University of California San Diego

CSE Honors Thesis

Citizen-Centric Infrastructure with an Artificial Intelligence and Data Science Backbone

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Contents

1 Acknowledgement

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Without any of those people, I could not have accomplished my thesis. I will always remember the hard time during the COVID-19 pandemic and appreciate the love and support I received.

2 Abstract

Citizen-centricity is a bottom-up approach that empowers citizens to engage in and address different natural and societal challenges. Sometimes people may refer it as citizen science. As COVID-19 is raging the world, we tried to build a citizen-centric infrastructure that allows every citizen to fight against COVID-19, exploring how citizens can contribute to, what user information is necessary, and what technology tools are needed. We started with contacting tracing by building a website, COVID Maps, to let users share their GPS history data and inform users of the population's intersectionality and density. Later, we created OASIS, a website for users to share their data, find trustworthy resources to deal with COVID-19, and get insights generated from COVID-19 stories shared by users. In the thesis, I will talk about the problems our team have met in those projects and how to address them using different tools. I will also talk about lessons learned from the study and outlooks for future research.

3 Introduction

3.1 Citizen-Centricity

At present, there are many natural and societal challenges on the planet, from the COVID-19 pandemic to disparity of wealth. There is an urgent need for actions to address those issues. However, how do we solve those problems?

The top-down approach applied by governments engages in system-level changes driven by policy and operational directives (Gallup, 2018). It could bring widespread changes to address natural and societal issues. However, it demands complicated governmental procedures and a long time for implementation, passing from the decision-maker down to the general population. Even though policy changes are successfully passed, whether citizens follow the rule or not is another story.

On the contrary, the bottom-up approach, which may have a limited impact that each person brings (Gallup, 2018). However, solving the world's problems is a big task that cannot be accomplished by a single person. Therefore, we should pursue such efforts using a citizen-centric approach, where people are empowered to engage and address these challenges. Through more recycling carried out by individuals in California, we lessen the impact of our throw-way culture on the environment, creating a cleaner, healthier, and more sustainable environment (Klug, 2020). In African countries, public participation in regulating mining ensures that the overall management of exploiting mineral resources is sustainable (R. Gisore, Z. Matina, and N. KenyA, 2015). At present, journalism transformed from newsroom cultures to a new communicative orientation, relying mostly on social networks to immediately reach tons of audiences who can react to a particular policy, issue, and topic (Kramp L., Loosen W., 2018). These are great examples of how individuals are empowered to have a significant impact on their daily lives. This is where we started. As COVID-19 is raging the world, we are interested in tools through which citizens can share information with the broad community to solve these challenges, information necessary for the solution, and tools to enable such processes.

3.2 Data from Citizens

There are multiple ways that citizens can contribute to a solution. For example, citizens can donate to an NGO for healthcare, volunteer for tree planting, clean the trash for local communities, or join protests for social justice, such as the Civil Right Movement in the 1950s, the Orange Revolution in 2004, and Black Lives Matter started in 2013. Of course, when everyone carries out practical actions in real life, there is a considerable improvement in the environment and society. However, from a computer science perspective, we seek a more scientific, systematic, and cost-effective way to address those challenges. Most importantly, each individual is a data source. From citizens' experiences, such as what issues they met, how they dealt with it, and what the result of their solution was, we can generate insights around those issues.

For example, some citizen-centric initiatives, which encourage the general population to take action, apply different strategies to address water pollution worldwide. By investigating what they are doing, how they motivate citizens to contribute to the solution, how many citizens get involved, what the result of citizens' engagement is, and so on, data scientists can determine what makes a citizen-centric environmental organization succeed in addressing water pollution.

A most recent example could be evaluating the impact of COVID-19 on people's daily life through social networking services and generating insights to fight against COVID-19. Tons of data points could be extracted from social media like Twitter, where users share their experiences and feelings about COVID-19. The DARPA Network Challenges illustrated the critical roles that the internet and social networking play in the real-time communications, wide-area collaborations, and particle actions required to solve board scope, time-critical problems (DARPA, 2009). Applying natural language processing techniques, such as finding the most popular topics, the trend of hot topics, co-occurrence and networks of words, and sentiment analysis on users' posts, scientists would know what people need.

In conclusion, citizens are an abundant and diverse database that scientists could always explore.Therefore, we decided to apply citizen science, in which public participants engage in any part of the scientific process –

promote public engagement as a mechanism to address complex problems (ASH CENTER, 2017). Specifically, we want to develop a citizen-centric infrastructure for data collection to deal with natural and societal challenges by artificial intelligence algorithms and data science methods.

3.3 Problem Statement

Many natural and societal challenges are going on globally, from wildfires in California, social justice in the U.S. to COVID-19 pandemic, and global warming. Based on the emergency and scale, we started with COVD-19 pandemic.

The COVID-19 pandemic presents a global threat never experienced in modern times. At the moment, the therapeutic strategies to deal with the infection are only supportive, and prevention aimed at reducing transmission in the community is our best weapon. Thus, further studies are needed to understand the mechanisms of transmission.

Simultaneously, as COVID-19 has affected every aspect of people's lives, including economics, healthcare, and politics, how to help people get back to normal life becomes another problem. However, how severe is each aspect on which people have been affected by COVID is not clear. Therefore, to help people return to normal life requires more feedback from the public.

Finally, we should consider applying what we have learned from COVID-19 to solve other natural challenges, like global warming. Both COVID-19 and climate change could be catastrophic for humanity. While COVID-19 disrupts societies in just a few weeks, climate change is much slower acting but ultimately more severe. (Cho, 2020) As we confront the current crisis, can we learn from it to deal with climate change? What can we learn about citizen-centric activities to address a challenge?

Therefore, this project investigates the situation, insights, and the impact of COVID-19 to fight against it and applies what we learn here to deal with other natural challenges, such as global warming. There are two main website products involved: COVID-19 Maps and OASIS. COVID-19 Maps was created around April 2020, where users can share their GPS data from Google Map Timeline and get informed of the risks of getting COVID-19 in different regions. It aims to analyze the level of social distancing through the intersectionality and density of populations. However, as COVID-19 Maps relates privacy concerns, we have to resort to another way to control the virus. Consequently, we started OASIS, which allows users to view up to date COVID-19 data, get personalized COVID-19 resources, share their personal stories about COVID-19, and view others' stories all over the world on one single map. The methodology for generating insights of COVID-19 is analyzing self-reported personal stories about COVID-19 and personal information on OASIS by Natural Language Processing(NLP) and data science methods. Besides, through OASIS development, we will learn how to build a citizen-centric infrastructure with an artificial intelligence and data science backbone to implement a similar infrastructure for future natural challenges.

3.4 Report Outline

Firstly, we will illustrate how we build up the website, COVID Maps, and a related framework, GIS System, including data capturing, data processing, data storage, and data displaying. We will also discuss its limitations, mainly on privacy concerns, and how we tried to avoid the same issues in the next project, OASIS.

About OASIS, we will focus on the principles to create a simple but engaging online platform for citizens to share data and get reliable information about COVID-19 and what possible ways that we can achieve those principles. Next, we will go through tools that helped us achieve those principles, address privacy concerns, and manage the development team.

At last, what work has been done in the two projects will be summarized. We will look at what we have learned from the projects and future research questions for citizen-centric science.

4 Contact Tracing

Social distancing can effectively decrease the disease transmission (Cascella, Rajnik, Cuomo, et al., 2020). Therefore, contact tracing is one of the most effective way to help people to avoid getting COVID-19. It is a process to identify, monitor, and support individuals who may have been exposed to a person with a communicable disease, such as COVID-19 (CDC, 2020). We decided to start from there.

4.1 GIS System

A geographic information system(GIS) is a conceptualized framework that can capture and analyze spatial and geographic data (Huisman and By, 2009). To develop the website COVID-19 Maps to display the population's intersectionality and density, we used the GIS system to capture, process, store, and display data. Tools involved are website development in Javascript, Google Maps Timeline, Firebase, and Mapbox.

4.2 Data Capturing

COVID-19 means contacting tracing on a constant and large scale. Hence, smartphones, which people can easily bring everywhere, would become the container of a contracting tracking app. Developing a mobile app by ourselves to track people's whereabouts seems a great way to implement contact tracking. However, it is not accurate enough to identify with whom people may have gotten in touch.

Other kinds of contacting tracking apps use Bluetooth to communicate with other Bluetooth-enabled devices nearby, generating an anonymous alert to other users based on proximity and length of exposure (C. N. Service. 2020). The University of California Health is piloting this smartphone technology that notifies users if they have had a high-risk COVID-19 exposure. However, users cannot prevent from getting COVID-19 with this solution.

Therefore, we decided to get the existing GPS data from Google and Apple that provide more precise GPS tracking and keep tracking users' locations if we got permission from users. Since Apple does not provide an API for getting users' location, it is not easy to get those data. Simultaneously, Google does not offer such an API either. However, Google supports users to download their location history through Google Takeout. One problem with it is that the downloaded file contains all the user locations, which is a significant burden when processing data. Besides, only location history for the past 14 days is needed because the approximate number of days for the symptoms to appear after a person got infected is 14 days. Another problem with Google Takeout is that users need to book their location history files, and exporting data takes hours long. Thus, how to get data by day and simplify the process becomes the most challenging part.

According to the tutorial Map Location History by Geffert in 2017, exporting GPS data on a particular page from Google Maps could be done by a python script. The tutorial shows how to get a user's cookie when logged into the Google Maps website and request an encoded URL with the cookie to download the user's GPS data as KML files. (KML, an XML notation for expressing geographic annotation and visualization within two-dimensional maps and three-dimensional Earth browsers) The method helps to get data by day but is still too complicated.

