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Space Analysis and Research Centers (SpARCs) **for Sharing and Utilizing SSA Data**

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Abstract

Widespread use of massive data and increasing reliance on space-based infrastructure are two of the emerging megatrends of the early 21st century. However, both come with liabilities: movement and processing of large data volumes is very expensive, and reliance on space-based infrastructure adds risk that problems in the still incompletely-understood space domain might cause work disruptions.

ExoAnalytic proposes the use of Space Analysis and Research Centers (SpARCs) to begin addressing both these issues. A SpARC is a facility which integrates volumes of data collected on satellites, centrally analyzes it, and makes available resulting useful information. The SpARC serves as a customer clearinghouse and a home for informed R&D centered around using data streams to extract useful information while limiting resources spent on moving vast data volumes. Accordingly, a SpARC would possess a systems-oriented research arm as well as a service-oriented customer arm. Housing these functions together matures both in tandem as institutional knowledge and experience related to the still-burgeoning SSA domain grows. In a future where research-derived knowledge of the space domain may grow as rapidly as business-driven utilization of the domain, it is important to have institutional constructs which are specifically designed to serve both needs. A SpARC is uniquely suited to this purpose.

ExoAnalytic has developed a concept for a commercial SpARC, to interface among and provide information to government, commercial, and academic users, and is working to stand up an internal proto-SpARC, followed by one or more operational SpARCs customized for customer needs.

Introduction

This paper introduces the concept of a Space Analysis and Research Center (SpARC) as a vehicle for collaboration between stakeholders in the space operations domain, describes how a SpARC might be architected and function, and lists several potential areas of interest where a SpARC might immediately take effective action. The analysis and use of space domain observation data can be a focal point for SpARC activities.

Widespread use of massive amounts of data is one of the emerging megatrends of the early 21st century. However, extracting valuable knowledge from big data requires both specific domain knowledge and a broad understanding of the mechanics of massive data analytics. Because some of these mechanics are similar between otherwise-separate domains of data (especially in domains of complex data, such as health data and surveillance imagery data), leveraging algorithms and translating between different domains can be a powerful means of understanding data. Like traditional domains, the space domain provides critical information which decision-makers must understand in real-time to make timely, effective decisions which preserve their advantage and enable continued provision of space-based services. A key contributing source of intelligence in the Space Domain is the information provided by detailed Space Situational Awareness.

Space Situational Awareness is the required knowledge to predict, deter, operate through, recover from, or attribute cause to the loss or degradation of space capabilities and services. As such, SSA is an interdisciplinary research problem which poses many challenges and represents a significant opportunity for commercial advancement and technical innovation in support of national defense and the private sector. Compounding the complexity of performing confident SSA data analysis is that the space domain observation infrastructure, the very backbone of Space Domain News Extraction which forms the underpinnings of Space Situational Awareness, has historically been addressed as a sparse data problem. Few observations were required to achieve modest understanding of objects in the space domain. Metric observations of limited quantity could maintain stable orbits of large satellites with limited mission capabilities, while infrequent but detailed photometric analyses were employed mostly during anomaly resolution and specific object-of-interest intelligence assessments. Today there are several trends motivating a revolution which brings SSA into the 21st century, joining other Big Data domains. These include the realization that space may be a congested and contested domain. The growing proliferation rate of small spacecraft companies like BlackSky Global and OneWeb and their planned *constellations from ten to one hundred times more numerous than the largest constellations* flown to date, combined with new thruster technology, *e.g.* electric propulsion, are leading to much *more dynamic mission behaviors demonstrated by larger numbers of actors in space than ever before.*

Recent legislation, like the American Space Renaissance Act currently in the US House of Representatives, suggests SSA functions should be performed primarily by civil agencies (including academia and industry), with government agencies in a supportive role. In the past two years, the commercial sector has begun to play a more important role in SSA, with the ExoAnalytic Ground Telescope Network (EGTN) and AGI Commercial Space Operations Center or (ComSpOC) providing significant performance in support of satellite owner-operator customers. Within the government, the Joint Space Operations Center (JSpOC) and the newly-authorized Joint Interagency Combined Space Operations Center (JICSpOC) perform 24/7 detection and tracking of more than 22,000 objects larger than 10 cm in diameter, and warn space operators of potential conjunctions.

Because the requirements for integrating technology into a national space operations center often necessitate using proven, validated, and locked-in software tools, it makes effective fusion of these tools difficult and potentially ad-hoc. Furthermore, the data sets that are available often consist of electro-optical sensor imagery that has been reduced to simple angles and brightness information. The original image data at the pixel level is not saved and archived, and forensic analysis of missed detections is not well supported. Additionally, it is difficult to add new sensors to SSA detection networks, in that new sensors must be shown to add operational value while doing no harm to the system. These are barriers to effective deep research and result-sharing of the kind which would do the most to advance the state of the art in SSA.

