

Stellar Command: a planetarium software based cosmic performance interface

Angelo Fraietta
University of New South Wales
Cnr. Oxford Street & Greens Road
Paddington NSW 2021, Australia
a.fraietta@unsw.edu.au

ABSTRACT

This paper presents the use of *Stellarium* planetarium software coupled with the *VizieR* database of astronomical catalogues as an interface mechanism for creating astronomy based multimedia performances, and as a music composition interface. The celestial display from *Stellarium* is used to query *VizieR*, which then obtains scientific astronomical data from the stars displayed—including colour, celestial position, magnitude and distance—and sends it as input data for music composition or performance. *Stellarium* and *VizieR* are controlled through *Stellar Command*, a software library that couples the two systems and can be used as both a standalone command line utility using Open Sound Control, and as a software library.

Author Keywords

NIME, Stellarium, Astronomy, Algorithmic Composition, VizieR

CCS Concepts

•Applied computing → Sound and music computing; Performing arts; •Information systems → Music retrieval;

1. INTRODUCTION

Musical composition and performance inspired or based on astronomy has been used in many cultures for millennia, with many civilizations creating songs and dances based on the astronomical calendar to reinforce the tracking of seasonal activities; such as planting and harvesting of crops, times of trade, and religious or cultural practices [33, 8, 25]. More recently, composers have used scientific data obtained from individual stars to generate sounds and have created compositions directly correlated to that data [14, 7].

The advancement of computing power has made the availability of planetarium software for both desktop and mobile platforms very accessible to many people. These software packages are not only used for scientific and research activities; such as astronomy, education and general stargazing; they have also been used by artists in presenting multimedia artworks and installations [39, 35].

This paper will introduce *Stellar Command*, a software system that integrates *Stellarium* planetarium software with

online astronomical data acquisition through *VizieR* database of astronomical catalogues [30]. *Stellar Command* can be used as an interface mechanism for correlating music and sound generation, allowing *Stellarium* to be used as both a direct input interface for performance or composition, and as a remotely controlled derivative multimedia display output.

2. RELATED WORK

Many composers have used the cosmos as inspiration or stimulus to their works, with many using scientific observations or data as input [18, 14]. The *Quadrivium* linked astronomy, mathematics, geometry and music as a standard part of classical education up until the renaissance [26]. Composers have been mapping mathematics and geometry to music since antiquity [20, 5]. Kepler stated “The heavenly motions are nothing but a continuous song for several voices, to be perceived by the intellect, not by the ear; a music which, through discordant tensions, through syncopations and cadenzas as it were, progresses toward certain pre designed six-voiced cadences, and thereby sets landmarks in the immeasurable flow of time.” [32, cited in 286]. This notion inspired Rogers and Ruff to compose *The Harmony of the World* (1979), describing their work as “A Realization for the Ear” [32, p. 286] of Johannes Kepler’s *Astronomical Data from Harmonices Mundi* 1619. More recently, composers have used measurements from online databases as inputs to automata or as stimulus to performers.

Nick Ryan developed a musical instrument called *Machine 9* that uses the location of 27,000 pieces of space junk as input to an automaton [19]. The instrument is a large cylindrical phonograph that maps space debris to sound as it directly passes overhead. Each groove on the cylinder is associated with a catalogued piece of space debris [1]. The system accesses publicly available databases that provides the telemetry data of space debris, which is then modelled in real-time. When the telemetry data indicates that one of catalogued items is overhead, the machine locates one of the grooves on the cylinder and plays a mapped sound mechanically through a record-player type stylus.

