Cloud Computing for Planetary Defense

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Abstract

In this paper we demonstrate how a cloud-based computing architecture can be used for planetary defense and space situational awareness (SSA). We show how utility compute can facilitate both a financially economical and highly scalable solution for space debris and near-earth object impact analysis. As we improve our ability to track smaller space objects, and satellite collisions occur, the volume of objects being tracked vastly increases, increasing computational demands. Propagating trajectories and calculating conjunctions becomes increasingly time critical, thus requiring an architecture which can scale with demand. The extension of this to tackle the problem of a future near-earth object impact is discussed, and how cloud computing can play a key role in this civilisation-threatening scenario.

Introduction

Space situational awareness includes scientific and operational aspects of space weather, near-earth objects and space debris. This project is part of an international effort to provide a global response strategy to the threat of a Near Earth Object (NEO) impacting the earth, led by the United Nations Committee for the Peaceful Use of Space (UN-COPUOS). The impact of a NEO – an asteroid or comet – is a severe natural hazard but is unique in that technology exists to predict and to prevent it, given sufficient warning. As such, the International Spaceguard survey has identified nearly 1,000 potentially hazardous asteroids >1km in size although NEOs smaller than one kilometre remain predominantly undetected, exist in far greater numbers and impact the Earth more frequently[1]. Impacts by objects larger than 100 m (twice the size of the asteroid that caused the Barringer crater in Arizona) could occur with little or no warning, with the energy of hundreds of nuclear weapons, and are “devastating at potentially unimaginable levels”[2] (Figure 1). The tracking and prediction of potential NEO impacts is of international importance, particularly with regard to disaster management. Space debris poses a serious risk to satellites and space missions. Currently Space Track[3] publishes the locations of about 10,000 objects that are publicly available. These include satellites, operational and defunct, space debris from missions and space junk. It is believed that there are about 19,000 objects with a diameter over 10cm. Even the smallest space junk travelling at about 17,000 miles per hour can cause serious damage; the Space Shuttle has undergone 92 window changes due to debris impact, resulting in concerns that a more serious accident is imminent[4], and the International Space Station has to execute evasion manoeuvres to avoid debris. There are over 300,000 objects over 1cm in diameter and there is a desire to track most , if not all of these. By improving ground sensors and introducing sensors on satellites the Space Track database will increase in size. By tracking and predicting space debris behaviour in more detail we can reduce collisions as the orbital environment becomes ever more crowded.

Cloud computing provides the ability to trade computation time against costs. It also favours an architecture which inherently scales, providing burst capability. By treating compute as a utility, compute cycles are only paid for when they are used. Here we present a cloud application framework to tackle space debris tracking and analysis, that is being extended for NEO impact analysis. Notably, in this application propagation and conjunction analysis results in peak compute loads for only 20% of the day, with burst capability required in the event of a collision when the number of objects increases dramatically; the

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[1] Population of NEOs larger than 100m is estimated at between 200,000 & 400,000, with an impact frequency of 2,000 to 4,000 years.
[2] Testimony of Russell L. Schweickart, Chairman, B612 Foundation, before the Space and Aeronautics Subcommittee of the House Committee on Science and Technology, 11 October 2007.
[3] The Source for Space Surveillance Data. *Space Track*. [Online] http://www.space-track.org.
[4] Hypervelocity Impact Technology Facility (Missions from STS-50 through STS-114). [Online] http://hitf.jsc.nasa.gov.

Iridium-33 Cosmos-2251 collision in 2009 resulted in an additional 1,131 *trackable* objects (Figure 2). Utility computation can quickly adapt to these situations consuming more compute, incurring a monetary cost but keeping computation wall clock time to a constant . In the event of a conjunction event being predicted, satellite operators would have to be quickly alerted so they could decide what mitigating action to take.

