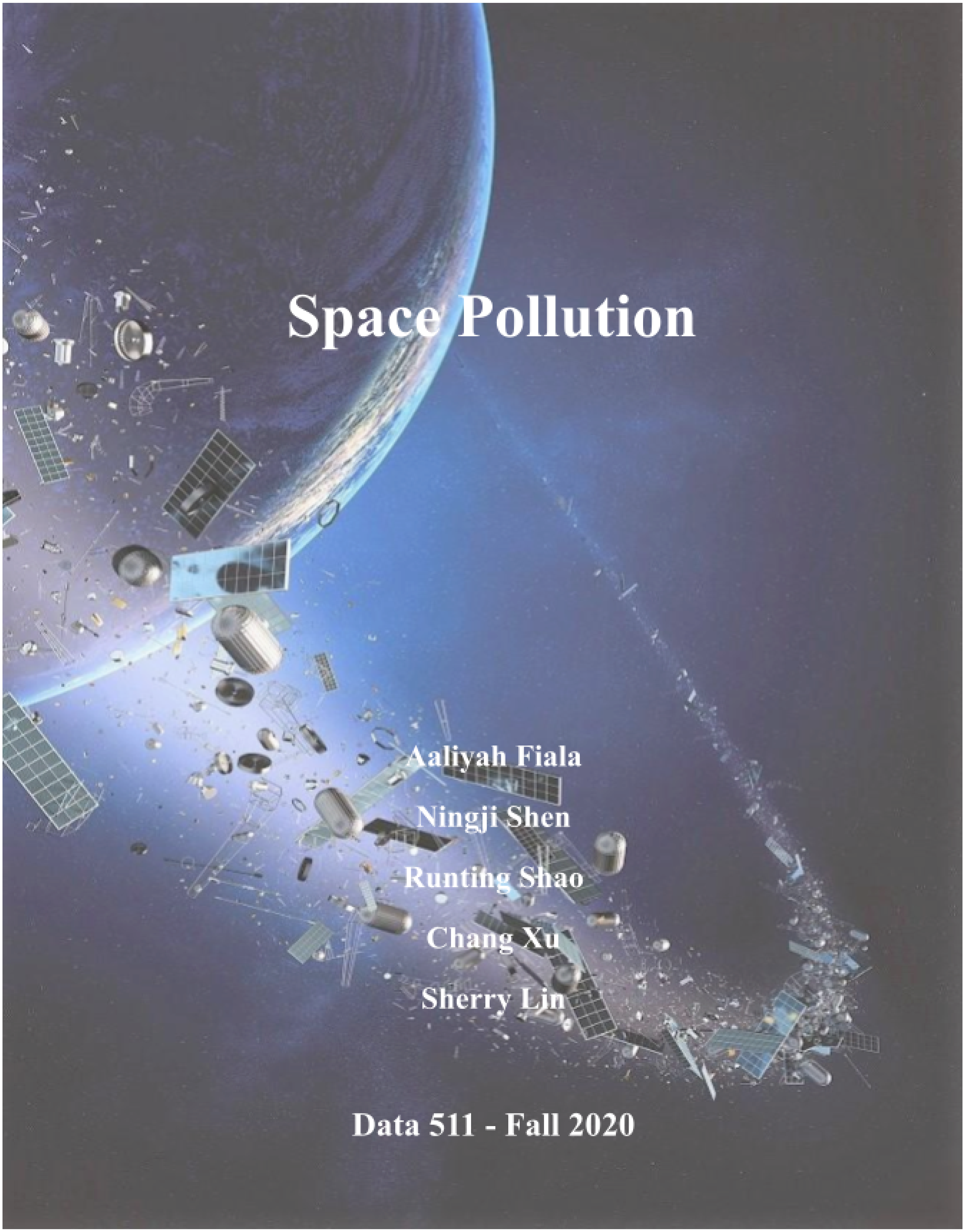

Space Pollution

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Data 511 - Fall 2020

Visualization Link: [Man-Made Objects in Earth Orbits]

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Introduction

There are an astonishing amount of objects in space. According to the European Space Agency, the number of debris objects in orbit: 34,000 for space objects that have a size greater than 10 cm, 900,000 for objects that have a size between 1 to 10 cm and 128,000,00 for objects that have a size between 1mm to 1cm ("Distribution of Space Debris in Orbit around Earth.", *ESA*).

In this project, we are interested in learning about man-made objects in Earth orbits and the space pollution associated with them. We care because space junk can impact satellites, causing network outages and costly damage. It will also impact future launches and global satellite internet endeavors. By definition space junk is defined as any piece of debris that is left in space by humans. There are no limits on size, and our space junk includes everything from satellites that no longer work, to paint flecks.

In this project, we use data mainly from *Space-Track.org*, a free access, excel exportable data source that also offers APIs to do data analysis and create corresponding visualizations in order to answer the following questions: Where did all of the space junk come from? How big is the space junk? What percentage of the earth's orbits are filled with junk? How has the amount of space junk changed over time and what will it look like in the future?

About the Data

Our visualization project, "Space Pollution", uses data provided by SAIC, *Space-Track.Org*. Space Track is an organization which promotes safety of space travel and protection of the space environment by sharing services and information related to space environmental awareness. The original dataset we used is "Satellite Catalog" dataset (abbreviation: "SATCAT"), which contains 47,238 entries and 24 variables.

These variables include both categorical and quantitative data. The categorical data include OBJECT_TYPE, COUNTRY, RCS_SIZE, OBJECT_NAME and etc., while quantitative data include LAUNCH_DATE, DECAY_DATE, LAUNCH_YEAR, INCLINATION, APOGEE, PERIGEE and etc. For data cleaning, I choose to exclude those variables that are useless for our visualization project such as COMMENT and COMMENT CODE and the null values in the dataset. I also create a new calculated field called "Lifespan" with the years between LAUNCH_DATE and DECAY_DATE.