Another system based on astronomical catalogues was the author’s own musical composition and performance interface using naked eye and binocular astronomy [14]. A specific star was determined by calculating its azimuth and height above the horizon—known as its *altitude*—using accelerometer and magnetometer sensors, and calculating the exact location of the star on the celestial sphere using the sensor data, time and geographical location of the observer. This calculation returns the star’s *right ascension (RA)*, which is based on its azimuth at Greenwich Meantime at the vernal equinox, and its *declination (Dec.)*, which is the stars north-south position at the same time [10, 14]. The resultant RA and Dec. are added as input to the *VizieR*



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database of online catalogues, returning data about stars—such as brightness and colour—within the defined radius. Various works were created using this interface. In one performance, which was conducted in conjunction with the Newcastle Astronomical Society on one of their field viewing nights, members of the public were enticed into viewing the night sky through high powered binoculars, while the sound generated, which was based on data from the stars they were viewing, was played through loudspeakers on the field [13]. Another set of performances was conducted with an improvising ensemble that featured various astronomical photos displayed as a slide show where the astronomical data was mapped as MIDI and functioned as inspirational impetus for the performers [7].

Although both systems are innovative and impressive, they have identifiable boundaries. First, Machine 9 exists as an installation piece using unique piece of specialised hardware [1]. Furthermore, a publicly available API to convert the space debris to a musical transmission protocol like MIDI or OSC [37] is not yet available for the wider computer music community. Secondly, although the binocular display has an awesome display—the actual night sky—“few people ventured outside to the astronomical equipment”[14, p. 50] because they were required to leave the room to look through binoculars while the ensemble played in a room. Furthermore, the work is severely bound by weather conditions and a clear view of the sky. In one of the performances, “the sky was completely covered with cloud and it rained, so there was nothing to see through the binoculars. The audience, however, enjoyed the ensemble performance with the NASA image slide show with samples fed from stored star tables.”[14, p. 50]. This weather constraint inspired the author to use planetarium software as the input and display mechanism as an alternative to binoculars.

Stellar Command enables composers to access astronomical data as input to their software using a common API. It also enables them to provide the audience an impressive planetarium software display that runs on a laptop computer without requiring the audience to leave the room. Furthermore, it facilitates creation of interactive celestial based installations. Stellar Command is available as open source software through GitHub [16].

2.1 Stellarium

Stellarium is a software program designed to enable people to create a virtual planetarium using their home computer [40]. It runs on Windows, OSX and Linux/Unix, including Raspberry Pi [40, p. 6]. Stellarium calculates positions of the Sun, moon, stars and planets based on the time and location defined by the user, and renders them to the display. Stellarium is used by both amateur and professional astronomers, and is used by the European Organisation for Astronomical Research in the Southern Hemisphere to facilitate distribution and sharing of visual data among scientists [6]. Stellarium has a very high quality graphical display, supporting spherical mirror projection that can be used with a dome [27] and is used in many schools and museums because it is both scientifically accurate and visually engaging [6]. Moreover, Stellarium can display constellations from several different cultures and has labels translated to more than 40 languages, making Stellarium both culturally aware and inclusive [6]. For example, Figures 1 and 2 display the same area of sky, however the first presents the constellations using the western sky lore while the latter presents them in the Tukano sky lore¹ [31]. A

¹The Tukano tribes are indigenous peoples of the north-western region of Brazil [21].

comparison reveals that *Scorpius* and *Cruce* are referred to as the *Fer-de-lance* and the *Tortoise*. This feature can make Stellarium an extremely useful tool in facilitating multimedia presentations for ethnomusicology or composing in non-western contexts.

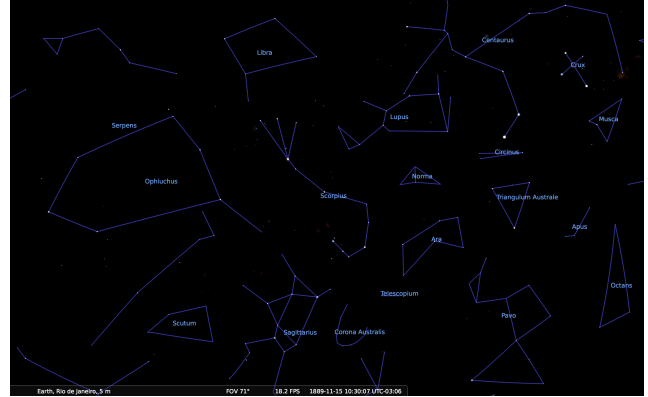


Figure 1: Constellations displayed in Western sky lore.

