Applications for Intelligent Information Agents (I^2As): Learning Agents for Autonomous Space Asset Management (LAASAM)

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Abstract – *Current and future space, air, and ground systems will continue to grow in complexity and capability, creating a serious challenge to monitor, maintain, and utilize systems in an ever growing network of assets. The push toward autonomous systems makes this problem doubly hard, requiring that the on-board system contain cognitive skills that can monitor, analyze, diagnose, and predict behaviors real-time as the system encounters its environment. Described here is a cognitive system of Learning Agents for Autonomous Space Asset Management (LAASAM) that consists of Intelligent Information Agents (I^2A) that provide an autonomous Artificially Intelligent System (AIS) with the ability to mimic human reasoning in the way it processes information and develops knowledge [Crowder 2010a, 2010b]. This knowledge takes the form of answering questions and explaining situations that the AIS might encounter. The I^2As are persistent software components, called Cognitive Perceptrons, which perceive, reason, act, and communicate. Presented will be the description, methods, and framework required for Cognitive Perceptrons to provide the following abilities to the AIS:*

1. *Allows the AIS to act on its own behalf;*
2. *Allows autonomous reasoning, control, and analysis;*
3. *Allows the Cognitive Perceptrons to filter information and communicate and collaborate with other Cognitive Perceptrons;*
4. *Allows autonomous control to find and fix problems within the AIS; and*
5. *Allows the AIS to predict a situation and offer recommend actions, providing automated complex procedures.*

A Cognitive Perceptron Upper Ontology will be provided, along with detailed descriptions of the I^2A framework required to construct a hybrid system of Cognitive Perceptrons, as well as the Cognitive Perception processing infrastructure and rules architecture.

In particular, this paper will present an application of Cognitive Perceptrons to Integrated System Health Management (ISHM), and in particular Condition-Based Health Management (CBHM), to provide the ability to manage and maintain an AIS in utilizing real-time data to prioritize, optimize, maintain, and allocate resources.

Keywords: Intelligent Agents, Space Asset Management, Artificial Learning

1 Introduction

Intelligence reveals itself in a variety of ways, including the ability to adapt to unknown situations or changing environments. Without the ability to adapt to new situations, an intelligent system is left to rely on a previously-written set of rules. If we truly desire to design and implement autonomous AI Systems (AIS), they cannot require precisely-defined sets of rules for every possible contingency. The questions then become:

- ***How does an autonomous AI system construct good representations for tasks and knowledge as it is in the process of learning the task or acquiring knowledge?***
- ***What are the characteristics of a good representation of a new task or a new piece of knowledge?***
- ***How do these characteristics and the need to adapt to entirely new situations and knowledge affect the learning process?***

CBHM entails the maintenance of systems and equipment, based on an assessment of current and projected conditions (both situational and health). A complete and modern CBHM system comprises many functional capabilities, including sensing & data acquisition, signal processing, condition & health assessment, diagnostics & prognostics, and decision reasoning [Scally, Bonato, and Crowder 2011] (See Figure 1). Such features are enabled through the application of autonomous AIS.

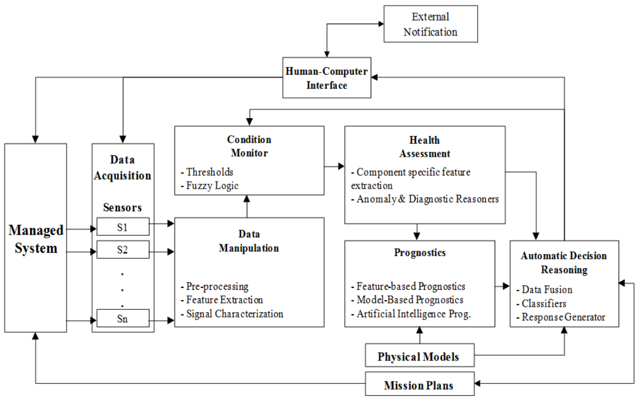


Figure 1 – CBHM Architecture

Discussed here will be the I²A Cognitive Perceptron architecture required to provide a system capable of autonomously managing a complex network of space-based assets to enhance situational awareness and optimize their utilization.