Based on the cookie-related mechanism, we improved on the process. When a user logs into the Google Account, Google OAuth 2.0 generates a security cookie that contains the user's login information. With this cookie, users can direct to other Google services without logging in. Also, a hyperlink embedded in the website could automatically direct to a URL when being clicked. Therefore, we created the website, COVID Maps, directing users to log into the website with their Google accounts and click on a hyperlink under which 14 encoded URLs for 14 days' KML files are hidden. By opening a blank window and changing the URLs for that window, 14 URLs will be opened one by one in the background, downloading those KML files.

4.3 Data Processing

After downloading KML files from Google Maps Timeline, users can upload their files to COVID-19 Maps. KML is a file format used to display geographic data in an Earth browser such as Google Earth. However, it is not compatible with more complex and flexible geodata displaying, like heatmap, circles, and layers.

Mover, those KML files contain users' personal information, such as email, home address, and name. Thus, instead of storing those KML files, COVID-19 Maps only extracts the necessary features: coordinates and timespan. Both of them are under the tag `<Placemarker>`. To simplify the documentation, we have:

```
<Placemarker>
    <name> ... </name>
    </address>
    <ExtendedData> ... </ExtendedData>
    <description> ...</description>
    <LineString>
        <altitudeMode>
        <extrude>
        <tessellate>
        <coordinates> lng, lat, height, lng, lat, height, ...</coordinates>
    <LineString>
    <TimeSpan>
        <begin> dateTime </begin>
        <end> dateTime </end>
    </TimeSpan>
</Placemarker>
```

Or

```
<Placemarker>
    <name> ... </name>
    <address> ... </address>
    <ExtendedData> ... </ExtendedData>
    <description> ... </description>
    <Point>
        <altitudeMode>
        <extrude>
        <tessellate>
        <coordinates> lng, lat, height, lng, lat, height, ... </coordinates>
    <Point>
    <TimeSpan>
        <begin> dateTime </begin>
        <end> dateTime </end>
    </TimeSpan>
</Placemarker>
```

Whether it is `<Point>` or `<LineString>` depends on if the geodata is a static point or a line of movement. Based on XML documentation, KML files can be easily parsed into GEOJSON objects.

4.4 Data Storage

Based on the simple query capacities, fast implementation, and demand for JSON objects, we applied Firebase to store that data. In the beginning, we have two main references: /Points and /Users. /Users contain different usernames (key), each of which has multiple data points. /Points contain different data points(key), each of which has one corresponding user. The database schema is as follows:

```
{
    "Database": {
        "Points": {
            "point1_key": {
                "begin": "date_time",
                "end": "data_time",
                "lat": "lat_val",
```

```
                "lng": "lng_val",
                "user": "user1_key"
            },
            "point2_key": {
                "begin": "date_time",
                "end": "data_time",
                "lat": "lat_val",
                "lng": "lng_val",
                "user": "user1_key"
            },
            "point3_key": ...
        },
        "Users": {
            "user1_key": {
                "point1_key": "",
                "point2_key": ""
            },
            "user2_key": {
                "point3_key": ""
            }
        }
    }
}
```

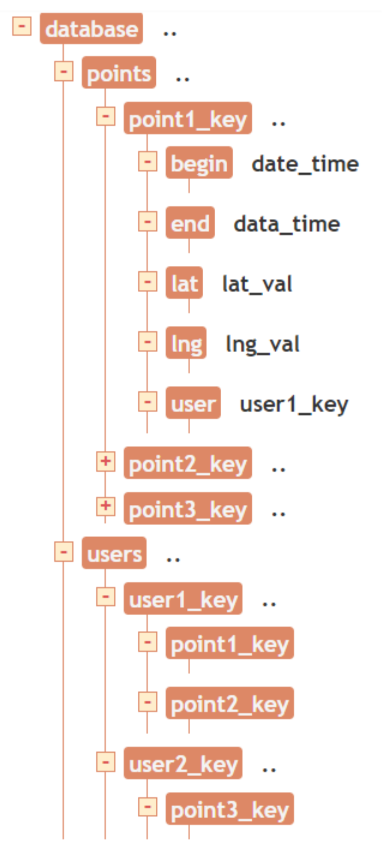


Figure 1: Database Schema

The solution is clean and straightforward. When showing the population's density, we just put all the points from /Points onto the heatmap. However, the time for map render becomes longer and longer when showing the intersectionality of people's trajectories. To show the intersectionality of users' trajectories, we calculate the distance between every two geographical points by the Haversine formula and mark their midpoint as intersection if the distance is smaller than 50 meters and the two points were generated in the same hour. Thus, the runtime is $C(2, n) = O(n^2)$. As the number of data points and users increases, the rendering time will grow exponentially. Consequently, we need to improve the runtime.

First, we changed the database. The new database schema is as follows:

```
{
    "Database": {
        "Points": {
            "country": {
                "state": {
                    "city": {
                        "zipcode": {
                            "date1": {
                                "point1_key": {
                                    "begin": "date_time",
                                    "end": "date_time",
                                    "lat": "lat_val",
                                    "lng": "lng_val",
                                    "user": "user_key"
                                },
                                "point2_key":...
                            },
                            "date2": ...(same as previous date1)
                        }
                    }
                }
            }
        },
        "Users": {
            "user1_key": {
            "Dates": {
                "date1": "",
                "date2": ""
            },
            "Points": ...(same structure as previous Points)
        },
            "user2_key": ...(same structure as previous user1_key)
            "user3_key": ...(same structure as previous user1_key)
        }
        "Covid": {
            "user1_key": ...(same structure as previous user1_key)
            "user2_key": ...
        }
    }
}
```

The arrows of the same color have the same structure. After parsing the XML files, COVID-19 Maps conducts reverse geocoding on the coordinates to get the country, state, city, and zip code. References Dates for Users and Covid at the root reference is added. Dates records the dates of the location history that the user uploaded. Based on Dates, COVID-19 Maps can remind users to share their location history if they did not share their location history in the past 14 days. Covid keeps track of the users who have already gotten COVID-19, as a result of which users who have contacted the infected users will get anonymous notification from the website.

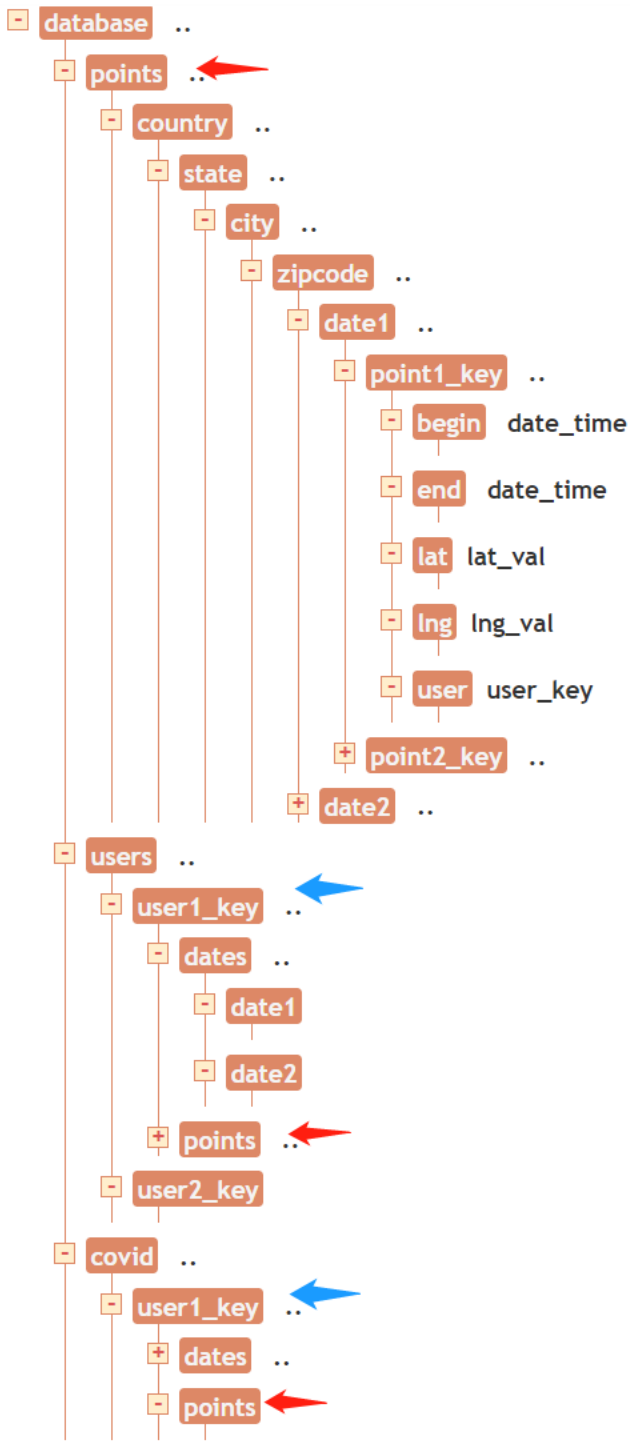


Figure 2: Database Schema

Besides the changes in the database, we redesigned the algorithm to find out intersections of people's trajectories. Querying on the database from the top to the bottom layer returns arrays of points at each zip code. Next, sort each array based on latitude and then loop through the array, checking if one point is within 50 meters to the next point and two points happen in the same hour. Finally, sorting each array based on longitude and doing the same check to find the intersections. Hence, the runtime for rendering the map of intersection nations is $O(nlogn/C)$, where C is the number of zip codes. Even though it is possible to calculate the intersection between two close points as two intersections and miss some points on a zip-code region's margin, overall, the algorithm's efficiency and accuracy are well-balanced.

