Toward unified query processing for ISR information needs and collection management

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ABSTRACT

The advance in sensing technologies, the acquisition of new sensors, and use of mobile devices result in the production of an overwhelming amount of sensed data, that augment the challenges for analysts to retrieve relevant information among heterogeneous collected data, and to process and analyze them adequately in a timely manner to better support decision makers. At the same time, the limited quantity and capabilities of intelligence, surveillance and reconnaissance (ISR) resources for the amount of requests for information collection requires to maximize their utilization in order to increase the accuracy of information gain and timely delivery of information. Considering the challenges for ISR intelligence requirements and collection management, as well as for information management and exploitation, the paper describes a unified approach for querying available information sources for enhanced ISR information collection and retrieval. The approach leverages and extends semantic models in the ISR domain. Enhanced ISR assets integration, optimized information collection and management should result in more relevant collected data and improve subsequent analysis.

Keywords: Intelligence Surveillance Reconnaissance, information requirements, information collection, ontology, sensor allocation

1. INTRODUCTION

The advance in sensing technologies, the acquisition of new sensors, and use of mobile devices result in the production of an overwhelming amount of sensed data, that augment the challenges to retrieve relevant information among heterogeneous collected data. In addition, the limited quantity and capabilities of intelligence, surveillance, and reconnaissance (ISR) resources to process multiple requests for information collection requires to maximize their utilization in order to increase the accuracy of the information gain and timely delivery of information.

From a holistic perspective, our research efforts are related to the concept of Total ISR asset visibility, which encompasses ISR asset visibility, ISR collection requirements visibility, and ISR intelligence, information and data visibility as introduced in the US Commander's Handbook for Persistent Surveillance[1].

- ISR Asset Visibility is required for commanders and collection managers to gain awareness of ISR assets to better plan and synchronize operations. Visibility of ISR assets thus reduces redundancy of similar collection requirements and also enhances cross-cueing of ISR assets.
- Collection Requirements Visibility within the area of operations and adjacent areas across all echelons is necessary to allow planners to combine similar collection requests and make best use of the available collection capacity.
- Intelligence, Information, and Data Visibility assist intelligence commanders and collection managers to more effectively plan, prepare, execute, and assess persistent surveillance missions. It can also reduce unnecessary collection tasks by satisfying collection requirements with information that has already been collected.

We first suggest that automated support for ISR asset visibility can be facilitated by defining a formal description of existing ISR assets (platforms/sensors) capabilities, location, availability, etc., so that this knowledge can be accessible and discoverable by tools as required. This aims at optimizing the utilization of any information sources available, considering limited ISR resources and to maximize information gain to fill intelligence gaps. The goal is to provide collection managers, analysts, soldiers, with decision aids tools to determine best asset suitability for collection requirements for better data exploitation, and ultimately to enhance commanders' situational awareness so that timely and informed decisions can be made. Enhanced ISR data visibility is also critical to ensure that data that is relevant against specific information requirements can be retrieved and provided to the consumers (e.g. analysts) who need it.

Such decision aid tools should help answering questions such as: Have we already collected data that meet specific information requirements (IRs)? What deployed assets best answer specific IRs?

In our context, an ISR information source is any information producer or container that can deliver information to consumers (analysts, planners, decision makers). It can be either a physical sensor or a human source from which data can be collected, or an information container (e.g. database) from which information can be retrieved.

We consider a unified approach for the querying or tasking of both types of information sources, given specific information requirements. However, collection assets have their own characteristics in terms the type of information they can deliver, the cost and risk of the collection depending on the mission context (operational environment), the time to deliver information, etc. These elements must also be taken into account when planning intelligence collection and tasking suitable collection assets.

Research for the development of sensor ontologies providing rich semantic descriptions of sensor capabilities and properties is active and has demonstrated benefits for sensor integration, ISR resource tasking and information fusion. Efforts in this area can be leveraged as a foundation and extended to meet the requirements of our research.

The paper is organized as follows. In the next section, we review the main steps of the intelligence cycle and Intelligence Requirements Management (IRM) and Collection Management (CM) processes. Then, we highlight some of the challenges facing collection managers, and requirements for improvement and automation in support of some processes. In order to optimize the collection and retrieval of ISR information, a unified querying approach is proposed and presented. In particular, the use of a common vocabulary for question answering, enhanced information management, and decision aids are recommended. We then present the contribution of semantic models and their exploitation. We conclude with complementary remarks and perspectives for future work.

