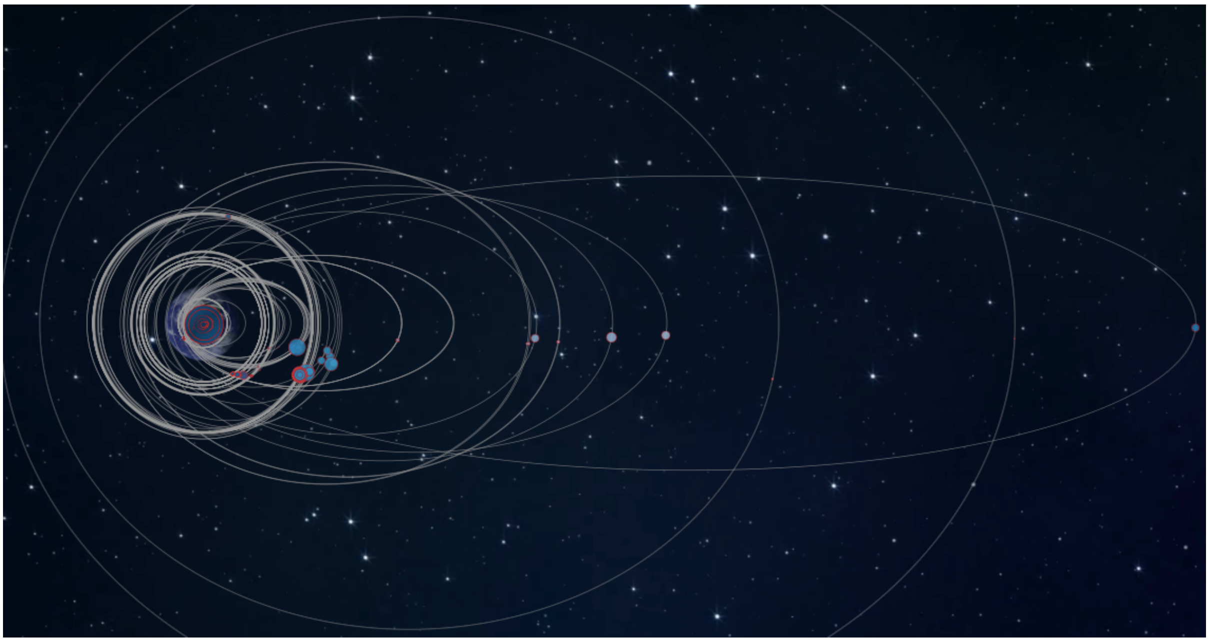
SatVis - Visualising the Satellites orbiting Earth

IN4086-14 – Data Visualization – InfoVis



Data: Union of Concerned Scientists Satellite Database

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1. Introduction

There are 1,738 satellites that are currently orbiting around the Earth catering to purposes ranging from communication, television to surveillance and defence. This project aims to understand the placement of satellites, their purpose and the agencies that use them. There is a space race where countries and companies are launching more satellites every year. The visualization shows the trend of growth not only in the number of satellites but also the amount of space debris. The domain for visualizations is the database of satellites with multiple abstracted views. The abstractions on data facilitate the rendering of visualizations that are related to the dataset. This project presents three new visualizations methods for visualizing the satellites based on their orbits and also their relative position to the earth (eccentricity and inclination).

2. Users and Data Domain

This section presents the discussion about the users for this visualization and about the dataset used and abstractions made on data.

2.1 Users and Need for Visualization

Space has always been interesting to mankind, everyone looks at the night sky in awe. There are the few, who track satellites and follow the International Space Station's path just to take a glimpse of it. This visualization is for them, to take the user closer to looking at where satellites are and how they revolve around the Earth. The visualization implicitly sheds light on a serious topic of space pollution and the impact of debris field interfering with the satellites. From this project, a question of how the debris after putting satellites in orbits need to be managed, satellite congestion and orbit overlaps. The questions that the visualization aims to answer are:

1. How do countries use their satellites? Is there any indication of a space race?
2. Are navigation systems dominated by the US or Russia, GPS vs GLONASS which is preferred?
3. Can the hypothesis of more the number of satellites, more will be the space debris be established?

The technical aspects of this data domain involve extrapolating distances into the size of the screen, placing satellites on the visualization and computing the orbit paths to animate. The technical challenges in creating the visualization and the curiosity to zoom into the night sky are the reasons to select this dataset.

