Using Incremental Direction Searches to Stay Away from COVID-19

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ABSTRACT

The COVID-19 pandemic causes a world catastrophe, but it also creates many research opportunities at the same time. Because of the COVID-19, people try to keep social distances and avoid the "hotspots" as much as possible. However, it is easier said than done since coronavirus is everywhere. This research uses incremental direction searches to find a "best" route to stay away from COVID-19 when traveling. Incremental direction searches are a progressive search, which finds the next changing direction as the subject moves. It begins the searching as soon as the subject starts moving. Intersection-by-intersection, possible directions away from the current path may be found and immediately presented. This immediate feedback allows the searching to take appropriate actions such as selecting a specific direction or terminating the searching. Preliminary experiment results show the proposed method is effective, but many details need to be filled in before it is put to work.

Keywords: COVID-19, Coronavirus, Location-based Services, Smartphones, Mobile Computing and Incremental Searches.

1. INTRODUCTION

The problem was due to the school shutdown in March 2020 because of the COVID-19 pandemic. The author had to drive from Grand Forks, North Dakota to Columbus, Ohio to pick up his kids studying at the Ohio State University. Traveling via airplanes or buses was not considered because the coronavirus may prevail in small, crowded space. However, driving is not without risk since we had to stop from time to time to do the tasks like filling up the gas tank, using restrooms, or buying food. There are numerous routes from Grand Forks to Columbus. To reduce the risk, we tried to take a "safe" route and avoid the "hotspots" like Chicago or Minneapolis as much as possible. This research uses the technique of incremental direction searches to find the "best" routes between two locations.

There are numerous routes between two distant locations. Finding the "best" route most likely is an NP-complete problem, so exhaustive methods should not be considered. This research uses the incremental direction searches to find the route. Instead of finding the route at once, the proposed method finds the next direction whenever a major intersection is encountered based on the number of COVID-19 cases [3] on each direction. Preliminary experiment results show the proposed method is effective and efficient, but details have to be filled in before it is put to work.

Many accomplishments have been achieved by this research. Three of them are listed as follows:

- *Finding a safe route*: Numerous routes are available between two distant locations. This research finds a safe route based on the numbers of COVID-19 cases. Though it is not a proactive method, it is considered much safer than risking the possibility of getting infected by entering the high infected areas.
- *Incremental direction searches*: Searching for the "best" route may not be feasible because of numerous cases. This research tries to find the best route by using incremental direction searches. Though the result may not be the global optimum, local optimum could be achieved for each intersection.
- *User privacy preservation*: Another issue of location-based services is user privacy preservation, so it would not be possible to associate the users to the locations, paths, or queries. Users of this research do not need to share their information other than their current locations and destinations to the system.

Other than the above three achievements, various subjects and methods such as human travel behavior recognition and prediction, and mobile computing are studied in this research too.

The rest of this article is organized as follows. Section 2 gives the background information of this paper including two themes: (i) location-based research and (ii) incremental searches. Section 3 introduces the proposed system and methods, and Section 4 gives some experiment results. The last section summarizes this research.

2. BACKGROUND AND RELATED LITERATURE

Two themes are related to this research: (i) related location-based research and (ii) incremental searches, which are discussed in this section

Related Location-Based Research (LBR)

Location-based research is based on the geographical position of a mobile handheld device. One of the LBR examples is to predict a destination and preserve the user privacy at the same time. Various kinds of location-based research can be found in journals and conference proceedings. This sub-section discusses several important location-based articles involving travel paths:

- Zheng, Zhang, Xie, & Ma [20] propose a method to mine interesting locations and travel sequences. Three steps based on a tree-based hierarchical graph (TBHG) are used in this research. The result shows their HITS-based inference model outperformed baseline approaches like rank-by-count and rank-by-frequency.
- In a paper from Zheng, Liu, Wang, & Xie [19], an approach based on supervised learning is proposed to automatically infer transportation mode from raw GPS data. Their approach consists of three parts: (i) a change point-based segmentation method, (ii) an inference model, and (iii) a post-processing algorithm based on conditional probability. The result shows the change point-based method achieved a higher degree of accuracy in predicting transportation modes and detecting transitions between them.