2. INTELLIGENCE REQUIREMENTS MANAGEMENT AND COLLECTION MANAGEMENT

2.1 Intelligence cycle and ISR

According to the Canadian Joint Intelligence Doctrine[2], the intelligence cycle is composed of four steps, namely direction, collection, processing, and dissemination, starting from defining what the decision-maker needs to know, to the reception of the answer that he asked for. The Direction phase consists of determining the intelligence requirements, planning the collection effort, issuing orders and requests to collection agencies and maintaining a continuous check on the productivity of such agencies. Collection is the process during which information and intelligence are collected from sources and agencies in order to meet the intelligence requirements.

ISR is an important aspect of the intelligence cycle. It is defined as the activities that synchronize and integrate the planning and operation of collection capabilities, including the processing and dissemination of the resulting product. ISR requires coordination/synchronization and integration.

Intelligence Management Requirements (IRM) and Collection Management (CM) are at the center of the intelligence cycle and ISR activities, as they deal with the coordination of these activities. The underlying processes help validate and refine the intelligence requirements, determine how they can best be satisfied, and coordinate collection tasks to meet the requirements.

The following figure provides details about the intelligence cycle and its relation with the collection management process.

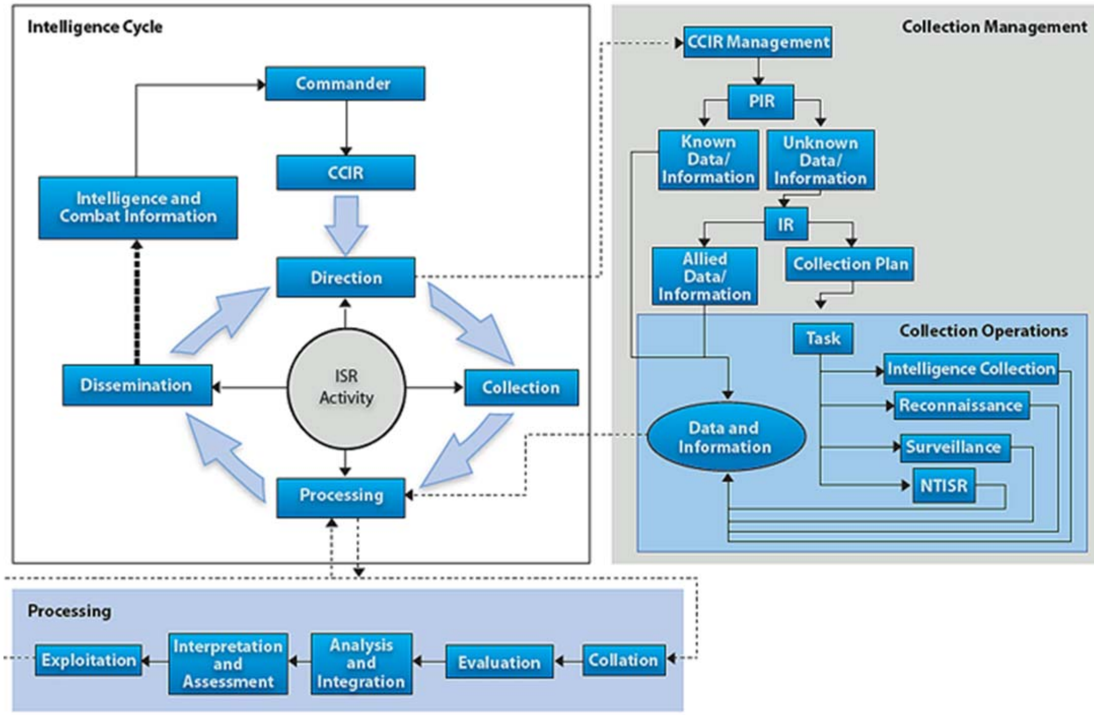

Figure 1. Intelligence cycle and collection management (from RCAF aerospace sense doctrine[3]).

2.2 Overview of IRM&CM processes

IRM starts with intelligence requirements identified in the commander's critical information requirements (CCIR) concerning areas that are either critical to the success of the mission or represent a critical threat. These form the basis for Priority Intelligence Requirements (PIR), which are those intelligence requirements for which a commander has an anticipated and stated priority in his task of planning and decision making.

