Interactive Worldwide Earthquake Analysis

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ABSTRACT
Earthquakes are a disaster of interest in current times especially with the increase in their frequency and damage caused. Given the dispersion of various resources of earthquakes over the internet, we propose and develop an end-to-end integrated system that can help users analyze the impact of earthquakes in an interactive manner. Our system also aims at providing scientific information about earthquakes and related disasters as well as information about specific earthquakes through related articles. This paper explores the various stages of the development of our integrated interactive worldwide earthquake analysis system.

Keywords
Visualization; Earthquake; Disaster; Interactive tool

1. INTRODUCTION
Earthquakes are geological events that result in the shaking of the surface of the Earth. They are mostly caused by geological faults but can also be impacted by volcanic activities, landslides and nuclear tests. These can become natural disasters which cause extensive loss of life and property or be so weak they cannot even be felt. Earthquakes can be powerful enough to cause other disasters including landslides and tsunamis [1].

Data and visualizations on earthquakes are of interest to public officials, scientists, construction companies, and the media. First responders can use such data to anticipate and be more prepared for a disaster. Apart from direct use, such visualizations can also be used in geology education. According to nationwide education standards, highschool students (by the end of twelfth grade) are supposed to have extensive knowledge about earthquakes [2, 3]. However, many of the current visualizations are targeted towards scientists and those with a geological background (e.g., [4, 5, 6]). Secondly, the various sources for earthquake information are scattered over the internet requiring users to scour the internet for the required information. To address these problems, we propose an end-to-end integrated system to visualize historical earthquake data with and added feature of education to make it truly inclusive of all types of resources. We set our project target audience as highschool students and propose a research tool targeted towards this age group that would help them understand the different concepts through various earthquakes that have occurred worldwide with the added information about the dangers and effects of real earthquakes that have occurred over time.

2. DATA SOURCE
NOAA National Centers for Environmental Information (NCEI) [8] provides the earthquake database that contains significant earthquakes from 2150 B.C. to present under several conditions. This dataset contains earthquake events that caused moderate economic damage which they defined as at least $1 million, 10 or more casualties, magnitude 7.5 or greater, or generated a tsunami. Using the NCEI dataset, we include not only the basic information of the earthquakes such as magnitude, intensity, and casualties, but also the related disaster, i.e., tsunami, to our application.

Another possible source for the earthquake data was the U.S. Geological Survey (USGS) [9] which also provides the recent earthquake data through the 2D visualization tool (Latest Earthquakes Map and List) [10] on their website. To regulate the scope of the system, we decided to stick with the NOAA dataset.

Our system has a feature that displays the summary of related articles for major earthquakes. To get related articles about major earthquakes to add to the system, we scraped the Google search to extract urls for the related articles, and chose to use the wikipedia articles as the source for the summary text.

3. USERS AND USE

3.1 Primary Users: High-school students and Educators
Educators can use the tool to create their lesson plan following the education standards. Students can use the tool for their own research, study purposes and build their knowledge about causes and effects of various earthquakes over time. Our tool will help develop a deeper understanding about the movement of Earth's plates and hopefully generate some interest among students to pursue further studies in the field. We will correlate the earthquake data with related disasters, the effect on human life, and attempt to tell a story about each disaster.

3.2 Secondary Users: Public Safety Officials/ Government Agencies/ Construction Companies
Even though our target use is in the field of education, we hope to make the design of the tool and the visualizations intuitive so the tool remains accessible to anyone who wishes to use it. In such a scenario, our secondary users would be public safety officials, researchers, government agencies, and construction companies. Using the historical data, agencies can track the earthquakes and related disasters to determine the future requirements of aid and evacuation. Residents of the areas that have the potential to be affected can be informed and trained if required. Visualization of earthquake data can also help in future construction and infrastructure development planning, in terms of the materials and structures to be used, or whether a particular location should be considered for such projects.

4. COGNITIVE ISSUES

Many of the current visualizations are either extremely dense and complicated or designed for very young audiences [7]. Many also showcase real time data, which sometimes can be overwhelming and not illustrate the 'real' impacts. Our goal is to create something that can accurately convey the dangers, consequences and effects of real earthquakes while still being approachable enough for high school students to learn and use as a research tool.

Currently, acquiring the various types of information including scientific information as well as the impact of various earthquakes, requires users to search the internet due to the dispersal of said resources. Providing an integrated tool can help reduce users' search time and cognitive load.

5. APPROACH

We took a user centered design approach by first determining the requirements of highschool students, researching various standards for education and classroom modules available online. Based on the set of requirements, we went through the available datasets to determine the data that can help in fulfilling the learning requirements for the students. We then iterated our website workflow and data visualizations over the different website pages. We divided the tasks of data acquisition and analysis, and the task of determining user requirements among the team members. Once the data to be visualized was obtained, 3 members focused on the UX and frontend of the application, designing and coding the visualizations, and 3 members focused on the backend of the website, handling data access. We also made a system evaluation plan, however, time did not permit is to conduct the user studies. We still outline our plan in the later sections of this paper.

