Design Document 1

Problem Statement & Intended Users

1.1. Problem Statement

Traditional location tracking technology such as Global Positioning Systems (GPS) often have a latency time between pings, meaning that the exact location of objects are unknown in between pings. One problem with the current method of estimating location is that it assumes that the moving object travels along a straight line between the two end-points and with a constant speed. In actuality, there is an infinite number of possible scenarios for the motion plan starting from Point A and ending at Point B: (1) the object could stay at point A until just before t_B, and then move to point B instantaneously; (2) conversely, it may quickly travel to point B, shortly after t_A, and then spend the rest of the time at rest until t_B; (3) in-between are many options for the objects starting faster or slower and moving away or towards point B. Thus, more realistic constraints are needed to capture the object's behavior which, in turn, would enable the creation of a more accurate (probabilistic) model for the potential whereabouts of the object. Although traditional location estimation methods may be effective in most typical scenarios, many research-based applications require a significantly more precise methodology.

To improve the estimation for the positioning of objects Dr. Goce Trajcevski has developed an algorithm utilizing conical geometry to efficiently determine the optimal semantically diverse Points of Interest (PoIs) and the optimal route between them given user constraints like maximum travel distance, preferred PoI categories, etc. [1]. There is also an additional algorithm developed by Dr. John Krumm that estimates the location of objects from large data sets in a 2D graphical map, known as the Bridgelet method [2].

The main objective of this project is to design and implement a web application that creates a visualization of the possible whereabouts utilizing the algorithms described above, where:

- only discrete location-in-time data is available
- in-between two such data items, the only known value is the limit on the velocity that the object can take

This web application will allow these algorithms to be used by a wider audience and reduce the effort to apply each algorithm to different applications individually. Creating an integrated system will also allow visualizations from both algorithms to be shared efficiently with others.

With this, the model of the possible whereabouts of a given moving object at a time-instant T between t_A and t_B can be created using the bounds on the jointly-limited locations with respect to both points A and B, which is, the respective maximum distances from each, for any given time t_X, where $t_A < t_X < t_B$. This idea of utilizing object behavioral constraints determining probabilistic whereabouts of moving objects between known locations is the center of our project, in which we aim to develop a system to visualize this idea. The figures below provide an example visualization of the conical method, which will be implemented in the application. In these figures, each cone represents the possible locations of an object over time based on starting location and maximum velocity.

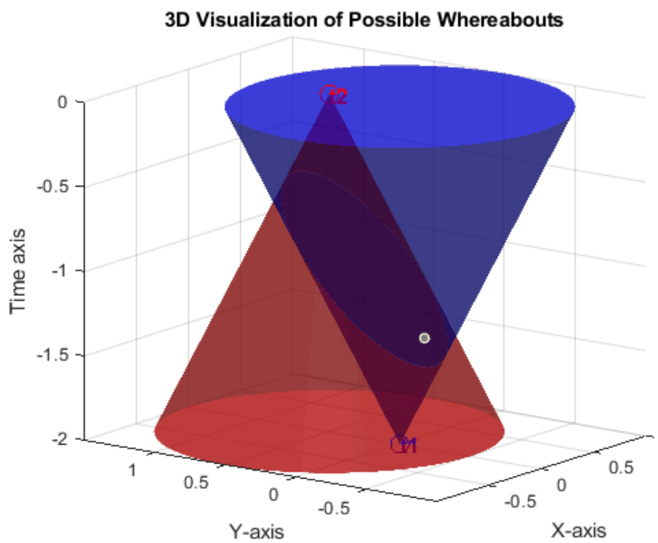

Figure 1 *Visualization of a given whereabout model to capture possible intermediate locations.*

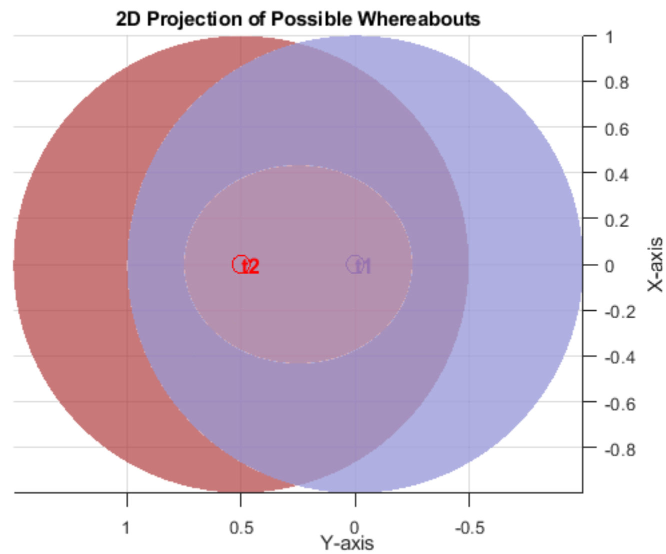

Figure 2 *2D projection of a possible whereabouts at a given time-instant.*

There are currently no applications that implement the algorithms described above with a visual display. The intention of this system is that users will be able to input data sets and choose settings that allow their sets to be visualized using the appropriate algorithms. This project aims to develop a prototype system that enables users from different domains to explore the (impact of the) motion model represented with the incorporation of the uncertainty of the possible whereabouts. The main functionalities of the can be summarized as follows:

1. Provide an informative landing-page for the users
2. Identify datasets from a particular application domain (to be coordinated with the client) that suit the user's interest(s)
3. Enable the user to:
    a. Select a particular dataset
    b. Enter parameters of interest (maximum speed; limit on time-intervals of interest; etc.)
    c. Identify queries of interest (e.g., possible intersection of motion of two objects; possible intersection of a particular object with a region).

   d. Access the corresponding datasets and extract the subsets corresponding to the user-provided parameters of interest.
   e. Perform the necessary calculations and provide visualization of the outcome for the user (cf. Fig. 1 and 2 above)
4. Provide options for the user to continue the interaction; store the outcomes; etc.

1.2. Intended Users

The following intended users were chosen as representatives from a broader spectrum as the ones who may interact with the system: (1) Zoologists are intended to represent the group who will primarily use the Bridgelet or 2D grid algorithm for predicting the location of objects [2]. (2) Chemists are intended to represent the group who will primarily use the conical, 3D method of determining probable locations of objects [1]. (3) Researchers who are intended to represent an intersection between these groups, who may want to use both methods and need more customization features for different projects.

Zoologist
A biologist who specializes in the study of animals, their behavior, evolution, and habitats. They conduct research, observe animal populations, and analyze data to understand animal life and contribute to conservation efforts.

- Key Characteristics
    - Want to preserve animals and be able to learn about their behaviors
    - Want to input large amounts of data that may track separate animals of the same species
- User Needs
    - Flat, map view with Bridgelet style positioning algorithm
    - Ability to input large data sets and share graphs with other Zoologists internationally

Zoologists will benefit from this application since it will give them a concrete way to visualize and share data they have collected. It will have customizable mapping outputs and allow for additional data such as maximum speed which will improve current tracking capabilities.

Chemist
A scientist who investigates the composition, properties, and behavior of substances at the atomic and molecular levels. They conduct experiments, analyze data, and develop theories to understand chemical processes and reactions.

- Key Characteristics
    - Want to get other Chemists and Graduate Researchers interested in their work
    - Like to share visualizations of their discoveries with other Chemists
- User Needs
    - 3D graph ability to visualize location of molecules with optional 2D ellipse "slice" view
    - Ability to change maximum velocity and start with unknown exact locations within a certain uncertainty

Chemists will benefit from this application since they will be able to utilize the 3D conical positioning algorithm in order to predict the position of molecules. This tool is specifically helpful since it is customizable and can take in large amounts of data. The application will also have a share feature, allowing data sets and visualizations from one user to be seen by another.

<u>Researcher</u>
Someone who systematically investigates topics to discover new knowledge or solve existing problems, through rigorous methodologies and analysis. Their findings advance understanding in various academic disciplines or practical applications in industry and society.

- Key Characteristics
    - Wants to track movement and probability of location for objects that cannot use traditional tracking methods such as GPS
    - Likes to be able to visualize the data he collects in order to increase funding from Donors
    - Likes to switch between many subjects and methods of tracking/predicting locations
- User Needs
    - Both 2D (Bridglet algorithm) and 3D (Cone algorithm) options to choose between for different applications
    - Ability to share large data sets and completed analysis with other researchers

Researchers will benefit from this application since they will have a new way to visualize the data they have gathered. They will be able to input several data sets and store the different visualizations produced using both or either algorithm integrated with the system.

Appendix A: References

[1] Trajcevski, Goce, et al. “Uncertain Range Queries for Necklaces.” 2010 Eleventh International Conference on Mobile Data Management, IEEE, 2010, pp. 199–208, https://doi.org/10.1109/MDM.2010.76.

[2] Zhang, Bing, et al. “Towards Fusing Uncertain Location Data from Heterogeneous Sources.” *GeoInformatica*, vol. 20, no. 2, 2016, pp. 179–212, https://doi.org/10.1007/s10707-015-0238-6.

[3] Krumm, John. 2022. Maximum entropy bridgelets for trajectory completion. In Proceedings of the 30th International Conference on Advances in Geographic Information Systems (SIGSPATIAL '22). Association for Computing Machinery, New York, NY, USA, Article 79, 1–8. https://doi.org/10.1145/3557915.3561015