Enhanced Collaboration for Space Situational Awareness via Proxy Agents

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ABSTRACT

The call for *dynamic partnerships* demanded in the US. Space Policy is confronted by two formidable challenges: adoption of technical innovations and the organizational and social constraints that minimize information sharing. There is a culture in the space domain that predisposes many stakeholders to guard their information and withold asset data, whether experiencing an anomaly or just providing status updates. This is unfortunate, because they have the most accurate and timely data pertaining to their satellite which can benefit the space community overall. Comprehensive Space Situational Awareness (SSA) requires the marshaling of disparate mission critical elements. The mission threads reliant on SSA are complex and often require analysis from a diverse team of experts with sophisticated systems and tools that may be dispersed across multiple entities including military, commercial, and public interests. Two significant trends are likely to further perpetuate this state of affairs: 1) the space environment continues to be more congested, contested, and competitive, and 2) further pressures to increase *SSA Sharing* with a greater number of stakeholders throughout the world. The challenge of delivering the right information to the right people, while protecting national security and privacy interests, is in need of an innovative solution. Our approach, entitled Space Collaboration via an Agent Network (SCAN), enables proxy software agents to represent stakeholders (as individuals and organizations) to enhance collaboration among various agency producers and consumers of space information The SCAN agent network will facilitate collaboration by identifying opportunities to collaborate, as well as optimize the processes given the mission context. The agent-based approach is uniquely capable of addressing the collaboration challenges from both the technical and organizational perspectives. The SCAN prototype will be used to assess modeling parameters and assumptions as well as collect user feedback.

1. BACKGROUND

Collaboration Challenges in Space Situational Awareness (SSA)

Scope, complexity, and interdependence of space operations continue to escalate the challenge and criticality of obtaining the best possible Space Situational Awareness (SSA). The growing number and diversity of stakeholders drive all of space operations to a more decentralized configuration, demanding increased coordination and collaboration. The growth of this phenomenon continues as many SSA concerns are tightly coupled with others' interests. Moving forward, it appears the marshaling of disparate data and distributed expertise required for robust SSA will often demand multiagency, and even multinational collaboration. Knowledge management systems will need to accommodate decision support and sensemaking at the individual level as well as in support of participation as a contributor to coordinated teams.

A recent case of successful multinational coordination revolves around the European Space Agency's (ESA) Envisat satellite [1] The earth-observing satellite experienced an anomaly early in 2012 resulting in loss of contact that made the object a potnetial conjunction threat. The Joint Space Operations Center (JSpOC) coordinated the tracking effort to monitor its impact on the space catalog. The French CNES (National Center for Space Studies), volunteered time with its agile Pleiades spacecraft to provide additional SSA insight. Completing the picture, Germany provided a ground-based radar system that was able to provide imaging for the resolution of attitude and health.

The call for *dynamic partnerships* demanded in the US. Space Policy (NSPD-49, [2]) provides impetus for moving U.S. entities to a more collaborative environment. However, greater coordination and interaction is confronted by two formidable obstacles. The first is evident in the lack of the adoption of technical innovations that can greatly enhance collaboration.

A substantial issue underlying the Envisat scenario (despite the successful outcome) is the antiquated processes and resulting manual efforts required to achieve this success. Telephone and email served as the primary technologies for information exchange. While the mission was executed successfully, efficiency, repeatability, and resource consumption could be improved substantially. In contrast with recent television advertisements, the JSpOC is hampered by similar constraints. Recent observations indicate the most utilized communication tool for space analysts is *chat*. This finding is quite rational when factoring analysts' operational requirements. They need the most current data available, which often require interpretation by experts. Secure chat is currently their best option, but is has significant limitations. The first is seen at analyst workstations as they may have 6-10 chat windows open simultaneously to monitor conversation on different topics ranging from intelligence reports to launch schedules. Chat history is also unreliable, squandering an opportunity to preserve and transfer useful information. This simply adds to the demands placed on operators requiring them to constantly pursue information. Another major shortcoming of their chat capability is the inability to collaborate and exchange information beyond text.