According to the terminology definition on *Space-Track.Org*: Perigee refers to the point in the orbit where an Earth satellite is closest to the Earth (units are kilometers). Apogee refers to the point in the orbit where an Earth satellite is farthest from the Earth (units are kilometers).Orbit Inclination refers to the angle between the equator and the orbit plane (units are degrees). Based on the knowledge of orbital mechanics from Robert A. Braeunig's "Orbital

Mechanics", we have implemented a method to transform perigee, apogee and inclination into 2-D position with X, Y coordinates. The detailed calculation will be introduced as follows:

For the orbital visualization, we were given the apogee, perigee, and inclination of the objects. The first step in plotting a 2D visualization was to calculate the radius of the objects from earth. We created a calculated variable called Radius as the average of the apogee and the perigee.

Radius = (apogee + perigee)/2

Next, we need to convert the polar coordinates to cartesian coordinates so that Tableau could interpret them. We created two more calculated variables,

X = Radius * cos(Radians(Inclination))

Y = Radius * sin(Radians(Inclination))

After plotting these variables, we found that we had forgotten to take into account the radius of the earth. The earth was defined as a single point (0,0), which did not help in our goal to visualize the density of pollution.

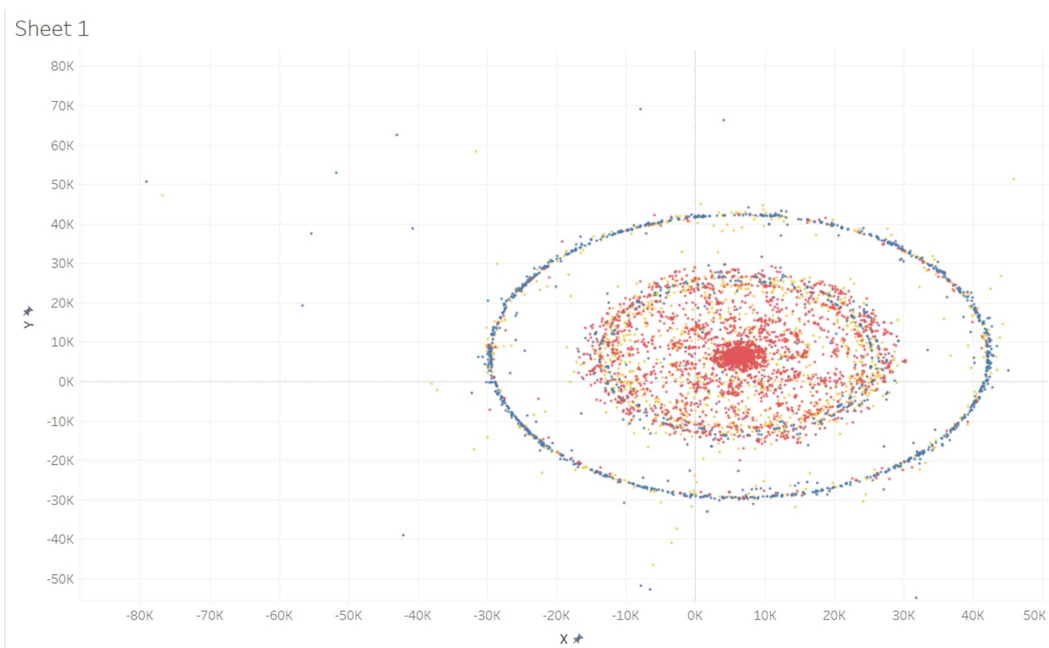

Figure 1: Plotting Space Debris (without Earth Radius)

The earth's radius is 6,371 km (Braeunig, Robert A. ORBITAL MECHANICS), thus we redefined our radius to be, the average of the apogee and perigee, plus the radius of the earth.

New Radius = (apogee + perigee)/2 + Earth Radius

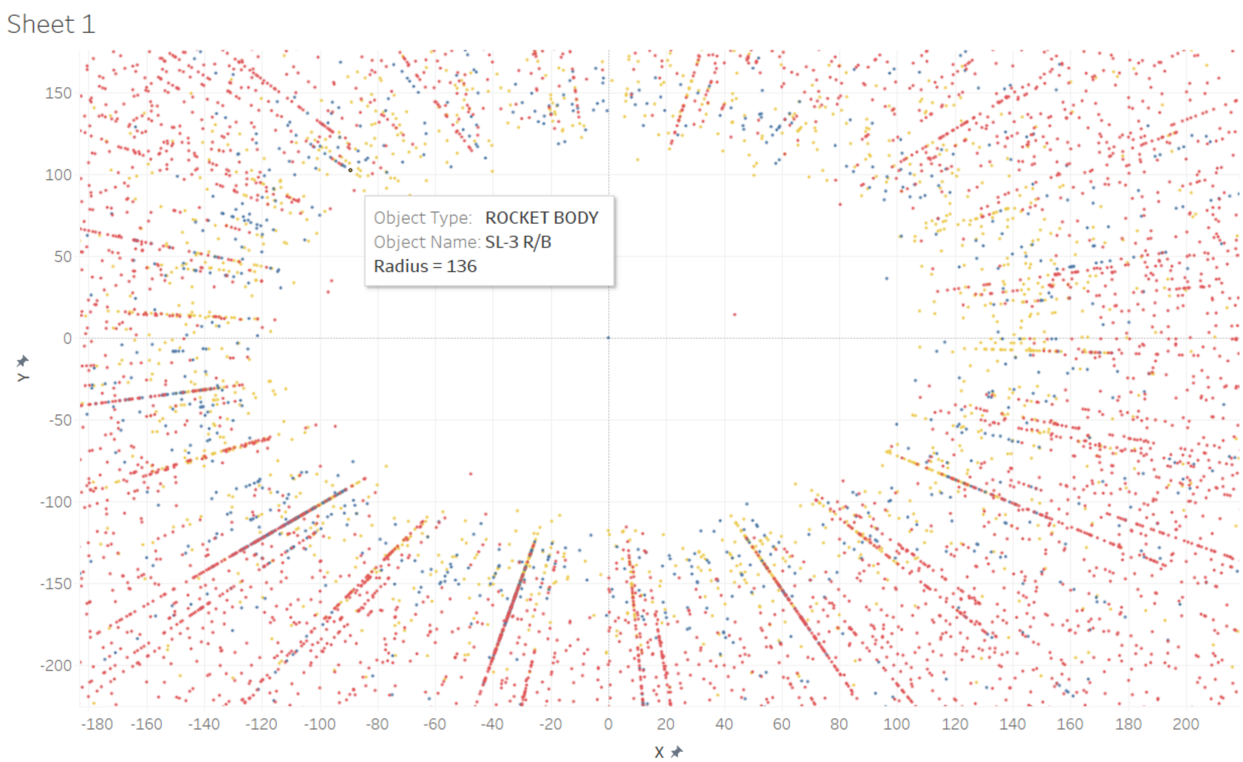

Figure 2: Plotting Space Debris (with Earth Radius)

