Dynamic Context Maintenance in Human Terrain

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ABSTRACT
Recent armed conflicts highlight the military’s need to develop new strategies that assist in situational assessment and planning for combating insurgent operations. Although insurgent warfare tactics have been used for thousands of years, the degree to which they have been recently employed presents an especially significant challenge. One of the challenges the intelligence community faces in counterinsurgency is developing the means to identify, track and predict insurgent activities. The success of discovery and tracking of insurgents and their activities depends on the presence of an up-to-date, coherent situational picture. Therein lies the challenge we address in this paper: effective dynamic context maintenance in social networks to support situational assessment. To address this challenge we apply, GeoFuse, an existing context-based sub-network extraction algorithm in a localized manner to achieve continuous context-driven network maintenance.

Key Words: Context-aware Computing, Human Terrain, Dynamic Social Networks
1.0 Introduction

Recent military conflicts have highlighted our military’s need to respond to our adversary’s strategy: asymmetric warfare. Asymmetric warfare relies on the development and activation of insurgent organizations that mount non-traditional attacks against their adversaries. The small and frequent attacks characteristically performed by insurgents differ from the activities of large armies. For example, insurgents rarely wear a standard uniform, so they easily blend in with the rest of the local population. They are typically residents of and have homes within the local community, so they do not have well-established bases where they gather. Because they are not easily identified, one of the challenges the intelligence community faces in combating counterinsurgency is developing the ability to identify, track and eventually predict insurgent activities.

The success of discovery and tracking of individuals, groups and activities depends on the ability to reason about dissimilar information to provide a coherent Human Terrain (HT) picture [3]. A coherent human terrain picture provides grounding for geospatial and temporal correlation that analysts use to assess activities and relationships between people. Not surprisingly, human terrain and social networks can contain large amounts of diverse data rendering correlation, visualization and consequently analysis ineffective [2]. We believe the success of any situational awareness assessment and analysis relies on a robust network representation and context awareness of the salient features of the network required for that analysis. The challenge is to develop methods for effective dynamic context maintenance in human networks. We propose an approach to continually assess the context of new and existing human terrain data based on available observables. Our approach extends an existing social sub-network extraction algorithm to dynamically re-assess the context of incoming data. We also propose a set of metrics to determine the similarity of sub-network extraction techniques that allow for comparison of competing methods that will follow as this research area expands.

In the remainder of this paper we discuss recent technological advances that enable effective generation and maintenance of human networks based on multi-source observables. Following the background discussion, we outline our approach to dynamic, context-based sub-network generation and maintenance and present two metrics that assist in comparing competing methods. Lastly, we conclude and provide future directions.

2.0 Background

Accurate and effective situational assessment and planning require effective social (human) network representation, persistence and management of complex human network dynamics as well as context-aware, spatiotemporally-equipped human network analytics. Lockheed Martin’s Advanced Technology Laboratories has been developing technologies that enable situational assessment and planning in environments affected by insurgent activities.

At the center of our functional capabilities is the Core Network Modeling Language (CoreNetML), our novel human network representation language capable of persisting the evolution of human network dynamics [1]. CoreNetML furthermore enables the storage and management of multiple, possibly diverging entity/relationship/attribute reports. CoreNetML extends DyNetML [7], another well-known network representation scheme developed at Carnegie Mellon’s Center for Computational Analysis of Social and Organizational Systems.

Currently, most human networks are constructed and maintained based on human observation reports (called soft reports). The nature of human-generated reports is that they may not be completely accurate due to a variety of types of reporting errors and human-generated bias. Together with university partners from SUNY-Buffalo, we have led the development of soft data fusion techniques capable of semi-automated normalization, alignment, aggregation and association processes necessary to generate state
estimates [4]. Accurate state estimates, sensitive to bias and error, are crucial to maintaining integrity within a human network.

The implementation of effective soft fusion techniques along with a robust network representation enabled us to develop GeoFuse, a geospatial and human network correlation algorithm that leverages a user’s information needs, or context in sub-network extraction [5]. The sub-network extraction step of GeoFuse employs a hierarchical ontology that defines context through activities and relationships. For example, a hierarchical ontology for a bomb-making context includes activities such as “purchasing of IED making chemicals” and “learning about explosives.”