The second category, and perhaps a greater impediment, involves organizational and social constraints that minimize information sharing. Compounding the technical challenges, the organizational barriers to collaboration present a different problem set. There is a culture in the space domain that predisposes most stakeholders to guard their information. Most owner/operators are reluctant to share asset data whether experiencing an anomaly or just providing status updates. This is unfortunate because the owner/operators generally have the most accurate and timely data pertaining to their satellite. These operational satellites are often maneuvered to optimize their orbits in order to fulfill their mission. JSpOC may not detect maneuvers initially, thereby propagating increasing error in their track estimation or causing them to "lose" a satellite if they are unable to correlate new observations with what it thinks should be the known track. Operator updated element sets can provide JSpOC with the ability to generate more useful satellite ephemerides which lead to improved conjunction assessment and cataloging.

2. METHOD

Enhancing Collaboration with Proxy Agents

Our approach, entitled Space Collaboration via an Agent Network (SCAN), enables proxy software agents to represent stakeholders (as individuals and organizations) to enhance collaboration among various agency producers and consumers of space information The agent-based approach is uniquely capable of addressing the collaboration challenges from both the technical and organizational perspectives. The SCAN agent network can facilitate collaboration by identifying opportunities to collaborate, as well as optimize the processes given the mission context.

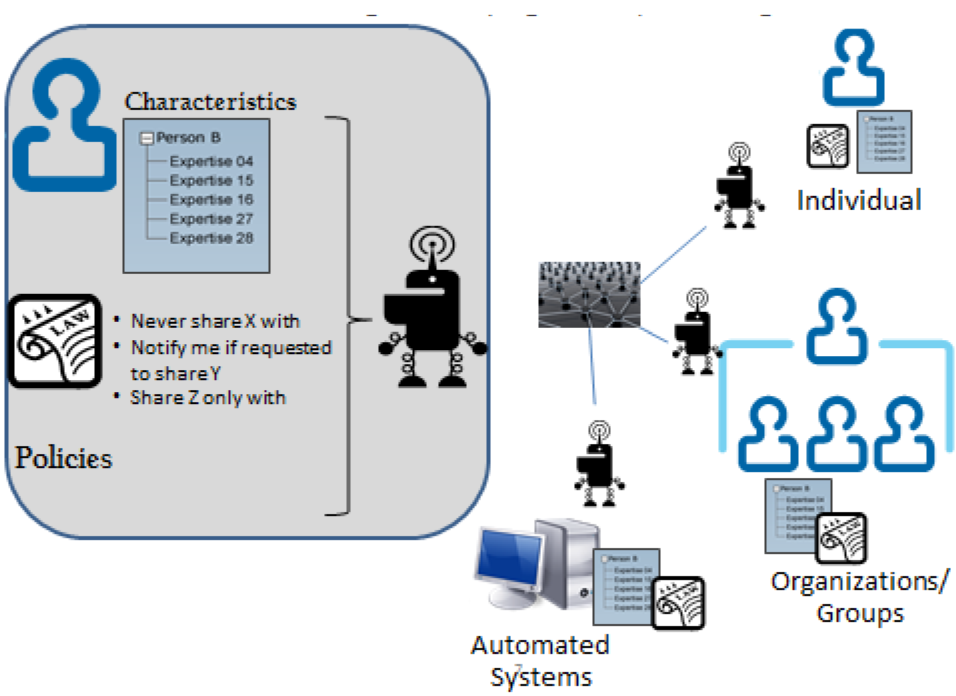

Figure 1. SCAN proxy agents. Each agent contains representative characteristics (capabilities, expertise, etc.) and sharing policies governing what and with whom it is willing to share and interact.

To construct an interaction environment as well as the rules governing collaboration and interaction, Aptima has leveraged two core capabilities for our human-centered engineering approach. The first is a framework that stores data and facilitates data exchange in order to establish and communicate important contextual information ranging from mission elements to operator characteristics. The second is an optimization approach called a Markov Decision Process (MDP), that computes and manages collaboration in terms of information sharing and teaming policies.

Context: Common Context Representation Framework (CCRF)
From a recurring need to better organize mission-based information, Aptima developed the Common Context Representation Framework (CCRF) specifically to improve the storage and exchange of mission and user profile data [3]. For humans and automated systems to effectively perform tasks in a shared environment, all participants need access to a consistent representation of the context for those tasks. This context consists of the tasks themselves, the environment, the goals and capabilities of the people and systems involved, as well as the interactions between the various elements (Figure 3).