6. TASKS

6.1 Data Acquisition

6.1.1 Clean and Analyze data

The data we get from NOAA was in "tsv" format so we converted it into our own database. We made sure there was no noise in the data as well as no data was lost during the pulling process.

6.1.2 Save data as local database

Based on the scope of the project as well as the scale of the data acquired, we decided to use the SQL database structure.

6.1.3 Determine the data that needs visualization

From the data set, we determined what combination of data would be useful for visualization. Our main goal is to provide visualization that display earthquakes combined with different subsequent disasters and destruction level (casualties and financial damage)

6.2 Application UX and Visualizations

Given that the major target audience are students, we focused on how we can effectively display data to facilitate their learning. To determine the user flow of the application, we completed the following steps.

6.2.1 Determine the pages of the website

Based on user requirements and the correlations found in the analysis phase, we determined the different views of the website. The user flow was prototyped using UI prototyping tool Figma [16].

6.2.2 Determine the types of visualizations to use

Based on the analysis, we determined which type of interactive visuals would be effective and experimented with various interactions to settle on the most intuitive ones.

6.3 Tool Development

This task consisted of working toward the product based on the data acquired and the visualization types, and creating a website that would convey useful information to the users.

6.3.1 Creating mock-up version

We created the mock-up for our visualization using Figma[16], and set the template for the website UI/UX.

6.3.2 Develop local visualizations

We constructed the website based on tasks 1 and 2, and converted the data to visualizations within the website.

7. RELATED WORK

We explore the various earthquake visualizers to understand the state of the art and identify gaps that can be addressed through our work.

7.1 Live Earthquake Visualizers

7.1.1 USGS Earthquake [12]

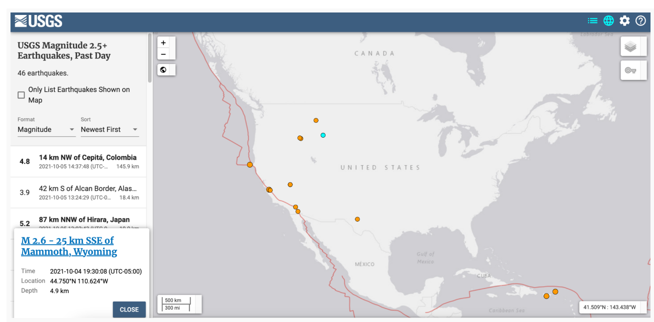


Figure 1: USGS Earthquake

The live earthquake visualization from USGS (United States Geological Survey) is based primarily on a map view (Figure 1) with earthquakes shown as bubbles with sizes according to magnitude and colored based on earthquake type. Latest earthquakes are available on the left hand side of the map view. Clicking on a specific earthquake will also bring up a contextual pane, which can be further clicked on to give more information about the specific earthquake.

7.2 Historical Earthquake Visualizers

7.2.1 Princeton Historical Earthquake Visualization [13]

The Earthquake visualizer from students at Princeton University attempts to visualize over 234,000 earthquakes using the Paraview software application (Figure 2). Although this visualization is not interactive, and is confusing to look at, this does show some interesting patterns across fault lines and deep ocean trenches.

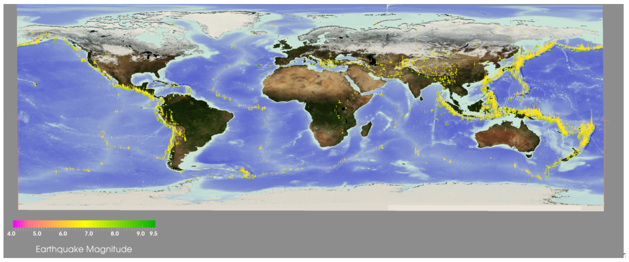


Figure 2: Princeton Historical Earthquake Visualization

7.2.2 USGS Significant Earthquakes by Year [14]

Another visualization from USGS (Figure 3) but with a world view map shows only significant earthquakes in this visualization. The bubbles' sizes are correlated to the magnitudes of the earthquakes. Our product is somewhat similar in terms of worldwide earthquake visualization but with interactive search.

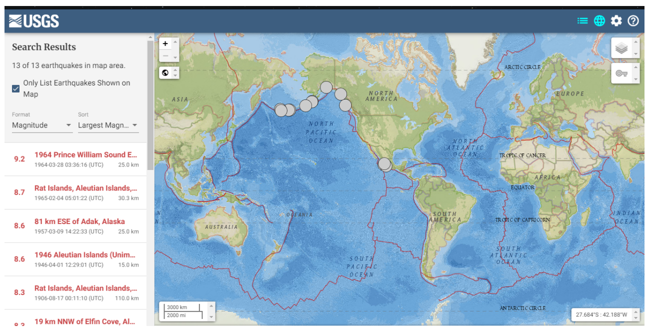


Figure 3: USGS Significant Earthquakes by Year

8. DESIGN AND RATIONALE

To visualize the location and related information of the earthquakes, we suggest four visualization approaches.