4.5 Data Displaying

There are three popular Map APIs: Mapbox API, OpenStreetMap API, and Google Maps API. Google Map API is heavy to render, not visually represented to display data, and expensive for beginners. The OpenStreetMap API is free. However, it is meant for map-editing purposes and has incomplete documentation. The most commonly used standard format designed for representing simple geographical features is GEOJSON. Therefore, we chose Mapbox for data visualization.

4.6 Result

COVID Maps offers 3 kinds of maps:

1. Density Map: shows the activity level of a community by drawing out all the trajectories of all users in the past 14 days.
2. Intersection Map: shows how good social distancing is in a community based on the number of people visiting the same place at the same time.
3. shows the contact between a user and all the COVID19 cases reported to this website.

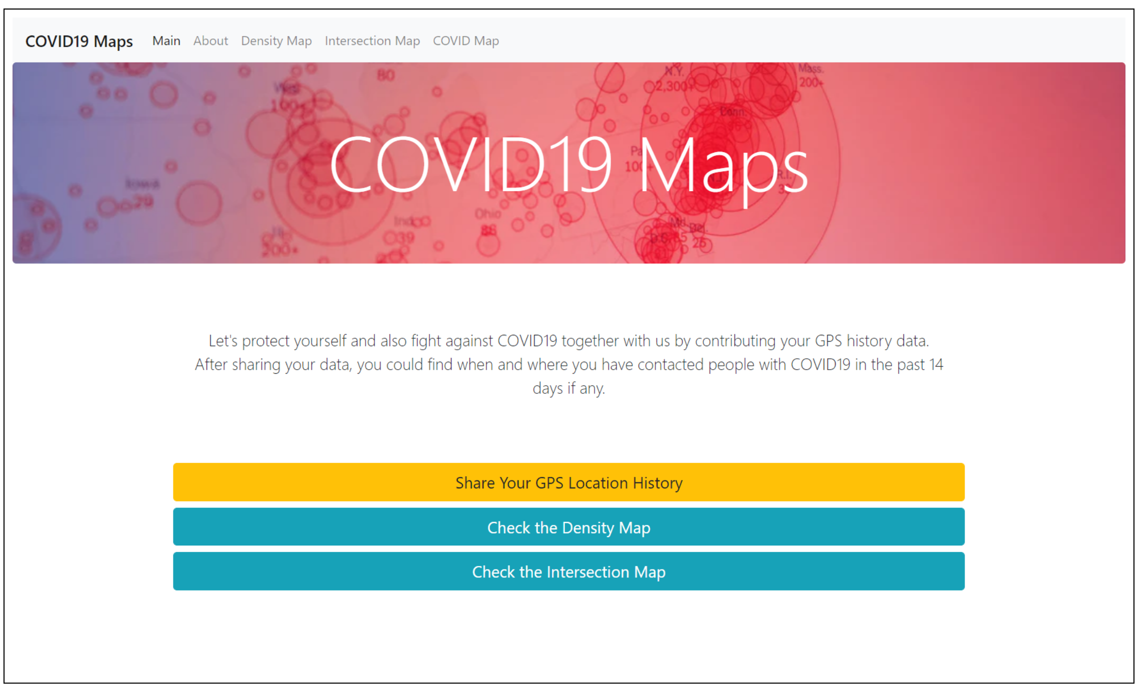


Figure 3: The Main Page

The Intersection Map shows the intersections of users' traveling trajectories in the past 14 days as a heatmap. However, since there are only 13 users in the database, no intersection exists in their traveling trajectories.

Therefore, the Density Map is empty.

The Density Map displays all users' raveling trajectories in the past 14 days as a heatmap. An example of the Density Map 05/03/2020 to 05/17/2020 shows as follows:

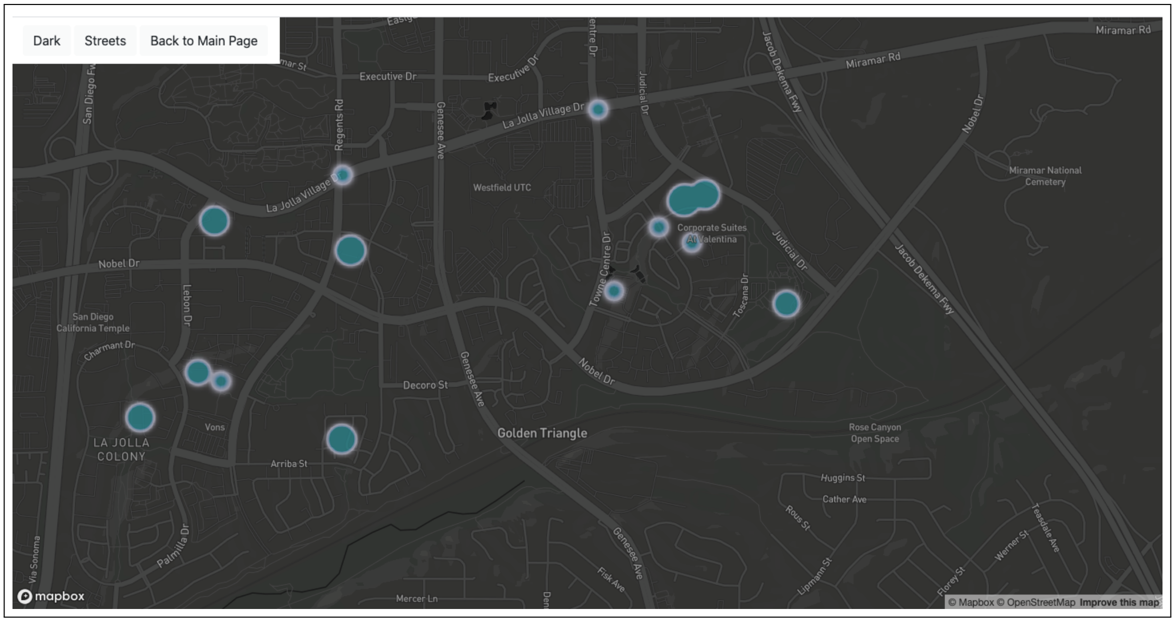


Figure 4: The Density Map

The Personal COVID19 Map marks a user's GPS points in the past 14 days as green circles but marks where that user met people self-reported with COVID-19 on the same day as a red circle. Since none of the 13 users are self-reported with COVID-19, circles shown on every user's Personal Map are green.

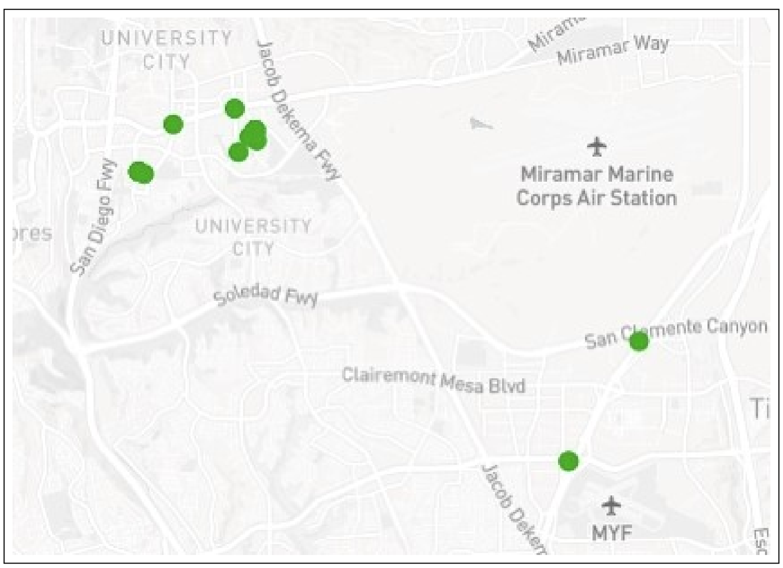


Figure 5: The Personal COVID Map

4.7 Limitations

The contact tracing strategy to prevent the spread of COVID-19 seems useful. However, there are three main obstacles of the project.

Firstly, the user interface and user experience designs are not simple enough for the users to share. COVID-19 Maps is developed by only one software developer(Yuling Shi, the author). Even though it has the basic functionality, it is not visually satisfying, inefficiently directing users to get their location histories from Google Map Timeline. It is not user friendly. The process for data sharing needs users to download their location history from Google Map Timeline and then upload it to COVID-19 Maps.