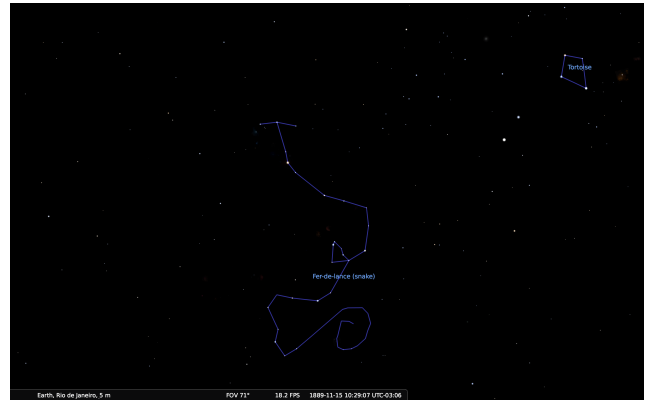


Figure 2: Constellations displayed in Tukano sky lore.

Many astronomers use Stellarium to display a prediction of the sky for a future time, such as organising a viewing night or planning an astro-photography session [4]. Archaeoastronomers also use the feature to generate an astronomical display from a location for a period sometime in the past [38]. Also, the landscape feature facilitates a connection between landscape and skyscape, so one can map the sky against a landscape for research or aesthetics [39].

Stellarium scripts are written in ECMAScript, also known as Javascript, and enables the programmer to generate and run an automated astronomy presentation, facilitating automation of all the functionality of Stellarium [40].

Stellarium has a Remote Control plugin that enables third party programs to communicate with Stellarium via a REST client. This feature was used by the author to create an interactive spacecraft game using a sonic ball as a preliminary test of Stellarium’s viability as a responsive performance interface [17]. The plugin also allows clients to query the status of Stellarium, including the area of sky currently being displayed. The exact celestial vector and field of view displayed are used as the input to the VizieR server in order to obtain data about stars in that location.

2.2 VizieR

VizieR is an online database of high quality astronomical catalogues collected by the Centre de Données astronomiques de Strasbourg (CDS), one of whose main goals “is to promote the usage of the reliable astronomical catalogues to the astronomical community” [30, p. 25]. One of the ways CDS ensures the reliability of their archives and catalogues is to only collect data that has been published or accepted in refereed scientific journals or literature. The number of catalogues available has grown from 3000 in 1999 [30, p. 24] to currently 18000 [3]. Catalogues can be selected by name or based on the wavelength, mission and astronomy type [29]. Wavelength dictates the frequency spectrum of the data in the catalogue, such as radio, infra-red, optical, x-ray, and Gamma-RAY. The mission indicates the purpose for which the catalogue was created or is used. For example, the purpose of the Kepler Mission is to “detect Earth-size planets in the habitable zone ... of solar-like stars... , determine their frequency, and identify their characteristics.” [22, p. 2]; and so catalogues created or used within this mission can be specifically targeted. The type of astronomy indicates the subject area of research that the catalogue belongs to; for example, black holes, galaxy clusters, planetary nebulae, red shifts, and photometry.

Once a user has selected the database criteria to search, they must provide VizieR a search window that consists of a target centre and area around that point to search. The target centre is the point on the celestial sphere referenced to a celestial equinox², and can be defined by object name, RA and Dec., or by IAU-coordinates [2].

3. STELLAR COMMAND MODULE

Although it is possible to communicate directly to Stellarium and VizieR directly through the HTTP interface, the stellar position parameters between the two systems are different. Stellarium returns its position information as three dimensional spherical points, with a separate query for the field of view; whereas, VizieR requires the data as a two dimensional geometric point with a defined radius. The Stellar Command module abstracts this information from the client software and removes the requirement to perform these calculations by the client. Stellar Command directs VizieR to query the Hipparcos catalogue because it provides a “complete all-sky survey of astrometric and photometric parameters for one million stars down to magnitude 11 ” [36, p. 201]. An attempt was made using other photometric catalogues, however, it was difficult to obtain consistent results for all sky locations.