2 Intelligent Information Agents (I²A)

Intelligent Information Agents (I²A) employ soft-computing techniques to generate Intelligent Software information Agents (ISAs). These agents mimic human reasoning to process information and develop intelligence. This intelligence takes the form of answering questions and explaining situations [Crowder 2010b].

The I²A architecture is a Java framework for constructing a hybrid system of Intelligent Information Software Agents. It provides a productivity toolkit for adding intelligent software agent functions to applications and modern architectural frameworks and for building multi-agent intelligent autonomic systems. This includes the framework for providing business rules and policies for run-time systems, including an autonomic computing core technology within a multi-agent infrastructure. Figure 2 illustrates an overview of the I²A architecture framework that is the infrastructure for a hybrid neural processing environment.

I²As are active, persistent software components that perceive, reason, act, and communicate. I²As are software structures that:

1. Assist people and act on their behalf;
2. Are used for automation, control, and analysis;
3. Assist people in finding and filtering information, automating tedious tasks, and collaborating with other agents; and
4. Enable automation and control for finding and fixing problems, finding “best fit” procedures, pattern recognition and classification, predictions and recommendations, and automating complex procedures.

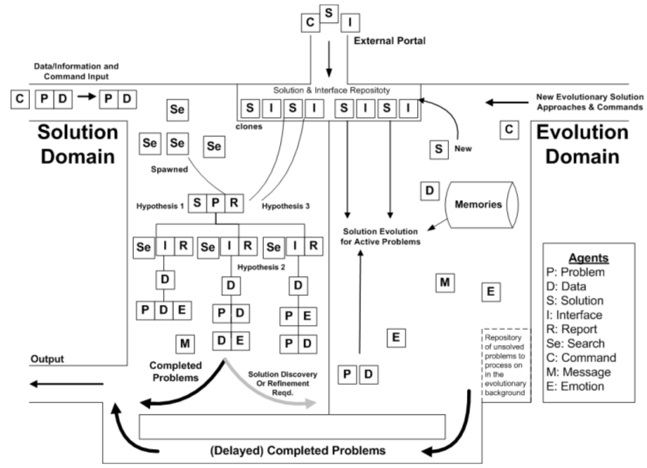


Figure 2 – I²A Intelligent Agent Infrastructure

2.1 I²A Tasking

Intelligent Information Agents have the ability to learn from experience and can be used to actually predict future states (prognostics). They are able to analyze sensor data using classification and clustering techniques to detect complex states and diagnose problems (anomaly detection and resolution). The I²As can interface with other autonomic agents and components via web-services. They have the ability to reason using domain-specific application objects and have autonomous (proactive) behavior and goals. They have the ability to correlate events to situations, reasons, and take action.

The I²A hybrid computing architecture uses genetic, neural-network and fuzzy logic to integrate diverse sources of information, associate events in the data and make observations. When combined with a dialectic search [Crowder 2010a], the application of hybrid computing promises to revolutionize information processing. The dialectic search seeks answers to questions that require interplay between doubt and belief, where our knowledge is understood to be fallible. This ‘playfulness’ is key to hunting within information and is explained in more detail in the section that address the Dialectic Search Argument (DSA).

2.2 The I²A Dialectic Search Argument

The Dialectic Search uses the Toulmin Argument Structure to find and relate information that develops a larger argument, or intelligence lead. The Dialectic Search Argument (DSA), illustrated in Figure 3, has four components:

1. Data: in support of the argument and rebutting the argument.
2. Warrant and Backing: explaining and validating the argument.
3. Claim: defining the argument itself.
4. Fuzzy Inference: relating the data to the claim.

