Component-Oriented Design Studies for Efficient Processing of Hyperspectral Infrared Imager Data

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Background

- The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instrument combines high spectral resolution soundings associated with Fourier Transform Spectrometers (FTS) with high spatial and temporal resolution, creating three-dimensional near real-time views of atmospheric radiance, temperature, water vapor, and winds.
- The volume and rate of data sent down by such instruments poses a considerable design challenge for the ground processing system to keep up with the data in real-time while maintaining a flexible architecture. This software must be largely reusable for validation and product delivery for future instrument systems such as the GOES-R Hyperspectral Environmental Suite (HES).
- The University of Wisconsin Space Science & Engineering Center is working with NOAA to overcome the long-term challenges of these terabyte-per-day scale instrument systems, applying and extending domain knowledge on distributed, real-time, and object-oriented software systems in order to maximize the positive impact of future imaging FTS instruments in meteorological remote sensing.

System Requirements

- Throughput (bits per second) of a full-scale system must meet or exceed that of the instrument. GIFTS produces 128 x 128 pixels x 6144 samples x 16 bits / 11 seconds = 139MByte/s uncompressed data.
- Reproducibility ensures that data products from the system have established truth value allowing by data to be traced back to its origins.
- Latency (seconds) of system must meet user requirements for timeliness.
- Reliability (percent) describes the acceptable loss of system function over a time period.
- Testability - the system components can be proven prior to final system integration.
- Maintainability - the design can be adapted to changes in implementation, limited changes of requirements, and changes in staffing.

Use Cases Supporting Data Processing

(Listed by component)

Use Cases for System Core/Pea/ Master
Accept metadata transfer for observation data from Kap/ Delivery component, and supplementary data updates from the Reference Database. Match observations with supplementary data and pipeline configurations to create jobs. Assign jobs to Pixel Pipeline instances using cost estimation heuristics. Dispatch work orders to subsystem components in order to complete work.

Use Cases for Pixel Pipeline/Worker nodes
Accept observation data, supplementary data and job requests. Sequence algorithm stages to generate products from observations. Forward products to Output Delivery component, send audit metadata to Audit Database.

Use Cases for Reference Database
Holiday holds opportunistic supplementary data for the pipeline needed by the Pixel Pipeline. Distribute reference data structures in another component upon request. Permit updating of reference entity values and entities, with configuration control for each entity. Permit creation of new reference symbols within the Reference Database, to support additional pipelines with alternate sets of symbols. Notify System Controller and Audit Database of updates to reference symbols.

Use Cases for Audit Database
Accept metadata transactions describing data processing and supplementary data updates. Produce detailed data processing reports organized by time, components used, or products.

Use Cases for Monitoring Component
Accept asynchronous monitoring events from other subsystems. Summarize system activity and exception status from operating entities. Log exceptions and performance statistics.

See related materials on the web at:
http://www.ssec.wisc.edu/gifs/noaa/101.html

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Software Components

- The system is recursively described as a set of capsules exchanging signals obeying protocols through specialized connectors.
- Functional requirements decompose into capsule requirements and specifications which guarantee system behavior.
- De-coupled interfaces between subsystems, including state-flow descriptions, aid software development and testing.
- Resource budgets are balanced to meet time, space, and accuracy requirements with a tractable implementation.
- The UML-RT diagrammatic vocabulary permits design decisions to be communicated independently of implementation technology.
- Component methodology is ideal for distributed software design of time-constrained systems.

Supplementary Data

- Reference data contains characterization and calibration parameters needed by pipeline algorithms that change with significantly lesser frequency than observation data.
- Metadata describes larger data entities. It provides information to the software components that required to correctly process, store, and analyze the data it represents.
- Audit data is a specialized subset of metadata describing the origins and history of a product.
- Monitoring data is live metadata for the computing system, representing its performance characteristics and significant events such as faults or failures.

Design Considerations for Deployment on Cluster

- Distributed multiprocessor systems (i.e. clusters) are an effective solution for processing large arrays of nearly independent spectra. Ensuring that the system design and implementation be “cluster-ready” is a priority.
- Split groups of pixels off to individual worker nodes containing one or more processing pipelines.
- Cache, proxy and delegate capsules may be inserted between distributed subsystems in order to account for comparatively slow link between node CPUs.
- Anticipate that some connectors between capsules will be implemented using middleware such as ACE, CORBA, or hardware-specialized transport APIs.
- Avoid bottlenecks by ensuring that the subsystems manipulate metadata proxies of large data structures where feasible.
- Ease implementation of system robustness by gathering and checkpointing system state.