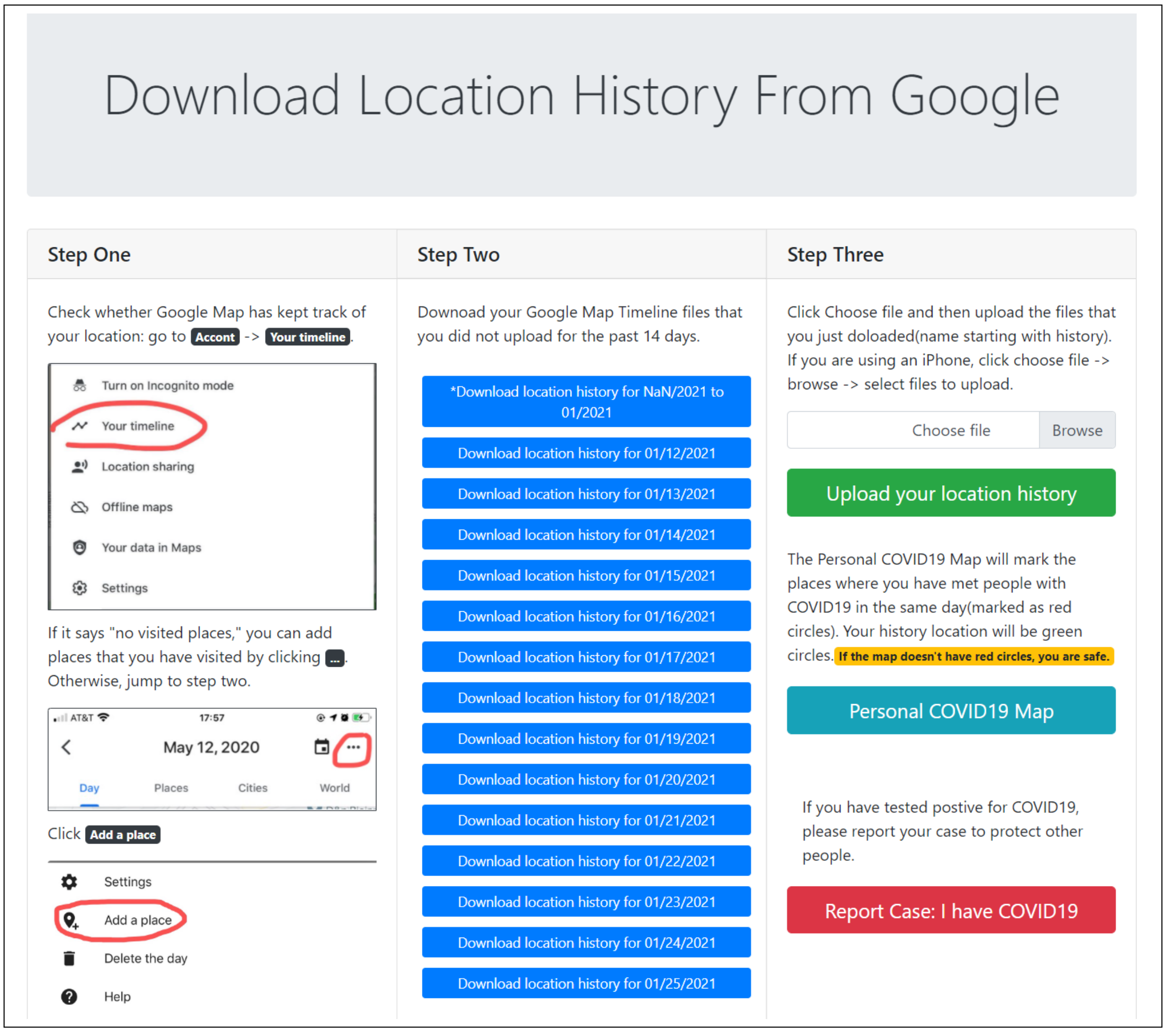


Figure 6: The User Interface for Data Sharing

Secondly, Google Maps does not provide an API for user location history. We cannot directly access users' location history but provide a way for users to download their location histories through authentication cookies. It makes a universal contact tracing app hard to be implemented. As a result, different governments, organizations, institutions, and companies invent their contact tracing app, attracting users to different platforms and having limited amounts of users on each product.

Thirdly, privacy concern is the most significant issue. No matter how cryptography and security of the system is, citizens always have concerns about their privacy. Feedback provided by around 20 beta testing users shows that the most important reason why users are not interested in COVID-19 Maps is that they do not want to share their private information, especially locations. Even though Google provides such an API for the third party to access the user's location history, if users do not open the Google Maps Timeline feature, their location history is still blank.

Based on the three limitations of COVID-19 Maps, we had to resort to another way to build a citizen-centric infrastructure that makes people more likely to share their experiences and information and utilize those data to generate insights for COVID by AI and data science methods.

4.8 Recommendations

Even though COVID Maps did not successfully be applied on a large scale to fight against COVID-19, it helped identify the two main principles to combat pandemic. First, data visualization for the pandemic hotspot to prevent people from getting infected is needed; a warning system to remind people that they might have been infected is needed. Then, how can we create an infrastructure that we can achieve those two goals and at the same time avoid privacy violation?

One solution might be combining anonymous geodata visualization and Bluetooth communication for altering. Open databases like OpenMobility and Safegraph provide anonymous foot-traffic. For example, researchers can use GPS pings from anonymous mobile devices on Safegraph to generate social distancing matrices for COVID-19 pandemic. For the altering system, developers can apply the existing technology on Bluetooth communication, generating an anonymous alert to users who have a high-risk of getting COVID-19.

5 Self-Reporting

The website OASIS is built to make the data sharing process more straightforward and, most importantly, transparent. At the same time, it should help the public to deal with COVID-19. Therefore, OASIS tries to avoid collecting users' GPS coordinates but relies on other types of data, like users' age, gender, medical histories, and personal stories about COVID-19. Through processing those data, OASIS can provide users with personalized resources for dealing with COVID-19 and discover insights into COVID-19.

5.1 Infrastructure Design and Its Principles

The primary purpose of building up OASIS is to collect data from the general public. However, how to build a simple but engaging platform that users are willing to share their information to fight against COVID-19? More generally speaking, how to build up a citizen-centric infrastructure that citizens are willing to contribute to the work of fighting against natural challenges, like annual pandemics or even global warming? Many aspects are involved in answering the question, including simplicity for data sharing, active interaction between users and the platform, tools for processing data, and features to attract users.

5.1.1 Simplicity for Data Sharing

As we learned from COVID Maps, the complex data sharing process and privacy concerns are the most significant issues that stop users from sharing their information with the platform. Therefore, OASIS should offer a simple solution for data sharing. The most intuitive factor that affects the simplicity of the data sharing process is the number of clicks that users have to carry out to finish the process.

To minimize that number, we identified the information that the population and the research team care about the most – people's personal stories about COVID-19, their location, and their health condition. As a result, we put all these questions on the home page, asking people to tell their personal stories about COVID-19, their current locations, whether they are sick, and whether they get tested. After clicking on the "Share My Story" button, they will be directed to the sign-in page. With one more click, if they choose to sign in with a third party account, they will see the map of up-to-date COVID-19 cases.

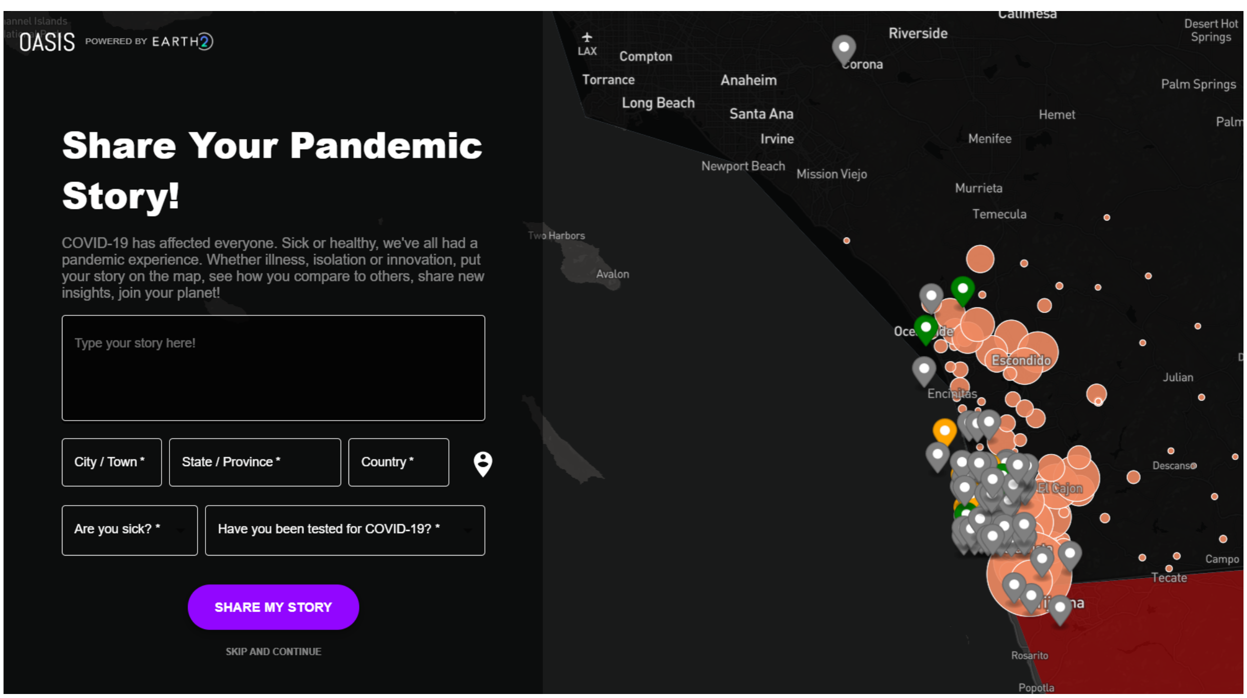


Figure 7: Home Page

5.1.2 Engagement Loop

Even though people are willing to share their data, they do not know how they will benefit society or get any new information from OASIS. People go to news websites because they want to learn about emerging events happening worldwide; young generations keep checking social media to see what is popular among their peers; students go to educational websites to learn technical skills. Then, why would they come back to share more COVID-19 stories or update their personal information? Other than the status of COVID-19 pandemic, OASIS must provide its users with information that they might be interested in or do not know to build up a long-term relationship with users. In other words, we need to create an engagement loop that, on the one side, users share their data with OASIS, and on the other side, OASIS provides users with the insights generated from those data. This engagement loop will generate a positive cycle, motivating users to share more information and enabling OASIS to get more diverse results from the data over and over again.

Two main elements are involved in creating such a feedback system: natural language processing and recommendation system. Natural language processing is used on mining text data, which is users' COVID-19 stories on OASIS. It will generate insights that users cannot directly get from viewing other's COVID-19 stories and display them on the dashboard. Recommendation systems will also be applied to users' COVID-19 stories, feeding users with stories that might interest them. By providing users more information and content through natural language processing and recommendation systems, OASIS is more likely to attract more users and consolidate existing users.