Next, to plot the low, mid, and high orbits, we had to create a variable for each orbit, with the low orbit being defined as 180 km, mid orbit is 2,000 km, and high orbit is 35,780 km (Braeunig, Robert A. ORBITAL MECHANICS), then taking into account the radius of the earth.

Low Orbit Radius = Earth Radius + 180 = 6551

Mid Orbit Radius = Earth Radius + 2000 = 8371

High Orbit Radius = Earth Radius + 35,780 = 42151

Previous Work

Given the importance of safety in space travelling, analysis of debris in space has proven to be a necessary task for any astronautical organization such as NASA and ESA or individuals who are interested in it. Therefore, there are many creative visualizations which attempt to describe the pattern of floating objects in space and understand the potential effect of the scattered debris through multiple dimensions.

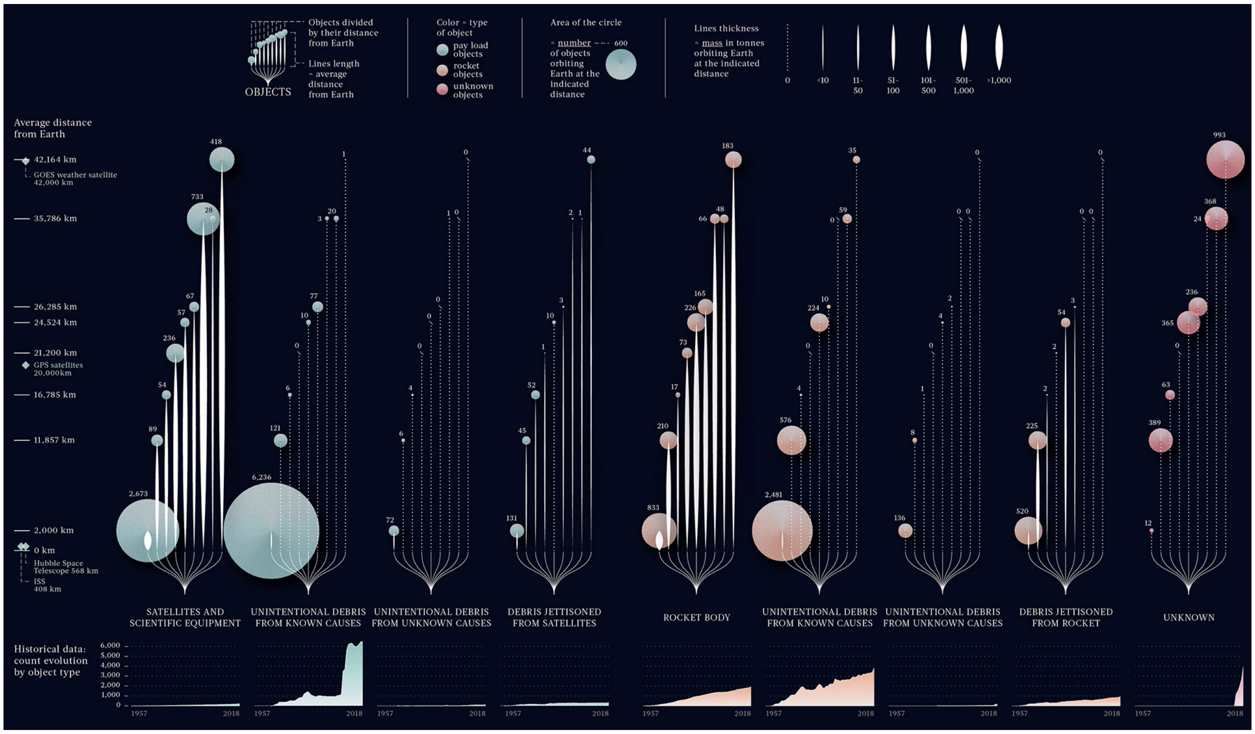

Figure 3: Space Junk BBC Science Focus

Figure 3 shows the space debris, categorized according to their average distance from the Earth and the type of space debris. For each type of debris, the number of objects orbiting the Earth and the mass at according distance is also visualized. We were inspired by this visualization therefore we decided to show some basic data points in our visualization as well, such as the size, the origin and the lifespan of the floating objects in space.