In order to simplify interfacing the two systems, querying of the Stellarium and VizieR systems were separated into separate modules. In addition to reducing coupling between them, resulting in more robust code [23], the modules could also be used independently for astronomical applications. In addressing the different target communities—artistic and scientific—the code would be expected to run on multiple operating systems, including Windows, OSX, and Linux. Moreover, it was preferable to have a single executable version of the software rather than having to configure and build a separate program for each different platform.

The interface required to control both Stellarium and VizieR was HTTP based, so a language that provided network functionality as a fundamental core feature was preferred. Also, it was imperative that third party users of the library should not have to learn a particular programming language, but instead, could easily interface with the library using their preferred music package such as Max MSP, SuperCollider or PD. Furthermore, it would be ad-

²The default equinox is J2000 [29].

vantageous for users to be able to integrate the library into the programming language of their choice, such as C, C++, Python, Ruby, or Java.

Developing the system as a Java Archive (JAR) fulfilled all these requirements. Using a JAR file allowed instantiation from the command line, running as separate processes and using OSC to communicate with other programs. Additionally, many other programming languages can connect directly to a JAR through the Java Native Interface (JNI) [24].

3.1 Launching Stellar Command Module

The Stellar Command system, displayed in Figure 3, shows how the different systems interact with the Stellar Command module and with one another.

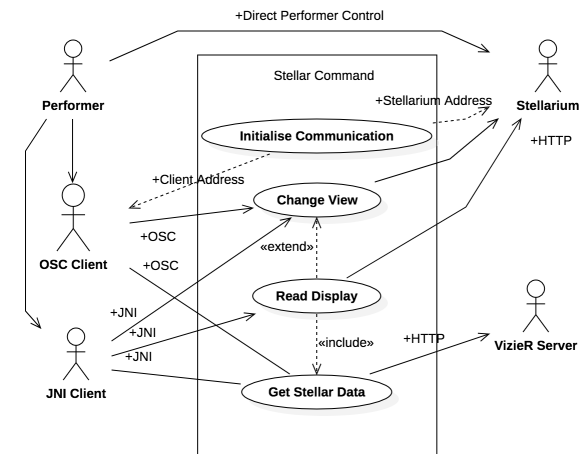


Figure 3: Stellar Command Use Case.

A performer is able to either control Stellarium directly, for example using Stellarium’s keyboard commands or a third party Remote Control client, or through the Stellar Command module via an OSC or JNI client³.

The Stellar Command module is instantiated by executing Java with the name of the JAR file and the required program arguments that define communication, such as the network port to send OSC messages to, and the OSC address space. For example, to start the StellarCommand module so it sends OSC messages on UDP port 1234 using an OSC address space of /Stellar,⁴ one would execute the following command:

```
java -jar StellarCommand.jar port=1234 \
osc=/Stellar.
```

When the server starts, it will open the first available UDP port, and notify the client of this port. For example, if the command module opened port 4567, it will send an OSC message /Stellar/osc 4567 to the client on the localhost. Allowing the command module to find its own port number removes the probability of port clashes as each client furnishes the other with a valid port number for communicating without requiring configuration in the command module. It is, however, possible to request the Stellar Com-

³Communicating via the JNI interface is done by the host programming language and is outside the scope of this paper.

⁴In this instance, the OSC client and Stellarium are on the same computer.

mand module try certain ports by adding the argument *try-port* with a comma separated list of ports. For example, the argument `tryport=3333,4444,5555` will cause Stellarium to sequentially try opening the ports listed, and if these all fail, will then open the first available port.

The OSC client and the Stellarium server do not have to be on the same physical computer as the Stellar Command module. For example Figure 4, shows three OSC clients and a Stellarium server on a LAN, and a remote Stellarium server accessible from the internet through *myserver.com*.