However, leaving such operational concerns to the large institutions (such as national governments) which typically conduct them allows smaller, more agile institutions to focus on research and developing new tools. A SpARC built around access to real data could provide this capability.

SpARC Stakeholders

A SpARC is meant to be an institutional structure permitting interaction among the various major stakeholders in the space domain. These stakeholders typically emerge from academia, government, and private industry, although secondary and tertiary stakeholders consist in part of nearly all elements of society that are affected or potentially affected by the use of infrastructure contained in or dependent upon the space domain. That includes everyone who relies on satellite communications (including television and mobile voice or data links), GPS positioning units, or weather data.

We may model the general stakeholder chain for a SpARC as consisting of four elements: a data collector, a news extractor, a news/data disseminator, and a news/data user. The term “news,” as used in this paper, refers to information that is of actual interest (as opposed to noise or irrelevant data), and “news extraction” refers to the generation of this information from a raw data stream. Typically, news is of smaller bit size than raw data, and as such is easier to store, transmit, and access than is a raw data stream. As such, news is a more valuable end product than raw data, in most situations. (News is distinguished from any processed data in that processed data may or may not contain information of interest or value.)

A data collector may be anyone with a sensor and the ability to operate it. A news extractor may be anyone with the ability to code an algorithm that extracts news of any kind from space data. A disseminator is, in the modern world, anybody who happens to own an internet connection. A user can be anyone who has an interest in space domain activities and infrastructure. Again, in the modern world, this may be almost everyone.

Sensor data, however, sees increases in the amount of news that can potentially be extracted as a nonlinear function of several characteristics of the dataset, including size and variety. As such, a general corollary is that more and larger sensor networks produce commensurately better and more news-filled data than sensors that are few and isolated.

Sensor data news extraction depends on the presence of domain knowledge, specialized knowledge, and the ability to use algorithms on data to generate news.

Disseminators of news or raw data can be anyone. In fact, secondary and tertiary dissemination of news or data may be valuable. Similarly, users can be anyone. Therefore, we may state that SpARCs are open-ended at these levels of the stakeholder chain.

At the other side, however, SpARCs are narrow – there are limited organizations or individuals that can perform news extraction, and fewer that can perform data collection. A SpARC provides a way for all four of these stakeholder classes to interact, and may be built on a key subset of data providers and news extraction providers.

Figure 1 shows a general version of the stakeholder chain, with a simplified description for each vertical element included as well.

<u>Stakeholder Chain</u> <u>(General)</u>	<u>Stakeholder</u> <u>Chain</u> <u>(Simplified)</u>
Collector	Sensor Owner
Extractor	Algorithm Owner
Disseminator	ISP customer
User	Space Beneficiary

Figure 1: Simplification of space data stakeholder chain.

Figure 2 shows several notional examples of stakeholder chains, including for government, commercial, and academic sectors.

<u>Stakeholder Chain (General)</u>	<u>Stakeholder Chain – Government</u>	<u>Stakeholder Chain - Commercial</u>	<u>Stakeholder Chain - Academic</u>
Data Collector	GEODSS/SSN	ExoAnalytic Global Telescope Network	University Partners
News Extractor	JSpOC	ExoAnalytic tools	University
Disseminator	AFSCN	Space Data Association	AIAA / JSR
User	GPS SPO	Satellite Owner/Operator	Spacecraft builders

Figure 2: Notional examples of stakeholder chains for space data.

Examples of actions that may occur along a stakeholder chain include:

1: Government stakeholder chain

Astrometric data collection – precise orbit determination – ephemeris update – GPS operator

In this example, astrometric data (RSO right ascension and declination from a known site on Earth’s surface at a known time) is used to develop an estimate for the current orbital elements of the RSO, at high precision. When applied to a position beacon satellite, such as GPS, this permits external updating of the RSO’s ephemeris, assisting the operating office in maintaining high-quality signals from the satellite.

2: Commercial stakeholder chain

Astrometric data collection – orbit determination – collision alert – satellite owner/operator

In this example, astrometric data (RSO right ascension and declination from a known site on Earth’s surface at a known time) is used to develop an estimate for the current orbital elements of the RSO, at high precision. Comparing these orbital elements to other tabulated elements permits prediction of impending collisions, and the dissemination of alerts about these events permits satellite owner/operators to take action to avoid collisions.

3: Academic stakeholder chain

Photometric data collection – lightcurve analysis – solar array degradation model – solar array designers

In this example, photometric data (the visual magnitude of the RSO) can be used to perform analysis of the changes in the sunlight reflected by the RSO over time. Careful analysis of this data might be applied to determining whether the amount of reflected light is changing over time, which could be correlated to the gradual aging and performance degradation of solar power arrays over a satellite’s lifetime. Developing a validated model for this process could be the subject of academic papers, which might then serve to influence the design of future solar power arrays.