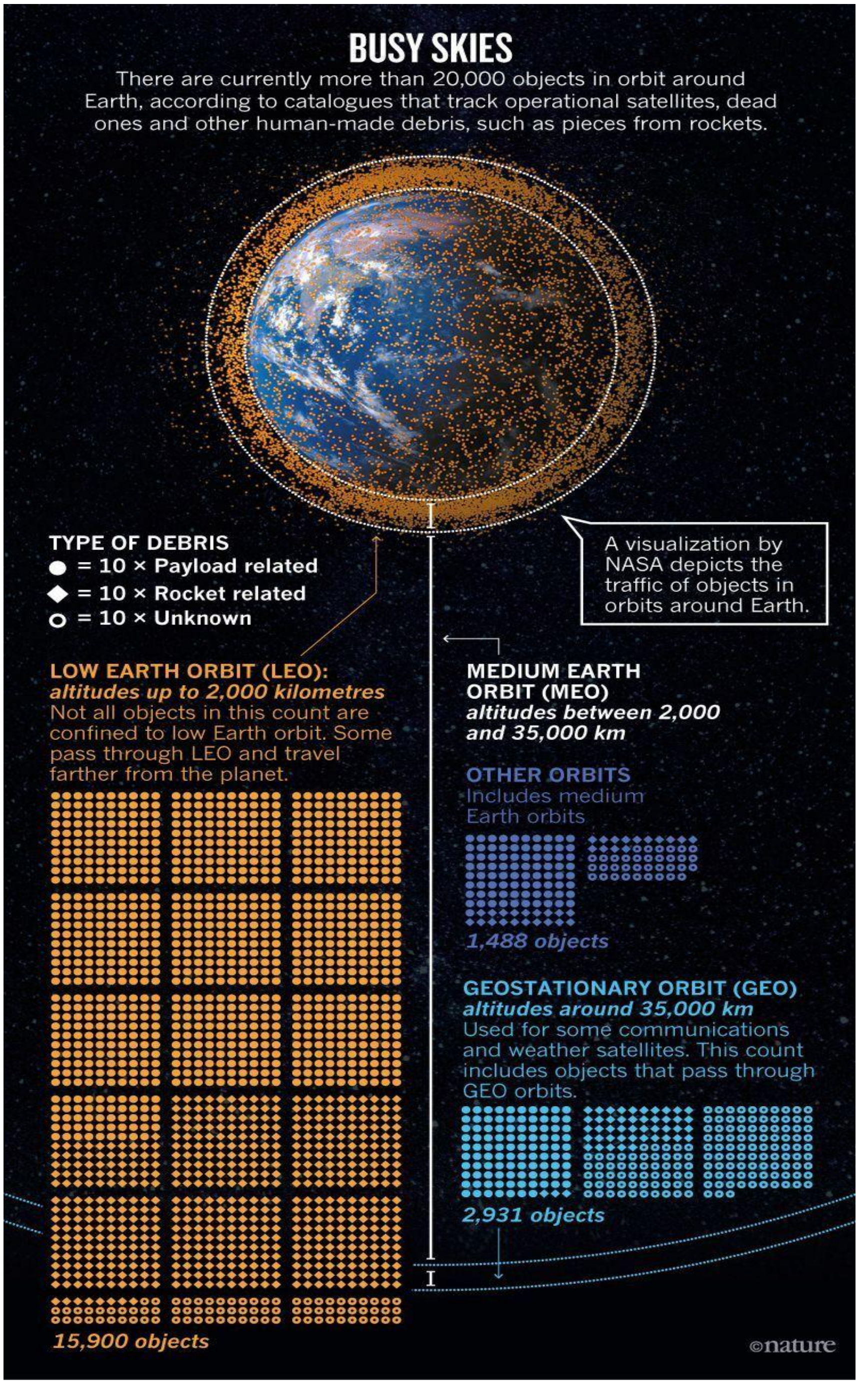

Figure 4: Busy Skies

Source: ESA Annual Space Environment Report. Earth debris image: NASA Goddard Space Flight Center/JSC

Figure 4 shows another visualization by ESA, which shows the density pattern of three types of debris in three orbits. This visualization gives us an idea on showing the density map of debris in space along with three earth orbits. However, to make our visualization more interactive, we decide to allow the users to filter down the types of floating objects in space .

Design Process

Our initial design for the dashboard had four separate visualizations with four tasks (see Appendix) that we anticipate the user to interact with and learn more about the detailed information. Our final dashboard is slightly different from our initial design due to technical difficulties and user feedback. We grouped all the objects in space into three categories, which are debris, payload and rocket body. We encoded the three types of objects with red, green, and blue, and we kept the colors consistent throughout the visualizations.

The first visualization is a horizontal bar chart showing the total number of objects in space. By clicking on each bar, the user is able to filter on only one object type for all four visualizations. Clicking on the bars will also trigger the first visualization to show the definition of each object type as well as a pie chart showing the different sizes of object. Based on some users' comments, we also added the definition of three types of objects in order to provide the user with better understanding of these objects.

The second visualization is a line chart showing the average lifespan of each type of object over the timeline. The lifespan is calculated by subtracting the lunch year from the decay year for each object. This visualization is intended to show the users how the trends of objects' lifespan changes over time.

The third visualization is a map showing the countries of origin where the different types of objects came from. Instead of plotting dots on the map, we used a small pie chart for each country to show the percentage of each type of object created by a given country, and encoded the total amount of objects with the size of each pie chart. Our initial design included a task that, by clicking on the pie chart, the user is able to see a vertical bar chart showing how many objects were launched in what year. However, we decided that there would be too much information packed into a single visualization. Instead, we simply show the detailed data of each pie chart when the user hovers the cursor over to the pie charts. Our initial design also included a timeline slider that controls both the third and forth visualization. By sliding the timeline slider, the user is able to filter on any time period between 1957 and 2020, to see the changes in the corresponding data. Due to technical difficulties, we only implemented the timeline slider for the third visualization, and revised the task for the last visualization to include different functions.

The last visualization is a 2D globe showing which orbit are the objects located. We plotted the colored dots in the low, medium and high earth orbits representing the height of the objects from the earth. The user can hover the cursor over each dot to see the details of each object. In our final dashboard, we also added a task so that the user is able to filter on this visualization to see objects in low earth orbit, medium earth orbit, high earth orbit, or all three orbits.

Prototype and User Evaluation

With a set of low-fidelity prototypes of our visualizations, we were able to survey some users, ask for impressions of the dashboard, evaluate the useability of all the tasks, and receive suggestions for improvement. By conducting several user interviews, we received some meaningful feedback.

For the first task, it was straightforward to the users that by clicking on the bars in the first visualization, the bar would highlight and filter out the corresponding data in the other three visualizations. It was clear to our users that once they click on one object type on the top left figure, the bar would be highlighted in the first visualization and the data would be filtered in the other three visualizations. Some users suggested that we should have definitions of the three object types under the first visualization, instead of showing them one at a time when the users click on the bars. The users also suggested having the same task for the second visualization so that we can filter on the object types by clicking on either the bars from the first visualization or the lines from the second visualization, but since it would be hard to implement, we make it clear that the user can only click the fist visualization in order to highlight the corresponding data in all visualizations.