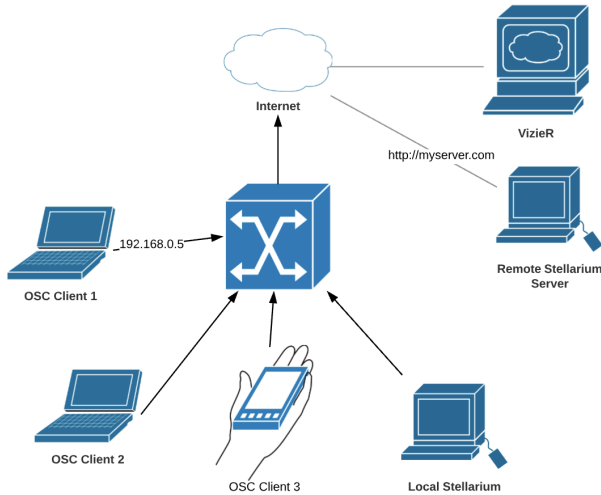


Figure 4: Remote Stellarium and OSC Clients.

Creating a connection between *OSC Client 1* and *Remote Stellarium Server* is effected by adding adding the arguments `client=192.168.0.5` and `stellarium=http://myserver.com` to the command line. This will cause the Stellar Command module to send OSC messages to “192.168.0.5” and Stellarium commands to `http://myserver.com` on HTP port 8090⁵, effectively acting as a proxy between the two. A typical sequence of events is shown in Figure 5.

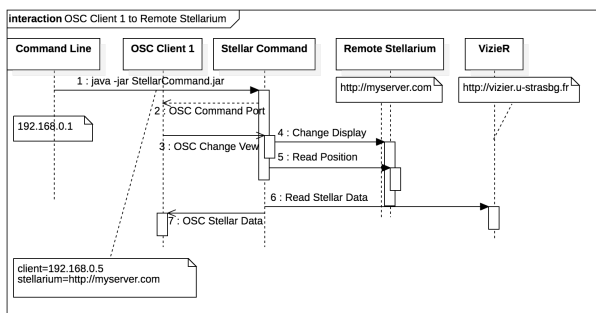


Figure 5: OSC Client to Remote Stellarium Server.

1). The Stellar Command module is initialised with the OSC Client and Stellarium addresses. 2). The Stellar Command module open its first available port and notifies the

⁵The default Stellarium Remote Control port is 8090, however, this can be changed inside Stellarium. It is assumed that port forwarding when not using a local area network has been configured to send packages to the correct computer hosting Stellarium

Table 1: Astronomical Data retrieved from VizieR

RArad	DErad	Hpmag	B-V
184.9737	-62.8541	6.8854	0.248
185.9260	-63.8700	7.4616	0.146
186.6497	-63.0990	0.6739	-0.243
186.8535	-63.7889	6.0467	0.052

OSC Client of this port so it knows which port to send OSC to. 3). The OSC client sends a message to Stellar Command to effect a position or display change in Stellarium. 4). Stellar Command decodes the message and sends an encoded HTTP message to Stellarium. 5). Stellar Command then sends a query to Stellarium to receive information about position state. 6). Stellar Command queries VizieR and obtains data about the stars displayed. 7). Stellar Command packs and sends the data to the OSC Client.

It is possible to instantiate multiple instances of the command module with different program arguments, so one could effectively control any number of systems running Stellarium on any number of computers, interfacing with any number of OSC clients.

It is simple to create sudo configuration files by creating shell scripts for OSX and Linux or a batch file for Windows with predefined program arguments. For example, executing the following in a shell script will run the command module with the port and OSC address defined in variables `PORT` and `OSC`:

```
#!/bin/bash
PORT="1234"
OSC="/Stellar"
java -jar StellarCommand.jar port=$PORT osc=$OSC
```

3.2 Decoding Stellar Parameters

The data received from Stellar Command by the client contains all the data for the field of view as a single event. When using an OSC client, the messages are packed into a bundle, with the column names in the first OSC packet with an address space of *names* while the data uses an address space of *value* is used for the actual data values. For example, if Stellarium was displaying 0.9 degrees at ACruX, the data returned from the VizieR catalogue would approximately be that shown in Table 1⁶, the bundled packets would be transmitted as below.

```
/Stellar/names RArad DErad Hpmag B-V
/Stellar/value 184.9737 -62.8541 6.8854 0.248
/Stellar/value 185.9260 -63.8700 7.4616 0.146
/Stellar/value 186.6497 -63.0990 0.6739 -0.243
/Stellar/value 186.8535 -63.7889 6.0467 0.052
```