8.1. World Map Visualization for Focus + Context

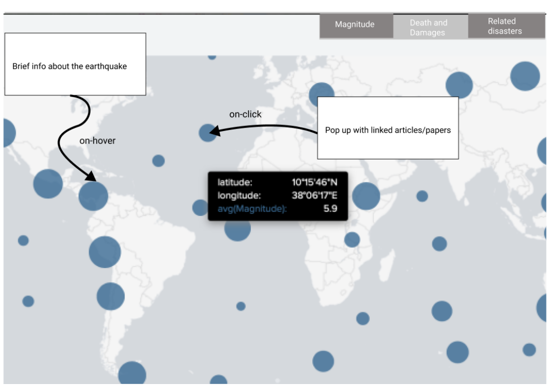


Figure 4: World Map Visualization

We use Mercator Earth map (features equally-spaced meridians and straight parallels perpendicular to each other. The distance between the parallel horizontal parallels increases with distance from the equator, allowing for the map's west-east and north-south stretching [11]) to visualize earthquakes across the world

Using a world map (Figure 4) with pins that represent the location of the earthquakes, we support users to get the overview (context). Users are able to hover a mouse pointer over the pins and get the detail (focus) of the selected earthquake event, including latitude, longitude, and magnitude, by looking at the small pop-up window on the pin.

8.2. Dynamic Queries for Advanced Search

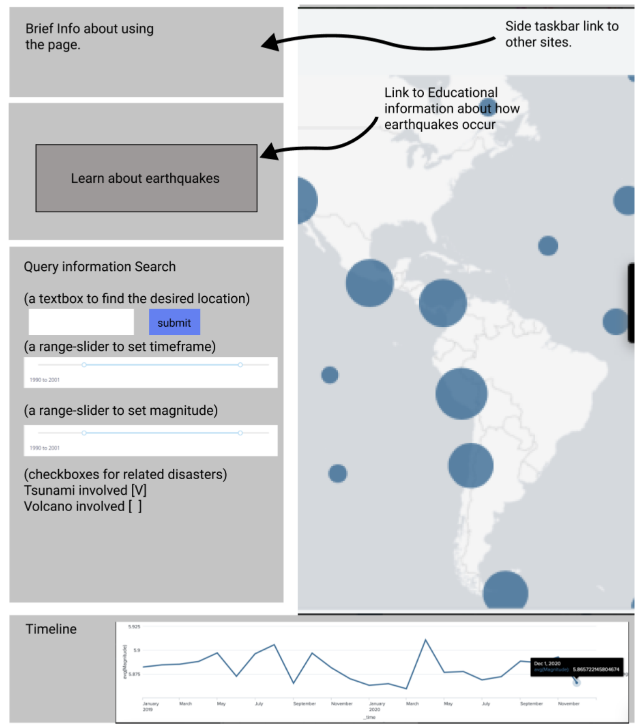


Figure 5: Dynamic Queries

We utilize query boxes on the left side of the world map (see Figure 5) to allow users who are searching for specific earthquakes or details about earthquakes to find the answers they are inquiring about in a timely fashion. Users will be able to, for example, search specific locations and time periods to view the earthquakes that occurred according to the query parameters entered. They can get the desired information quickly by adjusting two-sided sliders to set the time period and the range of magnitude, and use checkboxes for the related disasters, tsunami and volcano eruption, to see the specific earthquakes on the world map that satisfy all filter conditions. Users should accurately understand the function of all objects (e.g., sliders, textbox for search keyword, and buttons) in the query box that work together to get the right information they desire.

8.3. Filtering: Different Map Views for Multiple Features

We apply 3 types of views (Magnitude, Death and Damages, and Related Disasters) to compare different earthquakes on the map (see Figure 6). At each view, the characteristics of the earthquake representation will be correlated with the earthquake current view aspect. We will use different colors to visualize the pins (dots on the world map) for three features. For example, we would like to use red circles for magnitude and blue circles for death and damages, to support users' understanding in a more intuitive way.

Similarly, the size of circles will be correlated with the actual numeric values of the events. For example, in the magnitude view, the size of the circle will reflect the magnitude of each earthquake.

