Benefits of Applying Predictive Intelligence to the Space Situational Awareness (SSA) Mission

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Abstract

Recent events have heightened the interest in providing improved Space Situational Awareness (SSA) to the warfighter using novel techniques that are affordable and effective. The current Space Surveillance Network (SSN) detects, tracks, catalogs and identifies artificial objects orbiting earth and provides information on Resident Space Objects (RSO) as well as new foreign launch (NFL) satellites. The reactive nature of the SSN provides little to no warning on changes to the expected states of these RSOs or NFLs.

This paper will detail the use of the historical data collected on RSOs to characterize what their steady state is, proactively help identify when changes or anomalies have occurred using a pattern-of-life activity based intelligence (ABI) approach, and apply dynamic, adaptive mission planning to the observables that lead up to a NFL.

Multiple hypotheses will be carried along with the intent or the changes to the steady state to assist the SSN in tasking the various sensors in the network to collect the relevant data needed to help prune the number of hypotheses by assigning likelihood to each of those activities. Depending on the hypothesis and thresholds set, these likelihoods will then be used in turn to alert the SSN operator with changes to the steady state, prioritize additional data collections, and provide a watch list of likely next activities.

Introduction

The United States Space Surveillance Network (SSN) detects, tracks, catalogs and identifies artificial Earth Satellites or Resident Space Objects (RSOs) on a daily basis. The SSN provides orbital data to the Satellite Catalog, a database of over 22,000 objects 10 cm or larger in size[1]. Various organizations use the Space Catalog to determine safe usage of their satellites, including planned orbits, on-orbit assessment, and future conjunctions of other objects.

Due to the current limits of the SSN (number of dedicated and contributing sensors, geographic distribution of the sensors, their capability and availability, processing and collection power, etc.), not all objects can be as closely monitored as desired. During normal operations, the “steady-state” orbital data changes very slowly and requires only periodic track updates to maintain the accuracy of the ephemeris (Two-Line Elements (TLEs)) in the SSN Space Catalog. These anomalies may be detected if the object was monitored by the SSN and an analyst was able to detect the changes in the object’s state that are outside of the anticipated propagated track covariance since the last update. The processes of manually detecting and reacting to anomalous behavior is resource intensive and time consuming and are subject to the “luck-of-the-draw” as to whether they are detected with a high probability of success by the operators.

The primary focus of this paper is to use the current and historical SSN Space Catalog information as the input to an RSO pattern-of-life background database that will allow an Activity Based Intelligence Agent (ABIA) to detect changes that may be indicative of malicious activity in an automated fashion.

[1] See reference 1

Background

The current Space Surveillance Network (Figure 1) collects 380,000 to 420,000 observations each day. Due to limited resources, the sensors that make up the SSN "spot check" the objects that make up the Space Catalog rather than track them continually. Once the object's steady-state orbital parameters have been documented and updated, the majority of the observational data may not be archived for historical data analysis due the large data storage requirements needed. Further, the historical information on the objects themselves may not necessarily be saved or exploited for future use.

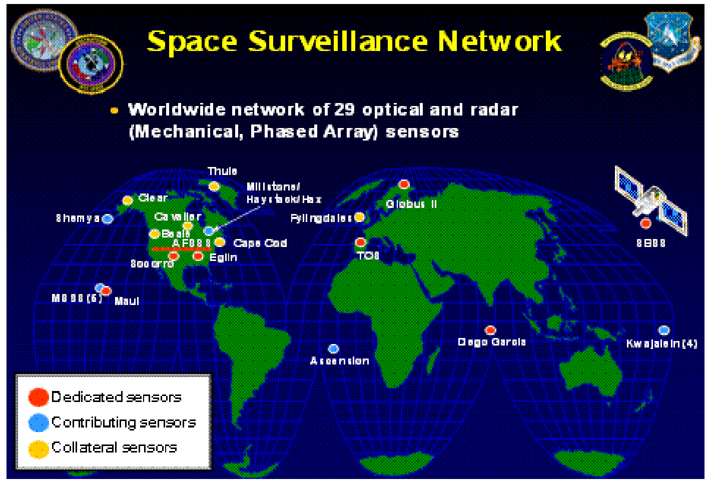

Figure 1. Space Surveillance Network illustration
(Source: https://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance)