Each PIR may be further subdivided into a set of more detailed questions known as information requirements (IR) represent those items of information regarding the adversary and the environment that need to be collected and processed in order to satisfy the PIR. IR will be further broken out into indicators that are specific requests for information tasked to collectors. Indicators are positive or negative evidence of enemy activity, or any characteristic of the area of operations. They help to focus the collection effort and are multi-dimensional in terms of such elements as time, space, activities, routine, etc. Essential Elements of Information (EEI) add the details to the specific information requirements regarding the adversary or environment that allow the production of an intelligence collection plan. This artefact specifies the collection tasks assigned to specific information collection assets. Enough information has to be formulated for collectors to understand the what, where, when and why of anticipated collection tasks.

Before ISR assets are to be tasked for collection, IR managers have to make sure that the required information has not already been collected and stored in an ISR related database (e.g. NATO Coalition Shared Database), before planning for collection. If the information is not available, or if the required information is about some event/activity expected to happen, then the appropriate ISR collection asset(s) has to be identified based on the analysis of capabilities, availability, etc., and integrated into the Intelligence Collection Plan which provides details on how each IR is to be satisfied by the best suited assets or agencies.

Collection management is the production and coordination of the plans for the collection, processing and dissemination of intelligence. It is the process of transforming high-level intelligence requirements into collection requirements, tasking or coordinating with appropriate collection sources, monitoring results, and re-tasking as required.

A key activity consists of matching the validated and structured intelligence requirements to the available collection assets. This process must take into consideration the availability of assets, sensor coverage and communications capabilities, their location to the collection target, physical or technical abilities to collect, and the prioritization of mission requirements. Finally, sensor tasking consists of providing guidance to specific collection assets based on information expected from the collection task.

IRM and CM staff must ensure that collected data is being analyzed to the level of quality required and that the resulting product is disseminated timely in the right format to the consumers who need it. The use of standardized formats and metadata is required to allow the interpretation, sharing, and linking of IRs, plans and intelligence products.

3. AUTOMATION SUPPORT FOR IRM & CM

3.1 Introduction

IRM & CM still present challenges to collection managers. A recent study[4] identified gaps to be addressed for improving the efficiency and effectiveness of the information collection process and provided recommendations for algorithms and automated decision aid tools to alleviate manual-intensive intelligence requirement and collection management processes. Among them are mentioned:

- Effective synchronization of information collection planning and assessment activities requires data and information interoperability and visibility across echelons.
- Plan and assess information collection holistically, from information requirements development to execution.
- Centralized decision making must be supported by decentralized synchronization of information collection efforts.
- Enable the automatic identification and delivery of tailored, relevant data and information to the collection management team.
- Convert manual scheduling into automated scheduling.
- Collection management teams need to know the value of matching information collection tasks to information collection capabilities.
- Collection management teams need to know, in near-real time, platform and sensor readiness (health and status) across echelon-levels along with the information they can obtain.

These requirements are in line with the concepts of Total ISR assets visibility presented above.

Also, IRM&CM functions present information management challenges in order to enable seamless interoperability, communication and sharing of heterogeneous data/information elements. One important aspect is to provide a standardized representation of information, both for information collection and for the dissemination and exploitation of information and intelligence products.

In the following, we focus on some aspects of IRM & CM, in particular the specification of information requirements to facilitate automated interpretation, and the ISR collection planning and source tasking based on a rich semantic representation of key concepts utilized in the reasoning process, in particular sources capabilities, collection tasks, and contextual aspects of the operational environment.

3.2 Information sources querying

An information source is any source that can deliver information through a query-answering process. The types of information that may be requested range from raw sensor data to high-level intelligence products. Moreover, either the required information already exists and can be retrieved from some information container, or some ISR collection assets have to be tasked to fulfill the requirements. In both cases, there is a gap between users' high-level information requirements and the data that can be collected from sources (in terms of languages, data interpretability, etc.) that has to be resolved for effective collection. Moreover, there is a gap between the information requirements and the information that can be delivered from the sources because of their level of quality, inaccuracy, data uncertainty, etc., so that further information may be required.

Each type of source has its own mechanism to deliver information, so there are various ways to query sources based on the source capability to collect or retrieve relevant information.