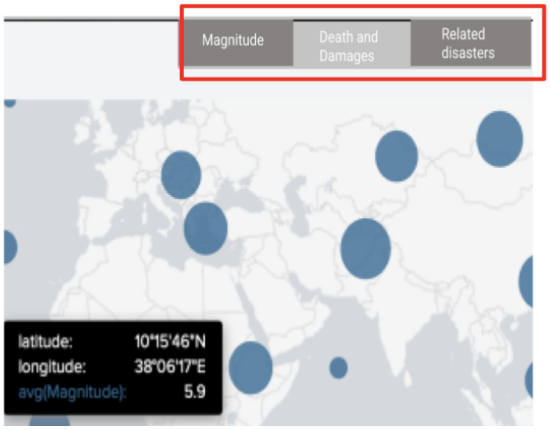


Figure 6: Filtering View

8.4. Educational Views for Related Articles or Academic Papers

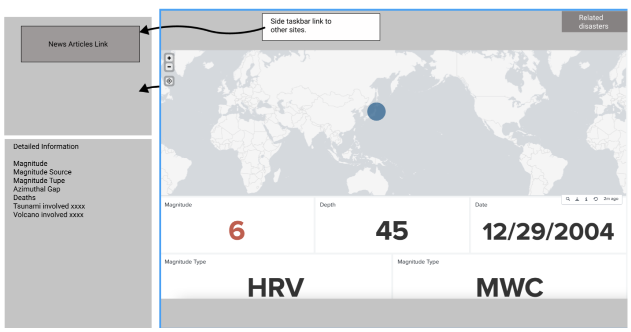


Figure 7: Educational View

For each earthquake, we will search for related articles and academic reports to support users to better understand the selected earthquake. We then later display that information in a more detailed view of each earthquake. This will serve the educational purposes for students or researchers. We will pre-determine some resources for students to look at, such as how an earthquake is formed, the impact of earthquakes, how often earthquakes occur, etc.

9. SYSTEM ARCHITECTURE

At the beginning, the user will choose the range input for magnitude/year, enter location, then the web will query the earthquake database and return those that are in that range. Then, depending on the map-view option the user selects, the web will display that information onto the site.

Using D3 visualization, we presented earthquakes with the bubble map visualization, as a circle dot with size correlates to other earthquakes and depends on the map-view type.

If the user wants to learn more about the specific earthquake event by viewing related articles, they can click on an earthquake event which will open the specific earthquake view on the left side and provide a visualization of text data of the related articles. The visualization will include a word cloud that shows word frequency used in the articles and a summarization module to convey the core idea and context of the several articles more effectively. Users can select a specific article to read depending on the word cloud and the summarization, or choose a random article to read. Figure 8 abstracts the system architecture.

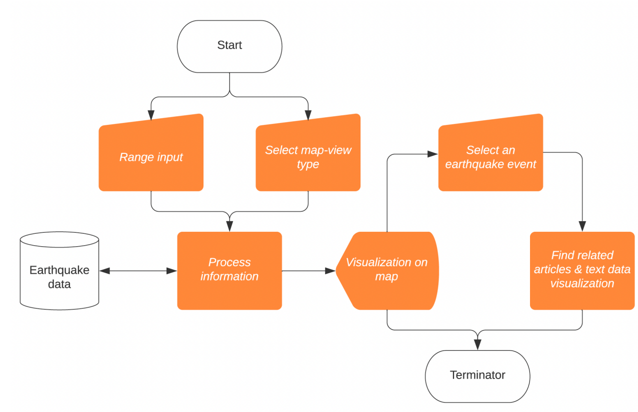


Figure 8: System Architecture

9.1. Frontend

Figure 9: Front End View

We utilize the previous bubble map visualization template [15] that was developed based on amchart, D3, and javascript (see Figure 9). It supports the hovering event that shows location name and a corresponding value upon users' selection of different views (magnitude / death / damage).

9.2. Back-end

For the back-end (see Figure 10), we successfully set up the database. For the database, we utilized PostgreSQL to store all the data retrieved. The data stored is all Earthquake specific data such as magnitude, death, damages, etc. After the data retrieval, we processed the data and loaded it into the database. For data processing, we converted 'datetime' to 'epoch' so we can query it easier. We also replaced null data with negative values that could be easily filtered out in query results.. We utilized SQLAlchemy ORM to facilitate querying of information that was present in the database.

We worked on the queries including coming up with queries designed to give us the earthquakes with the most casualties, damage and other such statistics. For the short summaries included, we used HuggingFace, an AI/ML tool to help with the text filtering and summarisation compositions.

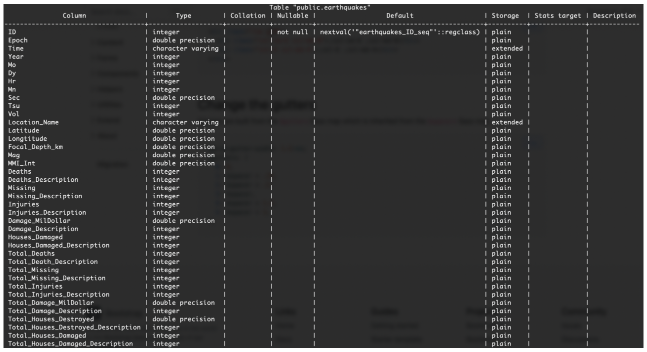


Table "public.earthquakes"

