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Advanced Virtual Archaeoastronomy

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Resumen

El planetario de computadora gratuito y de código abierto Stellarium es un programa de astronomía multiplataforma que se ejecuta en una amplia gama de computadoras, desde potentes PC de escritorio hasta computadoras de placa única de bajo consumo como Raspberry Pi 3 y 4. Los desarrolladores voluntarios finalmente han llegado a su versión hito "1.0" tan esperada, lo que significa tanto la finalización de los objetivos de precisión para los cálculos de efemérides astronómicas como la adaptación a una actualización importante del marco de programación subyacente, preparando el programa para un mayor desarrollo en los próximos años.

Stellarium es un programa de astronomía gráficamente detallado que es popular entre principiantes y astrónomos aficionados avanzados y profesores y estudiantes de astronomía. Puede sumergir al observador en cualquier lugar de la tierra bajo el cielo de cualquier momento de la historia humana más allá del 13.000 a. C., rodeado por un paisaje panorámico que proporciona un proxy confiable del horizonte real del paisaje en el lugar. Esto permite el estudio de puntos de vista desde interesantes estructuras hechas por el hombre u otros lugares en relación con características en el horizonte y fenómenos celestes como salidas y puestas extremas solsticiales o lunares. Las pistas diurnas para estos eventos y para varios otros objetos, y algunas líneas auxiliares más interesantes, pueden resaltarse fácilmente mediante una extensión de programa dedicada. Otra extensión incluso permite cargar un modelo 3D arquitectónico en su paisaje circundante (creado a partir de modelado basado en imágenes, escaneo láser o reconstrucción arquitectónica) bajo los cielos del período original para descubrir, investigar y demostrar orientaciones estructurales hacia objetivos astronómicos y simular fenómenos de luces y sombras. Usando el control de tiempo del software que puede controlar la visibilidad de las partes del modelo, también se pueden visualizar reconstrucciones de múltiples fases del paisaje y la arquitectura.

En los casos en que la aplicación requiera la interacción con las reconstrucciones tridimensionales, como los instrumentos de observación astronómica, Stellarium se puede combinar con un motor de juego como Unity, que proporciona los componentes básicos necesarios para la interacción similar a un juego de computadora con los objetos de la escena, mientras que Stellarium proporciona un fondo de cielo de alta precisión y control de tiempo astronómico.

Los últimos desarrollos incluyen además un nuevo modelo de tragaluz que proporciona una simulación mucho más realista del crepúsculo y efemérides detalladas para los eclipses, proporcionada por nuevos colaboradores.

Stellarium también es capaz de mostrar constelaciones y nombres de estrellas de culturas de todo el mundo. Esta característica original lo ha convertido en una herramienta popular para estudios y divulgación etnoastronómicos, y el proyecto Stellarium agradece contribuciones calificadas de la comunidad.

Palabras clave: arqueoastronomía, arqueología virtual, juegos serios, simulación, etnoastronomía.

Abstract

The free and open source desktop planetarium Stellarium is a multi-platform astronomy program that runs on a wide range of computers, from powerful desktop PCs to energy-efficient single-board computers such as the Raspberry Pi 3 and 4. The volunteer developers have finally reached their long-awaited "1.0" milestone, which marks both the completion of accuracy goals for astronomical ephemeris computations and the adaptation of a major update to the underlying programming framework, preparing the program for further development in the coming years.

Stellarium is a graphically detailed astronomy program that is popular with beginner to advanced amateur astronomers and astronomy teachers and students. It can immerse the observer in any location on Earth under the sky of any time in human history after 13,000 BC, surrounded by a landscape panorama that provides a reliable proxy for the real local landscape horizon. This allows the study of views from interesting human-made structures or other locations in relation to features on the horizon and celestial phenomena such as solstitial or lunar extremes. The diurnal tracks for these events and several other objects, as well as some other interesting auxiliary lines, can be easily highlighted using a dedicated program extension (plugin). Another extension even allows a 3D architectural model to be loaded in its surrounding landscape (created from image-based modelling, laser scanning or architectural reconstruction) under the sky of the original period to discover, investigate and demonstrate structural orientations towards astronomical targets and simulate light and shadow phenomena. Multi-phase reconstructions of landscape and architecture can also be visualised using the software's time control, which can control the visibility of model parts.