When collected information is stored within a container (e.g. database) or made accessible from the source (e.g. internet) it is retrieved using a language specific to the source. In the case of relational databases, SQL is the query language to be used with specific domain terms that have been defined for the application of interest. The NATO ISR community has defined an ISR interoperability architecture and developed a set of standards to facilitate ISR information sharing among coalition nations. The NATO Coalition Shared Database (CSD) is structured according to the STANAG 4559 (ISR Library interface) which is a standard interface for querying and accessing products maintained by various nations. Data can be retrieved based on metadata such as location, time, or product type.

This is not sufficient if one aims to optimize intelligence collection and make sure information consumers' expectations are met. Enhanced search within information sources would require an enriched description of information objects that is not only based on basic metadata but is also related to its information content. This means to attach the description of activities/events observed, the actors, as well as useful elements in addition to metadata. This is particularly applicable for human reports, or imagery data and products (e.g. annotation of a significant event in a video clip). There exist several military domain taxonomies that can support this process, e.g. for surveillance/reconnaissance of military targets. Moreover, recent developed models about human activities or behaviors for event detection or activity recognition should be exploited.

From an information collection perspective, users should precisely describe what they need without knowledge of the characteristics of sensors and their observations. Their information requirements should be made very precise and unambiguous so that they are understood by a human operator operating in the field, but also interpretable by automated tools in the future. Consequently, an IR query language should be defined to facilitate the specification of unambiguous information requests so that their interpretation and subsequent query processing including the collection of data by tasking appropriate ISR assets is possible. To be able to transform IRs into specific collection tasks, the main parameters to be considered should include: What type of data is required in terms of observable? What level of precision and type of collection task is required to acquire that quality of data (e.g. detect a presence, vs identify a target), i.e. consider the source expected interpretability. Various categories of observables should be predefined along with their properties to support the process. Military categories of physical entities already exist in standardized forms. Categories of activities/events as well as human behaviors should also be modeled in a standardized representation in support of requirements specification and subsequent analysis. Moreover, requirements regarding the geospatial area to be considered, at what time data must be delivered, etc. should also be specified in a standardized format. This set of elements carefully represented should enable the transformation of information requirements into collection tasks with precise parameters.

This process will leverage ISR domain ontological models to facilitate the interpretation of queries and guide the related information retrieval and/or tasking processes. Advanced approaches in related work promote the use of human-machine interaction using Controlled English (e.g. CE-SAM[5]).

3.3 Sensor assignment for information collection

Once information requests have been interpreted unambiguously, decision aids provide recommendations about the ISR assets that best meet the information requirements, and ultimately translate these into sensor tasking. The analysis process for sensor assignment based on specific information requirements takes into account a number of elements about the ISR capabilities in order to determine their suitability to the collection task, as well as their availability, the area of observation (e.g. target location), the mission context and operational environment considerations. The analysis also has to consider additional factors about platforms/sensors including their cost, risk for deployment, etc.

Considering traditional physical sensors in a first stage for this sensor/IR matchmaking task, the definition of a common vocabulary for sensors, together with an expressive conceptualization of the sensors properties and capabilities/performance for the different categories of sensors considered is an enabler for solving this problem. Such knowledge bases populated with sensor data facilitates the sensor assignment problem but can also support additional reasoning tasks, e.g. suggest sensor cross-cueing in certain circumstances, i.e. tasking an imaging sensor to get more precise information about a target in a particular location based on data collected from an acoustic sensor.

A challenge is to have a thorough characterization of available information sources, but also make sure that the knowledge bases about the sensors are kept up to date with dynamic information such as sensor status/availability, location, etc.

4. EXPLOITATION OF ISR SEMANTIC MODELS

4.1 Introduction

In the ISR domain, either for collection management, resource allocation or multi-source information fusion, the formal representation of domain concepts in the form of a semantic model (ontology), including their characteristics, properties and relationships among them provides a foundation for a common vocabulary, metadata, and enhanced exploitation of the underlying data. The NATO ISR community has developed a set of standards to facilitate ISR interoperability and information sharing for various types of sensor collected data (imagery, tracking, tactical links, etc.). These standard agreements define metadata and data models or schemas to be used. There has been less effort for the standardization of the command and control of ISR assets in general.

Research has been conducted by various sensor communities to develop well-defined models of sensors and their observations and measurements. More recently, the W3C Semantic Sensor Web capitalizing prior work in the domain developed an ontology that constitutes a rich semantic description of sensor capabilities and properties. Associated with models of platforms, properties of collected data, missions contextual information, etc., these ontologies can be exploited in different contexts, e.g. for information retrieval, collection planning and assignment of sensors to missions.

