

geospatial browser to server-based datasets — in particular, massively sized datasets — has been developed. The method specifically uses the Keyhole Markup Language (KML), an Open Geospatial Consortium (OGS) standard used by Google Earth and other KML-compliant geospatial client applications. The innovation is based on establishing a dynamic cascading KML strategy that is initiated by a KML launch file provided by a data server host to a Google Earth or similar KML-compliant geospatial client application user. Upon execution, the launch KML code issues a request for image data covering an initial geographic region. The server responds with the requested data along with subsequent dynamically generated KML code that directs the client application to make follow-

on requests for higher level of detail (LOD) imagery to replace the initial imagery as the user navigates into the dataset. The approach provides an efficient data traversal path and mechanism that can be flexibly established for any dataset regardless of size or other characteristics. The method yields significant improvements in user-interactive geospatial client and data server interaction and associated network bandwidth requirements.

The innovation uses a C- or PHP-code-like grammar that provides a high degree of processing flexibility. A set of language lexer and parser elements is provided that offers a complete language grammar for writing and executing language directives. A script is wrapped and passed to the geospatial data server by a client application as a

component of a standard KML-compliant statement. The approach provides an efficient means for a geospatial client application to request server preprocessing of data prior to client delivery.

Data is structured in a quadtree format. As the user zooms into the dataset, geographic regions are subdivided into four child regions. Conversely, as the user zooms out, four child regions collapse into a single, lower-LOD region. The approach provides an efficient data traversal path and mechanism that can be flexibly established for any dataset regardless of size or other characteristics.

*This work was done by Gregory Baxes, Brian Mixon, and Tim Linger of TerraMetrics, Inc. for Stennis Space Center. For more information call the SSC Center Chief Technologist at (228) 688-1929. Refer to SSC-00362/5.*

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## Automated Planning of Science Products Based on Nadir Overflights and Alerts for Onboard and Ground Processing

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A set of automated planning algorithms is the current operations baseline approach for the Intelligent Payload Module (IPM) of the proposed Hyperspectral Infrared Imager (HyspIRI) mission. For this operations concept, there are only local (e.g. non-depletable) operations constraints, such as real-time downlink and onboard memory, and the forward sweeping algorithm is optimal for determining which science products should be generated onboard and on ground based on geographical overflights, science priorities, alerts, requests, and onboard and ground processing constraints.

This automated planning approach was developed for the HyspIRI IPM

concept. The HyspIRI IPM is proposed to use an X-band Direct Broadcast (DB) capability that would enable data to be delivered to ground stations virtually as it is acquired. However, the HyspIRI VSWIR and TIR instruments will produce approximately 1 Gbps data, while the DB capability is 15 Mbps for a  $\approx 60\times$  oversubscription. In order to address this mismatch, this innovation determines which data to downlink based on both the type of surface the spacecraft is overflying, and the onboard processing of data to detect events. For example, when the spacecraft is overflying Polar Regions, it might downlink a snow/ice product.

Additionally, the onboard software will search for thermal signatures indicative of a volcanic event or wild fire and downlink summary information (extent, spectra) when detected, thereby reducing data volume. The planning system described above automatically generated the IPM mission plan based on requested products, the overflight regions, and available resources.

*This work was done by Steve A. Chien, David A. McLaren, and Gregg R. Rabideau of Caltech; Daniel Mandl of NASA Goddard Space Flight Center; and Jerry Hengemihle of Microtel LLC for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47875*

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## Linked Autonomous Interplanetary Satellite Orbit Navigation

**Single satellite can track another satellite elsewhere in the Earth-Moon system and obtain absolute knowledge of both satellites' states.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A navigation technology known as LI-AISON (Linked Autonomous Interplanetary Satellite Orbit Navigation) has been known to produce very impressive navigation results for scenarios involving two or more cooperative satellites near the Moon, such that at least

one satellite must be in an orbit significantly perturbed by the Earth, such as a lunar halo orbit. The two (or more) satellites track each other using satellite-to-satellite range and/or range-rate measurements. These relative measurements yield absolute orbit navigation

when one of the satellites is in a lunar halo orbit, or the like.