In this work we have migrated a series of discrete manual computing processes to the Azure cloud platform to improve capability and scalability. It is the initial prototype for a broader space situational awareness platform. The workflow involves the following steps: obtain satellite position data, validate data, run propagation simulation, store results, perform conjunction analysis, query satellite object, and visualise.

Satellite locations are published twice a day by Space Track, resulting in bi-daily high workloads. Every time the locations are published, all previous propagation calculations are halted, and the propagator starts recalculating the expected future orbits. Every orbit can be different, albeit only slightly from a previous estimate, but this means that all conjunction analysis has to be recomputed. The quicker this workflow is completed the quicker possible conjunction alerts can be triggered, providing more time for mitigation.

The concept project uses Windows Azure as a cloud provider and is architected as a data-driven workflow consuming satellite locations and resulting in conjunction alerts, as shown in Figure 3. Satellite locations are published in a standard format know as a Two-Line Element (TLE) that fully describes a spacecraft and its orbit. Any TLE publisher can be consumed, in this case the Space Track website, but also ground observation station data. The list of TLEs are first separated into individual TLE Objects, validated and inserted into a queue. TLE queue objects are consumed by comparator workers which check to see if the TLE exists; new TLEs are added to an Azure Table and an update notification added to the Update Queue.

TLEs in the update notification queue are new and each requires propagation; this is an embarrassingly parallel computation that scales well across the cloud. Any propagator can be used. We currently support NORAD SGP4 propagator and a custom Southampton simulation (C++) code. Each propagated object has to be compared with all other propagations to see if there is a conjunction (predicted close approach). Any conjunction source or code can be used, currently only SGP4 is implemented; plans are to incorporate more complicated filtering and conjunction analysis routines as they become available. Conjunctions result in alerts which are visible in the Azure Satellite tracker client. The client uses Virtual Earth to display the orbits. Ongoing work includes expanding the Virtual Earth client as well as adding support for custom clients by exposing the data through a REST interface. This pluggable architecture ensures that additional propagators and conjunction codes can be incorporated, and as part of ongoing work we intend to expand the available analysis codes.

The framework demonstrated here is being extended as a generic space situational service bus to include NEO impact predictions. This will exploit the pluggable simulation code architecture and the cloud's burst computing capability in order to allow refinement of predictions for disaster management simulations and potential emergency scenarios anywhere on the globe.

Summary

We have shown how a new architecture can be applied to space situational awareness to provide a scalable robust data-driven architecture which can enhance the ability of existing disparate analysis codes by integrating them together in a common framework. By automating the ability to alert satellite owners to potential conjunction scenarios we reduce the potential of conjunction oversight and decrease the response time, thus making space safer. This framework is being extended to NEO trajectory and impact analysis to help improve planetary defencs capability for all.

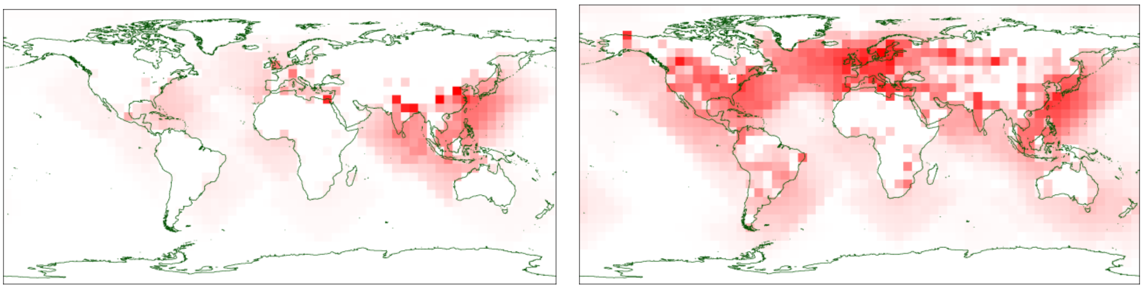
(a) (b)

Figure 1. Map showing the relative consequences of the impact of a 100m diameter asteroid at 12 km/s into global grid cells with shading denoting (a) casualty generation and (b) infrastructure damage.

