Terrain Maps and GIS Data on the Planets in the Planetarium Dome

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BIOGRAPHY
Raphaël Lerbour is a software engineer with 10-year experience in real-time computer graphics development. After a PhD about streaming and adaptive rendering of large terrains, he has had the opportunity to continue working with digital terrains at RSA Cosmos, bringing high resolution data from probes and satellites to planetariums.

ABSTRACT
Although the planetarium is historically dedicated to looking up at the sky and exploring space, digital technologies also offer the freedom to look down to Earth and land on other bodies of the Solar System. The scientific community uses satellites, probes and land surveys to produce an ever-growing public collection of high resolution imagery, elevation maps and other georeferenced data. We would like to raise awareness on how producers and animators can use those planetary data in a planetarium, even during interactive sessions. We will show real-world examples, explain the technical basics, and point out the best resources.

INTRODUCTION
First, we will explain what terrain maps and GIS data are, and where to find them. Next, we will present how high resolution terrain maps are used in planetarium software for realistic 3D navigation on the surface of the planets. Finally, we will share some resources and advice for importing, producing or importing new GIS data yourself, using dedicated tools.

I. TERRAIN AND GIS DATA
Geographical Information Systems (GIS) is a very general term. As the name suggests, GIS data can be any information related to geography, or the surface of planetary bodies. Here, we will talk about how such data can be displayed on virtual planets in planetariums, by projecting the information on the 3D surface at the correct coordinates. As this usually requires replacing or overlaying the terrain with the data to display, we will then indistinctly use the terms GIS and terrain. Furthermore, terrain maps like satellite imagery and digital elevation models represent a large portion of available GIS data.

In this section, we will present various kinds of terrain data, and show where some of them can be obtained.

1.1 Types of Data
Terrain data can be classified in several broad categories, each with its own applications.

Purpose: Terrain can be realistic for general high quality 3D navigation (eg. satellite imagery), or illustrative for showing specific information (eg. the distribution of people on the globe). See Figure 1 for examples.

Storage: Terrain datasets can be stored as raster data (images with pixels, eg. for photography), or vector data (lines and polygons, eg to show geographical areas and their borders). Raster data is more common and usually higher resolution, and it is required for realistic terrain, but it can get very large. See Figure 1 for examples.

Nature: Terrain raster is usually imagery (“colors” in various wavelengths), or elevation from a reference ellipsoid like sea level on Earth (for 2D storage of 3D surface geometry). See Figure 2 for examples. Various other information can be used, especially for illustrative purposes. However, in most cases those need conversion as imagery, typically using fake colors.

Extent: Terrain can provided as a global map, or cover only a smaller, local portion of the surface. Local datasets must be georeferenced (using metadata such as their coordinates) or they will not show at the right position and/or size on the planet.
There exists an incredible amount of GIS data for areas all over the world and beyond. Here we will list the resources we used for the images in our figures, mostly high-resolution terrain used for realistic 3D navigation.

Global Earth satellite data can be both freely obtained from public organizations like space agencies (NASA, ESA…) or purchased from private companies (Airbus, DigitalGlobe…). See Figure 3 for examples.

Those sources are generally disparate, and their data are often provided as raw records that require expert processing to become usable in contexts other than research. Companies like PlanetObserver fill that gap by selecting, merging and processing data from various sources to improve quality (natural colors, less clouds and artifacts…), ensure global image uniformity (seamless mosaic) and regularly update critical areas (like emerging cities), all in a ready-to-use presentation.
In addition, national and regional geography institutes often offer aerial photography and/or DEMs (Digital Elevation Models) from geological surveys. See Figure 4 for examples. Here are some online resources:

- USGS for USA: earthexplorer.usgs.gov
- IGN for France: professionnels.ign.fr/donnees

![Figure 4 – Aerial photography from local sources. Left: Brest Métropole (France) at 0.1m/px. Right: Yellowstone National Park from NAIP (USA) at 1m/px.]

1.3 Sources for the Solar System

For bodies other than the Earth, the only original sources are probes from space agencies (mostly NASA) and their partners. In some cases, at the end of missions, the result can be directly used as global terrain data. See Figures 2 and 5 for examples.