The geometry between a lunar halo orbiter and a GEO satellite continuously changes, which dramatically improves the information content of a satellite-to-satellite tracking signal. The

geometrical variations include significant out-of-plane shifts, as well as in-plane shifts. Further, the GEO satellite is almost continuously in view of a lunar halo orbiter. High-fidelity simulations demonstrate that LiAISON technology improves the navigation of GEO orbiters by an order of magnitude, relative to standard ground tracking. If a GEO satellite is navigated using LiAISON-only tracking measurements, its position is typically known to better than 10 meters. If LiAISON measurements are combined with simple radiometric ground observations, then the satellite's position is typically known to better than 3 meters, which is substantially better than the current state of GEO navigation.

There are two features of LiAISON that are novel and advantageous compared with conventional satellite navigation. First, ordinary satellite-to-satellite tracking data only provides relative navigation of each satellite. The novelty is the placement of one navigation satellite in an orbit that is significantly perturbed by both the Earth and the Moon. A navigation satellite can track other satellites elsewhere in the Earth-Moon system and acquire knowledge about both satellites' absolute positions and velocities, as well as relative positions and velocities in space.

The second novelty is that ordinarily one requires many satellites in order to achieve full navigation of any given customer's position and velocity over time.

With LiAISON navigation, only a single navigation satellite is needed, provided that the satellite is significantly affected by the gravity of the Earth and the Moon. That single satellite can track another satellite elsewhere in the Earth-Moon system and obtain absolute knowledge of both satellites' states.

*This work was done by Jeffrey S. Parker and Rodney L. Anderson of Caltech; and George H. Born, Jason M. Leonard, Ryan M. McGranaghan, and Kohei Fujimoto of the University of Colorado at Boulder for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*The software used in this innovation is available for commercial licensing. Please contact Dan Broderick at [Daniel.F.Broderick@jpl.nasa.gov](mailto:Daniel.F.Broderick@jpl.nasa.gov). Refer to NPO-48736.*

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## ➤ Risk-Constrained Dynamic Programming for Optimal Mars Entry, Descent, and Landing

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A chance-constrained dynamic programming algorithm was developed that is capable of making optimal sequential decisions within a user-specified risk bound. This work handles stochastic uncertainties over multiple stages in the CEMAT (Combined EDL-Mobility Analyses Tool) framework. It was demonstrated by a simulation of Mars entry, descent, and landing (EDL) using real landscape data obtained from the Mars Reconnaissance Orbiter.

Although standard dynamic programming (DP) provides a general frame-

work for optimal sequential decision-making under uncertainty, it typically achieves risk aversion by imposing an arbitrary penalty on failure states. Such a penalty-based approach cannot explicitly bound the probability of mission failure. A key idea behind the new approach is called risk allocation, which decomposes a joint chance constraint into a set of individual chance constraints and distributes risk over them. The joint chance constraint was reformulated into a constraint on an expecta-

tion over a sum of an indicator function, which can be incorporated into the cost function by dualizing the optimization problem. As a result, the chance-constraint optimization problem can be turned into an unconstrained optimization over a Lagrangian, which can be solved efficiently using a standard DP approach.

*This work was done by Masahiro Ono and Yoshiaki Kuwata of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact [iaoffice@jpl.nasa.gov](mailto:iaoffice@jpl.nasa.gov). NPO-48606*

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## ➤ Scheduling Operations for Massive Heterogeneous Clusters

*Goddard Space Flight Center, Greenbelt, Maryland*

High-performance computing (HPC) programming has become increasingly difficult with the advent of hybrid supercomputers consisting of multicore CPUs and accelerator boards such as the GPU. Manual tuning of software to achieve high performance on this type of machine has been performed by programmers. This is needlessly difficult and prone to being invalidated by new hardware, new software, or changes in the underlying code.

A system was developed for task-based representation of programs, which when coupled with a scheduler

and runtime system, allows for many benefits, including higher performance and utilization of computational resources, easier programming and porting, and adaptations of code during runtime.

The system consists of a method of representing computer algorithms as a series of data-dependent tasks. The series forms a graph, which can be scheduled for execution on many nodes of a supercomputer efficiently by a computer algorithm. The schedule is executed by a dispatch component, which is tailored to understand all of the hardware types that

may be available within the system. The scheduler is informed by a cluster mapping tool, which generates a topology of available resources and their strengths and communication costs.

Software is decoupled from its hardware, which aids in porting to future architectures. A computer algorithm schedules all operations, which for systems of high complexity (i.e., most NASA codes), cannot be performed optimally by a human. The system aids in reducing repetitive code, such as communication code, and aids in the reduction of redundant code across projects.