2.2 Data Domain, Abstraction and Exploration

In this subsection, the data domain used in the project, data related tasks like cleaning, trimming, modifying etc. are discussed with a summary of the results of the exploratory analysis. The data used to visualize satellites is the Satellite database provided by the Union of Concerned Scientists (UCS), USA. The dataset contains the information of each of the 1,738 satellites like name, type of orbit, distance nearest to Earth (perigee), distance farthest from Earth (perigee), the degree of inclination to the equator and eccentricity. The original dataset had 27 columns and 1739 rows. However, the entire 27 columns were not used in the visualization, hence deleted as they had a lot of missing values and new columns were added. This formed the preliminary dataset, which can be used out-of-the-box for the visualizations presented in tabs 1 and 3.

The visualizations in tab 2 depict the satellites based on their orbits and hence the need to compute the major and minor axes arises. The major and minor axes for the elliptical orbits are computed using the perigee(r_{Min}) and apogee(r_{Max}) with the formula:

$$\text{Major axis, } a = (r_{Max}+r_{Min}) / 2$$

$$\text{Minor axis, } b = a * \ 1 - (e*e)$$

The dataset is in comma-separated values (CSV) format but was converted into a JSON array to make it accessible across different scripts. The reasoning behind the format conversion of the dataset is a consequence of the d3 asynchronous callback functions that perform file handling of both JSON and CSV files.

With the dataset in place, we started creating multiple abstractions on it, for example reduce the dimensionality of the data to plot the total count of satellites that was launched year-wise, country-wise for 2D visualizations and an abstraction that has satellite count based on the combination of country, year of launch, purpose, and users for complex, multi-dimensional plots. In this dataset, each attribute column is considered as a dimension for visualizing and contains both numerical and categorical values. In the initial approach, multiple abstractions on the dataset were created which made visualizations disjoint and prevent interactions from taking place. To counter this issue, built-in grouping functions was used. The abstractions done on the dataset are thus specific to each tab where the data is abstracted using `d3.nest()` - as the grouping method where multiple keys are selected to filter the dataset and multiple keys are removed using roll-up.

2.2.1. Exploratory Analysis and fact findings on dataset

The exploratory analysis on the dataset indicated a growing trend in the number of satellites, from the figures from the dataset where it was 1 satellite launched in 1974 and as of the update in August 2017 there are already 310 satellites launched. It is also to note that in the year 2017, more satellites are launched by India and from the International Space Station which is maintained by the United States. From the exploratory analysis, one inference is the growth of India’s space programme and the other inference is the concentration of satellites at different classes of orbits. The *lower earth orbit (LEO)* which is defined as the orbits that are at a height of 2,000 km or lower has the highest concentration of satellites at 1,070. The satellites in LEO orbits are mostly used for technical research and for observation purposes. The other interesting inference is that there are 531 satellites in *Geostationary orbits (GEO)* which is at a height of 35,786km above the equator which is used for communication. GEO is gaining popularity as the most sought-after class of orbit to place satellites in the new millennium. There are 39 satellites in elliptical orbits which are used by the Military and also for the purpose of studying about space science. Finally, there are 97 satellites in the *middle earth orbit (MEO)* which is in between LEO and GEO levels and most of the satellites are used for the purpose of navigation with the GPS from the United States having 31 satellites in orbit and GLONASS by Russia has 24 satellites.

3. Task Abstraction and Visual Encoding

In this section, the design of the dashboard and design choices on the visualizations are discussed. The dashboard for the visualization is split into three tabs. Each tab is themed as in similar visualizations are drawn in the same tab. The first tab is the landing tab and needs to capture the user's attention and hence it features an animation of the satellites revolving around Earth with a tooltip that contains all the information of the satellite from the dataset. The second tab features visualizations based on the orbit shapes, eccentricity and inclination. This tab uses interaction by displaying the details of the satellite as a tooltip and in the plot comparing eccentricity and inclination additional user interaction is provided using drop-down menus which update the visualization based on user-selected inputs. The third pane serves as the stats page where trends are visualized based on the total number of satellites are launched by country and year. This tab presents interaction using tooltips and drop-down menus which update the plots in real-time.

3.1 Visual Encoding

Most of the visualizations done uses numerical data and some use a combination of numerical and categorical data. The satellites are represented as circles and based on their distance from Earth, they are color coded in tab1 additional encoding of each satellite's position is done as channels using animations to show them moving in their respective orbits. The coloring of satellites are done using their launch weight and two satellites are colored with a relative comparison of launching weights between them and not with Earth which has a significantly larger mass. For tab 2, ellipses and arcs are used to encode satellite orbits and circles is used to encode points on the scatter plot and also to represent the satellites. Color channels are also used in tab 2 to encode the information of the class of orbits and highlight the orbit path. The bars represented in tab 3 uses lines as marks and tooltips to provide additional information about the lines on the user's move over action.