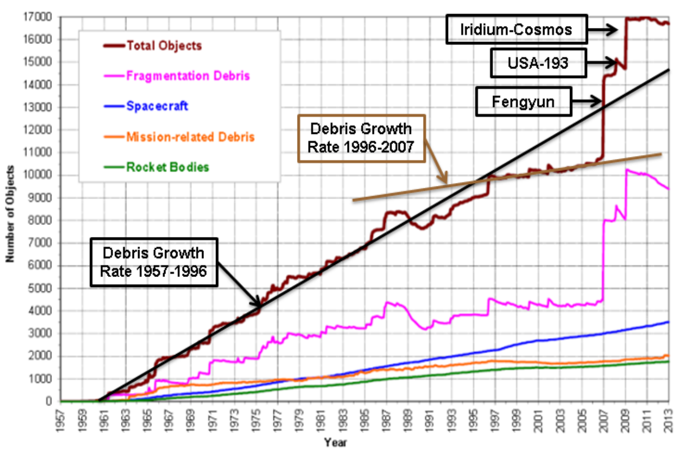

Figure 2. Number of objects in space over time
Source: (NASA Orbital Debris Program Office http://orbitaldebris.jsc.nasa.gov)

Collecting the orbital data on the objects that are contained in the existing Space Catalog needed to characterize and detect anomalous behavior is very challenging as the number of RSO's continues to grow. A simple plot of the number of objects as a function of time shows the complexity of maintaining and collecting on objects in space and can provide detailed associations and patterns, as shown in Figure 2. Optimal resource management may not be achieved due to the limited resources available as well as the timeline needed to make a decision. The increasing number of RSOs and the growing complexity of maintaining Space Domain Awareness (SDA) make the application of Activity-Based Intelligence (ABI) to the SDA mission a natural next step.

Activity-Based Intelligence has multiple definitions and is used synonymously with a multitude of other ideas. The definition that we will use in this paper as follows:

> *An application of intelligence analysis where the subsequent data collection is focused on the activity and transactions associated with an entity, a population, or region of interest.*

One usage of ABI compares data to events that make up a pattern-of-life for an activity or string of activities. The events that make up the pattern-of-life can be categorized in four ways.

1. A "known known" is an event that we know about **and** know how the event will manifest itself. An example of a known known is a person is going to go to the grocery store and buy cereal.

2. A “known unknown” is an event that we know about but **do not** know how the event will manifest itself. An example of a known unknown is a person is going to go to the grocery store but we **do not** know why.
3. An “unknown known” is an event that we **do not** know about but we know how the event will manifest itself. An example of an unknown known is sometime, somewhere, someone will go to the grocery store and buy cereal.
4. Finally, an “unknown unknown” is an event that we **do not** know about and we **do not** know how the event will manifest itself. An example of an unknown unknown is sometime, somewhere; someone will go to a store and buy something.

Creating a pattern-of-life using the first three types of events are straightforward. Discovering the “unknown unknowns” is one of the toughest challenges today. Despite the difficulty, ABI has been successfully applied across multiple disciplines to help discover these “unknown unknowns,” including the following applications:

- Direct Marketing (Amazon, Google, Yahoo, etc. track your interests, purchases, and tailor ads and promotions accordingly)
- Entertainment & Gambling (Internet Sites, Casinos track of the patrons, Nevada Gaming Commission monitoring the Casinos)
- Customer Service Organizations (Average Wait Time, Customer Satisfaction, etc.)
- Computer Network Protection (Detecting Internal and external malicious activities)
- Intelligence Surveillance & Reconnaissance (ISR) (Counter IED, Arms Trafficking)
- Financial Fraud Detection (Bank Transfers, Debit and Credit Card Activities)
- Law Enforcement (Airport Security, DEA monitoring of Harbor activities)

All of these applications have a common thread of that serves as the core of Activity Based Intelligence: analyze historical data collected by sensors to identify associations, patterns, and outcomes to aid in data discovery, identify anomalous behavior, and to anticipate the unknown knowns.

Approach

Applying ABI to the SDA mission space can provide dynamic, optimal performance of resource tasking and automatic response to changes in orbits. Leveraging the existing SSN and its architecture, our approach would augment the current analysts as well as the sensor operators by providing them with a capability to provide critical information in a timely fashion as shown in Figure 3 below.