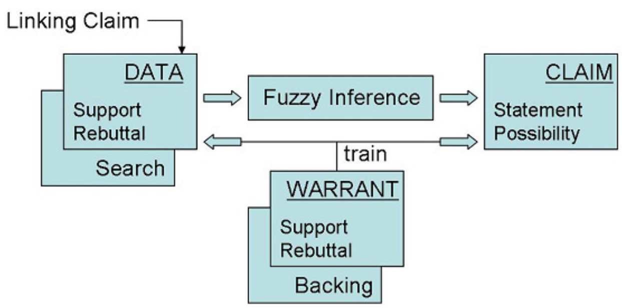


Figure 3 – The DSA Structure

The argument serves two distinct purposes. First, it provides an effective basis for mimicking human reasoning. Second, it provides a means to glean relevant information from the Topic Map [11] and transform it into actionable intelligence (practical knowledge.) These two purposes work together to provide an intelligent system that captures the capability of a human Intelligence Operative to sort through diverse information and find clues.

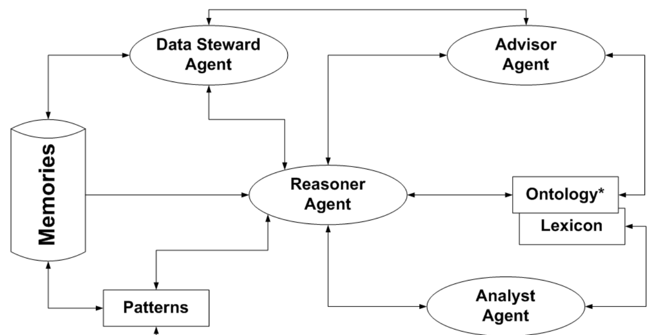
This approach is considered dialectic in that it does not depend on deductive or inductive logic, though these may be included as part of the warrant. Instead, the DSA depends on non-analytic inferences to find new possibilities based upon warrant examples. The DSA is dialectic because its reasoning is based upon what is plausible; the DSA is a hypothesis fabricated from bits of information.

Once the examples have been used to train the DSA, data that fits the support and rebuttal requirements is used to instantiate a new claim. This claim is then used to invoke one or more new DSAs that perform their searches. The developing lattice forms the reasoning that renders the intelligence lead plausible and enables measurement of the possibility.

As the lattice develops, the aggregate possibility is computed using the fuzzy membership values of the support and rebuttal information. Eventually, a DSA lattice is formed that relates information with its computed possibility. The computation, based on Renyi's entropy theory, uses joint information memberships to generate a robust measure of Possibility, a process that is not achievable using Bayesian methods.

3 The I^2A Software Architecture

The primary software component of LAASAM is the I^2A. Each software component, or ISA, provides different cognitive capabilities (called cognitive archetypes) that form a cognitive ecosystem within the LAASAM framework, allowing inter-agent communication, collaboration, and cooperation. Figure 4 illustrates this ecosystem. Each ISA archetype, while having separate capabilities, have a defined cognitive structure, or ontology [Raskin and Taylor 2010a, and Taylor and Raskin 2011a], shown in Figure 5.



*This consists of both a Conceptual Ontology and an Instantiated Ontology

Figure 4 – The LAASAM ISA Cognitive Ecosystem

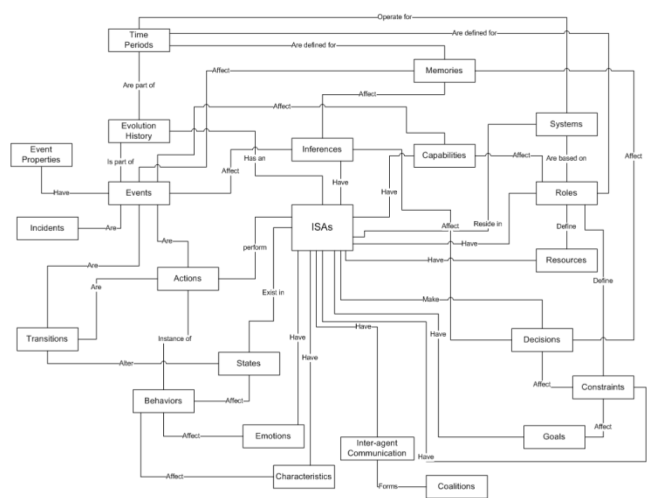


Figure 5 – The ISA Cognitive Perceptron Upper Ontology

Each LAASAM ISA is a self-contained software unit (agent) comprised of one or more services, shown in Figure 6. The combination of services defines an ISA's capabilities. There are five currently defined agent types within the LAASAM processing infrastructure:

1. Data Steward (ADS): this agent acquires raw data from a variety of sources, including sensors, and prepares incoming data for use by other agents. The Data Steward Agent generates and maintains metadata required to find and extract data/information from heterogeneous sources.
2. Advisor Agent (AAD): this agent disseminates the right information to the right place at the right time; it provides capabilities that allow collaborative question asking and information sharing by agents and end-users. Advisor Agents generate and maintain topical maps required to find relative information fragments, memories, and "expert" ISAs.
3. Reasoner Agents (ARE): The Reasoner Agent interacts with the Data Steward and Advisor Agents and utilizes the ontologies and lexicons to automate the development of domain-specific encyclopedias; it provides a mixed source of information and question answering that is used to develop an understanding of questions, answers, and their domains. Reasoner Agents analyze questions and relevant source information to provide answers and to develop cognitive ontology rules for the LAASAM CBHM system.
4. Analyst Agents (AAN): The Analyst Agents are fed by Reasoner Agents and utilize the developed ontologies and lexicons to expand upon questions and answers learned from collected information.
5. Interface Agent (AIN): The Interface Agent assesses the correctness of major decisions and adjusts the decision processes of the Advisor Agents. Interface Agents also accommodate human-in-the-loop structures.

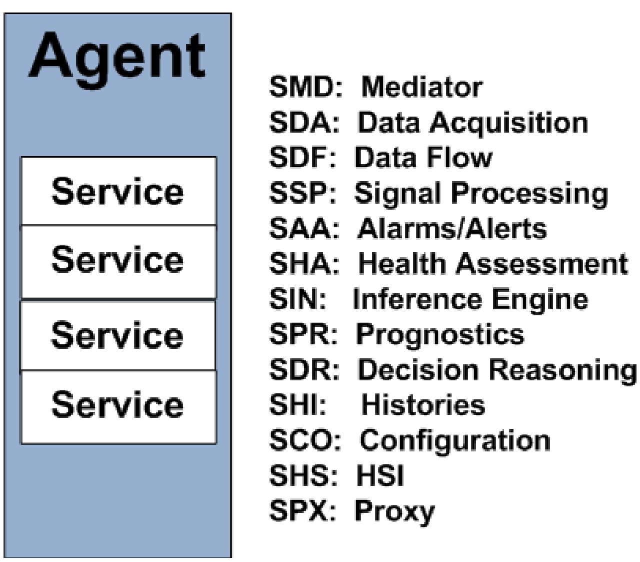


Figure 6 – Services that comprise ISAs

4 Cognitive CBHM (LAASAM)

LAASAM utilizes the I^2A technology to address the requirements of CBHM for space and ground asset management. LAASAM (illustrated in Figure 7) represents a significant advancement in the field of Space Asset Management by providing cognitive abilities similar to human reasoning. The LAASAM architecture provides the following high-level features:

1. An Intelligence Network: this includes mechanisms for gathering information, learning, inferences, and providing decision support to situational analysts.
2. Answer Extraction: these are mechanisms for posing hypotheses about situations and providing answers.
3. Situational Analysis: mechanisms for finding situations that require active investigation and provide actionable intelligence

