a hub amidst a variety of translators. This approach enables achievement of significant positive benefits through incremental improvement driven by pragmatic concerns.

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