In cases where the application requires interaction with the three-dimensional reconstructions, such as astronomical observation instruments, Stellarium can be combined with a game engine such as Unity, which provides the necessary building blocks for computer game-like interaction with scene objects, while Stellarium provides the highly accurate sky background and astronomical time control.

The latest developments include a new skylight model that provides a much more realistic simulation of twilight and detailed ephemerides for eclipses provided by new contributors.

Stellarium is also capable of displaying constellations and star names from cultures around the world. This original feature has made it a popular tool for ethnoastronomy studies and outreach, and the Stellarium project welcomes qualified contributions from the community.

Keywords: Archaeoastronomy, Virtual Archaeology, Serious Gaming, Simulation, Ethnoastronomy.

Introduction

Orientation studies of prehistoric or historic buildings and monuments, which are one focus of classical archaeoastronomy, typically provide survey results in the abstract terms of astronomical azimuths (directions) and altitudes (vertical offset from the mathematical horizon) of the intersection of building axes and the landscape horizon, or of potential 'observation windows' in arbitrary directions, which are then converted into astronomical declinations to find celestial objects that may have served as orientation targets for these presumably important directions of view (Ruggles, 2015). The mathematical process and the abstractions involved are often difficult to follow for researchers trained only in the humanities, and even more so for a wider public when scientists want to disseminate research results. To better understand the processes and phenomena visible in the sky, desktop planetarium programs have been used for many years to visualise and simulate the daily rising and setting of the Sun, Moon, planets and the daily motion and seasonal changes of the starry sky. In previous work (Zotti and Neubauer, 2015), we searched for a good astronomical simulation environment that could also visualise the landscape surrounding the observer. While a commercial solution showed noticeably incorrect behaviour in simulating the effect of atmospheric refraction, we found the free planetarium program Stellarium, which at that time was even further from being astronomically accurate, but its open-source nature invited its adoption for improvements and the creation of extensions for applications in cultural astronomy (Zotti et al., 2021). On the occasion of the long-awaited "1.0" release of Stellarium, in this paper we want to give a brief overview of its improvements relevant for archaeoastronomy and present a few applications of the software during the past decade.

Immersion in the landscape

The classical opto-mechanical projection planetarium, invented one century ago, consists of a dome housing the auditorium and a hemispherical screen inside on which the ‘upper half of nature’ can be projected by a specialized projection machine mounted in the centre of the room (Meier, 1992). Many early installations included a horizon mask made from sheet metal, cut to represent the city skyline of the installation location.
The development of personal computers with ever-increasing graphical capabilities in the 1990s allowed the creation of “desktop planetarium” programs which can display the sky for any date and time in human history over any location on Earth. Some of these programs allow the inclusion of a photographic or artificially computed horizon panorama, or at least a polygonal mask to estimate horizon obstructions, to experience the potential role of conspicuous mountain peaks in the skyscape at the point of observation. Around 2008, Stellarium allowed the inclusion of a decorative photo-based horizon. Meanwhile, the landscape configuration can include a

combination of an accurately placed photographic panorama or virtual rendering from a digital elevation model, e.g., from Horizon (Smith, 2020), surveyed polygon line, and a gazetteer of horizon features. Although Stellarium can be used in small planetarium setups, most users are not immersed under a dome, and the view on a regular screen combines the landscape and the sky beyond in a way more appropriate to archaeoastronomical studies than the dome planetarium: The dome traditionally ends at the mathematical horizon (Zotti et al., 2006), while archaeological features that should be seen in combination with the sky are on the ground or even below the observer's feet. The combination of sky and ground on the computer screen therefore provides a more complete view. Only the latest all-digital dome planetarium systems allow more than 180° of the sky to be squeezed onto the 180° hemispherical dome, providing a view onto the foreground terrain that is well suited to presentations for larger audiences.