- Previous routes can be used to recommend future travel patterns. Yoon, Zheng, Xie, & Woo [18] proposed itinerary recommendation based on multiple user-generated GPS trajectories. Users only need to provide a start point, an end point, and travel duration to receive an itinerary recommendation. Liu [8] presents a route recommendation system which guides the user through a series of locations. Their system uses the methods of sequential pattern mining to extract popular routes from a set of stored routes from previous users. It then recommends routes by matching the user's current route with the extracted routes.

An introduction of location-based services is given by Steiniger, Neun, and Edwardes [13]. Some related location-based research can be found from the articles [4], [5], [14].

Incremental Searches

Incremental search is a progressive search, which finds matched text as the search string is entered character by character. The immediate feedback allows the searching to take appropriate actions such as selecting specific matches or terminating the searching. Most incremental searches are based on the research of Aho and Corasick [1], who developed an algorithm to locate all occurrences of any of a finite number of keywords in a string of text. The algorithm consists of constructing a finite state pattern matching machine from the keywords and then using the pattern matching machine to process the text string in a single pass. Several incremental search methods have been proposed as follows:

- Meyer [9] gives a problem of searching a given text for occurrences of certain strings, in the particular case where the set of strings may change as the search proceeds. He modified the algorithm of Aho and Corasick to allow incremental diagram construction, so that new keywords may be entered at any time during the search.
- The machine of Aho and Corasick must be reconstructed all over again when a keyword is appended. Tsuda, Fuketa, & Aoe [15] propose an efficient algorithm to append a keyword for the machine. The simulation results show the speed up factor, by the algorithm proposed, to be between 25 and 270 fold when compared with the original algorithm by Aho and Corasick which requires the reconstruction of the entire machine AC.
- Koening, Likhachev, & Furcy [6] develop a search algorithm that combines incremental and heuristic search, namely Lifelong Planning A* (LPA*). It is named "Lifelong Planning" because it reuses information from previous searches. Their method repeatedly finds shortest paths from a given start vertex to a given goal vertex while the edge costs of a graph change or vertices are added or deleted.

A survey of incremental heuristic searches can be found from the article [7]. Other research related incremental search can be found from the articles [9], [11], [17].

3. THE PROPOSED SYSTEM

This research tries to find a safe route during the COVID-19 pandemic. Finding the "best" route most likely is an NP-complete problem because there are usually numerous routes between two distant locations. This research uses the method of incremental direction searches, which are explained in this section.

The Objectives

This research tries to find the "best" routes between two locations. Before creating the methods, an ideal route compared to other routes is defined as follows:

- the distance is short,
- the driving time (which is dependent on the traffic flows and road conditions) is short, and
- the number of COVID-19 cases is low in the surrounding areas of the route.

Figure 1 shows the results of using different methods. The direction provided by the Google Maps is shown in the Figure 1.a, where the direction is usually the shortest distance or driving time, but also passes through the COVID-19 hotspots like Minneapolis and Chicago. Figure 1.b shows the direction avoiding the hotspots and using the major interstate highways if possible. However, the nearby areas of major highways are also usually the most infected areas. This approach stays away from the hotspots, but it also introduces other issues. Our approach is shown in the Figure 1.c, which takes the route having less infected surrounding areas. It avoids the hotspots and seriously infected areas, but it may cause longer distance and more driving time because the routes may not be the high-speed interstate highways and may have to stop from time to time.

(a)

(b)

(c)

Figure 1. (a) the direction provided by the Google Maps, (b) the direction avoiding the hotspots including Minneapolis and Chicago, and (c) the direction found by our method, which avoids the hotspots and the seriously infected areas.