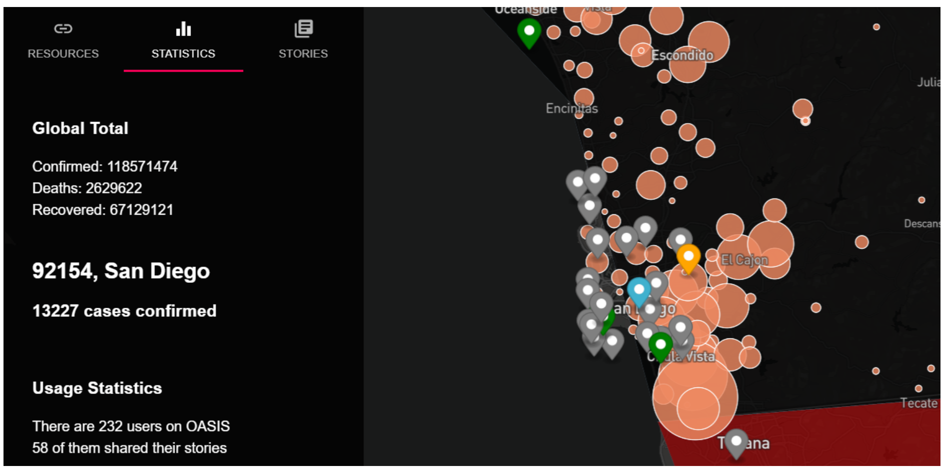


Figure 8: Zipcode Level COVID-19 Status on 3/12/2020

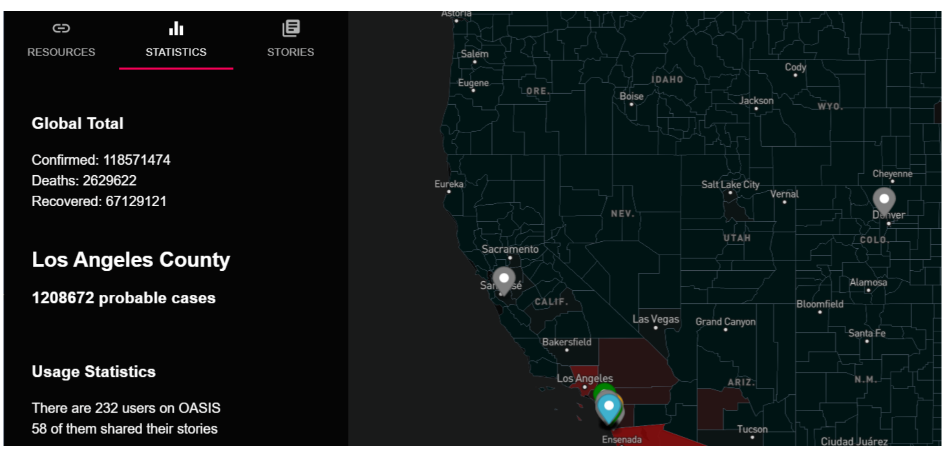


Figure 9: County Level COVID-19 Status on 3/12/2020

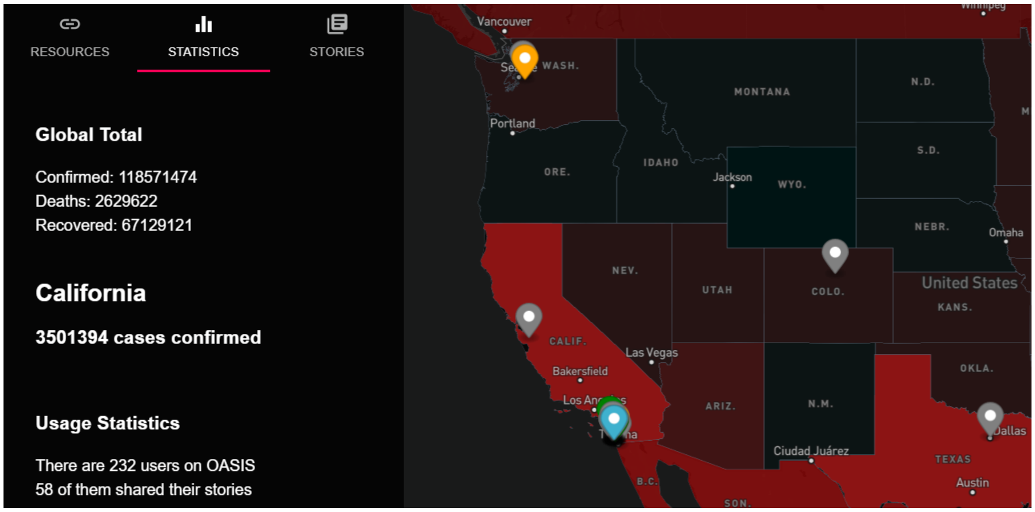


Figure 10: State Level COVID-19 Status on 3/12/2020

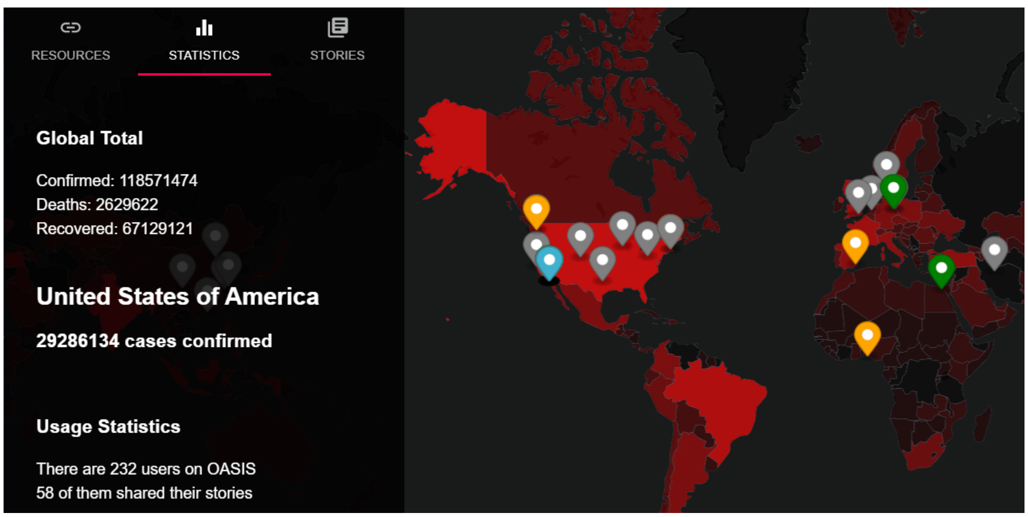


Figure 11: World Level COVID-19 Status on 3/12/2020

5.1.3 Natural Language Processing

Natural Language Processing(NLP) is a subfield of artificial intelligence that deals with the interaction between computers and human languages. At OASIS, we decided to use NLP to read and decipher the users' COVID-19 stories in order to generate useful information to fight against COVID-19. Several questions could be answered. Firstly, what is the most frequent word in the users' stories? By finding out the most frequent word, we would know what people care the most or what affected them most during the quarantine. We would then know which issue we should prioritize to solve to help people get through and recover from the COVID-19 disaster. Secondly, what is the users' attitude towards different events, like quarantine, online-learning, and working from home, triggered by COVID-19? It might reveal the preferable style of people's life, work, and education. For example, if students feel more productive during online learning, schools should consider offering online classes to offer students better educational experiences. We can also combine NLP with the personal information that users share on OASIS, such as age, gender, and professional, to get deeper insights. We might find the age at which people are more vulnerable to getting infected. Finally, we want to understand if we can use the same algorithm to process the data from citizens to get insight into other natural challenges.

```python
stop_words = set(stopwords.words("english"))
all_words = []

for text in all_texts:
    text = text.lower().translate(str.maketrans("", "", string.punctuation))
    for word in text.split():
        if word not in stop_words:
            all_words.append(word)

fdist = FreqDist(all_words)
```

```python
print(fdist.most_common(50))
```

```
[('testing', 113), ('covid', 24), ('im', 17), ('sick', 16), ('time', 13), ('get', 13), ('people', 12), ('story', 11), ('covi
d19', 11), ('home', 11), ('life', 9), ('working', 9), ('help', 9), ('really', 9), ('got', 8), ('world', 8), ('day', 8), ('fa
mily', 7), ('need', 7), ('like', 7), ('since', 7), ('test', 7), ('everyone', 6), ('going', 6), ('social', 6), ('isolation',
6), ('months', 6), ('work', 6), ('3', 6), ('hope', 5), ('much', 5), ('become', 5), ('would', 5), ('together', 5), ('studen
t', 5), ('bad', 5), ('lot', 4), ('feel', 4), ('ive', 4), ('school', 4), ('oasis', 4), ('challenge', 4), ('good', 4), ('thing
s', 4), ('see', 4), ('little', 4), ('could', 4), ('weeks', 4), ('able', 4), ('tested', 4)]
```

Figure 12: Most Frequent Words on 3/12/2020

5.1.4 Recommendation System

A recommendation system is a subclass of information filtering systems that suggest relevant items to users. Nowadays, recommender systems are an essential part of e-commerce and online advertisement. It can be applied to various applications, like Facebook, Reedit, YouTube, and LinkedIn, to attract users by offering them what they might be interested in.

OASIS mainly relies on content-based methods that use additional information about users, like age, gender, professionals, locations, and medical conditions, for the recommendation. Unlike collaborative methods based on the interaction between users and items, content-based methods suffer far less from the cold start problem than collaborative approaches (Rocca, 2019). As there are less than 300 users in the database, content-based methods fit OASIS more. OASIS offers users the nearest stories based on their locations, similar stories based on their gender, age, and professions, and popular stories among all the stories.