Column	Type	Collation	Nullable	Default	Storage	Stats target	Description
ID	integer		not null	nextval('"earthquakes_ID_seq"'::regclass)	plain		
Epoch	double precision				plain		
Time	character varying				extended		
Year	integer				plain		
Mo	integer				plain		
Dy	integer				plain		
Hr	integer				plain		
Mn	integer				plain		
Sec	double precision				plain		
Tsu	integer				plain		
Vol	integer				plain		
Location_Name	character varying				extended		
Latitude	double precision				plain		
Longtitude	double precision				plain		
Focal_Depth_km	double precision				plain		
Mag	double precision				plain		
MMI_Int	double precision				plain		
Deaths	integer				plain		
Deaths_Description	integer				plain		
Missing	integer				plain		
Missing_Description	integer				plain		
Injuries	integer				plain		
Injuries_Description	integer				plain		
Damage_MilDollar	double precision				plain		
Damage_Description	integer				plain		
Houses_Damaged	integer				plain		
Houses_Damaged_Description	integer				plain		
Total_Deaths	integer				plain		
Total_Death_Description	integer				plain		
Total_Missing	integer				plain		
Total_Missing_Description	integer				plain		
Total_Injuries	integer				plain		
Total_Injuries_Description	integer				plain		
Total_Damage_MilDollar	double precision				plain		
Total_Damage_Description	integer				plain		
Total_Houses_Destroyed	double precision				plain		
Total_Houses_Destroyed_Description	integer				plain		
Total_Houses_Damaged	integer				plain		
Total_Houses_Damaged_Description	integer				plain		

Figure 10: Back End View

10. GUI WALKTHROUGH

We will use a user scenario to walk through the user interface of the website. Consider a user Sam who wants to write a school report on different earthquakes throughout history. Sam first realizes he needs to understand in depth what earthquakes are and what related disasters can occur, and how they occur. He then goes onto the website.

10.1 Learn

On hitting the landing page, Sam sees the world map and a brief information about the website (Figure 11). He clicks on the "Learn About" button.

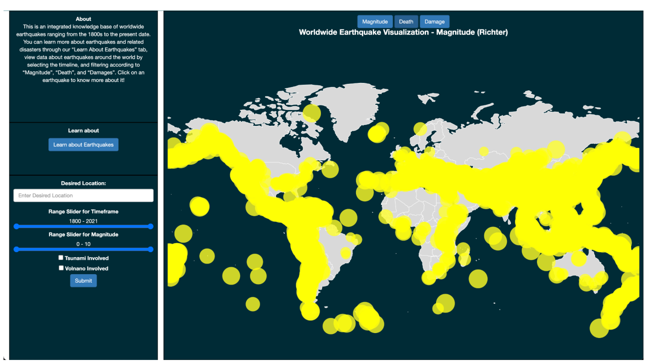
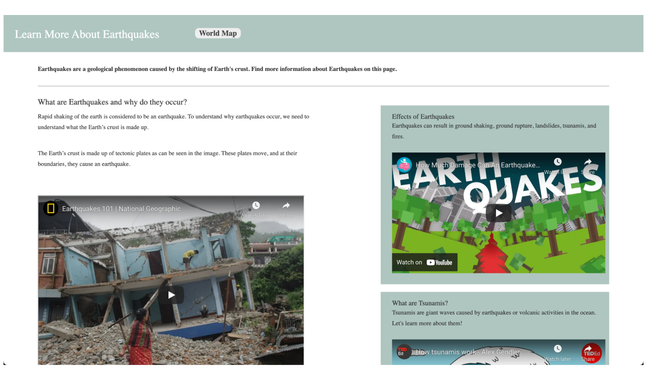


Figure 11: All time View



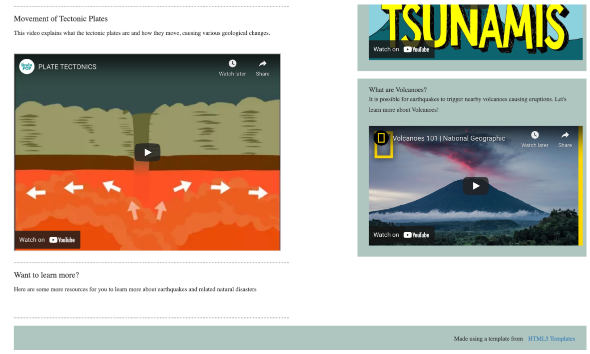


Figure 12: Learn about View

On this page (refer Figure 12), Sam can see various resources about earthquakes, how and why they occur and information about related events. Sam can even go through the posted videos for a more visual learning experience. Sam is now ready to get information on specific earthquakes.

10.2 View geographic earthquake information

On clicking on the "World Map" button as seen in Figure 9, Sam then goes back to the World Map view where he can get specific information through different queries. There are three views for the worldwide earthquake visualization: (1) Magnitude, (2) Deaths, and (3) Damages. Sam can toggle between these views after submitting his queries.The magnitude of the earthquakes is shown according to the Richter scale, the deaths are shown in the number of people, and the damages are shown in million dollars.