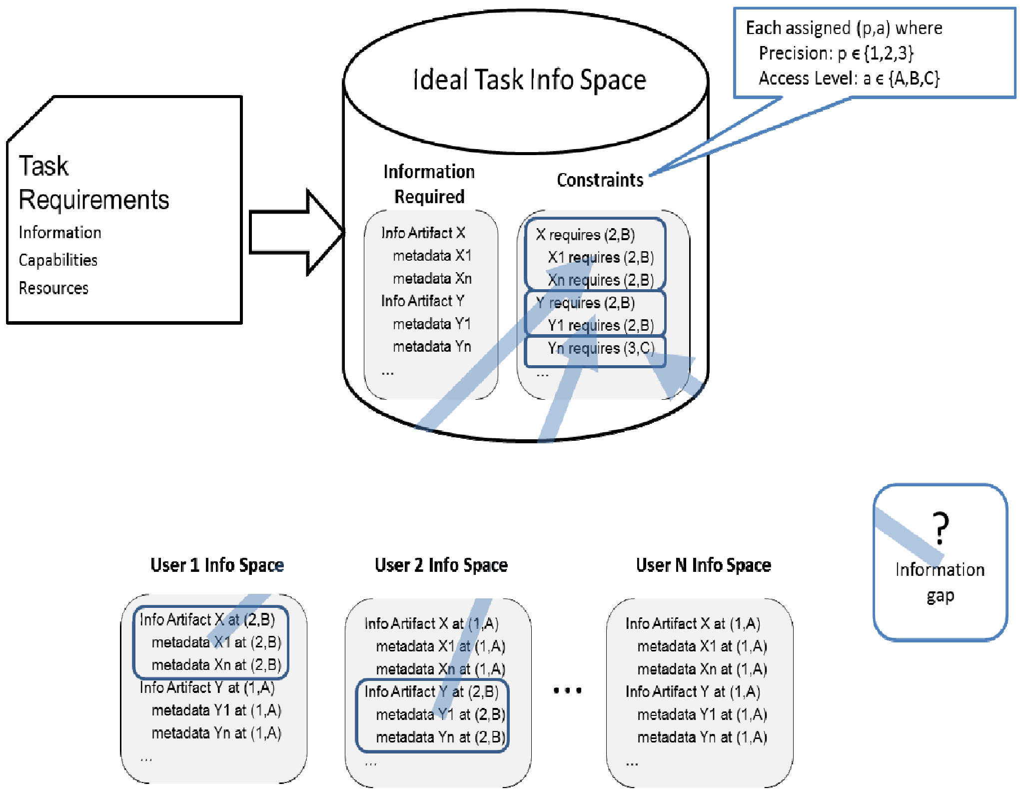

Figure 2 .Information Model and Collaboration. The information space is composed of a set of information artifacts and metadata, as well as a set of criteria for each piece of data that specify the precision level needed and the security level required to access that data at that precision.

A significant challenge when developing this model of context is in representing it at a level of abstraction that is understandable to a human and usable by an automated system. If the context is modeled at a level most natural for a human, meaning high level concepts and natural language, the machine will require advanced natural language processing and artificial intelligence techniques to understand and act on it. If the context is defined at the level that is most natural for a machine, meaning vectors, matrices, and complex data structures, the burden is placed on the human to make sense of a mass of low level data. What is needed is a contextual representation for the performance of tasks that bridges the gap between humans and machines. The solution should make conceptual sense to humans while remaining usable by a wide range of computing technologies.

The CCRF Abstraction provides a framework for representing the types of information needed for synthetic entities to interact with each other, and more importantly, to interact and cooperate with human users in the process of pursuing common goals. The CCRF Abstraction is divided into five main categories of information: *Environment* - A description of the state of the world relevant to the system. The CCRF environment is the interface to the world, whether that world is virtual or real, and filled with abstract concepts or concrete objects; *Performers* - A description of the actors or users operating within the environment. A performer can represent a decision maker that is able to take actions within the system, as well as an organization made up of decision makers. A performer might be a software agent residing on a server or a human interacting with a user interface; *Mission* - A description of goals, tasks that will contribute to achieving those goals, and the plans that can be enacted to accomplish those tasks; *Interactions* - A description of the various communications and actions that can take place between performers and/or resources in the environment; *Domain Model* - A description of the domain concepts necessary to bind the abstract concepts mentioned above to a real-world application domain.