ArchaeoLines

Many studies focus on the potential significance of solstices, equinoxes and intermediate dates (with various caveats, see e.g., Belmonte 2015). The solar declination arcs for these dates can be displayed using the dedicated program extension, or plugin, called "ArchaeoLines" (Zotti, 2016). It allows the display of similar declination arcs for the lunar standstills, the current declination of the Sun, Moon, a selected planet or the currently selected object. A vertical line can also be drawn from the selected object to the horizon. Further user-defined lines include custom altitudes, declinations, custom azimuths, or azimuths to important locations such as sacred places. These can be useful for many kinds of orientation studies.

Three-dimensional landscapes

The horizon panorama provides a view for one location only. For more advanced studies, a 3D renderer has been introduced with the Scenery3D plugin (Zotti, 2016), which allows the user to interactively walk in first-person perspective through a georeferenced 3D scenery consisting of an architectural reconstruction in its surrounding landscape, and to investigate and demonstrate the possible connections between architecture, light and shadow, landscape and the sky beyond (Frischer et al., 2016; Zotti, 2019; Zotti et al., 2019). Even the temporal evolution of a landscape and monuments can be controlled in Stellarium's Scenery3D plug-in using the same date control panel which usually just changes the sky (Zotti et al., 2018). Conspicuous landscape features in the vicinity should be included in the 3D model so that the parallax shift caused by walking in the relevant part of the landscape is automatically reflected in the view. The landscape model is however represented on a tangential plane at the geographical location of the observer. Very remote mountain peaks thus may appear too high (Zotti et al., 2021). We therefore recommend adding a horizon panorama to the model, which encloses the scene and may more accurately represent the distant horizon as seen from the most relevant location.

Interactive models

The graphical appearance of models in Stellarium's Scenery3D plugin is somewhat limited: Firstly, the scenery is static, so that e.g., vegetation does not look very realistic. This is not the aim of orientation studies with a tool designed mainly for non-experts in 3D modelling, where the creation and integration of at least simple virtual reconstructions should not be too complicated. More important for some applications in historical astronomy seems to be the inability to interact with 3D objects such as medieval observation instruments.

Larger landscape visualisations and simulations of virtual archaeology are nowadays often presented with the help of computer game engines. These provide the basic building blocks for computer game-like immersive interaction and vivid, naturally looking scenes which can be utilized in a "serious gaming" approach (Vaz de Carvalho et al., 2013). On the other hand, given that the sky and natural astronomical phenomena are usually of minor importance in computer games, the sky background and astronomical-celestial details have to be programmed from scratch (Zotti, 2014; Zotti and Neubauer, 2019). For applications that require both interaction and a complete sky simulation, recent development (Zotti et al., 2020) allows Stellarium (as sky rendering program) to be directly combined with applications based on the Unity game engine, which provides the full spectrum of fea-