10.3.1 Search by Location

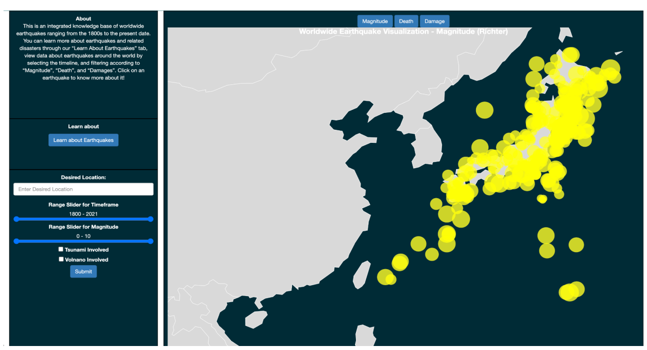


Figure 13: Japan All Time View

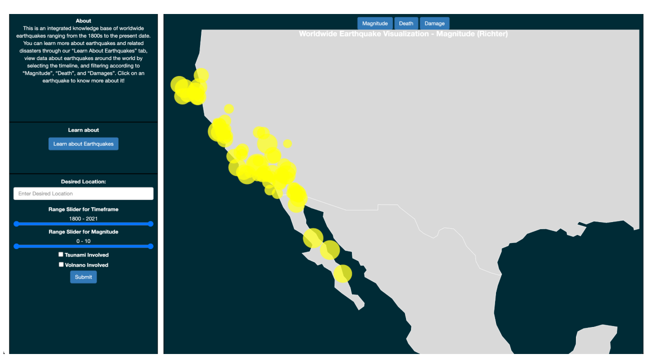


Figure 14: California All Time View

Sam starts by searching different locations and through the cluster of the earthquake circles, he realizes that a few locations have quite a lot of earthquakes, for example, Japan, USA, China, Indonesia, etc. as can be seen from Figures 13, 14, 15, and 16. He then decides to focus on Japan for his school report.

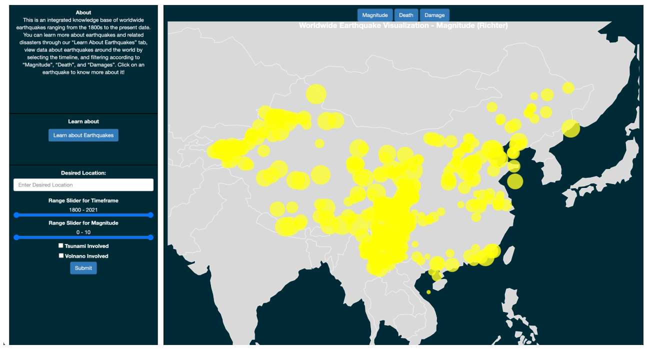


Figure 15: China All Time View

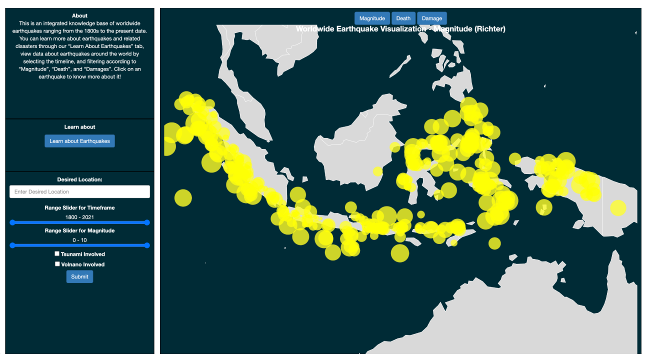


Figure 16: Indonesia All Time View

10.3.2 Search by Timeline

To understand in depth the history of earthquakes in Japan, Sam then sets various timelines. The timeline feature helps him to understand the frequency of earthquakes over time (see Figure 17).

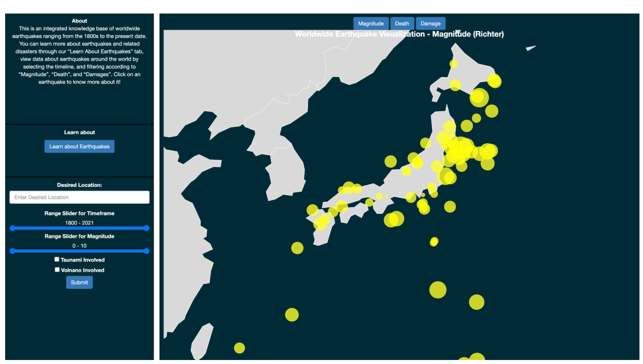


Figure 17: Japan 2000-2021 Earthquakes

10.3.3 Search by Related Disasters

Sam then selects Tsunami as a related disaster and location as Japan (Figure 18) and realizes why the 2011 earthquake in Japan was so prominent. He toggles to the "Death" view (Figure 19) and the "Damages" view (Figure 20) to find out the deaths and damages during the 2011 earthquake to help add to his report. The different colors used for "Deaths" and "Damages" helps Sam decouple the three different views, putting the impact of the earthquake in context.