Optimization Markove Decision Process (MDP)
To achieve these objectives, we are employing a modeling approach based on a Markov decision process (MDP). MDPs are very general models for optimizing decisions under uncertainty. Given the extent and dispersion of data, numerous stakeholders, and uncertainty of the physical quantities typically of interest, uncertainty is an inherent part of the collaborative computations. The key aspect of MDPs is that it is a sequential model, not only does it represent uncertainty for single decisions and outcomes, but estimates the state of the world in the future and optimizes decisions based on these future expectations.
An MDP is defined by a tuple, <S,A,P,R>.

S represents the State Space of the MDP. A state is a member of the state space, and represents a snapshot of the status of the agency at any given point in time

A represents the Action Space of the MDP. Actions are simply to request a collaboration or to accept one. Actions can be described in terms of their ability to change the state.

P is a table which represents the effects of taking actions, from each state. The effects are often probabilistic.

R is a table which specifies the reward for taking an action, or being in a state. Reward will often depend on priority of the task.

In brief, at each given point in time, each agent is assumed to be in a state S, which represents its status. It picks an action from set A, which will change its state. The effects of the action are modeled through a lookup into matrix P. The goal of the agent is to maximize its reward, represented in matrix R, over a series of steps [4]. The MDP is described in further detail below:
. In Phase I, we defined the State Space as a quantification of (1) the resource needs of the SCAN agent's agency and (2) the resource availability of the other agencies. In Phase II, we propose to expand the state to include a fuller description of the agencies' status, including information about relevant properties of the resources available and required, and information such as security concerns that would affect the availability of a collaboration. Most importantly, we propose to expand the number of resources that a SCAN agent can account for, so that the agent can automate requests for many collaborations at once.

As a simple example, a Collaboratee may be in a state where two experts are available to participate in a collaboration.. A Collaborator requests access to one of those experts, and the request makes its way to the Collaboratee's SCAN agent. The action of making that expert available will have an effect of changing the Collaboratee's state to having one free expert. The reward for this collaboration is a large number if the collaboration is high priority, and a smaller number if the collaboration is low priority.
The output of the algorithm is a policy for the SCAN agent. On the Collaborator side, the agent policy will be a plan as to where to secure resources, based on its models of the other agencies. On the Collaboratee side, the agent will plan how to allocate its resources. For example the agent may deny a low priority collaboration, because the agent anticipates that the resources will be needed for a higher priority collaboration at a slightly later point in time.

3. CONCLUSION

Comprehensive Space Situational Awareness (SSA) requires the marshaling of disparate mission critical elements. The mission threads reliant on SSA are complex and often require analysis from a diverse team of experts with sophisticated systems and tools that may be dispersed across multiple entities including military, commercial, and public interests. Two significant trends are likely to further perpetuate this state of affairs: 1) the space environment continues to be more congested, contested, and competitive, and 2) further pressures to increase *SSA Sharing* with a greater number of stakeholders throughout the world. The challenge of delivering the right information to the right people, while protecting national security and privacy interests, is in need of an innovative solution.

The JSpOC Mission System (JMS) under development is a promising step for integrating space superiority needs and supporting collaboration. The goal is even more ambitious than just marshaling assets for SSA. The JMS integration also includes responsibilities pertaining to Space C2 and Space Threat Characterization resulting in a subset of responsibility that includes [5]:

> *Catalog Maintenance; Maneuver; Maintain Force Status; Ground Attack; High-/Low-Energy Laser; Proximity Operations; Commercial & Foreign Entities; Orbital Safety; Direct Ascent Anti-satellite (ASAT); Space Nuclear Detonation (NUDET); Breakup/Separation; Decay/Re-entry; Launch; Co-Orbital ASAT; and Electromagnetic Interference (EMI)*

These important but varied missions exacerbate the problem of distributed expertise and data outlined above. This diverse set of responsibilities results in higher probabilities that the needed assets and information reside in a network that is increasingly distributed. There is a critical need to not only facilitate, but enhance collaboration between personnel, systems, and organizations to fulfill the numerous space missions.

The solution is not simply a matter of improved technology. Multinational coordination requires the right tools, procedures, and mindset to address the substantial challenges arising from disparities in: human-computer interfaces; multi-level security and access; culture; and command structure. Coordinated solutions of people, technology, and organizational optimization are needed.

4. REFERENCES

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