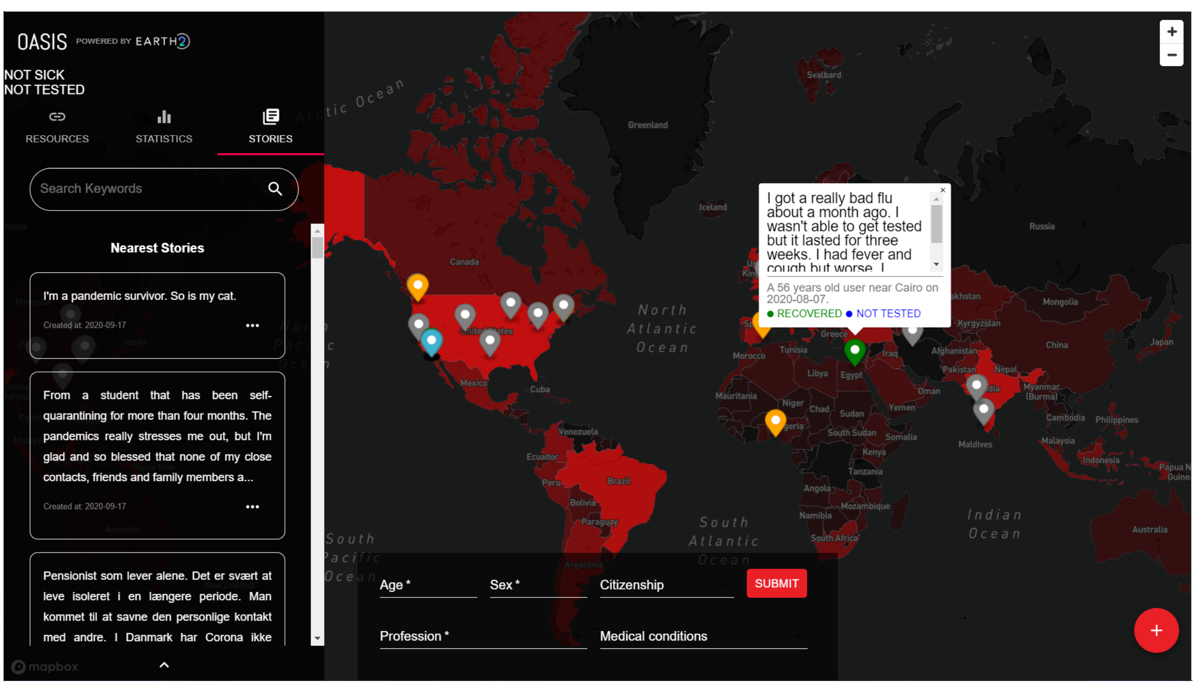


Figure 13: Recommended Stories

5.1.5 Social Engagement

Apps with a social component are typically more attractive to users than those without. According to the most popular iPhone apps Ranking on SimilarWeb, out of the most 20 popular iPhone Apps in the United States in 2020, more than half of them have a social component. Therefore, to better promote OASIS among the public, this website needs to get social. There are two attributes to make it social: being innately social and promoting social sharing.

Being innately social means a feature for communication, sharing, and network should be embedded in the apps. Therefore, besides the feature that users can share their stories about COVID-19 and view others' stories on OASIS, they should be able to like, dislike, and comment on any story. Usually, users share strategies to deal with the situation that the story describes, discuss the opinions in the story, or express their satisfaction with the story. All these activities can improve the interaction between users and the platform.

To advertise OASIS, we decided to allow users to share their stories on other social media, such as Facebook, Instagram, and LinkedIn. People on those platforms get to know OASIS when they see the posts made by users on OASIS. Besides, if anyone on those platforms replied to a particular post shared from OASIS, OASIS will collect its comments and store it back to the database, having more data for NLP and recommendation systems aforementioned.

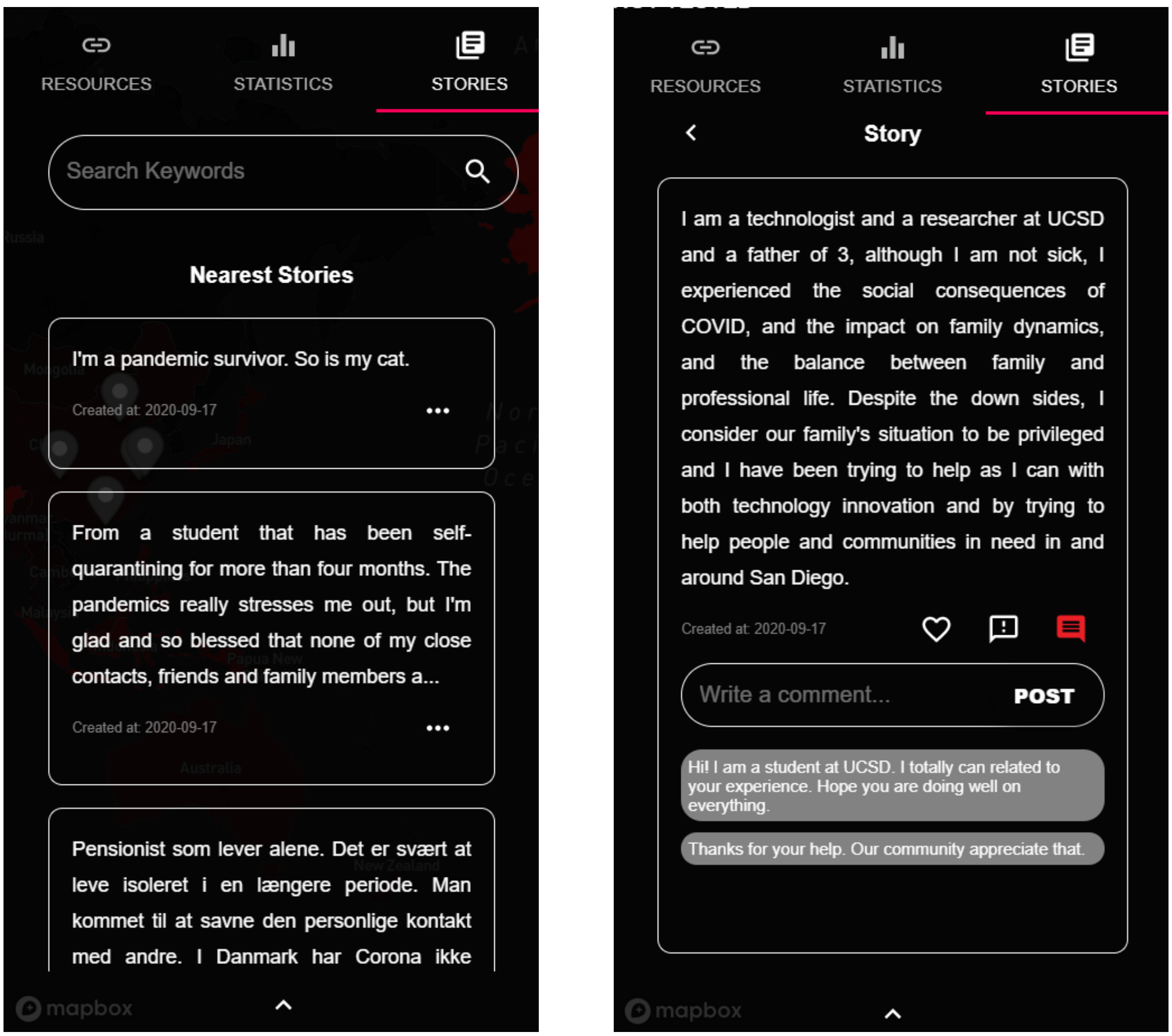


Figure 14: Nearest Stories and Comments

5.2 Privacy Concern

Recall the most significant issue in COVID Maps: users are unwilling to share their data due to privacy concerns. Therefore, for OASIS, we need to make sure:

1. Avoid getting access to the private informations on user's Google account,
2. Avoid storing geodata on the server.
3. Keep geodata at all times disassociated from personally identifiable information: while data is in transit, in memory, and so on, we need to make sure it cannot be associated with the user.

Firstly, OASIS allows users to "continue as a guest," allowing anonymous sign-in. Instead of email and password combination, it creates a cookie for identification, which gets expired after five days. To balance privacy and data collection, we require every user to input their city, province, country, test status, and stories about COVID-19. If they do not fill in those pieces of information on the home page but clicks on "skip and continue," which directs them to the sign-in page, they have to redirect to the home page and share those pieces of information.

Secondly, we gave up on GPS history sharing. We require users to input their country, city, province, and country to put their stories on the map. However, we do not store any geodata, like coordinates, anymore.

Thirdly, we avoid the association between the user's identification email and geographical data. Since the email address is the only way to identify the user, OASIS API calls do not return the user's email address and the geographical information simultaneously. Also, we randomize the markers on the map to avoid associating a user with a particular place.