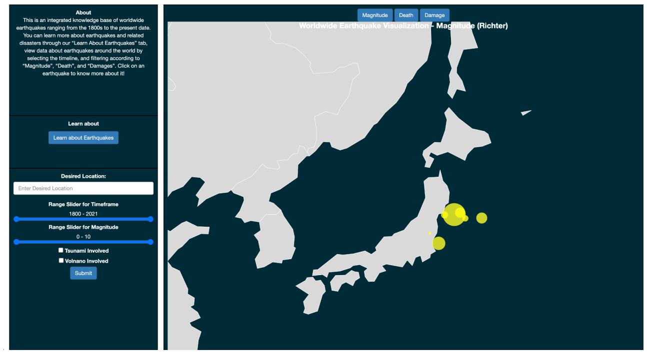


Figure 18: Japan 2011 Earthquake, Tsunami

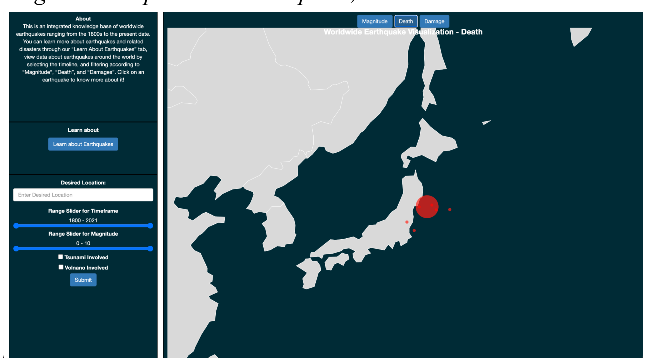


Figure 19: Japan 2011 Deaths

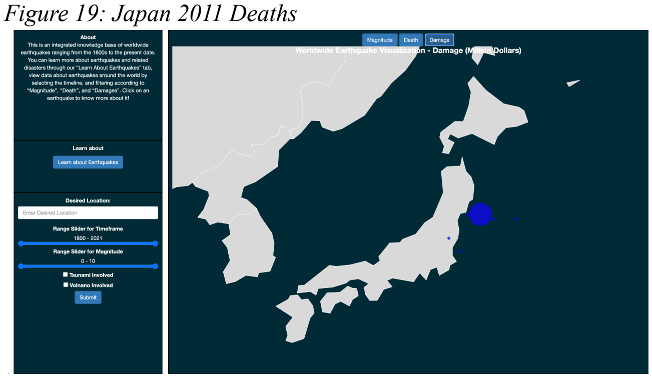


Figure 20: Japan 2011 Damages

10.3.4 Related Information

Figure 21: Japan 2011 Related Info

To know more about the earthquake itself, Sam clicks on the bubble and a window with the summary of the earthquake appears. He is now able to get a short description of the earthquake (Figure 21).

10.3.5 Search by Magnitude

Sam also wants to know the highest magnitude earthquakes throughout history. So he selects magnitude 9 and above and finds that there have only been 5 such earthquakes documented since 1800 (Figure 22). Sam is now ready to write his report.

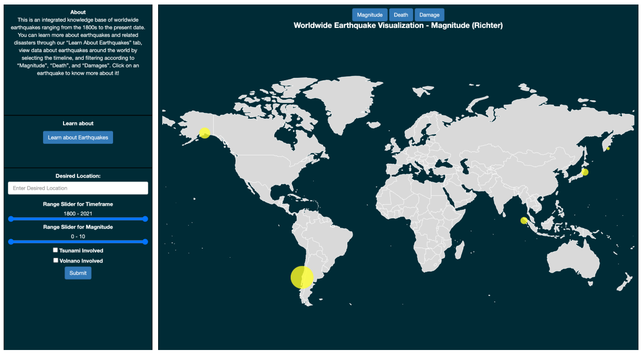


Figure 22: Earthquake magnitude >9

11. EVALUATION PLAN

11. 1. Participants & Procedure

Considering the objectives and the target group of our system, we will recruit students or people who are interested in earthquakes, geology education and historical data. We will recruit 16 participants in total. Participants will be using our system and the typical baseline method, whatever they would like to use to complete the tasks, such as google search, previous earthquake visualization tools, etc.

To better understand the different performance between our system and the baseline method, we selected a within-subject study protocol that lets participants experience both conditions in doing the task. To remove an ordering effect that could hamper the result, half of participants will use the baseline method first, while the other half use our system first. After each condition is done, we will ask participants to answer the survey that asks the perceived effectiveness and cognitive load that they felt while using the system or baseline method.

11. 2. Tasks

The first task is finding the desired earthquake using different conditions. As our system has the dynamic query features that support the user to find the desired earthquake event quickly, we would like to measure the performance of the search functions with the several conditions, such as timeframe, location name, and related disasters, compared to the typical method.