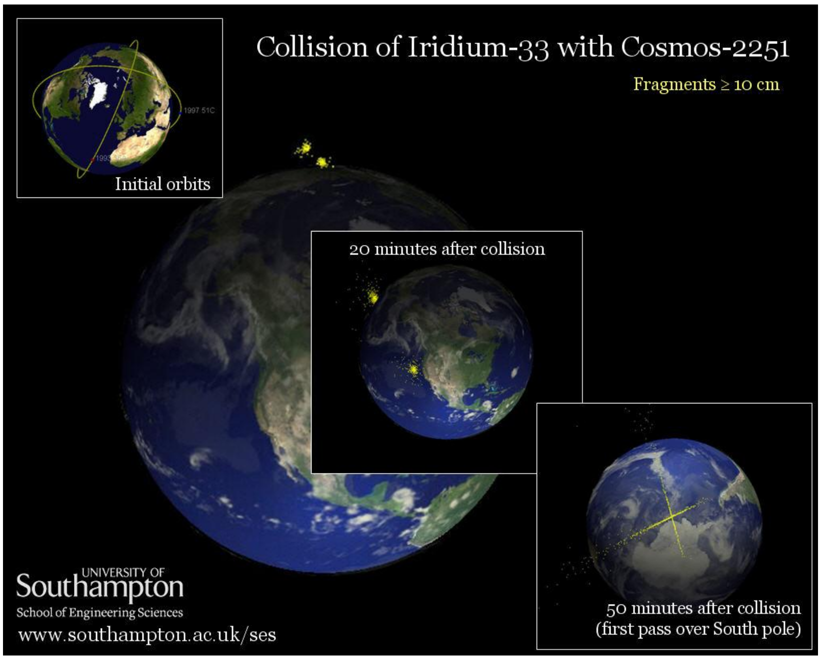

Figure 2 Iridium-33 collision with Cosmos-2251

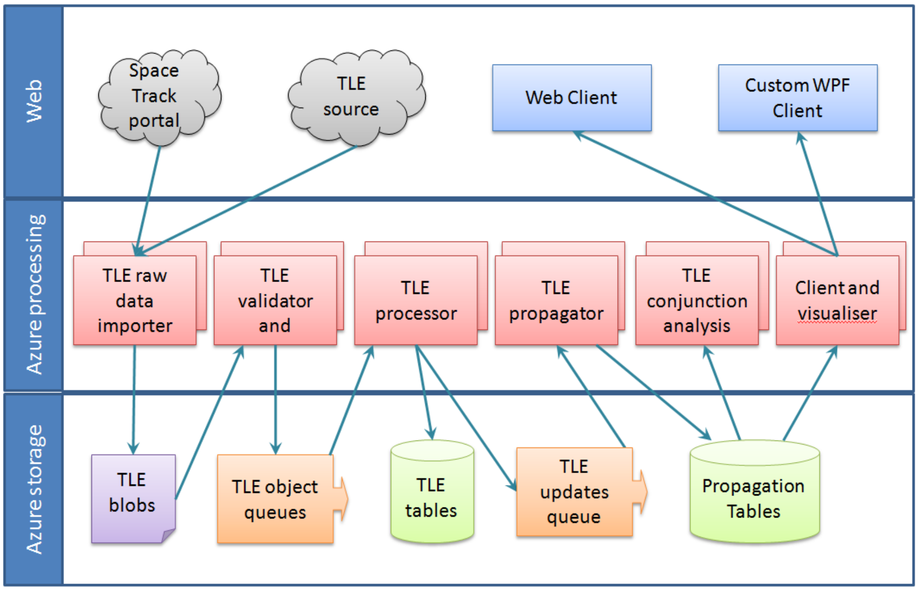

Figure 3: Space situational awareness architecture