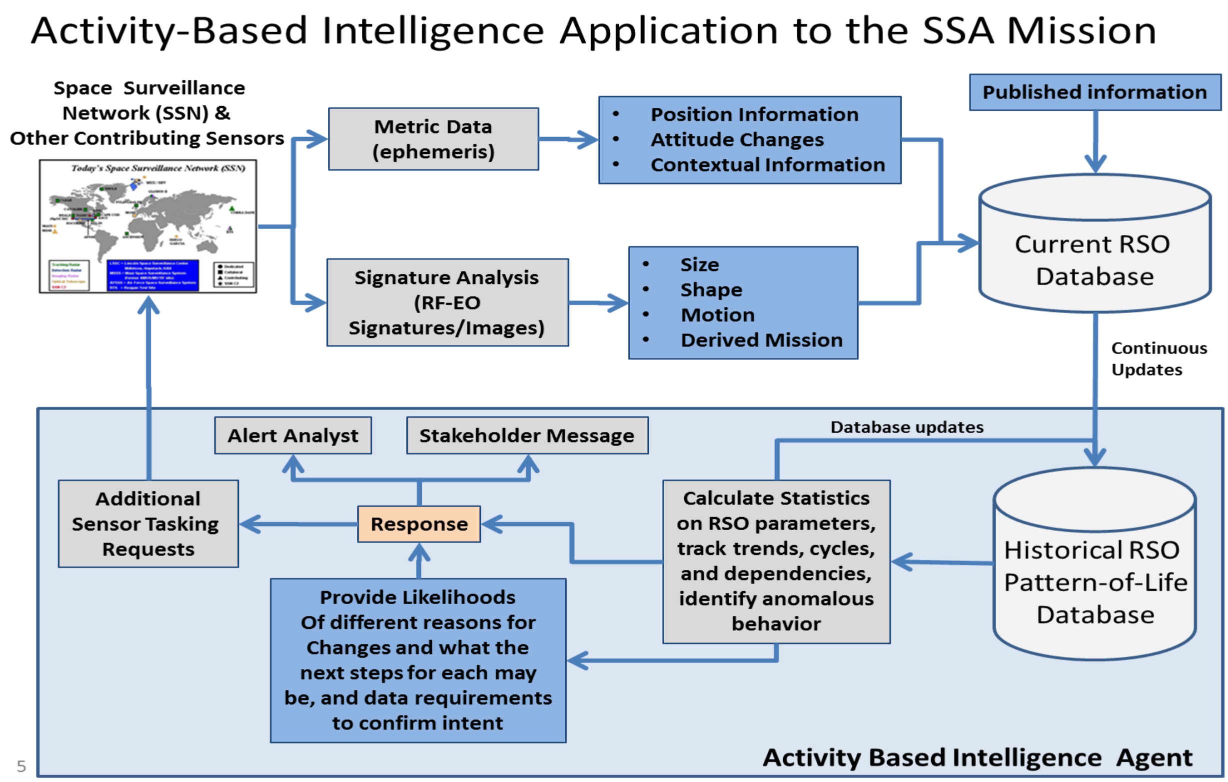

Figure 3. Top Level Flow Chart of How Activity Based Intelligence (ABI) Can Support the SSA Mission

First, the existing Space Catalog is "mined" for historical information to create the pattern-of-life database for objects of interest. The data that is included in the database is the metric data (ephemeris of each object), signature data (size, motion, etc.), and other information, such as published mission (weather, communications, etc.). The knowns and unknowns of the object are described and created in the database. The Activity Based Intelligence Agent (ABIA) has to not only have access to the historical RSO catalog data, but it also has to have the data pre-processed or conditions as it collects the information from the current RSO database and other sources. This step will help ensure data "sequence neutrality" and not perform integration or establish hard associations that may adversely affect the interpretation of the data by the ABIA. This is one of the challenges of ABI, to collect data without necessarily knowing whether it will be useful or not, and resist the pitfall of data "Integration Before Analysis". This challenge is exasperated by the fact that some of the associations (such as proximity) of the SSA mission are dynamic due to the relative motion of the ensemble of objects in orbit, but we would like to also keep track of their origins (object type, country of origin, etc.).

Next, the existing scheduled SSN sensors continue to perform updates to maintain the accuracy on Space Catalog and feed the data into an Activity-Based Intelligence Agent (ABIA) that monitor potential off-nominal pattern-of-life behavior, including changes in orbit, motion, orientation, configuration, tasking/operation, and/or conjunction with other objects. This is accomplished by a suite of algorithms used by the ABI Agent to build and analyze the large permutations of possible combinations of associations between past and events and predict likely outcomes. These algorithms are then integrated into a Decision Architecture (DA) that runs the appropriate algorithms in parallel depending on what portion of the "The Knowns" are being addressed. Results from the Decision Architecture are weighted based on the *a priori* probabilities, *post priori* likelihoods, and operator inputs/intervention. Ultimately the ABI Agent acts to assist the user/operator by elevating particular RSOs actions and possible intent to their attention.

If the ABIA detects a change to the steady-state of the object, the ABIA provides potential likelihoods of the behavior, the reasons for the behavior, and suggested responses for the next course of action. The ABIA also provides the system operator/user playback abilities that allow the operator/user to see the time progression forward & backwards of the data used to make the predictive alert to the operator. These responses may include alerting an SSN Operator, release a message or alert to the owner of the object, a tasking request for additional collects or information to the SSN, or reconstruct the orbit with finer accuracy and fidelity.