The second task was also easy to understand and was a reasonable display. The relationship between the size of the pie charts and the amount of objects that the given country ejected into space made sense to most of the users. One user made the comment that, “pie charts are generally not a good thing, but it works here.” However, because some countries only launched a small amount of objects, some of the pie charts are nearly not visible. During our presentation, we received the suggestion from Nathan to “log scale the Pie Chart size to make some of the smaller ones more legible” so we incorporated this in our final dashboard.

Another concern that was mentioned by several users when we are presenting our low-fidelity prototypes, was that this visualization may quickly become too busy and may not be useful for making comparisons between multiple countries. However, our final dashboard appears to not have this issue.

For our last visualization, most users would recognize the globe as a visualization to show the density pattern of the objects in space at their first sight. However, some of them were confused with the three orbits on the space map. This reminds us that not all the audience possess enough aerospace knowledge to understand this visualization. Therefore we added explanatory definitions for the earth orbits. Some users had concerns about showing a huge amount of data points on a single map and the users may not be able to identify each object because the dots would be too dense. One of the potential solutions we came up with is to assign 20 objects of the same type as a dot marked on the map in order to fix the overwhelming visualization. Our final dashboard appears to not have this issue visually, but the amount of data points does slow down the load time. One of the potential factors is the use of separate data sources for each visualization. We overcame this by joining our data sources together in order to minimize the number of rows Tableau needs to read as the input.

For the timeline slider, most of the responses from users were positive. The users clearly understood that dragging the slider can show the changing trends of objects in different years, which is consistent with the original intention of our design. One user was confused about whether the chart is showing cumulative data or a snapshot of a given year when dragging the slider. Our potential solution is adding a concise introduction of this visualisation. In addition, three users suggested that all visualizations should show the corresponding year when the users drag the slider. We did not implement this refinement due to the amount of time we had for this project, but this would be one of our further areas for improvement.

Final Visualization

Our final visualization consisted of four sub-visualizations that interact with each other to tell a story, the story of "Man-Made Objects in Earth Orbits".

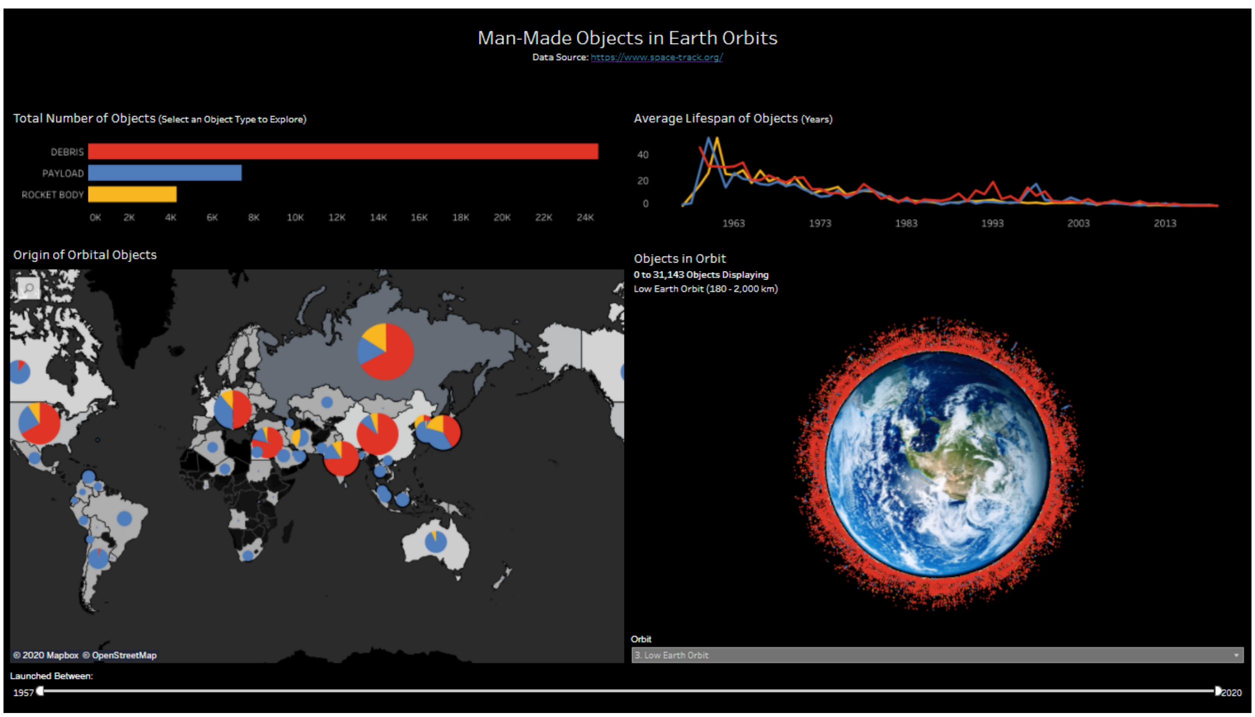

Figure 5: Man-Made Objects in Earth Orbits

The first thing that the user is prompted to do, is to select an object type, which then filters the rest of the data in the visualization, as seen in Figure 6. Also, by hovering over an object type, the user can see the distribution of size of that object, categorized by small, medium, and large objects.