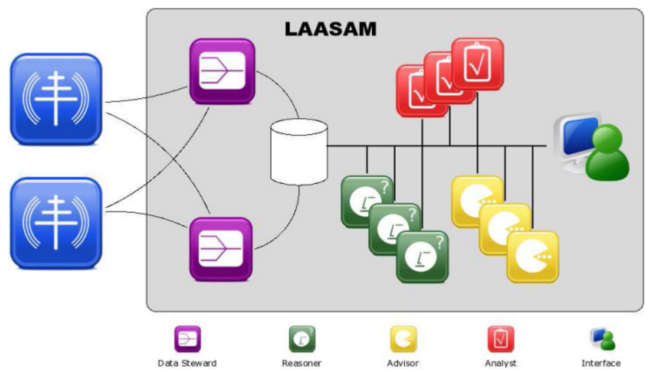


Figure 7 – LAASAM provides I^2A-Based Asset Management for Enhanced SSA

These features define the core of LAASAM and are realized by I^2A technology infrastructure. The I^2A cognitive processing infrastructure provides the intelligence within the LAASAM system through an implementation of an artificial prefrontal cortex [Crowder and Friess 2011a], associated artificial neural memories and data management [Crowder 2010a, Crowder and Carbone 2010a, b, and c], and derived strategies for reasoning, analysis, and inference [Crowder 2010b, Crowder and Friess 2010a &b, Crowder and Friess 2011 a and b].

The LAASAM software architecture defines the I^2A functions that range from data collection through providing recommendations for specific actions. Agents take on roles within the system, implemented through dynamically changing services and functional nodes, in support of system defined goals [Crowder 2010b].

The LAASAM high-level features discussed above are enhanced by evolutionary processes embedded within the I^{2}A cognitive processing framework [Crowder 2010a] and implemented utilizing functionally distributed capabilities provided by the I^{2}A infrastructure. Figure 8 illustrates Figure 1 with the I^{2}As distributed across the system.

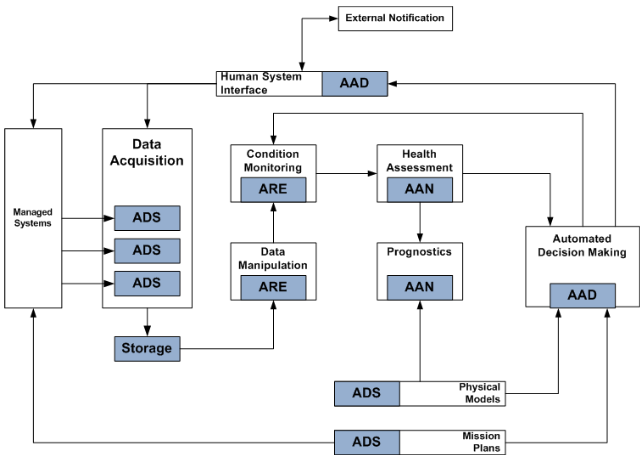


Figure 8 – Distribution of I^{2}As for CBHM

LAASAM is based on the concept that I^{2}As carry personalities. A personality is a collection of state information carried in a personality state token (shown in Figure 9) that describes the agent. Agent personalities can then be cloned and distributed utilizing these stored tokens.

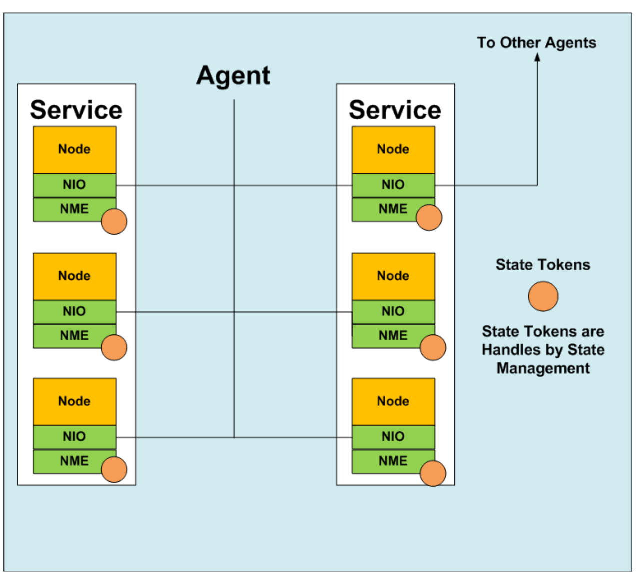


Figure 9 – I^{2}A Personality Tokens

In this way, agents are mobile in that their personalities are mobile. This mobile nature of agent personalities, or state mobility, allows agents to evolve on a self-determining basis. LAASAM operates on a collection of host systems that support Java clients connected through a secure network. Interface agents provide the authentication and authorization for the processing infrastructure, allowing secure access to I^{2}As within the network. Policy management for distribution of code updates and state tokens to agents within the LAASAM I^{2}A infrastructure is handled through Interface Agents that provide User Interface (UI) capabilities. I^{2}A personalities are partially based on their need to cooperate, learn, and function autonomously within the LAASAM framework. Figure 10 below illustrates these capabilities for the various I^{2}As.

