Agent-based Spectral Analysis Automation (SAA) for On-board Science Data Processing

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Abstract

The major objective of the Spectral Analysis Automation (SAA) work is to develop an agent-based system that is capable of filtering spectral analysis data and making the selected data available for a complete spectral analysis processing. In particular, we are pursuing a goal-driven data filtering capability that assesses observations for their relevance to mission goals. This type of data filtering will eventually find its way onboard a spacecraft and the filtering will result in less demand for restricted download capabilities and enable onboard or in-situ science event detection and response. The agent-based SAA approach is described in this paper.

1. Overview of the SAA Architecture

We have developed an agent-based architecture for filtering science data on-board a spacecraft prior to download, so as to maximize the efficient use of communications resources between the spacecraft and the ground. The architecture is depicted in Figure 1.

The flow of information in the filtering architecture is as follows. Data arrive from the spacecraft instrument and subsystems in the form of packets, which are assembled periodically. The period is called a Data Gathering Interval (DGI), and by an abuse of language we refer to the packet itself as a DGI too. A DGI contains spectral data from the instrument, as well as engineering data pertaining to both the instrument and the spacecraft, and tracking and ranging data to assist in the interpretation of the spectral data.

Each incoming DGI is placed in a database. The exact form of this database – e.g., whether it is stored in RAM or in a persistent storage device, whether it provides Database Management System (DBMS) functionality, etc. – is an open issue. The purpose of the database is to enable the filtering functions to consider DGIs in the context of other DGIs when deciding which of them should be downloaded. In addition, the database serves as a queuing area pending a downlink pass.

When a DGI is placed in the database, several agents are notified about this event:

- Evaluation agents
- Evaluation arbiter

There is an Evaluation Agent for each mission goal, as defined by the Consumer. The Consumer may be the science user on the ground; alternatively, it might be a supervisory or intermediate communications spacecraft. The Consumer conveys the goals, and their relative priorities, to the Goal Manager (GM). The GM is responsible for activating and deactivating the appropriate evaluation agents, and for communicating goal priorities to the Arbiter.

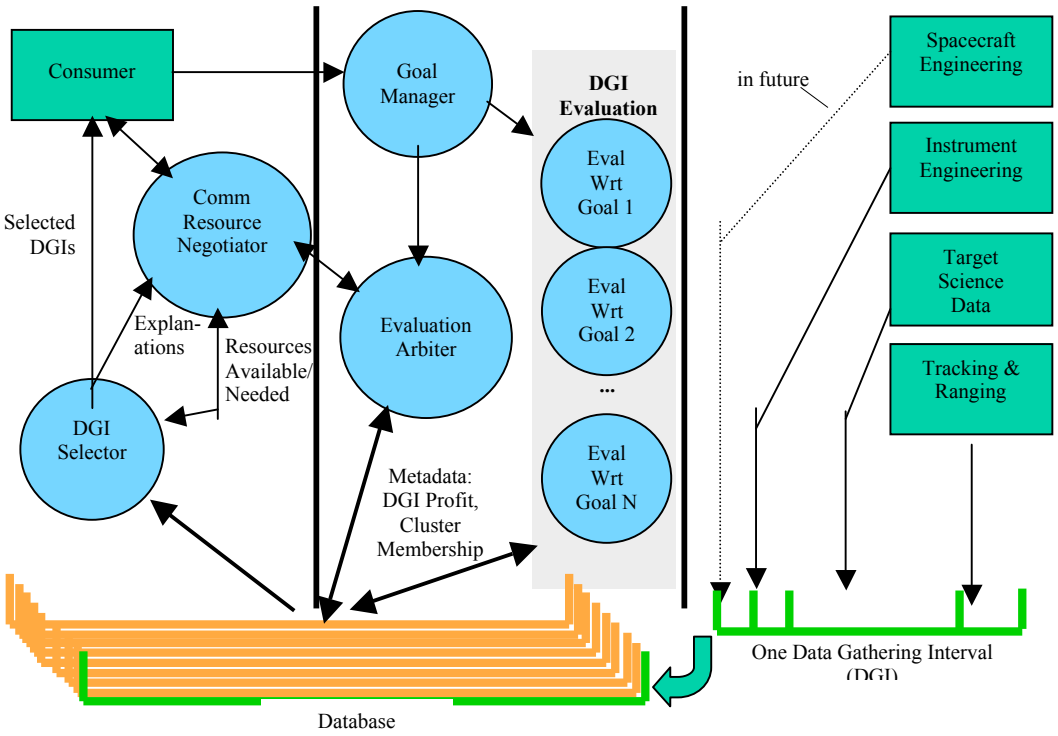

Figure 1: Spectral Analysis Automation Agent Filtering Architecture

When a new DGI arrives in the database, each evaluation agent assigns a profit that is, a measure of value to the DGI. In the process, it may also revise its previous profit assignments to earlier DGIs. The Evaluator may also define clusters of DGIs and assign a profit to the entire cluster, meaning that the individual DGIs derive their value only in the context of the rest of the cluster. The Evaluators contribute their information by tagging the DGIs with metadata indicating profit (with respect to a particular goal), cluster membership, and potentially other forms of information. This approach provides a great deal of flexibility in the kinds of information that may be contributed by the Evaluators. (The current prototype uses only profit assignments to individual DGIs, although the mechanism is in place for recording cluster information.)

