Preventing Pandemics Via Emergent Behavior

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***Abstract*—Attempts to avoid "massive noise" in large data sets associated with social networks have moved away from technical approaches that attempt to filter or classify social network data into meaningful elements through key words or other classification schemes. Rather, new approaches have an increased emphasis on communication flows between people in order to determine situational awareness. This paper summarizes recent innovative projects that stress agents (individuals) interacting with each other to generate an emergent and evolving social network. The projects build on Norbert Wiener's concept of "emergent behavior" and show how it is applied to communications between individuals reporting on emerging biological diseases. Socio-technical analyses have concluded that the lack of feedback explains why Severe Acute Respiratory Syndrome (SARS) was widely transmitted. A pro-active approach to disease detection using feedback loops is introduced to help the Influenza-Like Illness (ILI) detection community communicate in a social network dedicated to the prevention of pandemics. This network does not depend on pre-determined categories of information. Rather, it tracks a pandemic as it evolves in such a way that "digital pheromones" help to prevent the risk of wide transmission in a changing socio-ecological world.**

I. Introduction

Attempts to avoid "massive noise" in large data sets associated with social networks have moved away from technical approaches that attempt to filter or classify social network data into meaningful elements through key words or other classification schemes. Rather, new approaches have an increased emphasis on communication flows between people in order to determine situation awareness. The Office of Naval Research (ONR) is sponsoring a program in social networks and computational social science that will be helpful in providing a structural approach to the incorporation of cultural knowledge in adaptive behavior models. These models will be used largely to develop the basic science and applications in social networking, social computing, computational social science and other social sciences related to human security domains of military operations. This paper discusses how Norbert Wiener's concept of "emergent behavior" can be applied to social networks when they are used by individuals to determine situational awareness for emerging biological diseases.

II. A Self-Organizing Ontology for Bio-Defense

The Center for Biosecurity at UPMC (University of Pittsburgh Medical Center) recently commissioned several articles written by leaders in the field who describe the current state of affairs in biosecurity policy and practice, remaining challenges, and priorities for the field in the years ahead. Reference [1] discusses the advent of "digital disease detection" and the role of proMED-mail. This e-mail system, originally envisioned as a direct scientist-to-scientist network, has grown along with the internet, currently reaching more than 40,000 subscribers, in at least 185 countries.

A. Trails of Messages

ProMED-mail has a unique attribute of citing references when it reports on disease outbreaks. Messages usually cite references to previous messages on the same or related subjects. Often a message references a previous message which references a yet earlier message. If all messages related to each other through their references are retrieved, the resulting "reference-connected set of messages has been found to uniquely identify disease outbreaks. This is especially valuable to epidemiologists who can track the evolution of specific outbreaks for further analysis. Perhaps the greatest benefit of this classification system is that it does not depend on pre-determined categories of information. It is a system that is able to identify threatening events as they evolve across a broad spectrum of environments [2].

B. A Pro-Active Approach

Could a tool be developed to **pro-actively** build reference-connected sets for disease surveillance? Yes, it could be done by keeping track of messages that are sent from person to person in a social network. The network would be dedicated to the surveillance of biological events and the tool would maintain a record of the communication flows. As the network grows it would isolate specific biological events and show how they are related and evolving. A content analysis could be conducted in the same way that ProMED-mail subject matter experts provide context and comments. (All reports in proMED-mail are edited by scientists, who vet the reports for scientific plausibility and provide commentary.

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The context and comments from the moderators, who are subject matter experts, is a unique feature that many subscribers have noted as especially useful, emphasizing the value of contextualizing raw information.) With the use of such a tool, the digital disease detection community should be able to leverage the potential capability of a social network to provide early warning of a biological threat.

Tracking tools for social media are in their early stages of development and typically use keywords, profiles, and other search techniques to meet various business/marketing objectives. The goal should be to develop a tracking tool for the surveillance of biological threats in real time. ProMED-mail would then determine its utility for early warning as a supplement to its current e-mail-based surveillance system.