The second task is understanding each earthquake event that they retrieved in the first task. Our system supports the effective access to the content of related articles (i.e Wikipedia articles so far) by the summarization tool in the backend, which will reduce the users' cognitive load in reading lengthy related articles retrieved by google search. We will have questionnaires that ask the details about the earthquakes, such as the distinct features of the earthquake, possible cause, intensity, geophysical effect, etc.

Finally, as the third task, we will ask them about basic earthquake knowledge at the end of the study. For example, participants will be asked to describe what the tsunami is and possible effects that can happen due to the earthquake. This questionnaire will be used to see if the participants could understand the earthquake itself under two conditions.

11. 3. Evaluation Metrics

11.3.1 Behavioral Efficiency & Effectiveness

An evaluation metric we employed was behavioral efficiency and effectiveness of our application. By this, we aimed to evaluate the ease of use for first time users in navigating through the various map views and also ease of access for the side features of these views e.g., time sliders, time filters, summaries etc. The aim of this evaluation was to understand how an average unskilled user would navigate the web application and what possible hiccups would the user experience whilst navigating. For example, we would ask users to find the earthquake events that happened in the certain timeframe (based on certain features such as magnitude, death), and observe the user's ease in navigation to find these events. Finally, the user will be asked a few questions revolving around navigation and ease of use and measure the user's confidence level.

11.3.2 Attitudinal Efficiency & Effectiveness

For attitudinal efficiency and effectiveness, we will ask their cognitive load using two conditions and usability of our system. In the survey after each condition, we will ask them about what they felt while doing the task. For example, the question will be asking what was the degree to which participants felt that using the tool in the condition helped them to use less effort to accomplish the task. Also, they will answer what was the degree to which they felt that using the tool in the condition enabled them to find a good solution. Participants will answer these questions in Likert Scale, on the scale of 1 to 7. We will also refer to The Official NASA Task Load Index (TLX) in constructing the usability questionnaire.

11.3.3 Learning Effectiveness

As we previously mentioned in section 11.2, we have the basic knowledge questionnaire at the end of study of two conditions. As there are two conditions, we will have two sets of questionnaires that have different questions but asking the similar level of questions in terms of their difficulty. For example, we have a questionnaire set 1 and set 2, and in the first group that experiences the baseline method first, half of the group (4 participants) will solve set 1 first with the baseline method, and the other half (the other 4 participants) will solve set 2 right after the baseline method. This will reduce the learning effect from the participants' answers. Finally, we will check how many questions they were able to answer, not only limited to an accuracy, to measure their own confidence level in answering the questions about the earthquakes.

12. LIMITATION & FUTURE WORK

The goal of our work is to provide an end-to-end integrated system for users to find and understand information about various aspects of world wide earthquakes. We have a few limitations to our work and we propose future work to address these limitations.

12.1. Content

The data we have collected for the "Learn About" page is from various sources. It is currently limited in the scope and our vision for it is to be all inclusive. In order to do that we require curated resources which can only be obtained through the consultation of an expert. We plan to add more resources accordingly.

Secondly, on clicking a major earthquake bubble, users can currently see the summarization of various Wikipedia articles for that earthquake. We wish to expand that scope to other news articles as well as provide links to said articles if the user is interested in reading further.

12.2. Host database on cloud server

Creating a postgres database on cloud platforms such as Google Firebase, Amazon S3, Microsoft Azure. Using python packet psycopg2 to connect the Flask app with the database with the credentials provided by the cloud server.

12.3. Host project on Heroku

Host the website on Heroku platform. Heroku has automatic redeployment for every change we push to the project. Heroku also handles the production environment for us and hides our credentials for the database. Providing users an accessible URL at all times.

12.4. Explore additional color bubble options

Although we have different color options for deaths magnitude and damage that provide an easy to visualize and dramatic distinction for each option, there are those who think having a time based coloring gradient could also be beneficial. For example, having the colors go from dark to light depending on how recent the earthquake is can be an interesting option. However this runs the risk of confusion and is something that can be explored in user studies

13. CONCLUSION

In this work, we explored the drawbacks of existing earthquake visualization systems, such as USGS Recent Earthquake Visualizer and Princeton Historical Earthquake Visualization, and came up with the design considerations of the novel integrated end-to-end interactive earthquake visualization system.

Our interactive earthquake analysis system supports users to effectively find the desired earthquake events using dynamic queries with several user inputs such as timeframe, location, and magnitude. Users can quickly get the related information about the selected earthquake event with the three different views in the bubble map. Also, our system enables users to explore related articles quickly by summarization module, reducing their efforts in reading the multiple articles.

In future work, we will host our system and make it accessible to everyone, and conduct the user study to evaluate our system in terms of its behavioral / learning effectiveness and usability, in finding and understanding desired earthquake events with the real users, especially with students who are willing to learn about the earthquakes.

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