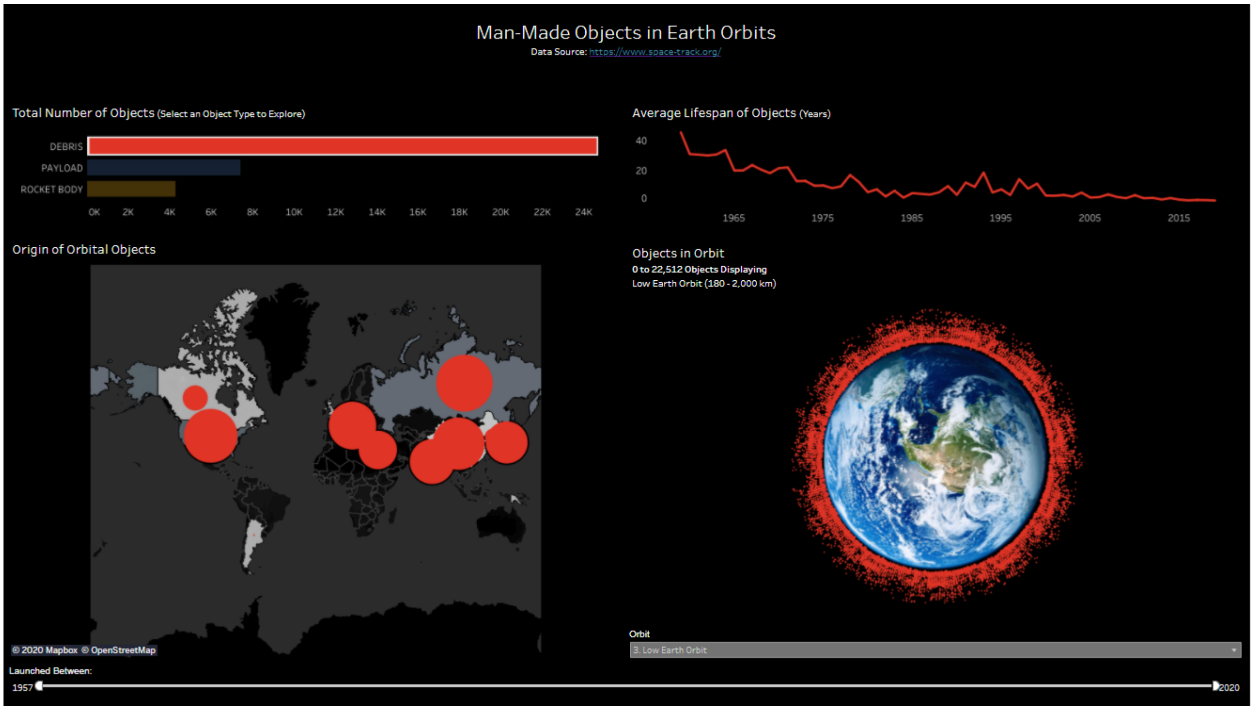

Figure 6: Select an Object Type

The bottom two visualizations allow the user to view object distributions over time, by location and in orbit. The "Launched between" filter in the bottom of the display in Figure 7, will filter these visualizations to only display objects launched between the two end dates. Hovering over the orbital origin pie charts will reward the user with a view of object type break-down metrics, by country. The orbital visualization can be filtered to show one of three orbits, or all orbits simultaneously.

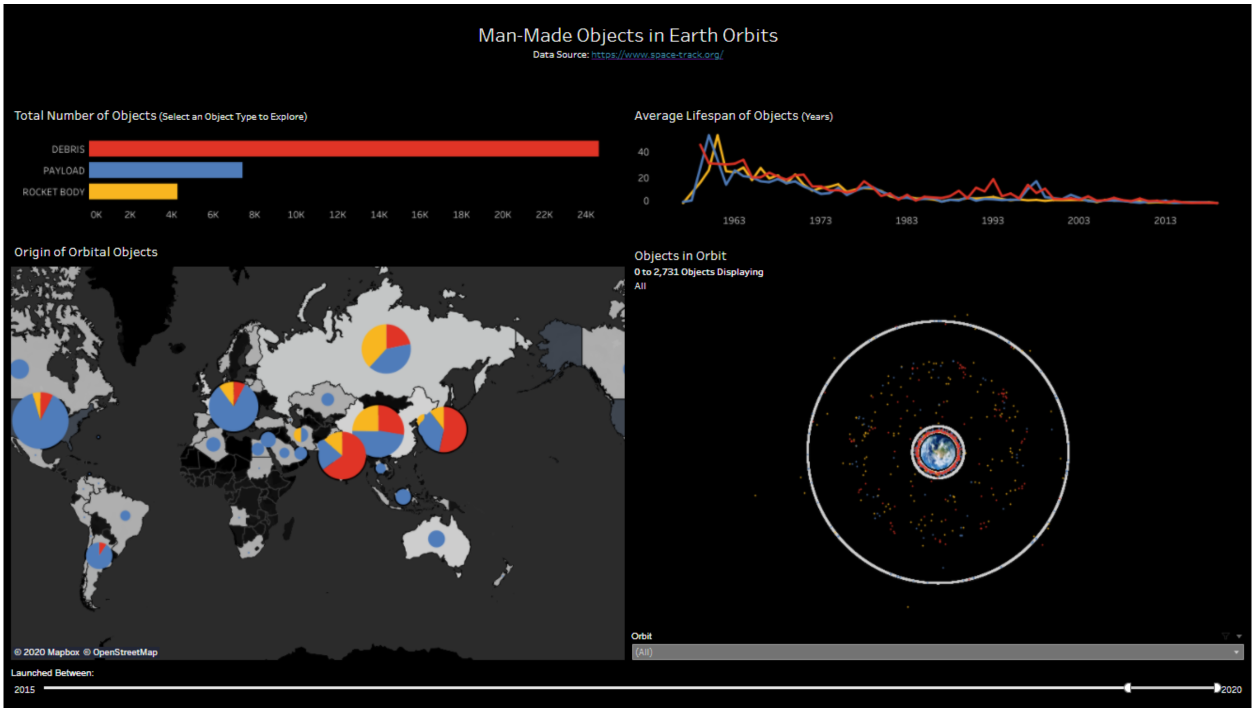

Figure 7:Object Distribution in the Last Five Years

Conclusion

Looking at our visualization, we can observe and learn some interesting information. In Visualization 1, we can see that debris takes the largest percentage of total number of objects in space (24k, which is about 3 times the number of payload and 6 times the number of rocket bodies) and the sizes of debris in space are generally small. Payload has the second largest total number, and the rocket body has the smallest, and their objects are generally larger, falling into the “large” size category.

In the second visualization “Average Lifespan of Objects”, we can observe a trend that the average lifespan of all three kinds of objects reach the peak around launch year 1960 with an average lifespan of 53 years. The average lifespan gradually decreases as the time becomes more recent, now less than 1 year in 2015. Our guess is that this may be because the players who invested in launching satellites and putting space crafts in orbits have changed from research purposes and government space race to commercial or telecom companies.