In the following sections, we briefly review the main efforts in the development of sensor-related models and ontologies, then we present the problem and the domain areas to be modelled and provide details about the ontologies.

4.2 Related work

Significant work aimed at characterizing and conceptualizing hard data sensors and observations have been conducted, and several data models, schemas and semantic models (ontologies) have been developed, as described in Eastman and colleagues survey of sensor ontologies[6]. They provide a common representation of the characteristics of sensors, platforms, observations & measurements data, networking/security, etc., to reason upon these concepts in support of ISR activities (in particular for sensor management).

In order to harmonize these efforts, the W3C Semantic Sensor Network Incubator group (SSN-XG) produced the Semantic Sensor Network (SSN) ontology[7,8] to describe sensors in terms of their accuracy and capabilities, measurement processes, observations and deployments concepts, etc. The SSN ontology conciliates several existing schemas and ontologies based on a review of existing efforts, in particular the Open Geospatial Consortium (OGC) Observations & Measurements and the SensorML models. The SSN ontology is being made generic, and does not include domain-related concepts (description of specific sensor characteristics). Those aspects are kept aside, to be included in applications that require such elements. Thus, SSN constitutes a good basis for the construction of sensor application ontology.

Gomez, Preece, de Mel, and colleagues[9, 10, 11] make use of ISR related ontologies as formal models for representing Intelligence Surveillance Reconnaissance (ISR) requirements, ISR capabilities, sensors, sources and platforms to support the effective allocation of ISR assets to multiple competing missions. They have developed the ISTAR ontology that is utilized in their Sensor Assignment to Missions (SAM) tool. A rich representation of these elements, associated with deductive reasoning mechanisms, facilitate the matchmaking process and recommendations of suitable assets for a particular mission/task. Russomanno and Qualls[12] have also proposed models and algorithms using a similar approach to solve this problem.

In our work, based on prior efforts in the domain, in particular components of SSN and SAM/ISTAR, we are developing an ISR ontology (or set of linked ontologies) that extend and refine the concepts, to constitute rich semantic models and knowledge bases to reason upon in support of IRM&CM.

4.3 What is the problem, what has to be modeled

The objective is to develop an ISR ontology that can support both information retrieval from various information sources and information-driven ISR asset collection planning and management.

The resulting models, knowledge bases and reasoners built on top of it should help answer questions such as:

- What are the sources available? What are their properties, capabilities, availability?
- Are there similar collection requests, or collectors looking in the same area?
- Are there events that occurred (or are expected to occur) in a certain geospatial area during a period of time?
- What are the best suitable ISR assets to meet the collection information requirements, or at least the best compromise?
- What is the cost/benefit of the recommended assets for the collection task?

Consequently, the scope of the models focuses on the following sub-domains:

- ISR platforms and sensing assets (sensors/sources): characteristics/properties, capabilities/limitations;
- ISR data/Information (source output):
    - Data properties;
    - Data interpretability;
    - Data content for exploitation in terms of targeting elements (threat, events/activities);
- Mission/Task;
- Information requirements;
- Context/environment;
- Communication and policy.

4.4 Source and platform characteristics

Various types of ISR platforms (mobile or static) coexist in a particular mission context and carry different multimodal sensors. The representation of platforms properties, into a taxonomy discriminating platforms categories should be described in terms of their ISR capabilities and specificities (e.g. remote vs close-in sensing). Moreover, sensors on airborne ISR platforms (aircraft, UAVs) are sensitive to environmental conditions, but these sensors can collect data from different look angles, while platforms like aerostat can perform persistent surveillance by remaining stationary in the air. Such properties should be characterized.

As mentioned above, static sensor characteristics can be described in terms of sensor performance, accuracy, drift, latency, sensing range, coverage, mode of operation, etc. The SSN ontology extended with more specific sensor models provides a good basis.

In addition to static sensor properties, dynamic information are also key for exploitation in the reasoning process, in particular sensor position/placement, status/availability, etc. While external to ISR sensor models, these properties are complementary and needed in the conceptualization.