![Figure 5 – Recent high resolution datasets from NASA space probes. Left: Mercury from MESSENGER. Right: Ceres from DAWN. See also figure 2 for Pluto from New Horizons.](image)

However, like for the Earth, we prefer sources that gather and process global data to make high quality, ready-to-use maps:

- USGS Astropedia is an incredible resource for global maps as finished products, especially when the original source is hard to obtain or process: astrogeology.usgs.gov. They also sometimes improve on the originals by merging data from various sources, as can be seen on Figure 6.
- For ongoing missions like Juno, amateurs are usually the first to produce nice looking and usable results from raw records. They can be found at unmannedspaceflight.com and planetary.org. See Figure 7 for examples of their work.

![Figure 6 – Recent improvement to Mars elevation from USGS. Left: global 460m/px MOLA data from 2001. Right: MOLA blended with local 50m/px HRSC data (on half of planet’s surface) for a global map at a compromise 200m/px.](image)
Finally, ongoing orbiter missions release very high resolution local imagery and elevation on a regular basis, for example:

- HiRISE from Mars Reconnaissance Orbiter: [http://hirise.org/catalog/](http://hirise.org/catalog/) (example result can be seen in Figure 11)
- LROC NAC from Lunar Reconnaissance Orbiter: [wms.lroc.asu.edu/lroc](http://wms.lroc.asu.edu/lroc)

**II. CLASSICAL USE IN PLANETARIUMS**

In this section, we will explain how terrain data are handled by real-time planetarium simulators to allow realistic 3D navigation on the surface of the planets. We will then show examples of applications that require no effort to use in planetarium shows: it’s what we do so you don’t have to.

**II.1 Real-Time Technology**

Terrain datasets can be huge. In the case of high-resolution global maps reaching well over several gigabytes, it becomes impossible to load and display all of the data at once. To enable real-time rendering at 60 frames per second and still get great quality, some compromises need to be made, and preprocessing is required. Here we will describe the basis of the approach used in my PhD thesis as well as by the technology I currently use, called Proland.

Maps are subdivided in a multi-resolution fashion using a quadtree. This allows to progressively load and selectively render only what is needed. The subset of used data is constantly adapting to the current viewpoint, in order to get the best resolution where it counts, as illustrated on the left part of Figure 8. Those structures and algorithms are usually designed for square 2D maps (like in video games), so they require a projection to handle entire planets and their curvature.

The equirectangular projection is the most commonly found. It is easy to use as it maps longitude and latitude directly onto the X and Y axes, but it produces high distortion and redundancy towards the poles. For real-time rendering applications we, like many others, prefer gnomonic projection on a cube (shown on the right part of Figure 8). That projection offers relatively low distortion, fast math, and friendly squares.
II.2 Global Maps

Planetarium software distributions provide complete global maps, using their simulator’s native file format and projection to ensure the best rendering speeds. Those maps are loaded automatically when the viewpoint gets close to the terrain, and they include elevation data, as they are intended for high quality 3D navigation. Figure 9 demonstrates some of those global maps. Sometimes multiple maps are available, from various sources, so you can choose the one that best matches your needs or your taste. New maps get added and others are improved regularly, as new data become available from geospatial sources.

Figure 9 – Examples of data included in vendor distributions. Left: global 15m/px imagery (PlanetSAT: Landsat) and 30m/px elevation (PlanetDEM: SRTM + ASTER), also used to compute Earth’s dynamic terrain shadows and cliff effect. Right: additional maps for night lights (VIIRS) and water mask for reflections (MODIS).

II.3 On-demand Patch Integration

Patches of terrain with higher local resolution can be added on areas of interest. Some examples may already be included in vendor distributions. However if you have a specific request, vendors may also offer services for integrating new patches. You can give the source data, or the vendor can use their contacts to find them for you. Then, the dataset will get processed to the native format and projection of their simulator, and finally installed in the planetarium. Figures 10 and 11 show some very high resolution terrain patches that were imported this way.

Figure 10 – The Cité de l’Espace (Toulouse, France) at various levels of precision. Left: global map (PlanetSAT) at 15m/px. Middle left: IGN national survey at 5m/px (free version). Middle right: IGN at 0.5m/px. Right: Toulouse Métropole at 0.1m/px.

Figure 11 – Example patches on Mars. Left: Layered Rocks (HiRISE: imagery + elevation). Right: Crater Within Crater (composited from THEMIS + HiRISE for Mission to Mars demo by Jim Sweitzer).
III. DO IT YOURSELF

Just like you can add images and videos to your planetarium shows, it is also possible to add GIS data on your own. Any 2D dataset with coordinates can be added on the surface of the planets. However, this often requires processing data yourself, to make them look as you want and to ensure they are correctly displayed in the simulator. In this section, we will give you some tools and advice to help you begin that journey.