From Visualization 3 “Origin of Orbital Objects”, we can learn that Russia (previously the Soviet Union) has launched the most space objects with a total number of 15,364. The United States is the second with a total of 11,304 space objects launched, and China is the third, with a total of 5,480. This can be explained by the historical periods such as the Cold War. One interesting fact to notice is that the breakdown of the space objects launched by these three countries are similar - debris consists of the overwhelmingly large percentage, and payload and rocket body consist of similar percentage, but the percentage of payload is slightly larger. However, this breakdown of object types is not the case for the European Union and Japan, which take the fourth and the fifth place in the total number of objects launched. We can also see interesting changes when moving the slider from left to right, showing changes from an earlier time to a more recent time. The United States started to launch objects to space the earliest, then the Soviet Union, then Japan and the Europ joined and later China also joined the game. This makes sense because launching objects to space is closely related to the target country's economic level and technology development.

Next in our “Objects in Orbit” visualization, we can observe that most space objects are found in the Low Earth Orbit, and as the distance becomes further from the Earth, space objects launched become more and more sparse. Payload and rocket bodies are generally located near the three orbits, making it a roughly three-separate-ring structure, but it is not the case for debris.

Our visualization generally meets our concept goals except we did not incorporate the time slider bar to the orbital graph (Visualization 4) and show a change of objects locations in relation to the time because it was too difficult to implement. Another thing is we deleted the feature that, when clicking on the count/break down of space objects by country, a bar graph as what is in the Appendix which has the colored break-down of number of objects as its y-axis and launch year as its x-axis will be displayed, because we think the functionality has already been achieved by the combination of the time bar, the country map, and the pie chart for each country in the visualization, and adding this feature will cause a duplication.

Future Work

After the presentation, we gained a lot of valuable comments and suggestions. Most of the suggestions focused on three visualizations: bar chart, origin map and the density map. For the bar chart, we will consider adding the data label in this part, then users “can read the value at first glance”. Some audience pointed out that the white space in the tooltip “seems a bit out of place on a black background”. However, we have tried several times and found that tableau does not support this feature. In the meantime, we will also consider changing the colors of the pie charts to make them consistent with the type they represent. For the origin map, some audiences were confused by the pie charts in this part. In order to make it more efficient for users to access the information, we will add necessary legends and adjust the color and log scale the pie chart size to “make some of the smaller ones more legible”. In addition, we will consider disabling the zoom function on the map for a better viewing experience. For the density map, due to time constraints this time, we were unable to create a timeline slider in this part. In future work, we will try to add this feature and make all visualizations show the corresponding year when the users drag the slider.Besides, taking into account readers' comments, we will also make this orbital map can be filtered by country to enrich the information provided by our dashboard.

Through this project, our team learned about the three main components of space junk: debris, payload and rocket body; explored the reasons for the rising population of space objects; mastered the main source countries of space objects and understood the distribution of space objects in the universe and their distance from the Earth. From a technical point of view, the team project allowed us to consolidate what we learned in class about data visualization and developed new skills according to the specific needs of this project, which helped us expand the scope of knowledge. At the same time, the valuable comments and suggestions from instructor and classmates made us aware of potential areas for improvement in the future.

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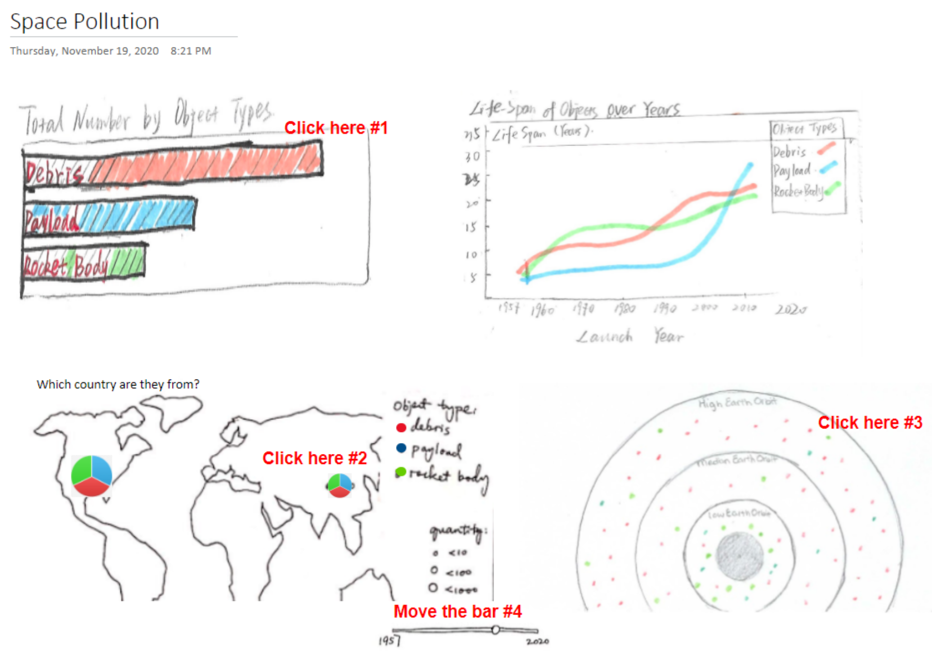
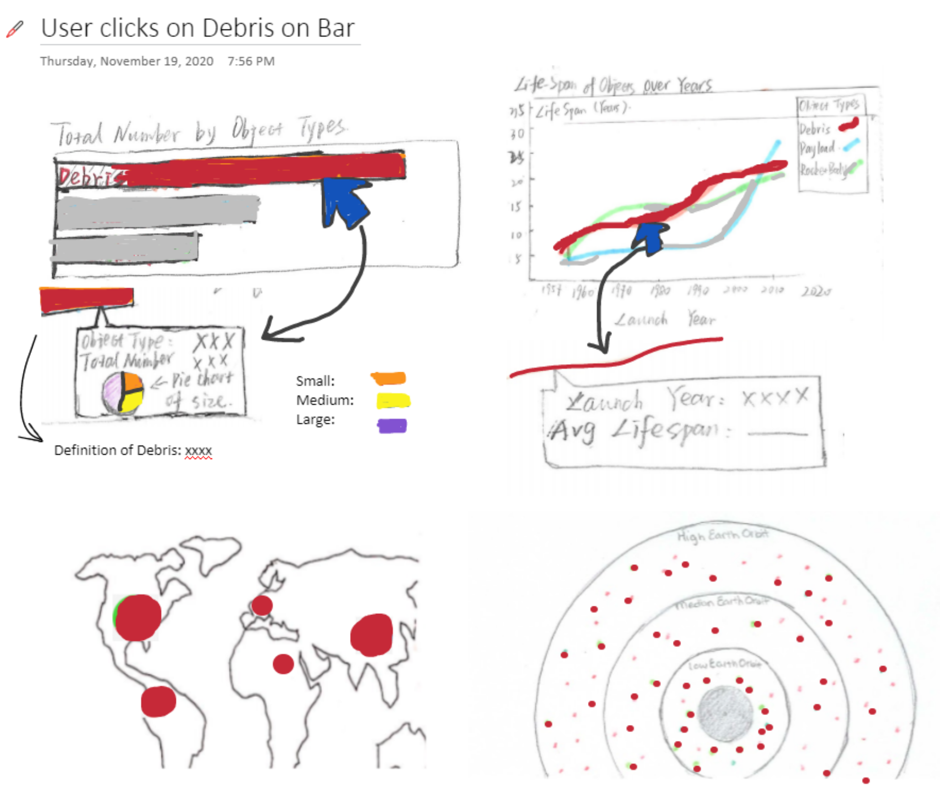
Appendix