The Proposed Method

Inertia has a moving object follow a path or trajectory that resists any change in its motion. Human travel patterns normally have the similar inertia feature. For example, the vehicles on a highway usually stay on the highway or people tend to walk towards a popular destination such as a mall or park. Incremental direction searches are a progressive search, which finds the next changing directions as the subject moves. It begins the searching as soon as the subject starts moving. Location-by-location, possible directions away from the current path may be found and immediately presented. This immediate feedback allows the searching to take appropriate actions such as selecting specific directions or terminating the searching. This research proposed incremental direction searches to avoid seriously COVID-19 infected areas or hotspots. Figure 2 shows the county status of Iowa from the COVID-19 Tracker of Microsoft Bing [10], where the darker the color is, the more infected cases the county has. A discussion of the proposed algorithm is given next.

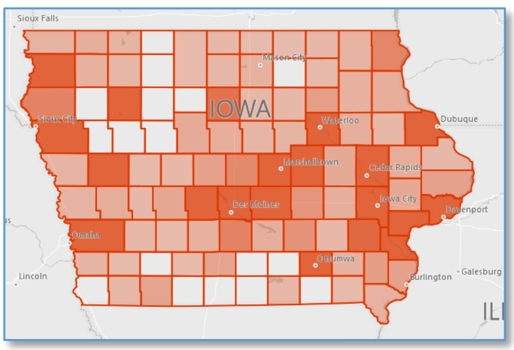


Figure 2. The county status of Iowa by the COVID-19 Tracker from Microsoft Bing [10].

Two representations of the proposed method are given in this section. Figure 3 gives the flowchart of our method, incremental direction searches, and the corresponding algorithm is shown in Figure 4. The subject keeps driving until he/she reaches the destination or is about to encounter a major intersection. The app stops if the destination is reached. Otherwise, if a major intersection is about to be reached, call the function *Find_Direction(n)*, which performs the following steps:

- Collect all directions at the intersection.
- Drop the directions, which are leading towards to the opposite of the destination.
- Calculate the weight of each remaining directions, which is the sum of COVID-19 cases of the following *n* counties of the direction.
- Returns the direction having the smallest weight.

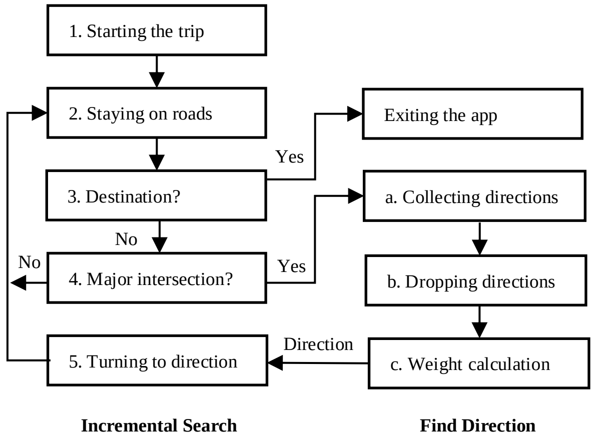


Figure 3. Flowchart of our method, incremental direction searches.

Incremental-Direction-Search

1. *Enter the destination and hotspots to the app.*
2. *The subject starts moving.*
3. *The subject stays on the main roads until arriving at the destination or encountering a major intersection.*
4. *If the destination is reached, stop the app.*
5. *Otherwise, call the function* Find-Direction(intersection) *before the major intersection.*
6. *Turn to the direction returned by the function.*
7. *Go to Step 3.*

Find-Direction(intersection)

1. *Collect the major directions passing through the intersection.*
2. *Eliminate the directions that head away from the destination.*
3. *Calculate the number of COVID-19 cases of* n *consecutive counties for each direction.*
4. *Return the direction with the lowest number.*

Figure 4. Algorithm of our method, incremental direction searches.