4. Visualization

The visualizations are done purely in D3 and JavaScript and in this section the visualizations drawn for each tab will be discussed in detail.

4.1. Visualizations in Tab 1

This is the visualization on the landing page of the dashboard, where the satellites are animated to move along their orbits. The orbits of the satellites are also shown in the visualization and each of the satellites is drawn as circles which vary in radius based on the relative launch masses. This condition to plot satellites based on their relative launch mass and based on the mass of the earth or all the satellites help to clearly visualize each satellite on their orbits. The satellites' color becomes lighter as it goes farther away from the Earth. Apart from showing the distribution of satellites based upon their distances from the Earth, this color changes per satellite basis as well to showcase the elliptical and uneven “height” orbit they revolve in. This makes it easy for the users to picturize the satellites moving along their orbits. The animations are done using transition method of d3 with delay attributes. The larger satellites represented on this visualization are space stations like the International Space Station, etc. Given the congestion with the number of satellites, this tab is made zoomable and draggable to make give more control to the users.

4.2. Visualizations in Tab 2

There are three visualizations implemented in tab2 which relates to each satellite’s orbit shape and class of orbit. The first is a visualization of the satellites based on their orbits where a user can select values from two drop-down lists to view the satellite’s orbit. This is the first interaction for the user and on mouseover action, the color of the orbit changes to black and information about the orbit is displayed on a tooltip. The visualization is implemented using the computed major and minor axes to draw the ellipses which are color-coded based on the class of orbits. The drop-down features selected by a country which includes India, USA, China, South Korea, Japan, Norway, and Russia. The other drop-down lists the users of the satellites with options like Military, Civil, Commercial, and Government. Both menus have an “All” option which lets the users view the entire data without any filters.

The second visualization is a zoomable scatter plot implemented to visualize the eccentricity versus inclination for each satellite. The scatter plots are color-coded based on the class of orbit for each satellite. The zoom feature is implemented using the brush method of d3. There is a need for a zoom in the scatterplot as there is significant overlap of satellites which makes it important to interact with the user to zoom-in to the visualization to render a clear picture which is meaningful.

The first image is similar to the atomic model with concentric arcs constructed with inner and outer radius to replicate the three main classes of the orbit: LEO, MEO, and GEO. For the satellites in an elliptical, a horizontal ellipse was drawn and satellites were shown moving either on or close to the ellipse. The ellipse is used as an indicative path for the satellite. All the satellites are represented as circles with a low opacity value to show as many satellites as possible. A tooltip is attached with each of the satellites that provide information about the name of the satellite, owner country, and class of orbit. The satellites are colored according to their class of orbits and hence there is a need for a tooltip which serves as an interaction on mouseover action over a satellite. This visualization provides an overview of the satellites and their distribution across different classes of orbits.

All the visualizations in this tab are wrapped by the class of orbit which is used as the basis for coloring in all three visualizations.

4.3. Visualizations in Tab 3

The visualizations presented in tab 3 relate to the number of satellites launched by country and year of launch. The initial version of the visualization of two bar charts each plotting total number of satellites against the country and year of launches.

The interactions for the initial version was provided as a tooltip which showed the number of satellites on mouse over action in each of the graphs. In the second graph, of plotting the total number of satellites launched by a country the color of the bar is changed and then a tooltip is displayed. Each of the bar charts was plotted using an abstraction of the original dataset where the number of satellites launched was coupled with the year of launch and country. However, this approach was not able to provide an interaction and hence it was revised with two drop-down menus. For the second version of visualizations on this tab, a single dataset was used with data abstractions done using built-in d3 methods that were used to group the data. Based on the values from the selected menu, the bars get updated.

5. Result and Discussion

From the visualizations presented in this project, the following informations about the dataset can be inferred:

1. There is a constant growth in the number of satellites, many countries are joining the space race.
2. The US, Russia, China, Japan, Norway, United Kingdom and India are countries with good space programmes as they are countries with that constitute the majority of the 1,738 satellites.
3. There Low-Earth Orbit has more than 1,000 satellites which makes it the most densely packed and completely utilized satellite orbit. Global-stationary Orbits (GEO) is the next most occupied class of orbit, given the increase in distance from the Earth, GEO orbits can accommodate more number of satellites.