When the Evaluators have all finished evaluating the new DGI, the Arbiter derives an overall profit value for the DGI on the basis of the "votes" provided by the Evaluators. In the current prototype, several algorithms are available to the Arbiter to derive the overall profit value. The relative merit of the algorithms is a topic for further experimentation and analysis.

When a downlink pass occurs, the Selector agent uses the Arbiter's profit assignments to decide which DGIs should be downloaded to the Consumer. The Selector may simply download the DGIs in order of their profit values, until the capacity of the communications channel (and/or the time period of the pass) are exhausted; alternatively, the Selector may trade off the profit of a DGI against its size (also called the DGI's *weight*) in order to maximize the overall profit of the downloaded information. There are numerous issues concerning the utility of the science data that arise when trading off profit against size, and these are a topic of continued investigation.

Agent	Role
Consumer	Entity for whom filtered spectral data are intended. Could be scientist on ground, or intermediate spacecraft in swarm
Information sources	Origin of data to be filtered and downloaded. Includes spacecraft engineering data, instrument engineering data, target science data, and tracking & ranging data
Data Gathering Interval (DGI)	One batch of source information. Collected over (and representing) a particular time interval
Database	On-board store of DGIs. Staging area prior to downlink of selected DGIs. Memory limited
DGI Evaluators	Agents responsible for assigning "profit" value to DGIs. Profit may be assigned to individual DGI or a cluster of DGIs determined by the evaluator. Evaluators may consider any or all of the current database contents, e.g., in light of most recently stowed DGI, or backing up to reconsider a previously stowed DGI. Evaluators output a profit for one or more DGIs, possibly in the context of other DGIs (i.e., requiring their presence too). In the simplest case (maybe sufficient) the assignment is to the latest DGI, by itself
Goal Manager	Agent responsible for creating, configuring and prioritizing the Evaluators on the basis of goals specified by Consumer
Evaluation Arbiter	Agent that arbitrates between conflicting profit assignments. Each evaluator represents a specific goal. Arbiter tries to balance the goals to derive an overall profit for each DGI and/or cluster. May query Communications Resource Negotiator about bandwidth possibilities. The resulting profit assessment summarizes the results of the Evaluation Arbiter. If context is used, this may be a complex data structure. Also, if context is used, it is an open issue what the DGI Selection algorithm should be (even Greedy Knapsack algorithm, which trades profit against weight, may not suffice)
DGI Selector	Agent responsible for choosing DGIs for downlink to consumer. Trades off profit against weight (= size of DGI) using one of several possible algorithms. Tries to produce downlink set of maximal usefulness given limited bandwidth. May request bandwidth change from Communications Resource Negotiator, or explain selection decisions in light of available bandwidth (as support info for negotiation). DGI selection uses the arbitrated profit assessment plus weights (sizes) of DGIs in database plus available communications resources to select DGIs to send to consumer. If weight is constant (i.e., constant-length DGIs), a simple "shop-til-you-drop" algorithm highest profit DGIs first suffices. If compression is used, Greedy Knapsack algorithm may be required to obtain maximal aggregate profit of the download. If individual DGIs are *not* assigned profit (i.e., complex context is used), this is an open issue
Communications resource negotiator	Agent that negotiates for downlink bandwidth. Interacts with Arbiter and Selector to stay informed of status and downlink needs. •Resource negotiation may include negotiation of futures, e.g., "We're having a good day…" or "I'm especially interested in feature X…"

Table 1. Each agent in the filtering architecture has a well-defined role.

One of the ways in which the tradeoff can be mitigated is by enlarging the capacity of the communications link. This may be appropriate, for example, if the recent DGIs indicate that large amounts of valuable science data are being collected. In such cases, the Communications Resource Negotiator may request additional bandwidth from the Consumer. The request is supported by information provided by the Arbiter, the Goal Manager, and the Selector concerning the value of the science data and the potential losses if the communications resources are not increased.

A summary of the roles of the various agents and other entities is provided in Table 1.

2. Conclusions

A prototype of the SAA system architecture has been developed and demonstrated. Further work is planned on fleshing-out the SAA infrastructure over the coming year. It is planned that this SAA system will eventually be of use for both ground-based and space-based spectral data filtering.

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