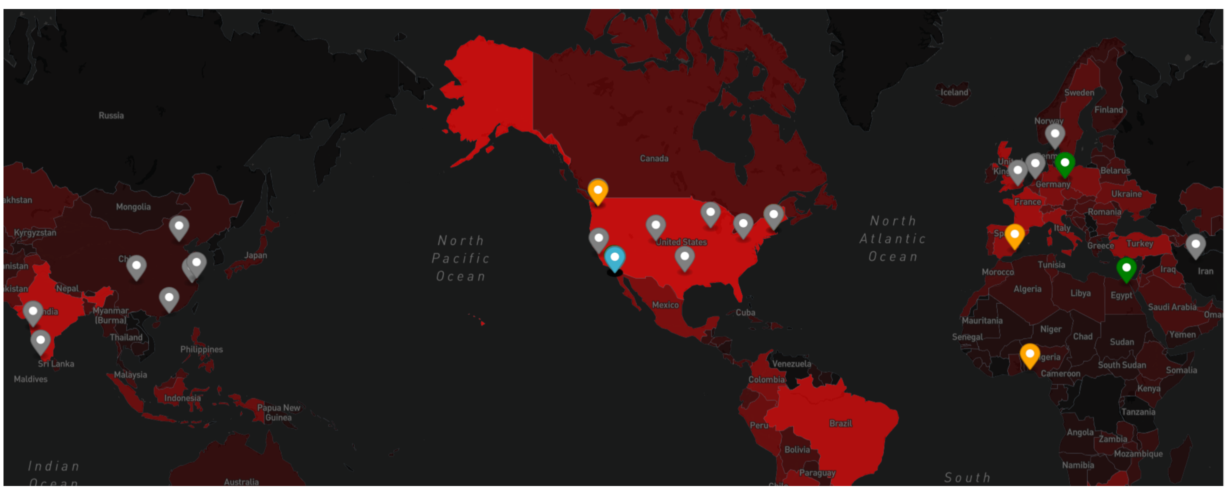


Figure 15: Randomized Markers

5.3 Development and Toolbox

We used React JS to develop the front-end of OASIS. We also used Redux for application status management. For data visualization on the user side, we applied Mapbox to build the map for COVID-19 cases and user story display.

On the back-end, we chose Python and MySQL for the database systems. Flask allows us to quickly create a ReST API and provide the front-end with safe function calls to the database. To better manage the database's version, we utilized alembic for data migration.

To integrate different stacks, we used Github project management for task assignment and code review. We also dockerized the local development environment for testing. Besides human testing, we applied Travis on GitHub to do automated testing, avoiding branch conflict and API function call bugs.

Finally, we applied AWS for the server and Rancher to run containers in production. Now, we are trying to migrate everything to Heroku for simple usage.

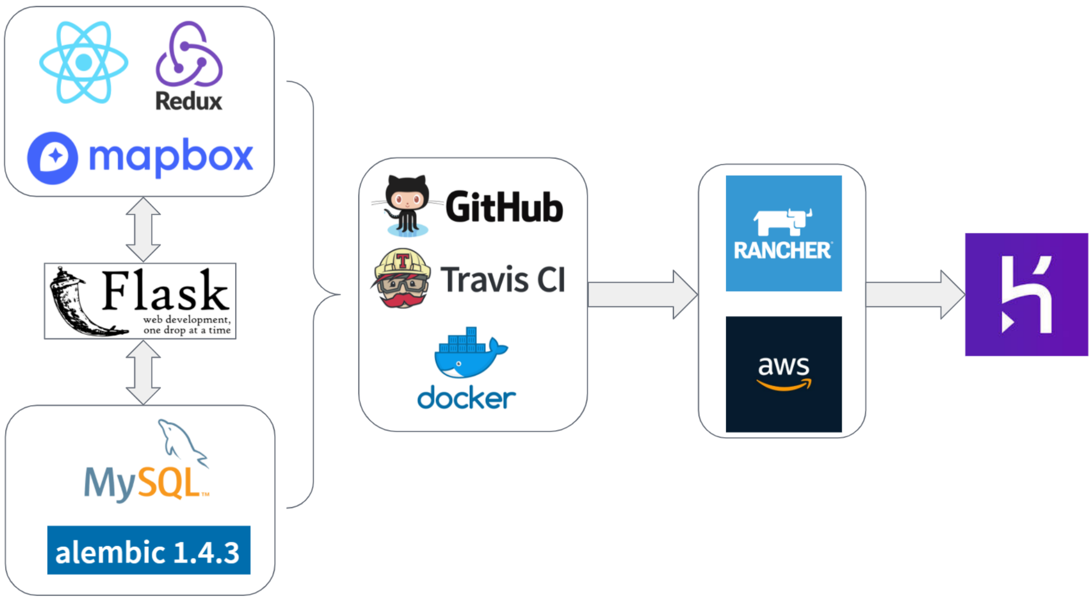


Figure 16: Toolbox

5.4 Result

The OASIS team started to build the platform in June 2020, trying to simplify the process of data sharing and processing. After 6 month's work, OASIS has the following linear user flow:

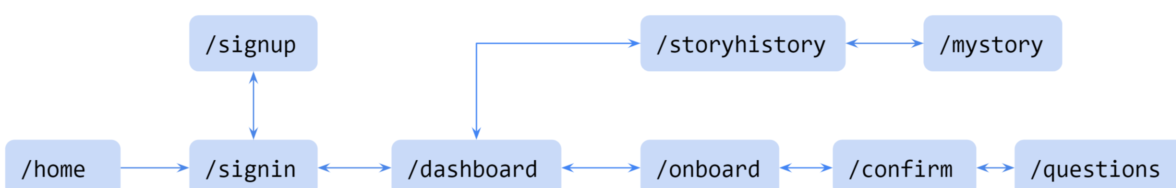
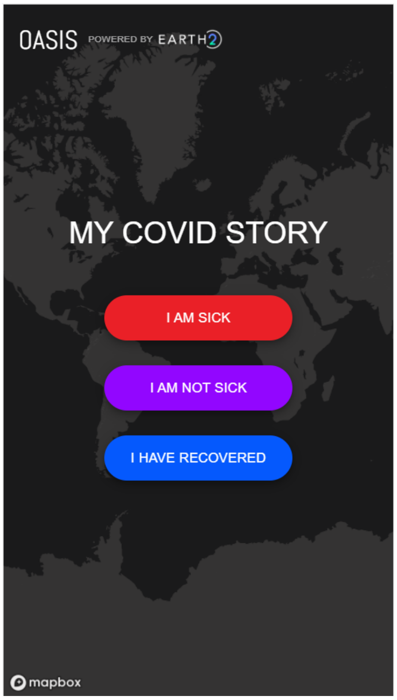


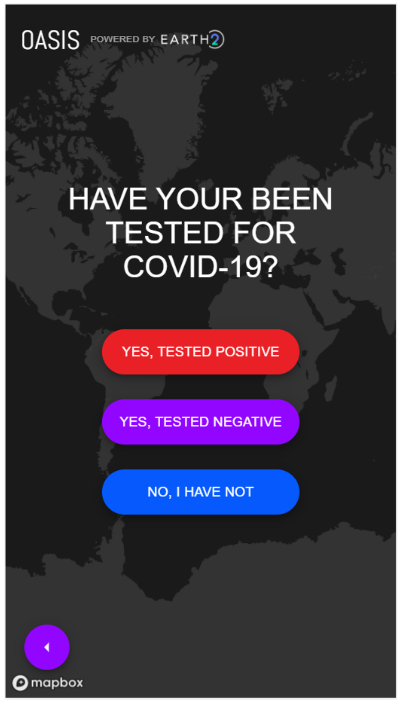
Figure 17: User Flow

Users share their COVID-19 story, location, and test status on the home page, or choose "skip and continue" to directly go to the sign-in page. However, if the current user does not have an account and has not shared a story, they must go back to the home to their such personal information first. The user can then create an account through the sign-up page and redirect back to the sign-in page. In other words, users must at least share their COVID-19 story, location, and test status in order to get the information and service provided in the dashboard.

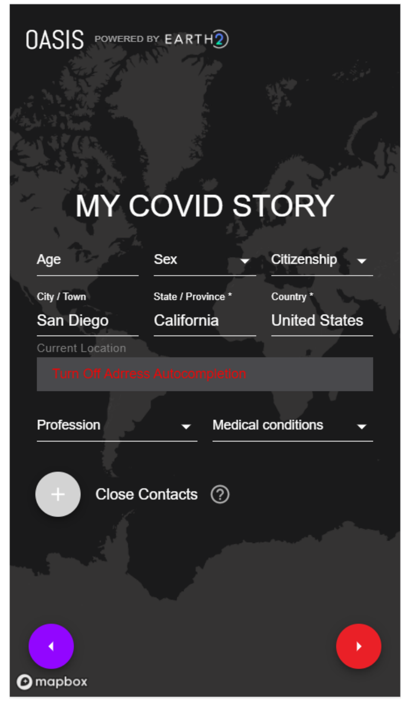
In the dashboard, users can get confirmed cases of COVID-19 in different regions from the country level to zip code level. They can also view, search, and comment on other users' stories and get recommended stories from the system. They also can get trustable resources for dealing with COVID-19. Through the /storyhistory to /mystory chain, users can share their own COVID-19 stories. Through the /onboard, /confirm, to /questions chain, users can share or update their personal information, including age, sex, citizenship, professions, and medical conditions.