The visualizations presented as part of this project are effective in to represent each satellite based on their orbits. The tabs in the dashboard layout group visualization based on a theme. The animation of satellite along their orbits, filtering satellites based on type of orbits, purpose, representing the satellites based on orbits are effective ways to understand how satellites are placed around Earth. These visualizations are effective as the user can get the entire view of all the satellites scaled to the screen. The interactions with tooltips add more informations to be represented in this visualization which would have been possible after performing a lot of analysis on the given dataset.

This project had its own share of *challenges* that were persistent. The first was with data abstractions which prevented interactions to update multiple graphs. This was solved using the grouping function of d3 called `next()` with keys to group similar objects and rollup to remove the duplicates. The next issue was drawing the satellites on various plots, the following were the issues:

1. Scaling satellites, satellite orbits to fit the screen width was addressed with a few mathematical computations involving the angles of the circles.
2. The interactions and updates on the graph were not working as they plots were built using separate abstractions of the original dataset which was solved by using d3 grouping function on the same dataset.
3. The arrangement of satellites based on concentric circles was difficult because of the high density in the LEO orbits, there was a lot of overlapping. For the final version of the project, opacity attribute is used to make the

circles representing the satellite as small as possible and the spacing improved marginally.

The additional insight which is implicitly visualized is the amount of space debris that will be present once these satellites get decommissioned. It was studied that satellites after their lifetime are pushed to decay orbit from which they either plummet back to Earth or drift away from Earth in due time. Until that time, they can interfere with active satellites. The second factor that serves as an indicator to space debris is the number of satellites launched. The remains of fragments of launch vehicles that put satellites on their orbits constitute space debris.

6. Conclusion

The project finds answers for the questions in section 2.1 where we confirm that there does exist a space race, where the US, Russia where initial competitors in the race to build navigation systems: GPS (US) and GLONASS (Russia). It is also to note that China has also emerged as another competitor as a provider of navigation services. It is evident that there is a pseudo-space race, as there are no two countries that are competing with each other. But from the visualizations, we conclude the rise of India which has been increasing the launches of satellites from 2010. There is an increase in the competition between the Indian Space Research Organization with NASA as well as SpaceX in launching satellites. And for the third question, the hypothesis is valid as there is an increase in the number of satellites will result in debris from launch vehicles which support the hypothesis.

Bibliography

1. Munzner, T. (2014). Visualization Analysis and Design. CRC Press.
2. Dataset - Union of Concerned Scientists Satellite Database - https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database
3. Orbital patterns - https://stackoverflow.com/questions/25217759/how-to-simulate-simple-orbiting-behaviour-in-d3
4. Laramee, R. S. (2011). How to read a visualization research paper: Extracting the essentials. *IEEE computer graphics and applications*, *31*(3), 78-82.
5. D3 Examples - http://techslides.com/over-1000-d3-js-examples-and-demos
6. Hibbard, William L., Brian E. Paul, David A. Santek, Charles R. Dyer, Andre L. Battaiola, and M-F. Voidrot-Martinez. "Interactive visualization of earth and space science computations." *Computer* 27, no. 7 (1994): 65-72.

Appendix A: Individual Reports

Sharad Shriram
The project was done by all the members and the work as evenly distributed amongst us. We split the work based individually as per the needs of the project. I was responsible to build the atomic model of representing satellites based on the class of the orbits.

Shivam Miglani
The strategy was to explore d3 first independently and then after we decided the dataset, we had in mind that we would make 3 tabs to divide the work individually. My work included developing of satellites according to their masses revolving around Earth in their elliptical/circular orbits in tab1. It was a challenging task and I looked into many libraries but in the end, I ended up using my own code. In other tabs, I worked on ideas and debugging.

Kazi Injamamul Haque
We did the whole project altogether. We basically got together whenever it was time to do the InfoVis project. We shared our ideas about how to visualize this dataset and agreed upon the selected visualization as it is seen as the output. Specifically, I am responsible for the second tab of the visualization, namely, Orbits and Orbit types. There are two visualization parts and a navigation part in this tab. The first part shows the orbits and their paths where the center point is the location of the earth, and the orbits of the satellites are represented. The second part shows a scatter plot, which is zoomable. The x- axis is the inclination whereas the y-axis is the eccentricity. Since the distribution of the LEO satellites are mainly towards the zero value of the y-axis, zoomability is a must. And also I added the zoom out capability to the scatter plot to go back to the. The navigation changes both the part of this tab accordingly.