III. NORBERT WIENER'S BREADTH OF INFLUENCE

Vannevar Bush was perhaps the first person to come up with a new way of thinking about searching for information. Influenced in large part by Norbert Wiener, he suggested that an individual's personal information storage and selection system could be based on direct connections between documents instead of the usual connections between index terms and documents. These direct connections were to be stored in the form of trails through the literature. Then at any future time, the individual himself or one of his "friends" could retrieve this trail from document to document without the necessity of describing each document with a set of descriptors or tracing it down through a classification tree. Other scientists in the Technical Information Project at MIT have also suggested grouping scientific papers through "bibliographic coupling", and many projects have been conducted to develop advanced software and algorithms for searching, filtering, and summarizing large volumes of data, imagery, and other information in an environment in which users are linked through interconnected communications networks without the benefit of pre-established criteria for arranging content.

A. Communication and Control

In his book, *Cybernetics,* Norbert Wiener brought the insights and techniques of many disciplines to bear on problems of communications and control. Now well established as a field of study which deals with the role of feedback both in engineering design and in biology, cybernetics can also be applied to many of the approaches to learning and self-organizing systems that are being explored today. More recent studies have also shown that feedback loops are an essential requirement for control when decisions are made during crises. It has been shown that information flows break down with more than three decision-makers in a non-hierarchical organization, and many researchers feel that a clear command structure is still needed for control in collaborative decision making. An example of the importance of feedback loops has been found in socio-technical analyses of the Severe Acute Respiratory Syndrome (SARS) outbreak, where analysts concluded that a lack of feedback explains why SARS was widely transmitted. (ProMED-mail is credited with the first report of SARS in China on February 10, 2003.)

B. Emergent Behavior

Professor Wiener also discusses another concept in his book That has captured the interest of a multi-disciplinary community. He points out that intercommunication of ants, in which the only means of communication appears to be the sense of smell, seems to lead to a highly standardized course of conduct in which information is conveyed. This led to his conclusion that social animals may have an active, intelligent, flexible means of communication that results in communal information that can be distinguished from the amount of information available to the individual members of the community. An example of this phenomenon, which he called "emergent behavior", is the ant routing algorithm which tells us that when an ant forages for food, it lays pheromones on a trail from source to destination. When it arrives at its destination, it returns to the source following the same path it came from. If other ants have travelled the same path, pheromone value is higher. Similarly, if other ants have not travelled along the path, the pheromone level is lower. If every ant tries to choose the trail that has higher pheromone concentration, eventually the pheromones accumulate when multiple ants use the same path and evaporate when no ant passes. A growing number of research scientists are beginning to explore emergent behavior as an approach to the study of complex adaptive systems which are characterized by "agents" interacting with each other in dynamic, often nonlinear and surprising ways.

C. A Next-Generation Research Challenge

Techniques for understanding how to effectively leverage social behavior in bio-defense are still in their initial stages. Does the social network have an ability to "funnel" information on biological threats without any central control? Would it be possible to combine Dr. Bush's model of "trails of messages" with Norbert Wiener's "emergent behavior" approach to proactively construct paths through social networks to improve biological surveillance? Could a dynamic information retrieval system be based on communications paths and direct connections between individual communicators rather than upon traditional technologies that mechanically or electronically select information from a store? We have an opportunity to address this next-generation research challenge, and this paper suggests the development of a tool to do this as a benefit to society and a contribution to an important security need.

IV. BENEFITS

The application of "digital pheromones" that result in trails of messages related to specific biological events has several benefits in addition to providing the ability to identify, analyze, and report potential disease outbreaks as reliably and quickly as possible. They include the following:

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- The approach helps epidemiologists in their effort to trace outbreaks and to identify their origin. Laboratory tests for an outbreak's identification will be initiated more quickly;
- If all reporters along the path are **automatically** kept informed of all previous reporters in the path, it achieves the important feedback loop identified by Norbert Wiener as an essential requirement for control when decisions are made during crises.
- The approach avoids the need to define an evolving biological event which may not fit into a pre-determined classification category.
- The approach can be used as a planning tool to help in the analysis of ways in which social media can be used to provide information, thus enhancing situational awareness during a biological event and providing lessons learned over the course of the event.

REFERENCES

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