(a) /onboard

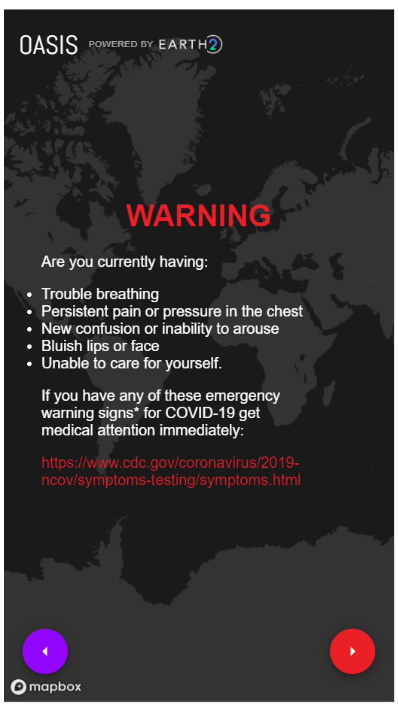


(b) /confirm



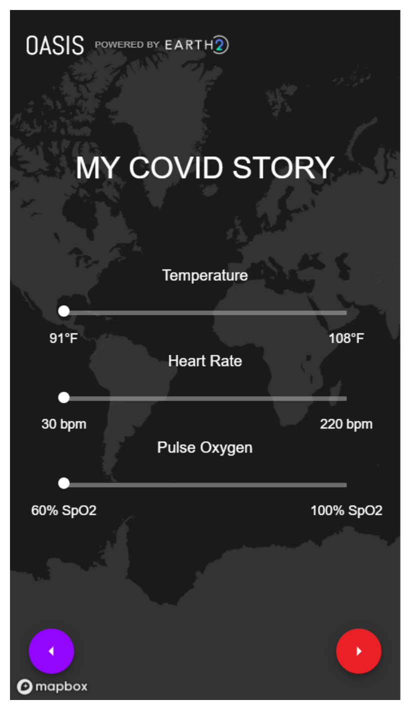
(c) /question

Figure 18: Mobile View of Updating User Profile



(a) /onboard

(b) /confirm

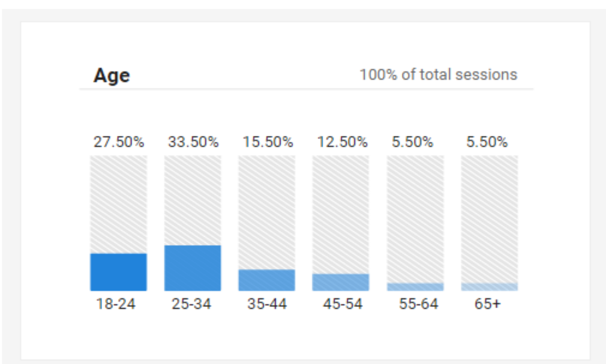


(c) /question

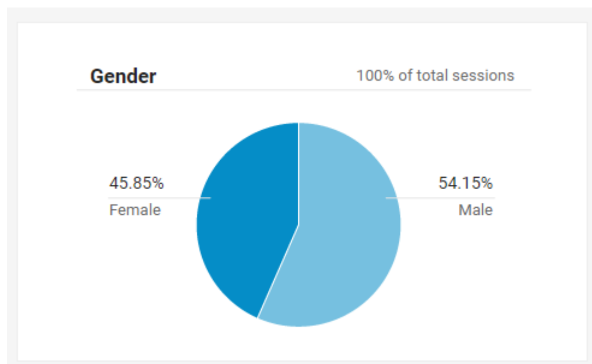
Figure 19: Input Health Status If Input Tested Positive

Figure 20: Share COVID-19 Stories

Until 01/27/2020, OASIS has attracted about 230 users. Most of them come from America, China, Indian, Singapore, and Europe. About half of them are between 18 and 34 years old. Finally, about 45% of them are female, and 55% are male. The following charts are data from Google Analytics since September 2020.



(a) Ages



(b) Genders

Figure 21: Data from Google Analytics Since September 2020

6 Conclusion

6.1 Summary

To fight against COVID-19, Professor Henrik I. Christensen and I proposed COVID Maps. We designed a website that allows users to share their GPS location histories from Google Maps Timeline and inform the hotpots of COVID-19 transmission. In this project, I was the programmer and designer to achieve the following three functionalities through JavaScript, HTML, Bootstrap, and Firease:

1. It parses the shared GPS data from KML files into GEOJSON objects.
2. It stores the data in a tree structure for further efficient usage.
3. It informs users of the occupancy and intersectionality of a city by Mapbox based on the GPS data that they provided.

Later, we created OASIS to address privacy concerns discovered through COVID Maps. It creates an online platform where users can:

1. view up-to-date COVID-19 cases from country level to zip code level
2. get personalized resources for dealing with COVID-19
3. share their stories about COVID-19 and view, search, comment on other users' stories

In this project, I led a 7-person research team composed of graduate students, undergraduate students, and professors in agile development and deployment based on Travis, Docker, AWS, and Rancher. As a team leader, I held weekly stand-up meetings, coordinated with the third-party company InSTEDD for early-stage development and deployment, helped teammates with technical challenges, delegated tasks through GitHub project management, and assured the quality of team deliveries. As the main programmer, I visualized data by React, Python, MySQL, and Mapbox, conducting code reviews on GitHub, and testing in local and production environments. Even though we delivered many features of OASIS, it still faces the challenge of attracting users.

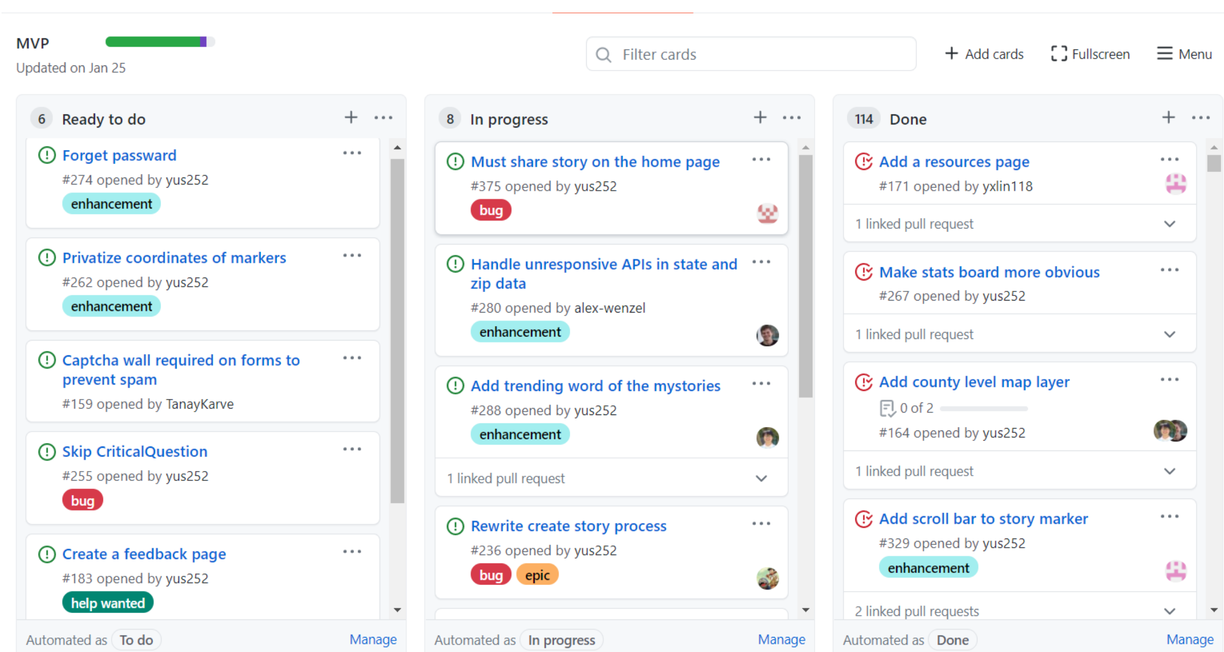


Figure 22: Project Management on GitHub

6.2 Lessons and Outlooks

Firstly, through COVID Maps, we learned that privacy safety is users' most significant concern on every application. An IBM study found that 81% of consumers say they have become more concerned about how their data is used online (Chakravorti, 2020). One solution is legislative fixes, such as Europe's General Data Protection Regulation (GDPR), providing rigorous rules about collecting and using personal data. However, under particular circumstances, such as the COVID-19 pandemic, we might need more flexibility about data collection and usage. Is there any other way to address users' privacy concerns instead of avoiding collecting data? Computer security scientists might view this question as "how to protect users' data," which is a big question. One aspect to consider is how we can process users' data to get insights without storing their data, retrieve the insights later on, and update them with the newly collected data?

Secondly, through OASIS, we learned that to build a citizen-centric infrastructure, we need to simplify the process for sign up but multiple features for people to interact with. In both OASIS and COVID Maps, users gave up on sharing their data because the data sharing process is complicated. Therefore, at OASIS, we tried to minimize the number of clicks users have to complete the data sharing ("fill my information") process. Such an infrastructure should "reward" users for their data sharing as soon as possible to attract their attention by allowing users to enter the dashboard quickly. Next, in the dashboard, users should interact with multiple features, just like viewing COVID-19 statistics, checking out other people's COVID-19 stories, getting the trending words, and recommended stories on OASIS.

Finally, the open question is, "can we build up a centralized database or data-sharing platform that the public can trust in?" During the COVID-19 pandemic in the U.S., governments and some local citizen-centric organizations published contact tracing apps or resource sharing platforms. As a result, people were directed to different platforms. Each of the platforms has much fewer users. Since there is no connection between them, they failed to share resources and information, not able to generating insights through artificial intelligence. Therefore, how can we connect citizens, experts, governments, NGOs, and industry to solve a single issue? Or is there any other way to solve resource/data distribution?

7 Appendix

7.1 The Haversine Formula in JavaScript

Calculate distance, bearing and more between Latitude/Longitude points (Veness 2019)

```
const R = 6371e3; // metres
const φ1 = lat1 * Math.PI/180; // φ, λ in radians
const φ2 = lat2 * Math.PI/180;
const Δφ = (lat2-lat1) * Math.PI/180;
const Δλ = (lon2-lon1) * Math.PI/180;

const a = Math.sin(Δφ/2) * Math.sin(Δφ/2) +
          Math.cos(φ1) * Math.cos(φ2) *
          Math.sin(Δλ/2) * Math.sin(Δλ/2);
const c = 2 * Math.atan2(Math.sqrt(a), Math.sqrt(1-a));

const d = R * c; // in metres
```

7.2 The General Data Protection Regulation

From Wikipedia:

The General Data Protection Regulation (EU) 2016/679 (GDPR) is a regulation in EU law on data protection and privacy in the European Union (EU) and the European Economic Area (EEA). It also addresses the transfer of personal data outside the EU and EEA areas. The GDPR's primary aim is to give individuals control over their personal data and to simplify the regulatory environment for international business by unifying the regulation within the EU.

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