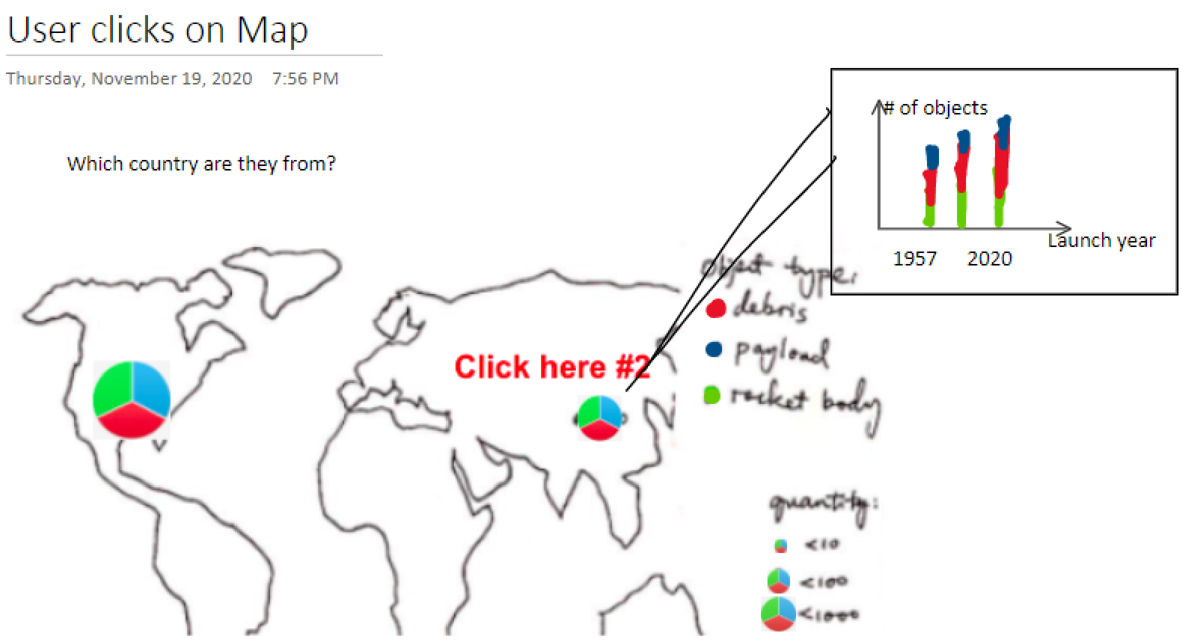
Space Pollution Visualization Prototype



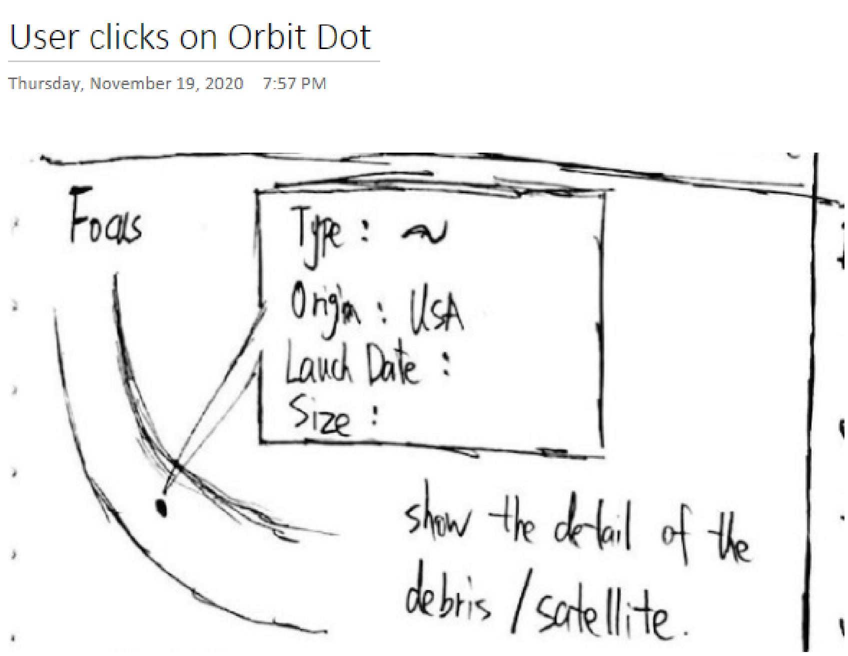
First Task: User clicks on Debris



Second Task: User clicks on Map



Third Task: User clicks on Orbit Dot



Fourth Task: User moves Timeline Bar