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INTRODUCTION

The DEVELOP Global Remote Sensing Network Solutions (GRSN) team at the NASA Langley Research Center has recently completed the first phase of a scientific research tool for the Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite (CALIPSO) research team at the NASA Langley Research Center.

This software has been designed to support large three-dimensional datasets from remote sensing satellite platforms and features an expandable software framework for interaction with data and the rapid development of specialized Earth science research tools.

DEVELOP is a NASA Science Mission Directorate Applied Sciences Program that fosters human capital development to extend science research to local communities. In this program student teams research NASA science capabilities relevant to community concerns and create computer generated visualizations demonstrating research results.

DEVELOP Program: GRSN Team Roster

Figure 1: GRSN Team Roster (Fall ’06 – Spring ’07)
TEAM BACKGROUND

Global Remote Sensing Network Solutions (GRSN) is a student led team of scientists and engineers from the NASA Langley Research DEVELOP National Program dedicated to building software solutions to further extend the audience of NASA remote sensing data resources for applied Earth science research. By focusing on the design of user-friendly and expandable software the team pursues a long term vision of building a framework to encourage research collaboration and extend scientific visualization to local communities.

GRSN Milestone Deliverables:

Figure 2: GRSN Phase 1, 2 & 3 Milestones

The second and third phases of this framework focus on building an information hub and social network for greater sharing of ideas, observations and results. The goal of GRSN to remove roadblocks to scientific research serves two purposes: providing smaller science teams with the financial justification to explore applied science remote sensing solutions at the local community level and enabling researchers to access high-detail NASA remote sensing datasets and make discoveries using consumer grade computers.

The team’s completion of first phase marks an exciting milestone for the GRSN team and provides the first example of the GRSN framework used to accelerate the development of a specialized science research tool for the CALIPSO science team.

The DEVELOP National Program has supported the efforts of the GRSN team starting fall ‘06 as part of a one year, long distance collaboration between sites in Virginia, New York and Massachusetts. These team members maintained regular contact via cell phone, e-mails and teleconferences to research, plan and complete the first of a three phase plan to build a next generation framework for remote sensing research on consumer PCs.
This report describes the following set of completed objectives:

- Research open-source and commercial scientific visualization software packages
- Formulate project plans, balancing time, features and expenses to meet objectives
- Engineer a framework to streamline the development of scientific research tools
- Build a three-dimensional visualization client and flexible software architecture for the NASA Langley Research Center’s CALIPSO scientific research team
- Experiment with software features and solve challenging performance issues

**PHASE I: SOFTWARE RESEARCH**

GRSN team members Jonathan Bidwell, Jonathan Gleason, Brian Tisdale and Ben Hughes worked with student colleagues at the NASA Langley Research DEVELOP Program during the summer ’06 to produce scientific visualizations of LIDAR remote sensing data at the request of Dr. Charles Trepte, Depute Principle Investigator of the CALIPSO satellite platform.

These images produced using an interactive geospatial modeling tool resulted in a second call from the CALIPSO team to design a software tool for exploring polar stratospheric cloud (PSC) formations and remote sensing datasets on multiple monitors. The LIDAR format and memory requirements required for this assignment led the team to research existing open-source and commercial software options.

The two-week research and development period that followed led to the discovery that most software packages, available for less than $15,000, offered limited support for the three-dimensional, vertical profile, LIDAR remote sensing datasets. These limitations challenged the group to re-evaluate open-source software options and begin designing a software framework to support large datasets and benefit from regular updates from the open-source community.

This desire to push the remote sensing visualization envelop coupled with a working partnership with the CALIPSO science team and support from the DEVELOP National Program led to the formation the Global Remote Sensing Network (GRSN) team.

The following outline describes software limitations encountered by GRSN team:

- Memory limitations resulting from storing all imported data in RAM
- No support for Level of Detail (LOD) with the exception of expensive software
- Limited support for third-party peripherals and multiple monitor displays

The team continued researching and experimenting with existing open-source software configurations into September ’06. These studies resulted in the evaluation of concepts for a visualization framework for the CALIPSO mission and the decision begin moving forward with project planning.
PHASE I: PROJECT PLANNING

The GRSN team proposal document, written by Jonathan Bidwell, received approval from the DEVELOP National Program in late October. This document outlined a basic project plan for the fall ‘06 term and setup part-time employment for team members and marked a kick-off for phase one software development.

This software development has focused on the construction of an extendable software framework to provide support for specialized science applications and the interactive three-dimensional display of large NASA remote sensing datasets.

The considerable scope of this goal required extensive backgrounds in data-processing, geospatial visualization and computer hardware that were not present on the team. This assessment prompted a search for knowledgeable faculty advisers and establishment of fall semester independent study programs at Old Dominion College, VA and Rensselaer Polytechnic Institute, NY.

These independent study programs served as an invaluable assets to the group enabling better design decisions to be made earlier in the semester. Jonathan Gleason established an independent study at Old Dominion University and Jonathan Bidwell consulted with independent study adviser Professor W Randolph Franklin for advice regarding memory management. The leadership of advisers Jonathan Gleason and Amanda Ross from the DEVELOP National Program guided the group initial planning stages and together this support structure enabled the team to move forward with early programming milestones.

The following timelines provide an outline of GRSN team phase one deliverables:

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Figure 3: GRSN Phase I Timeline: Fall ’06 - Spring ’07
PHASE I: SOFTWARE PLANNING

The GRSN team completed a specialized scientific visualization client for the CALIPSO science team. This client program has been implemented using the GRSN framework and includes support for the following requested features requested by Dr. Charles Trepte:

- Interactive user-interaction with large datasets from the CALIPSO satellite
- Support for multiple computer monitors for side-by-side weather trend analysis
- Fast performance and data-processing features for future datasets such as MODIS

Figure 4: Illustration of Proposed Software Features

The following outline describes planning considerations for fall ’06 software:

- Balancing research vs. development time, budget and features
- Encountering technical issues with Scriptable vs. QT / VTK framework
- Enabling Unix based code to run on Windows 32 operating systems

Team member Ben Hughe’s completion of a graphical software framework based on open-source three-dimensional libraries in fall ’06 enabled provided support for a full featured CALIPSO visualization client.

Figure 5: Screenshots of the GRSN framework user-interface

The software considerations for spring ’07 consisted of the following:

- Feature refinement following CALIPSO science team feedback
- Research and development for improved client performance
- User-interface refinement and future next steps for the GRSN
PHASE I: FRAMEWORK DEVELOPMENT

The GRSN framework has been configured to enable users to explore three-dimensional Light, Detection and Ranging (LIDAR) datasets from the CALIPSO earth observation satellite. This framework uses the popular open-source libraries QT and VTK to enable the interactive display of remote sensing data and simplify process of building specialized science tools. The following figure provides an outline of GRSN framework:

![GRSN GUI software implementation](image)

Figure 6: GRSN GUI software implementation

These libraries support object oriented programming paradigms that have enabled GRSN developers to use QT “plug-ins” as a mechanism for implementing Visual Toolkit (VTK) rendering environments. This QT and VTK open-source software combination provides an exciting, high performance software package for scientific visualization.
PHASE I: CALIPSO CLIENT DEVELOPMENT

The software client built for the CALIPSO science team uses the GRSN framework and uses the Visual Toolkit (VTK) and QT open-source Application Programming Interfaces (API) to interactively display geo-referenced data using a consumer PC computer.

The following figure shows this software in action:

Figure 7: (Top) Software screenshot of multiple CALIPSO-LIDAR datasets (Bottom) Screenshot showing results on a dual monitor display system
Team member and adviser Jonathan Gleason programmed the GRSN-CALIPSO client using VTK. This software served as a provided a foundation for subsequent software and milestone for CALIPSO science team feature requests.

The user-interface for the CALIPSO visualization client supports users to pan, zoom and rotation using a standard computer mouse. These features have been expanded to run on both the Unix and Windows operating systems.

Figure 8: (Top) CALIPSO-VTK software on Windows XP operating system  
(Bottom –Left) Screenshot of CALIPSO software showing wireframe mode  
(Bottom –Right) Screenshot of a LIDAR curtain file dataset in close-up view
The GRSN CALIPSO client uses meta-header files or .MHD files to describe the data attributes of respective LIDAR dataset displayed using the software. Jonathan Bidwell has programmed a Matlab user-interface program to automate this process and produce .MHD formatted files for each LIDAR curtain file.

The following figure provides a screenshot of this batch formatting utility:

![Screenshot of GRSN-Matlab client for batch processing LIDAR datasets](image)

The technical issues associated with cross-platform support represented an unexpected challenge for the team. The original assumption that cross-platform between Windows and Unix would be guaranteed using the QT and VTK APIs was false; code had to be carefully re-written for each operating system.

Team member Ben Hughes resolved these cross-platform problems and used an online patch to enable the QT API to operate in the Windows environment. Jonathan Bidwell compiled this software using Microsoft Visual Studio on an IBM T40 Thinkpad, and the client is now available to Windows users via CD or internet download upon request.
PHASE I: BENCHMARK / SOFTWARE ALGORITHMS

The GRSN team researched memory management techniques to build prototype software for reducing CALIPSO visualization client memory requirements. This focus on memory management and performance has played a central role in software design given the large size of CALIPSO datasets, \( \approx 416\text{MB} \) per file.

The GRSN CALIPSO client loads datasets measured by the satellite’s onboard LIDAR instrument. These datasets describe precise location of cloud and aerosol products in the form of LIDAR curtain files or two-dimensional arrays.

The index or row-column location of each intensity value stored in a two-dimensional LIDAR curtain file dataset is referenced to describe the geo-referenced position of that point with respect to longitude, latitude and altitude. This information is used to generate an interconnecting “triangle strip” surface for mapping points from rectangular LIDAR curtain file datasets (Figure 11) to positions with respect to the curvature of the earth.

This “triangle strip” method has been shown to exhibit good performance on computers with high-end graphics cards but support a limited number of datasets on consumer grade computers. The current software relies on a large number of 3D triangle coordinates that are loaded into graphic card memory for each dataset on startup; this presents a problem for computers without powerful graphic cards.

The following memory management concept describes one solution the team has investigated this spring:
GRSN team members Jonathan Bidwell and Ben Hughes have taken a number of steps to reduce memory required for referencing vertices and improve software performance.

The coordinates of each triangle vertex shown here as the intersection of black lines between layers are stored into memory on the user’s graphics card.

These memory requirement can be considerable during interacting with multiple datasets. GRSN is exploring a method to reduce the number of vertices that must be stored in memory to display curtain files.

Figure 11: Illustration showing triangle strips and data mapping

Figure 12: LIDAR curtain file image preprocessing concept using limited vertices
These performance enhancement efforts have focused on mapping geo-referenced data from LIDAR curtain files to simple polygons. Bidwell programmed a two-dimensional transform in Matlab for preprocessing images with respect to Earth’s curvature. The following figure describes these preprocessing steps:

**Figure 13:** (Top) Matlab pre-processing results showing spherical Earth curvature (Bottom) Enhancement concept to reduce texture coordinate and vertices
These results prompted the team to evaluate next steps for VTK implementation. Bidwell modified Jonathan Gleason’s original VTK CALIPSO client program to generate a single polygon textured example. Hughes performed a series of benchmarks between the single polygon and triangle strip implementations to compare performance.

Figure 14: (Left) Screenshot from single polygon VTK test implementation (Right) Screenshot from actual VTK performance benchmark

These performance metrics enabled the team to compare algorithm results without performing a complete implementation and provided insight for the future runtime enhancement of GRSN plug-ins. The performance of the proposed solution has been shown to be 100%-300% faster than the triangle method; at the time of this report more details about these results are expected next month in a separate report by Ben Hughes.

Figure 15: Screenshot of GRSN-CALIPSO client with support for future enhancement
PHASE 2 & 3: MILESTONES & OBJECTIVES

The successful completion of phase one software development serves as an exciting milestone of progress in terms of extending collaboration and remote sensing science benefits to scientist and local communities.

The CALIPSO software client developed by the GRSN team provides researchers with software features unavailable in commercial software, and the GRSN framework behind this software simplifies the process of developing specialized science applications.

![GRSN Development Milestones](image)

Figure 16: GRSN milestones for the next generation of remote sensing collaboration

GRSN Online Community represents the next step for the GRSN framework providing an information hub designed to connect scientists from around the world to encourage communication, problem solving and information sharing to solve problems of National Priority using NASA remote sensing data products.

The GRSN team has the historic opportunity to become one of the first groups to build collaborative, online, remote sensing toolsets for the purpose of expanding audience of remote sensing research, sharing ideas and results and accelerating the pace of Earth science discovery using NASA remote sensing data products.
PHASE 2: TOOLS FOR SUCCESS

The DEVELOP National Program challenges student-led teams to investigate pressing earth science questions from state and government partners. These teams utilize NASA remote sensing data products to explore connections between environmental issues and present findings to state and local decision makers.

This remarkable program presents exciting synergistic opportunities for the second phase of the framework. The following outline describes concepts for enhancing the existing scientific visualization at the DEVELOP Program and building second phase features:

1. DEVELOP student teams design specialized scientific visualization tools

The focus of this collaboration between GRSN software developers and student science teams is to place domain students and mentors center stage in the design of specialized science research applications. These science teams are involved during all steps of the process, participating in user-interface design, suggesting software features. The goal is for science teams to finish the term with a sense of ownership and feel 100% comfortable presenting and using the software.

GRSN software works great on consumer PCs. This framework lets students share results, continue research using the software between terms at DEVELOP and use these experiences to the GRSN team the following term for future improvements.

This iterative software development enables the GRSN team to produce software templates for future programmers and provide effective domain specific research tools for scientific niches where such tools would otherwise be unavailable.

2. GRSN partnership with the DEVELOP web-team to streamline result publications

The GRSN framework has open-ended support for web-services. This presents an exciting opportunity to use meta-data for streamlining the process of publishing results online. GRSN supports service oriented architecture and can export data in formats that web-applications understand.

This meta-data can be programmed to appear as formatted by the DEVELOP web-team to publish results online. The GRSN framework enables teams use common sets of tools. Building a tool that makes saving screenshots or other information in a meta-data format would enable the DEVELOP web-team to provide research teams with a streamlined process for publishing online daily status reports, troubleshooting guides or automatic software description online.

These second phase collaborative tools enables groups to share information with the click of a button (no more building websites with an editor or by hand). The web-team can easily adapt web-publishing behind the scenes to respond to policy changes such as “triangle charts;” GRSN should conform to web-team standards.
PHASE 2: NEXT STEPS FOR THE TEAM

These steps highlight an exciting opportunity to leverage expertise and existing applied science research at the DEVELOP National Program with GRSN software development to assist teams with day to day research and deliver custom science tools that provide features that are not supported by mainstream commercial products. The second phase objectives for GRSN are as follows:

1. Build otherwise unavailable scientific visualization software that scientists use, improve and champion as research tools

2. Enable researchers to access this software and expand GRSN to support online web-services for scientific collaboration

DEVELOP-GRSN software would use the GRSN framework to deliver applied Earth science research tools geared for consumer PCs. These efforts are to result in an ever expanding set of research tools that are made available to scientists around the world through the GRSN Online Community web-portal and include specialized research and collaboration features designed by NASA Langley Research Center domain experts and science peers at the DEVELOP Program.