Earth Science Data Fusion: NAIADS Concept and Development

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- NAIADS: NASA Information And Data System
- Naiad is derived from the Greek naein, which means “to flow”
- In this project context it is plural: multi-data “flows”
Geostationary mission are not shown (15);
Next 10-15 years: JPSS-1 and JPSS-2, GOES-R;
Decadal Survey and Venture missions;
Missions last longer, sensors become more complex;
We can predict the type and size of Earth Science data;
The Climate Model outputs oversize the observations.
Earth Observations and Climate Model Data

1. Observations:
- Expected volume of *used data products*: exceed 100 Petabytes in 10-15 years.
- Data is *distributed* nationally (NASA, NOAA), and internationally (ESA, etc.).
- NASA observational data *format is standard* HDF (Hierarchical Data Format)
- NOAA observational data *format is standard* NetCDF (Network Common Data Form)
- Observations from different sensors are *NOT synched / merged*!
- Each sensor/mission has a *separate data product line*!

2. Climate Models Output:
- Expected volume of CM outputs: may exceed Exabyte in 10-15 years.
- Data is *distributed* nationally (NASA, NOAA, DoE), and internationally (UK).
- Multiple Climate & Earth System models (30 – 50).
- Perturbed Physics Ensemble (PPE) for a single model: about 5 Petabytes.
- Climate Model output *format is standard* NetCDF

3. Relevant Data Centers:
- Observations: Langley and Goddard (NASA), NCDC (NOAA), LPDAAC (USGS), NSIDC.
- Climate/Weather Models: Goddard, GISS and Ames (NASA), NCAR (NSF), LLNL and LBNL (DOE), etc., etc., etc.
Earth Science Data Fusion (L1 Requirement): To Maximize Information Content and Science Output

1. National Strategy:
   - OSTP’s Earth Civil Observation from Space (2013): Integrated Portfolio Management
   - NASA Strategic Space Technology Investment Plan (2013) and Budget Memorandum (2014)
   - NASA Strategy Plan 2014: Strategic Objective 2.2

2. Relevancy: Outstanding Science Output
   - CERES, Earth’s Radiation Budget: multi-sensor data fusion, up to 16 (NASA LaRC)
   - CERES/MISR/MODIS data fusion: multi-sensor calibration validation on-orbit (NASA LaRC)
   - CALIPSO, CloudSat, CERES, MODIS (A-Train) data fusion – Level-2 information (NASA LaRC)
   - Required for future missions: CERES/RBI, TEMPO, CLARREO, ACE, and GEO-CAPE
   - Required for future satellite constellations (baseline or small sats)

3. Major Challenges:
   - IT infrastructure is not optimized for the task: data is distributed, slow connections, security…
   - Traditional PGE-based workflow is I/O bound (job-per-file-per-CPU);
   - Traditional configurations are network bound for heavy data handling;
   - Time and resource intensive, the costs are very high.
   - Opportunities are not realized: e.g. MISR/MODIS, A-train Level-1, etc.
NAIADS Test Case: SCIAMACHY/MODIS Data Fusion

OBJECTIVES:
- To demonstrate NAIADS approach and full functionality using existing data;
- To benchmark NAIADS performance versus traditional job-per-file cluster approach;
- Available data: 9 years of near-coincident measurements of from SCIAMACHY and MODIS;
- Create new fused SCIAMACHY/MODIS data product (requested by a number of NASA projects).

SCIAMACHY DATA:
- Spectral measurement for every footprint: 30 km x 230 km;
- Swath 950 km (4 footprints) from 10 AM Sun-synch orbit.

MODIS/Terra DATA:
- Multi spectral measurement: 19 RS Bands;
- Level-2 Cloud and Aerosol Data
- Spatial scale: 1 / 5 km and 10 km spatial;
- Swath 2500 km (global coverage daily);
- 1:30 AM Sun-synch orbit.

N.B. Reflectance
NAIADS Framework L2 Requirements

- **IO Optimizer**: Data Event Builder in off-line software before any scaling!

- **Networking**: Ability for local and distributed data-Event building. Distributed software approach – move code to data, not otherwise.

- **New workflow / scaling**: Complete in-memory data-Event streaming, massive scaling;

- **Multi-lingual**: Support new and heritage codes, optimal language for given service.

- **Flexibility**: Re-configurable to multiple applications (fusion, processing, data mining, etc.). Service Oriented Architecture (SOA) approach.

- **Adaptability**: Supporting various hardware configurations (cluster, cloud, servers, etc.), and various file systems: NFS, GPFS, Apache Hadoop / Spark, etc.

- **Portability**: Support various OS platforms (Unix, Linux, MacOS, …)

- **Standards**: I/O, transient data, and metadata.

- **Provenance**: track metadata at any stage of processing.

- **Traceability**: end-to-end test cases, extensive and transparent code documentation.

- **Modern good practices**: from management to coding, persistence.
Technology Infusion: CLARA Framework from Jefferson Lab

1. xMsg (DOE Jefferson Lab):
   - Publish/Subscribe messaging middleware;
   - Based on the ZeroMQ socket library (C++);
   - Multi-lingual binding/support (Python, Java, C++)
   - Author: V. Gyurjyan

2. CLARA Framework (DOE Jefferson Lab):
   - Service Oriented Architecture framework for Physics data processing applications;
   - Multi-lingual support (Python, Java, C++ planned);
   - Documentation: claraweb.jlab.org
   - Implementations up to date:
     CLAS12 physics data processing framework (Jefferson Lab, Hall-B);
     Old Dominion University (Norfolk, VA) data mining.
   - Publication:

3. NASA LaRC & DOE Jefferson Lab: Inter Agency Agreement
   - Established in December 2014;
   - Renewed on annual basis;
   - Royalty free software license for the US Government use.
NAIADS Architecture

- SOA CLARA/xMsg for flexible and multi-lingual applications.
- PS: multi-sensor coincident data predictor service.
- SS: into-memory fast data staging service (multi-file).
- RS: parallel from-memory data reader service (pre-sorting).
- CS: data concentrator service in a data center (IO/network optimization).
- EB: complete data-Event Builder (adaptation to algorithm).
- Scaling: data-Event streaming to Cloud with minimized IO.
NAIADS Workflow Example: shown for a Single Node

- xMsg (ZeroMQ) messaging.
- EB: complete data-Event Builder.
- RS: parallel data reader service.
- S1: science algorithm service.
- WS: data persistence service.
- SS: stats service (e.g. histograms).
- FE: front end user web service.

Scaling: Automatic multi-treading in nodes.
NAIADS Project Management

NAIADS Wiki and Git Repository on EARTHDATA: https://wiki.earthdata.nasa.gov/display/NAIADS/
NAIADS Test Case 1: SCIAMACHY/IGBP Data

1. DATA:
- SCIAMACHY data location: AWS S3 Bucket (9 years of data);
- SCIAMACHY data format: binary (small header + spectral records [5287]);
- Aux data: stationary IGBP Surface Index (binary, 10° map with 20 integer values per grid-box);

2. DATA FUSION:
- EB: Provide 5 locations of SCIAMACHY footprint (corners and center) with IGBP value.
- Enable option: persist merged data before processing.

3. DATA PROCESSING (SC services, SCALED, output persisted via WS):
- SC1: Convert N-photons to Watts for every spectral record [5287];
- SC2: Clean up every spectral record [5287] from bad data;
- SC3: Gaussian spectral resampling: from original [5287] to [1510] (1 nm wavelength sampling);
- SC4F: Data Filter for IGBP = 17 (ocean) only;
- WS: Persist new data product (data-Event sorting by orbit! Every event has an ID)

4. STAT SERVICES (under development, Java):
- Histogram Types: 1DF, 2DF,
- Averaged data objects: 1DAv, 2DAv

LANGUAGES: Java (baseline & optimizations) and Python.

BASE CASE to compare with: C++ optimized code (traditional file-per-job-per-core).

AWS Setup:
- S3 Bucket / Storage;
- Initial Cloud configurations: traditional Cluster (shared file system) and Cloud.
NAIADS Status and Progress: CLARA/xMsg & Python Tests

CLARA Service Bus Performance
Orchestrator -> DPE(Service1 -> Service2) (same node)
Intel 2.3 GHz Core i7, Mac OS 10.10.2

**CLARA/xMsg Framework Performance:**

- jCLARA/xMsg transport is capable of transporting 360 MByte/sec data between processes/services within a single node (test on Intel 2.3 GHz i7 CPU);
- With heavy processing load: jCLARA/xMsg overhead contribution should be negligible.

**NAIADS in Python Dialects:**

NAIADS performance with pCLARA easily outperforms a traditional Python solution and can be coerced to approach the performance of a traditional C++ solution.
NAIADS Status and Progress: Streaming, Scaling and Web API

I/O and Transient Data: NetCDF Streaming
Input: Binary, NetCDF, HDF; Output: NetCDF;
Transient data payload: NetCDF;
From Unidata (UCAR) fixed and debugged;
Java implementation (C++ is possible).

Examples of Web APIs (Python and the Django REST):

WEB API Objectives:
Get the registration information from all components;
Get filtered information by querying the system;
Deploy CLARA DPEs;
Deploy CLARA Containers;
Deploy NAIADS Services;
Handle NAIADS/CLARA message subscriptions.

Java NAIADS/CLARA performance test:
Java FastMath lib: with 25% of the C++ base case;
Data-Event streaming implemented;
All Science Services implemented;
Writer Service with sorting output data-Events;
Java implementation - baseline for tuning up.
64 SCIAMACHY L1 files, data moved to local disks.

16 nodes x 12 cores each = 192

Number of nodes (12 cores per node)
NAIADS Status and Progress: AWS Cloud Configurations

NAIADS on AWS Cloud Scenario 1

C3.node001: worker
CLARA Install
NAIADS compute (c3.8xlarge)
32 vCore, 108 GB RAM,
640 GB local disk /scratch

C3.node002: worker
CLARA Install
NAIADS compute (c3.8xlarge)
32 vCore, 108 GB RAM,
640 GB local disk /scratch

C3.node003: worker
CLARA Install
NAIADS compute (c3.8xlarge)
32 vCore, 108 GB RAM,
640 GB local disk /scratch

R3.master:
On-demand instance
NAIADS master node
(r3.8xlarge)
32 vCore, 244GB RAM
640 GB local SSD disk

AWS Compute Facility Configurations:

- Traditional Cluster configuration with shared file system;
- Cloud Star Cluster configuration;
- NAIADS Cloud Scenario 1 (shown);
- NAIADS Cloud Scenario 2: performance worker nodes only w/ RAM disks. (expected winner)
NAIADS Summary & Future Work

SUMMARY:
- Objectives: real data fusion with existing 9-years of Earth Science data;
- CLARA/xMsg technology infusion in Java and Python;
- Test case: 4 science services for existing Earth Science data;
- Simple data-Event Builder in software implemented;
- Data-Event streaming implemented;
- IO and Transient data via NetCDF Streaming;
- Initial WEB APIs.
- Testing in AWS Cloud compute environment.

WORK IN PROGRESS:
- The NAIADS Test Case: extend to MODIS L2 and ECMWF re-analysis data;
- Development of Test Case data-Event Builder algorithm;
- Benchmark performance of the NAIADS IO and transient data envelope;
- Benchmark the NetCDF and HDF into-memory data Staging Services;
- Development of C++ CLARA, testing and benchmarking;
- Design and development of NAIADS statistical services;
- Continue to improve jCLARA, pCLARA performance;
- Continue to develop NAIADS/CLARA Web APIs.

NAIADS/CLARA Demo: Java Implementation

jNAIADS/jCLARA demo