4.5 Sensor data interpretability

Sensor collected data have their own properties in terms of time and space elements (e.g. date and location of a picture), resolution, uncertainty, pedigree, etc. These basic characteristics are considered as metadata, they are valuable for information sharing but not sufficient for an advanced representation of data source content, that would be required for advanced information retrieval (content-based retrieval from multiple sources), as well as informed collection management (sensor allocation).

Content-based information retrieval

Content-based information retrieval requires intelligence data and products to be tagged (annotated) with more significant content-based elements, either human-generated or computer-assisted. For that purpose, the support of a domain ontology could facilitate the task by proposing a common vocabulary of what is observed in the data and made it interoperable.

A good example is the concept of content-based annotation of video clips. Imagery analysts spend a lot of time analyzing imagery for the production of intelligence, often reported in a document format. Both the raw video data and the intelligence product would benefit content-based semantic annotation of the data, with support of an ontology that helps describe the scene. As an example, existing taxonomies of human activities defined for human activity recognition can be leveraged along with more detailed information about the observed scene (movements, etc.).

Information collection

For information collection, collectors are used to ask for specific ISR assets ("I would need UAV imagery of this area") rather than expressing precisely their information needs. To move toward information-driven collection based on well-defined information requirements as described above, there is a need to have a precise representation of the expected quality and interpretability of the data provided by each type of sensor to maximize information gain.

Consequently, beyond the sensor characteristics, it is necessary to formally represent the quality of data produced by the sensors (about raw and processed data from the sensor systems) and the corresponding level of "interpretability" of collected data in order to assess to what extent it can satisfy the information requirements.

The National Imagery Interpretability Rating Scale (NIIRS)[13] is a standard for quantifying the interpretability of imagery acquired from imaging systems. It is used in the intelligence community by imagery analysts, collection managers, and sensor designers, for managing the tasking and collection of imagery, and measuring the performance of sensor systems and imagery exploitation devices. It consists of 10 graduated levels that express the level/precision of information that can be extracted at a given interpretability level (beyond scale or resolution), the type of recognition task, i.e., detect, identify, or distinguish, and the type of the object (equipment, a structure, or a natural feature). The NIIRS provides a good way to predict the interpretability of imagery data that can be exploited for collection.

More recently, The Video National Imagery Interpretability Rating Standard (V-NIIRS)[14] has been proposed and consists of a ranked set of subjective criteria to assist analysts in assigning an interpretability quality level to a motion imagery clip. The V-NIIRS rating standard could also be useful to support the tasking, retrieval, and exploitation of motion imagery, in particular for moving target recognition (track the movement of convoy, vehicles, confirm the movement of persons up to the movement of body parts).

In the same way, the interpretability of data for various sensors modalities should be represented to extend the approach (acoustic, seismic, biometrics, etc.).

4.6 Context/environment

Contextual mission information, environmental factors such as terrain and weather also impact the conduct of missions at various levels. The operational environment (urban, mountain, desert), the size of the operational area, trafficability, and severe weather conditions affect when and how assets are deployed and may degrade sensor capabilities.

Moreover, the representation of spatial and temporal concepts (based on well-defined ontologies) should be included to facilitate spatial and temporal reasoning about sensor capabilities and availability, e.g. to discover sensors that are available in the vicinity of a specific target to collect more information about it, and eventually perform cross-cueing.

4.7 Communication

Depending on the context, in particular in tactical networks, communication aspects should be taken into account in the process because connection is not always available, there are bandwidth limitations to route collected data to processing nodes. Consequently, concepts related to communication devices and network should be represented in order to automatically reason about them.

5. CONCLUSIONS

In this paper, we have presented ongoing research for enhanced ISR Asset visibility in support of IRM&CM processes. In particular, we have highlighted some requirements and potential for automated tools to better assist collection managers and collectors in these tasks. We propose a unified approach for querying and collection of information based on enhanced information management practices that would result in better link between information collection, management and exploitation. The semantic representation of ISR domain concepts together with enhanced information management and collection tools is a crucial stage in this direction. In particular, the description of ISR assets capabilities, their properties, constraints and the types of data they can produce would help in the selection of collection assets. Moreover, the precise description of collected data in a structured manner beyond metadata would help better represent various types of data and perform enhanced queries as well as sensor tasking. We will look at utilizing the same approach for other type of information sources, or sensor modalities by extending and refining these models. Enhanced ISR assets integration, optimized information collection and management should result in more relevant collected data and improve subsequent analysis.

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