Lastly, visualization for exploration of social networks is one of the most challenging types of human-computer interactions due to the sheer volume of information and the typically constrained viewing area. As they grow, networks quickly become unwieldy. Furthermore, while temporal dynamics can play an integral part in situational awareness analysis processes, these dynamics are even more challenging to visualize. One of the leading researchers in dynamic social network visualization, James Moody from Duke University, has developed the concept of Network Movies [2]. We leverage Moody’s network movies concept in the visualization step of our GeoFuse algorithm. Context-based sub-network extraction and persistence are key to enabling social/human network visualization and exploration.

3.0 Approach

Effective social network visualization and exploration are key to enabling timely situational assessment by human operators and analysts. Sub-network extraction is a necessary step to enabling exploration, and domain-specific ontologies provide a means to identify the nodes and relations that are relevant to a particular context. We have developed an algorithm, GeoFuse, that generates sub-networks [5], and in this paper we propose to apply it, in a localized manner, to automate dynamic network maintenance. GeoFuse has previously been applied to creating context-based sub-networks from a given human/social network. We now provide a means to update the existing sub-networks as the larger network changes based on observables and reports received in real time.

Our approach, shown in Figure 1, uses network state estimates that result from our soft data fusion process, and their first-degree neighbors from the current network, as input to GeoFuse. Through its very nature, a state estimate demonstrates the extent of the changes that have occurred in the human network as a result of an ingested observable. This approach allows us to run the extraction algorithm locally on only the state estimates and their nearest neighbors and not performing unnecessary work that would result in re-running GeoFuse on the entire human network every time a minor change is introduced. The results are ready to be incorporated into the existing sub-network.

Through this approach we use our dynamic context-based extraction technique to maintain an up-to-date sub-network in a rapidly evolving dynamic environment.

4.0 Comparison Metrics for Dynamic Sub-network Extraction Algorithms

The processes of analyzing a large, unwieldy human network to develop an accurate situational assessment is not only time consuming, but may be untenable due to the sheer volume and complexity of the data persisted in the network. On the other hand, analysis of an incomplete sub-network may be impossible if critical nodes and relations have been omitted or not updated due to sub-optimal network extraction algorithms. While it is challenging to automate the evaluation of any one sub-network extraction algorithm, we have developed a set of metrics to evaluate multiple sub-network extraction algorithms by comparing the networks they produce.
The first metric is called the \textit{symmetric difference metric}. This metric suggests the extent to which incomplete a sub-network may be or how many superfluous nodes and relations it may contain. Given a social network represented as the graph $G \equiv \langle V, E \rangle$ let $A \equiv \langle V_1, E_1 \rangle \subseteq G$ be the sub-network from the first context-driven sub-network extraction algorithm. Let $B \equiv \langle V_2, E_2 \rangle \subseteq G$ be the sub-network from the second such algorithm. Let $V_s = V_1 \oplus V_2$ be the resulting set of vertices that signify the \textit{symmetric difference} of the outputs of the two algorithms.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Step-by-Step view of Context-Based Sub-Network Maintenance}
\end{figure}
The second metric is called *relevance assessment estimate*. The *relevance assessment estimate* attempts to evaluate whether or not a node present in one sub-network is necessary given the context of the sub-network. The input to this metric is the result of the *symmetric difference metric*. Let $V_r \subseteq V_s$ be the set of vertices of degree $d \geq 1$ in the intersection graph of $G$ formed from $V_1 \cup V_2$. $V_r$ will therefore contain all the nodes present in one of the sub-networks but not the other that have a path to any nodes in the latter sub-network.

### 5.0 Discussion

The resurgence of insurgent operations in recent military conflicts has highlighted the applicability of social and human network analysis in situation assessment and planning operations. Significant advances have been made in the area of generation, persistence and maintenance of rapidly evolving and dynamic networks. In this paper, we highlight the challenges in analysis of large, rapidly evolving networks. We address this challenge through application of GeoFuse as a localized change estimation algorithm and highlight the advantages of this approach with dynamic human networks.

We hope that the challenges identified here will implore the research community to develop other dynamic, context-based network maintenance techniques. Furthermore, evaluating the efficacy and robustness of these techniques is paramount. To that end, we indentify two metrics that can be used to evaluate the efficacy of such context-based sub-network extraction algorithms.

### 6.0 References