III.1 Tools You Can Use

First, you need to get terrain data one way or another. You can download an existing dataset from the web, use WMS (Web Map Service) or an equivalent protocol to stream a map on-the-fly over the network, or produce your own dataset from raw data or from scratch using dedicated GIS tools. Such tools are very diverse, and can also be used to adjust or troubleshoot the result. Here are some of the most popular:

- ArcGIS or ERDAS Imagine (general, commercial),
- GRASS or QGIS (general, free),
- ISIS (from USGS, for space probe data),
- Google Earth (mainstream, KML format),
- GDAL (powerful command-line tools and library).

When your dataset is ready, you need to export it in a format and projection supported by the software of the planetarium. If it uses GDAL as a back-end, any standard format and projection will work: the simulator will load and process the data on-the-fly for rendering. This is slower than using the simulator’s native format, but it is much more versatile.

Finally, you can use the simulator to load your datasets, configure patch compositions, and fine tune the result to your needs. For example, you may want to exaggerate the elevation, or adjust the colorimetry to match that of another dataset such as the background. Example applications are shown in Figures 12 and 13.

![Example compositions. Left: 15m/px PlanetSAT global map + 1m/px NAIP local aerial photo + translucent overlay simulating a water reservoir project (Ball State University of Muncie, Indiana). Right: Black Marble global map + crop land (green) + pasture land (orange) (California Academy of Sciences, data from earthstat.org).](image1)

![Example compositions. Left: Tahiti seafloor elevation data (IPGP), topography shading and lighting are computed dynamically from elevation. Right: WMS dataset of OpenStreetMap global road network, streamed live from online server.](image2)
III.2 Terminology

To be productive while handling GIS data, you need to understand how it works. Even simple raster images require special care to be correctly manipulated and displayed, which can become head-scratching otherwise. We will thus conclude with a short introduction to some terms often encountered while working with GIS data and tools, in the hope of demystifying them.

**Mosaic:** Large maps often come as a collection of smaller files that tile to form a mosaic, for example using 1 arc-minute subdivisions. Those mosaics can be assembled using GIS tools to form a single dataset.

**Metadata:** Any GIS dataset requires metadata to be correctly handled by software. Those can be embedded in the same file as the dataset, using GIS-specific formats like GeoTIFF. Metadata can also come in accompanying “sidecar” files like WLD or VRT, if the dataset uses a more classic image format like JPEG or PNG.

**Georeferencing:** This is the most important metadata that must come with GIS datasets. It contains information about the dataset’s projection, reference ellipsoid, bounds and resolution. Georeferencing is required for correct positioning of the dataset on the globe, and it can be adjusted using GIS tools. A useful list of spatial references can be found at [spatialreference.org](http://spatialreference.org).

**Nodata:** This metadata is a special value used to identify pixels contained within the dataset’s area but with no valid data. Those pixels will not get displayed, instead such areas will use the background global dataset. Dedicated alpha channels are less error-prone (and allow for partial transparency), but nodata is much more common.

**Band:** Also called channel or component. Most common datasets are 1-band grayscale or 3-band RGB. That is how bands will be interpreted by default, as that is what gets displayed using current display technologies. If a dataset uses anything else, like infrared wavelengths, GIS tools can be used to remap those bands to RGB. Elevation is always single band.

**Range and units:** Imagery usually comes in classical gamma-corrected “colors”, but may also be HDR. Elevation is usually stored as meters relative to reference ellipsoid, but that may differ. GIS tools can be used to fix any issues arising from those differences, often simply with offset and scale.

**Overviews:** Although not as powerful as a quadtree subdivision, overviews allow some progressive loading to take place. They are versions of the dataset in decreasing resolutions, which can be computed using GIS tools and stored alongside the main dataset. Even better are wavelet formats such as JPEG2000 and ECW, inherently multi-resolution and with great compression.

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REFERENCES

Dayna Thompson, Kevin Turcotte – GIS Data to Planetarium Dome – GLPA 2016
Dan Tell – Mapping the Planets: Geographic Information Systems and High Resolution Maps in the Dome – GLPA 2014