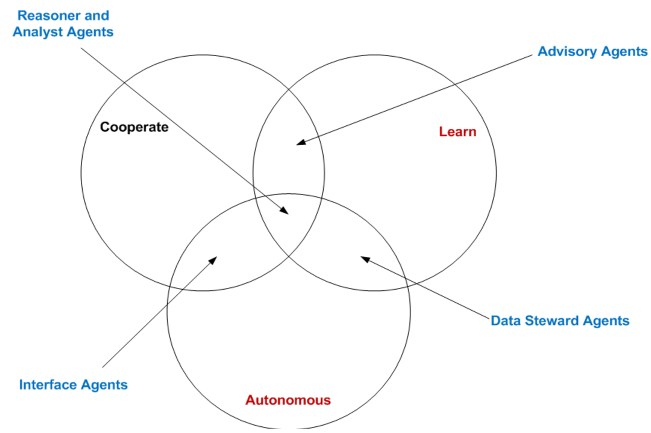


Figure 10 - I^{2}A Venn Diagram

6 Conclusions and Discussion

In summary, the LAASAM system significantly enhances the analyst's ability to make timely and efficient decisions, and to take action to protect and maximize the utility of space, ground, and air assets. LAASAM provides context for space-related events and can alert analysts to potential space-based events. LAASAM's unique I^{2}A cognitive processing infrastructure establishes the foundation for assigning attribution to hostile activity and for analyzing emerging activities through the application of advanced data-agnostic acquisition, reasoning, and analyst I^{2}As (see Figure 11).

The thrust of the LAASAM research has been to realize a CBHM architecture that provides enhanced Situational Awareness for space-based assets. The cognitive I^{2}A processing infrastructure provides the required analysis, learning, and reasoning framework to provide LAASAM the ability to analyze, diagnose, and predict health, status, and situational awareness within a complex system of space assets. This CBHM approach ideally involves synergistic deployments of component health monitoring technologies as well as integrated reasoning capabilities. The LAASAM system described here organizes various system elements into a maintenance and logistics architecture that governs integration and interoperation within the overall space asset system, between the on-board elements and their ground-based support functions, and between the system health management and the external maintenance and operations functions. In short, LAASAM represents enhanced Space Situational Awareness and Operational Management of the multiple assets contained with an overall space, air, and ground system consisting. LAASAM can not only identify problems that are caused by asset component failures, but can highlight system issues that are, or could be, caused by external forces, maximizing system availability and minimizing downtime.

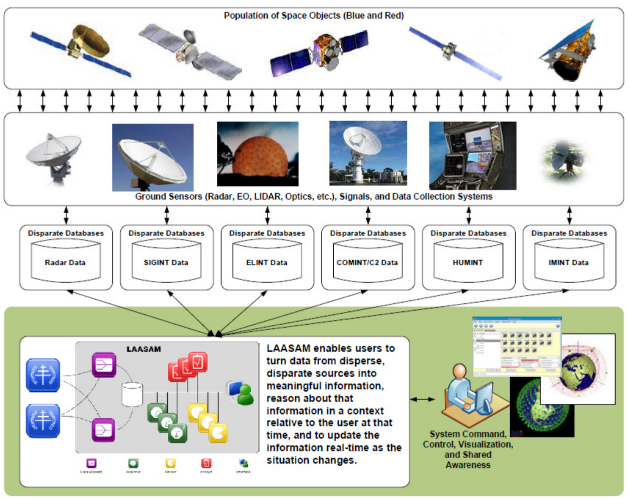


Figure 11 – Enhanced Space Situational Awareness using LAASAM

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