Finally, the ABIA updates the pattern-of-life database with the new information and continues to process the data that is being provided by the SSN. The pattern-of-life database is "living document" that continues to grow and provide support to the analyst and provide historical data to not only support ABIA, but also provide forensic support after a space based event (collision, intercept, etc.). In those cases, the forensic data can then be used to train the ABIA to help improve its performance on future "unknown unknown" events. Our vision for ABI for the SSA mission will provide the operator/user with a view of "What Has Happened" and "What May Happen" in the future. ABIA will assist the analyst on what indicators and events to be on the lookout for via a data driven timeline that allows the analyst to move forward and backward in time through the RSO data associated with the events of interest. The ABIA will assist the operator/user by continuously searching the database for data that support the multiple "What May Happen" hypotheses and provide the operator/user with the probability of those outcomes coming to fruition an illustrated in Figure 4.

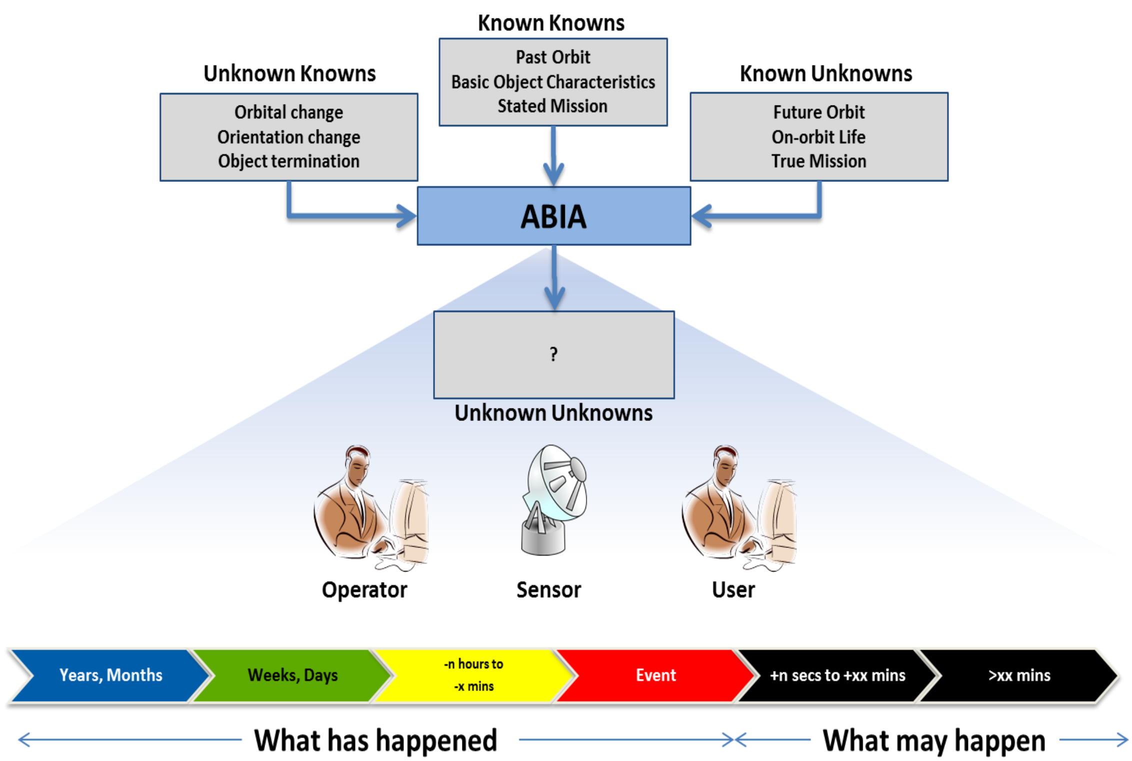

Figure 4. ABIA augments the SSN, finding the Unknown Unknowns and aiding the user/operator

Summary

All of the activities described above are done automatically to augment and aid the existing users and analysts of the SSN. The approach is designed to be human-on-the-loop, rather than "in" the loop. It aids the operator/analyst to focus on objects of interest and helps optimize the short timeline and limited resources of the SSN. ABI Reduces Operator Workload as the Number of RSO Continues to Increase the amount of data collected by the SSN on daily basis. It also provides the ability to generate tasking requests to SSN sensors and to computationally intensive object orbit determination software that could provide critical information needed for the next response or activity. ABI also aids the User/Operator by finding the "Unknown Unknowns" assisting the discoveries of RSO's actions and intent. No major change in the SSN operations is required; rather, it utilizes data that is already being collected and provides operator/analyst with information for an actionable response. Finally, ABI Will Provide the SSA/SDA Community low Cost High Payoff Capabilities and addresses the "Big Data" aspect of the SSA Mission as both the number of sensors in the SSN and number of RSOs increase in the future.

Acknowledgements

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References

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2. https://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance