Space Situational Awareness Data Processing Utilizing Google's Compute Cloud Services

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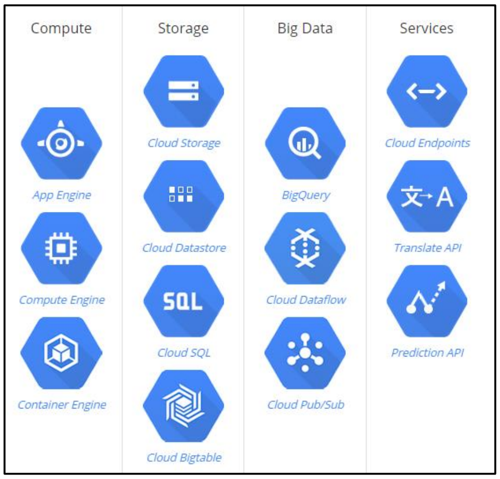
Space Situational Awareness is defined as the knowledge and characterization of all aspects of space. SSA is now a fundamental and critical component of space operations. Increased dependence on our space assets has in turn led to a greater need for accurate, near real-time knowledge of all space activities. With the continued growth of the orbital debris population, high-risk conjunction events are occurring more often. Consequently, satellite operators are performing collision avoidance maneuvers more frequently. With the addition of the new Space Fence sensor, LEO operators will be faced with hundreds of conjunction events each week that will require analysis and evaluation. This paper presents the details of SpaceNav's latest technology, a collaborative online environment where various SSA applications are deployed into a cloud-based environment. We summarize the key tools that are in operational use now. We present the overarching architecture, which is deployed in the Google compute environment.

1. INTRODUCTION

Space Situational Awareness is defined as the knowledge and characterization of all aspects of space. SSA is now a fundamental and critical component of space operations. Increased dependence on our space assets has in turn led to a greater need for accurate, near real-time knowledge of all space activities. With the continued growth of the orbital debris population, high-risk conjunction events are occurring more often. Consequently, satellite operators are performing collision avoidance maneuvers more frequently. With the addition of the new Space Fence sensor, LEO operators will be faced with hundreds of conjunction events each week that will require analysis and evaluation. Preparation for processing numerous warning messages includes: Precise orbit determination that updates in real-time, an understanding of the space weather environment, notification of changing in space weather predictions that will affect trajectory predictions of the space object catalog, and a sophisticated, automated collision risk management process that generates optimal collision avoidance strategies.

This paper presents the details of SpaceNav's latest technology, a collaborative online environment where various SSA applications are deployed into a cloud-based environment. Access to the applications occurs through a secure webpage. We highlight three of the mission critical tools that are in operational use now; the Collision Risk Management System, the Orbit Estimation and Realistic Covariance Generation software, and the Space Weather Analysis page. The overarching architecture, which is integrated in the Google compute environment, is presented. The following sections contain additional information. Section II summarizes the Google Cloud Platform. Section III describes key components of SpaceNav's SSA software, and the corresponding solution architecture. Section IV captures near-term future work.

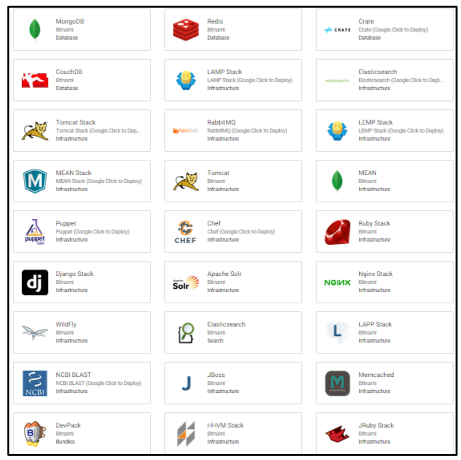
2. DESCRIPTION OF THE GOOGLE CLOUD PLATFORM



The Google Cloud Platform (https://cloud.google.com/) is a complete platform as a service solution. There is a robust toolset, products and APIs that enterprises can use to develop and quickly deploy applications to a variety of platforms. The Google Cloud Platform can be used for virtually any style of system by utilizing many technologies including Virtual Machines, Application Engines, Compute Engines, SQL Relational Databases, Java, and Prediction APIs.

2.1 Available Software

The flexibility of the platform provides the developer or system administrator with the ability use many of the "Launcher deployment" options or the ability to create their own custom environment from scratch. Virtual Machines (VM) can be created, and spun up very simply by using one of the pre-loaded images that contain a variety of Operating Systems, such as Debian Linux, CentOS, RedHat Linux, and Window Server 2008 and 2012. The Google Launcher allows the user to quickly install a variety of applications and development environments without having to do manual installs keeping each environment consistent. There are over 150 different options creating a powerful and convenient way to install products into your environment.

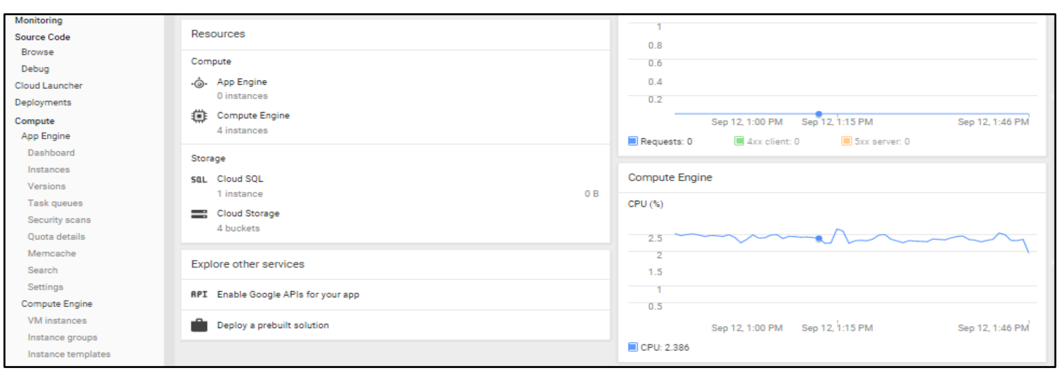


2.2 Performance

The Google Cloud Platform provides a variety of standard, high performance, and high memory options when creating virtual machines in the cloud environment. Individual VMs can be created that utilize one or more cores of processing power up to a total of 32 cores. In addition, the high memory option for a 32 core VM utilizes a total of 208 GB of memory.

2.3 Google Cloud Platform Console & Administration

The Google Console provided for the administration of your cloud environment provides information about all aspects of the products that you are utilizing in the cloud environment. When you log into your project at the https://cloud.google.com/ link, you will see a user-friendly menu on the left hand side of the screen that provides navigation through all aspects of the cloud products. Privileges for individual users can be set up for access to the cloud console providing separation of duties within your organization. Below is a section of the home page dashboard provided by the Google Platform Console:



2.4 Features/Benefits of Google Cloud Platform

The Google Cloud Platform provides a highly reliable environment by utilizing multiple data centers around the world. As an enterprise, you define where you want your environment to be deployed via regions and zones. In the United States there are 3 regions each with multiple zones.

us-central1

Zones	Instances	Disks	Planned Outages
Zone A	3	14	No maintenance windows
Zone B	0	16	No maintenance windows
Zone C	0	0	No maintenance windows
Zone F	1	3	No maintenance windows

Data is automatically mirrored so that the user does not have to worry about data backups and other administrative type issues that normally need to be managed in an in-house data center. By using the Google Cloud Platform, there is no need to maintain a data center complete with all the requirements that are involved with hardware and the maintenance of that hardware. Personnel can concentrate of the development of new features and products that are a direct cost benefit to the company.

2.5 Deployment and Scalability

Utilizing persistent disks, snapshot disks and multiple virtual machines, scaling and deploying multiple versions of the application is fast and simple. When a VM is started, a persistent disk is created that is attached to that VM. Once your custom application (or any other application) is installed on this persistent disk you can save this disk and re-use it on as many machines are necessary.

Creating a snapshot of this persistent disk, allows you save from this disk for later use or for back up purposes. If you require more processing power, all that needs to be done is to attach this disk to a more powerful virtual machine, and applications will run with more processing power, memory, or both. For testing purposes, you could have multiple versions of your SW installed on multiple persistent disks, and then attach each of those disks to different types of VMs, and run comparisons for benchmarking and test.

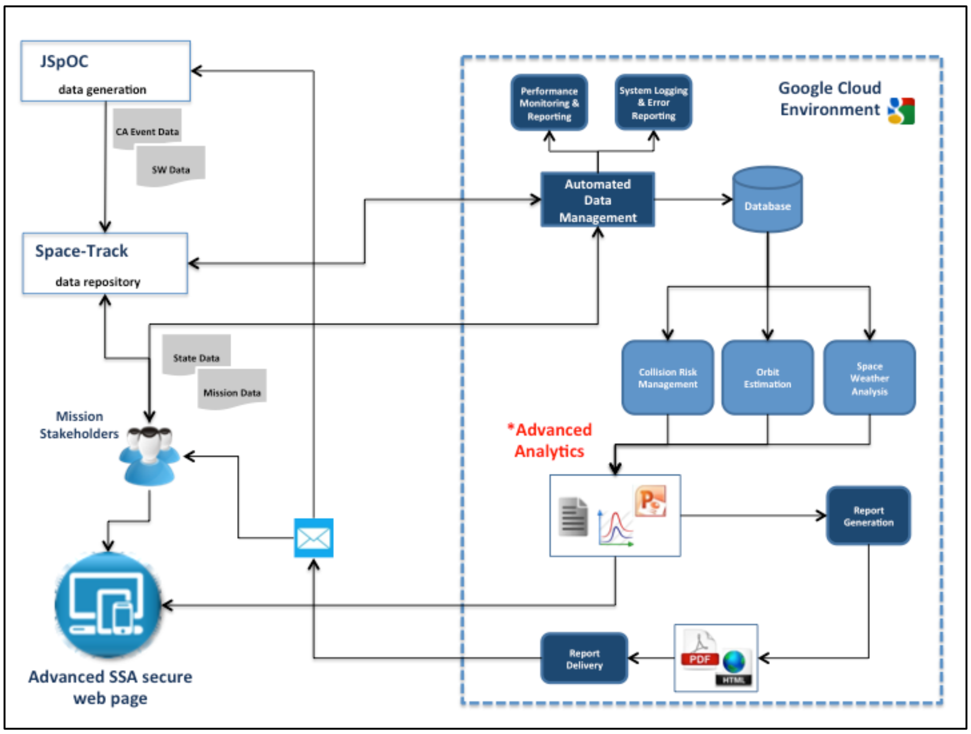
2.6 Community Support

There are several options that provide free support for the Google Cloud Platform. Multiple Google Groups have been created for different areas of the Cloud Platform as well as Stack Overflow and Server Fault threads.

3 FUNCTIONAL COMPONETS OF THE SOLUTION ARCHITECTURE

SpaceNav has developed various tools that comprise SpaceNav's SSA Tool Suite. Included in the software suite is a space-based observation simulator, a probability forecasting method for predicting conjunction event evolution, and an approach for determining how best to execute a collision avoidance maneuver. SpaceNav's latest technology is to deploy these applications into the Google compute environment, where simultaneous users can access the various applications from anywhere. Additionally, our Software as a Service (SaaS) model makes available data analytics, graphs, decision aids, and recommended courses of action, all available via a collaborative online environment.

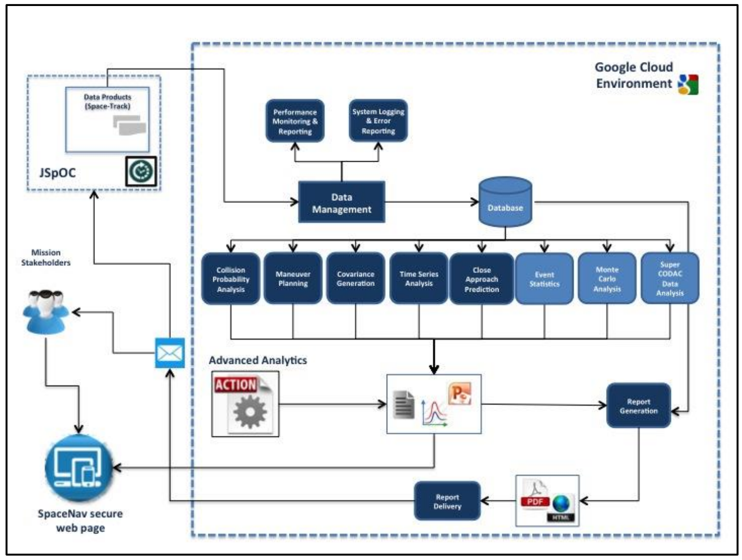
Figure 1: Architecture and Workflow



In addition to deployment of the individual tools, we have built supporting architecture that enables real-time data exchange between the spacecraft owner/operator, the JSpOC, the Space-Track.org website, and other mission stakeholders. Figure 1 provides details of the existing architecture and workflow. Shown in Figure 1 is data being generated by the spacecraft owner/operator. Data can either be posted to Space-Track.org and then retrieved by the SpaceNav automation, or data can be automatically delivered to the Google Compute environment. Once received, data is automatically processed, analysis performed, and the results automatically delivered to the various mission stakeholders. The webpage allows mission stakeholders to have access to additional analysis and to examine data for their mission from almost any location. The interactive design of the architecture provides a platform for multiple users to collaborate on a particular high-risk conjunction event.

3.1 Automated Collision Risk Management

SpaceNav's collision risk management software suite enables satellite operators to quantify and mitigate high-risk conjunction events. The SpaceNav software suite is comprised of several analysis tools, a Monte Carlo simulation to forecast how risk evolves, and an optimal maneuver planning utility to reduce the overall collision risk.



The SpaceNav collision risk management software first processes conjunction event data that is generated by the Joint Space Operations Center (JSpOC). Output from the SpaceNav software consists of graphs and figures that are used to develop Course of Action (COA) strategies for the spacecraft operator. The software is designed to operate in either manual or automation mode. SpaceNav software operates on standard JSpOC data: Summary Reports, Orbital Conjunction Messages (OCMs), Conjunction Data Messages (CDMs), Vector Covariance Messages (VCMs), and Sensor Tracking & Tasking Files.

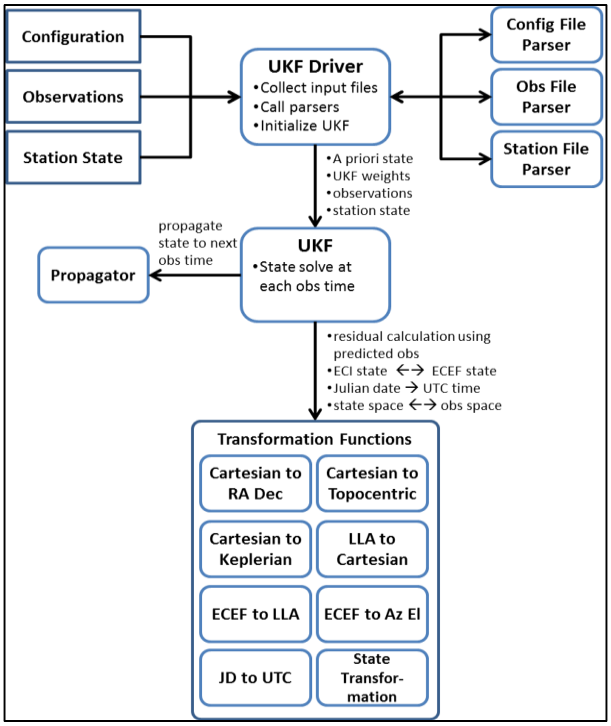
Data products received from the JSpOC are automatically processed as soon as they are received. Quality checks are performed on the data, derived parameters are calculated, and the data is written to a database. Analysis figures are produced and uploaded to the webpage. The report delivery service sends e-mail and text to customized distribution lists to ensure that customers only receive the information that they desire. A description of the various software modules is presented in Section 3.3.1.

3.1.1 Software Module Description

- *Probability Analysis Service* – Computes miss distance and collision probability for given close approach warning message [at TCA]
- *Maneuver Planning Service* – Generates one or more maneuver plans for a given set of operational targets and constraints
- *Covariance Generation Service* – Generates realistic, predictive covariance for a given spacecraft. Expected maneuver errors are also included.
- *Time Series Analysis* – Graphical display of various parameters, spanning multiple warning messages
- *Close Approach Prediction Service* – Generates close approach predictions for multiple primaries vs. a user-defined set of secondary objects
- *Event Statistics Service* – Generates various event statistics, including miss and probability distribution. Characterization of the secondary object population is also included.
- *Monte Carlo Analysis Service* – Computes collision probability via Monte Carlo simulation. Output includes miss and miss geometry distribution.
- *SuperCODAC Data Analysis* – Utility that processes SuperCODAC statistical error files produced by the JSpOC
- *LaunchCOLA Analysis* – Collision Probability analysis utility that processed launch trajectory files spanning a given launch window.

3.2 Orbit Estimation & Realistic Covariance Generation

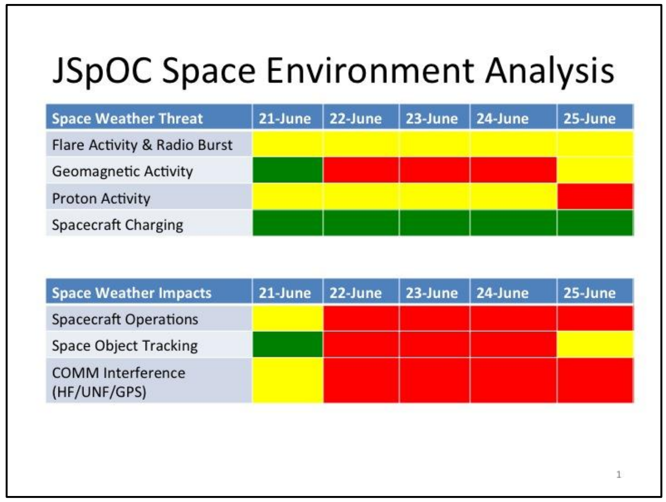
SpaceNav's Orbit Estimation and Realistic Covariance Generation Utility is used to process satellite-tracking data, and produce realistic state and state uncertainty predictions. State estimation can be performed using angles, range/range-rate, or GPS measurements. The measurements can be from a ground or space-based observer. The state estimation module utilizes an Unscented Kalman Filter (UKF). This method generates a state and covariance update following the processing of each observation. Figure 1 provides the software architecture for the state estimation module. The user will populate the UKF with a set of files prior to orbit estimation. The relevant data files include: a configuration file, the observation data file, and a file that contains the station location (or space-based sensor ephemeris file). A driver program that controls the execution of the estimation process collects the data. The UKF function performs the state estimation for each observation time. It relies upon a set of functions to perform various transformations; which vary depending upon the observation type. The propagator is called upon to propagate the state between each observation time and between tracks. The final output is the state and covariance at the last observation time.



Output covariance is determined by assessing the residuals of the measurements used as inputs into the orbit estimation tool. For future ephemeris and covariance generation, this output covariance is propagated forward with the orbit state and additional sources of uncertainty are incorporated. In order to more accurately reflect the role of non-conservative forces in orbit propagation, one of two methods is employed. The first option is a consider parameter which incorporates uncertainties in atmospheric density modelling into spacecraft covariance. The second option is state noise compensation (SNC) which allows the user to incorporate uncertainties in spacecraft accelerations into the satellite covariance propagation.

3.3 Space Weather Analysis

SpaceNav's Space Weather Analysis application fuses information from various sources, including NOAA, Air Force, and Academia. Web users can log-on and view real-time information from the JSpOC Space Environment Analysis group. The application shows the current and future space weather threats and impacts. For example, if a satellite operator observed a large or unexpected change in the reported close approach predictions, one possible reason could be that a space weather anomaly affected the trajectory predictions. The JSpOC data feed provides insight to observed anomalies. Additional information on the Space Weather Analysis page are the results from the JSpOC-generated atmospheric calibration used as part of the atmospheric drag prediction. Also displayed is a real-time, time series of the Disturbance Storm Time (DST) Index, an index of geomagnetic activity.



4 CONCLUSIONS & FUTURE WORK

SpaceNav's latest technology is a collaborative online environment where various SSA applications are deployed into a cloud-based environment. The technology is designed to scale, across multiple users with multiple data sources. As the size of the space object catalog grows, leveraging the high performance-computing environment will become more important. Real-time processing of the operational data is critical to establishing a complete SSA picture. Future work will include deployment of additional SSA tools into the Google environment.

5 REFERENCES

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