These three examples show possible steps that can be taken at each of the four levels of the stakeholder chain. Notably, crossover between parts of the stakeholder chain is very possible. For instance, data collected by a university or commercial organization can be used to perform external ephemeris updates on satellites that require precise position knowledge (such as GPS), and in fact the canonical case for collision avoidance is for data collected by the US government and analyzed by the JSpOC to be used to disseminate collision avoidance information to commercial satellite owner/operators.

One of the functions of a SpARC would be to develop and improve methods for integrating the stakeholder chain both vertically (from data collectors to users) and horizontally (across government, academia, and the commercial sector).

SpARC Goals

By integrating members of these groups under one roof, a SpARC can:

- (1) **Allow the entire world to contribute technology at appropriate levels of security**
 - a. For early technology algorithm development and assessment, anyone may collaborate in a SpARC to access data which supports evaluation of their technology to address any relevant challenge, e.g. those listed above
 - b. Support academic study where the technology shows great promise
 - c. Produce notable academic research (technical papers) on SSA and the SpARC concept.
- (2) **Operate a farm-team system for new space domain news extraction technology**
 - a. Facilitate tool submissions to transition testing and operational environments.
 - b. Demonstrate modeling of the sensor architectures supporting operational SSA today.
 - c. Enable technical utility assessments for augmented sensor architecture concepts.
- (3) **Take advantage of unique positioning in multiple technology sectors to become centers of gravity for research and education in SSA**
 - a. Develop lines of academic research that cross Big Data and traditional SSA barriers.
 - b. Collaborate with universities on exposure to SSA data, algorithms, and theory.
 - c. Collaborate with emerging high-tech sectors in other complex, data-rich fields.

SpARC Design and Operations

A SpARC is a collaborative framework. ExoAnalytic, envisioning playing a key role as a data provider, has a corporate vision for space domain news extraction and its critical role in supporting all actors in the space domain, wherein its existing telescope network of more than 125 networked, automated telescopes on 5 continents and Hawaii could be as a key data source for a SpARC. Figure 3 shows the state of this network, including planned expansions in 2017.



Figure 3: ExoAnalytic Global Telescope Network.

Connecting SSA domain expertise and relevant outside expertise, especially from academia, is a key challenge. ExoAnalytic hopes to address this by standing up a prototype corporate SpARC in the near future, to pilot the concept, kickstart collaborations, and examine the potential for a SpARC to grow in tandem with SSA operational research.

SpARC Activities - General

The goal of standing up a prototype SpARC is to enable deeper domain awareness on tactical timelines in support of space actors' decision process. Key to achieving this goal are two activities which may be hosted within SpARC facilities.

First is the *frequent interchange between tool developers/news extractors pushing the state of the art and those who directly support the users*. Training of personnel on new phenomena, processing tools, and emerging options for analysis, visualization, and reporting, and training of developers on emerging needs of users resulting from experience are both key elements. Bilateral feedback between both sides will provide increasingly effective technology to meet user needs.

Second is *support of direct operational deployment of tools*. When a provided tool has become trusted to a point where it is used routinely in operations, requires little interaction from users, and is instrumental in informing a decision process, it may be automated and executed within the operating facility, or deployed directly to computational resources at the sensor. (An example of existing direct operational deployment already exists in the accepted approach to the reduction of pixels at the sensor sites and reporting of right ascension and declination values back to the operations centers to increase efficiency). As the number of sources of data increases at an accelerating rate, and as new sources of information emerge, this deployment method will ease bandwidth-driven limitations. This is critically important should in-depth modeling be desired in support of operational decisions.

SpARC Activities - Specific

While the space domain contains many worthy academic problems, the solutions to which will push the state of the art, and the investigation whereof will doubtless open up multiple additional avenues of research, connecting these results to practical, useful, actionable outcomes that are of immediate interest to paying customers is a separate problem.

SpARCs can serve to support and channel research into open-ended solutions, while also directing attention to specific practical problems. Accordingly, we suggest that SpARCs be structured to address specific issues such as:

- The ability to review missed detections (via forensic review of collected data) would add major robustness to the existing SSA architecture.
- The ability to assess new sensors using realistic situations (derived from operational data) would ensure that the SSA architecture stays abreast of challenges by incorporating new technologies on a regular basis.

These two lines of approach could be centerpieces for new SpARCs. There are potentially numerous other lines of approach that members of the space community may wish to propose as SpARC collaborations.

Conclusion

Space Analysis and Research Centers will enable collaborative development of analytical approaches to the use of space domain observation data. ExoAnalytic is interested in establishing a prototype commercial SpARC facility to test the concept and generate initial products and research. Within the SpARCs, data access can be granted to collaborators for developing and testing algorithms before deploying them. This makes SpARC facilities valuable resources for academic research and development, as well as commercial and government purposes. As the SpARC concept and supporting technology matures, more SpARCs, possibly with specific focuses, may also be created.