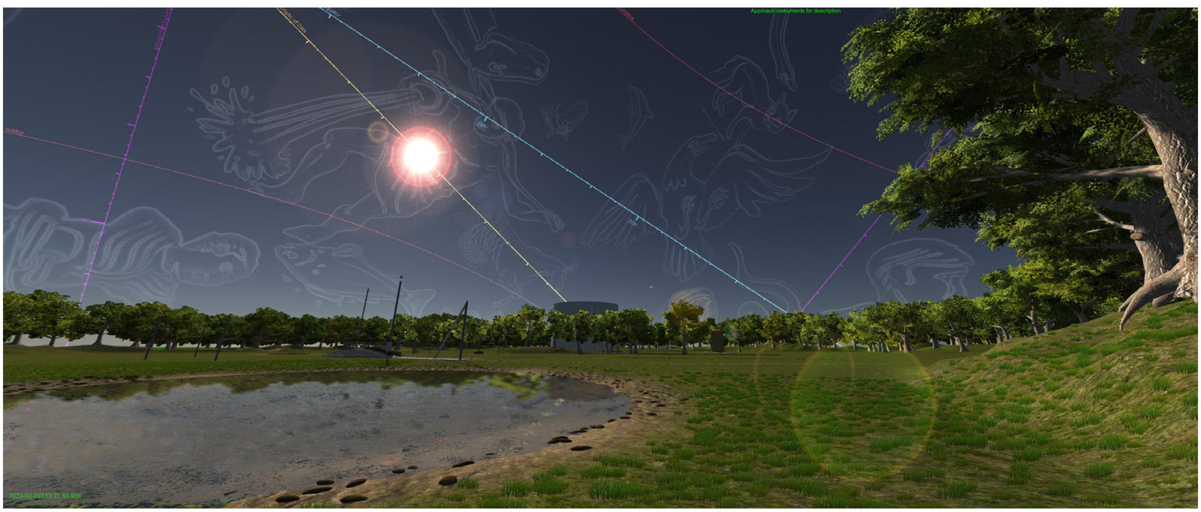

Figure 1: Stellarium 1.0 combined with the Unity game engine (Zotti, 2021). The foreground is a scene in a virtual park of medieval astronomical instruments. It also includes a pond with reflecting water. The sky is rendered by Stellarium and is controlled by interprocess communication.

tures a typical game engine has to offer. In a proof-of-concept application (Zotti, 2021), we have implemented wind-animated and seasonally changing vegetation, birds singing in the trees, and reflections on bodies of water (even with moving waves! See Figure 1). These elements provide a deeper nature-like experience nowadays expected by casual users. The more important aspect of using the game engine is that reconstructed machinery, in our case astronomical observation instruments from previous centuries, can be both animated and even react to user manipulation. In other applications, again the temporal development of an archaeological site, e.g., the architectural phases of a temple, could be displayed together with changes in the sky, all controlled by Stellarium's time control. Such scenes require a much higher effort in development than the static models that can be explored in Stellarium but can add an even deeper sense of immersion to the simulation. A web deployment of the Unity-based application, where the live feed from Stellarium is not available, can still utilize a set of pre-created static skyboxes.

Version 1.0 and beyond

The astronomical computation engine has also been significantly improved in the last years (Zotti et al., 2021) to finally allow the accurate simulation of celestial processes and phenomena over many millennia. For uses in cultural and historical astronomy, other recently added plugins provide dates expressed in tens of calendars and can retrieve additional data from online resources (Zotti et al., 2023). Finally, the long-awaited final tasks of accurate planet axis orientation and annual aberration correction have been solved. After the necessary adaptations to the recent upgrade of the underlying Qt programming framework (Qt, 2023), it was finally time to declare two decades of "zero" versions finished. Version 1.0, released on October 1st, 2022, includes two more major features contributed by new developers: A new, much better skylight model based on the work of Bruneton and Neyret (2008), and a way to export Solar eclipse maps as KML files for use with Google Earth.

Future releases will adopt a year.release version numbering scheme such as 23.1. Given that many legacy computers are not supported by the new Qt6, Qt5-based builds will need to remain available for some time.

Sky Cultures

Another feature of Stellarium not found in other desktop planetaria is the ability to display the constellations and star lore of non-European cultures. This, and the multilingual nature of the software, makes it an almost perfect tool for ethnoastronomy research and outreach (e.g., Rodas Quito and Mejuto González, 2020), also considering the recent interest in star naming by the IAU Working Group on Star Names (WGSN; Hoffmann and Wolfschmidt, 2022). We have identified a few shortcomings in Stellarium's features related to this topic (Zotti and Wolf, 2019), which should be addressed in the foreseeable future.

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