The data in Table 1 represents less than a one degree field of view, whereas the skyscape shown in Figure 1 displays a fourteen degree field of view, which would return over 3000 stars. Although a user could filter these in the client application, parsing and decoding an OSC bundle message containing more than 3000 OSC packets would use a significant amount of resources. It is possible to reduce the number of messages received by applying a filter inside the Stellar Command module. For example, to retrieve data about stars brighter than magnitude 6, one would send the following OSC message to Stellar Command:⁷

```
/Stellar/filter/Hpmagr/less 6
```

⁶RArad is Right Ascension, DErad is Declination, Hpmag is Hipparcos magnitude and B-V is Colour index

⁷Brighter stars have lower magnitude values.

After receiving the command, Stellar Command will apply the filter to all messages until the filter is reset. Also, the server can be configured to only send a notification that new bundle of stars being available instead of sending thousands of OSC messages every second.

It is possible to save Vizier tables to a file and access them later. The advantage of this is twofold. First, the system can be used when little or no Internet access is available. Secondly, accessing the data from a file significantly reduces latency when used in a choreographed work.

4. COMPOSITIONAL EXAMPLE

When considering a method to demonstrate mapping astronomical data with music, the challenge was to compose a work that not only demonstrated the possibilities and capabilities of Stellar Command as a composition and performance interface, but to compose a work whose subject celebrated the conference theme and location. The Brazilian national flag, shown in Figure 6, was chosen as the subject because the author was not only able to blend art, science and politics into a multimedia performance; the flag also depicts a hidden astronomical event at a fixed point in Brazil's history that can be verified and analysed in detail using Stellarium.⁸ The flag displays twenty-seven stars from nine constellations as they would have appeared above the sky of Rio de Janeiro at 8:30 a.m. on November 15, 1889, with each star representing a different state [9]. The audience is taken for a cosmic tour of Brazil in that they are escorted across the sky from one star on the flag to the next, while being presented scientific data, the state represented by the star, and music that has been created from star data retrieved from the Vizier catalogues that have been mapped to musical parameters. The idea of this work was influenced by the author's proposed musical tour of the Southern Cross [14].



Figure 6: Flag of Brazil

The primary method of audio generation was through the use of the HappyBrackets creative coding toolkit, which facilitated granular synthesis of samples from recordings of indigenous Indians of Brazil, complex digital signal processing, and effective quantisation of azimuth values to rhythmic timing and altitude to pitches modes. The star colour and magnitude were mapped to grain width and note duration respectively. Communication between Stellar Command and HappyBrackets was effected by directly interfacing the Java library to the Java algorithmic composition

⁸A video showing the composition can be viewed at <https://youtu.be/NhXRdd-MNoo>.

software, which in turn reduced inefficiencies inherent of OSC decoding [28, 12, 11, 34]. Sending the data via OSC would require allocation and decoding of the string parameters in memory, coupled with communication through the localhost, whereas, using the Java event directly allowed the system to pass the data structure by reference, significantly reducing valuable system resources. The complete details of the composition and mapping strategies are too detailed to be included in this paper and are presented in a separate paper in these conference proceedings [15].

5. FUTURE WORK

Although the system is effective for obtaining astronomical data based on Stellarium's display, it is bound in that it requires Internet access to Vizier between composition and performance. If for example, a composer wanted to create a new work and they were in a remote location with no Internet access, then they would be unable to continue. The system could be improved by accessing the database used by the actual Stellarium program. Moreover, this research could be used to provide mapping and sonification of stellar information in the Stellarium program in a future release.

6. CONCLUSIONS

This paper detailed a mechanism for correlating a display from the Stellarium planetarium software and scientific data from the Hipparcos astronomical database through the Vizier database of astronomical catalogues. Furthermore, it presented the Stellar Command software package, which facilitates the correlation of the two systems into both a library that can be called directly within other software programs, and as a separate process that communicates through OSC. The system is able to connect with multiple instances of Stellarium on both local area networks, and remote networks through the Internet.

Finally, a brief description of how Stellar Command was used to implement a multimedia composition based on the Flag of Brazil.

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