Road Intersections and Direction Weights

This research is about long-distance travel, so only major intersections are needed to be found. A major intersection is located in a county with at least two main roads because the two roads most likely intersect if the traffic in that county is not too complicated. For example, the county Woodbary in Iowa has a major intersection in Sioux City, where two roads I-29 and US-20 intersect. In order to find the major intersections, Table 1 shows the database table *Roads*, where the FIPS (Federal Information Processing Standard) [12] is a unique code for each US county, and sequence # is the county number starting from 1 and from west to east or north to south for that road. The county of an intersection can be found by SQL commands like

```
select FIPS, COUNT(*)
from Roads
group by FIPS
having COUNT(*) > 1;
```

Table 1. The *Roads* database table and some sample values.

Road #	County FIPS Code	Sequence #
US-20	19193	32
I-29	19193	12
US-20	41003	2
I-70	39049	40
US-20	41041	1
I-29	38067	1
…	…	…

Once a major intersection is encountered, the subject may turn to the direction with the smallest weight, which is the sum of the numbers of COVID-19 cases from the next *n* counties passed through by the road. The counties can be found by the following SQL command, for example:

```
select FIPS
from Roads
where road_#='US-20' and sequence_# >
  ( select sequence_#
    from Roads
    where FIPS=19193 );
```

The numbers of COVID-19 cases by the county can be found from the Excel spreadsheet provided by USAFacts [16].

4. EXPERIMENT RESULTS

This research is related to mobile computing, so the proposed method is implemented in an app. This section shows the experiment results of our method and gives discussions about the results.

System Setup

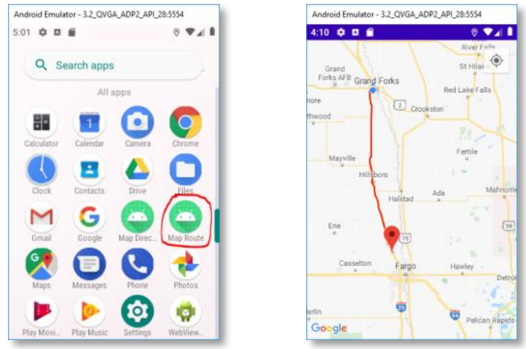
Travel path drawing using Google Maps Android API is not easy. Therefore, old versions of Android are used because they are more stable compared to the newer ones. The proposed system is implemented in the environment including:

- Android Studio [2] IDE 2.0,
- Android 6.0 (Marshmallow) Platform (API 23),
- Android Virtual Device (AVD) (API 23 and 3.2” GVGA), and
- Google Play Services 8.4.0, which includes Google Maps Android API.

Since the system is still in its early stage of development, most data are entered via simulation, instead of actual road tests. The simulation sends a location (including longitude and latitude) to the app via the AVD’s Advanced Control.

Screenshots

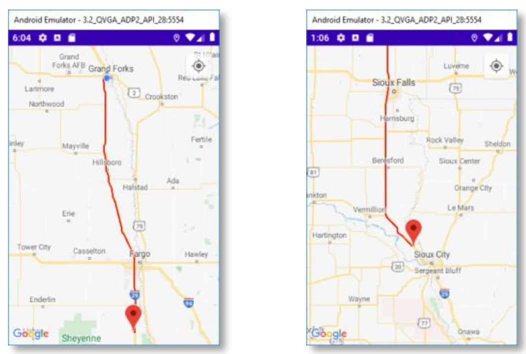
Figure 5.a shows the proposed app displayed on the Android launcher window. The destination, Columbus, Ohio, is entered into the app before starting. While the subject is moving, the app will suggest which direction to turn to when a major intersection is encountered. The user can either follow the suggestion or just ignore it. The only way to Columbus is traveling on I-29 southbound from the start. Figure 5.b shows a direction using I-29 from the beginning location in Grand Forks, North Dakota to Fargo.



(a) (b)

Figure 5. (a) the app on an Android launcher and (b) a direction from Grand Forks to Fargo.

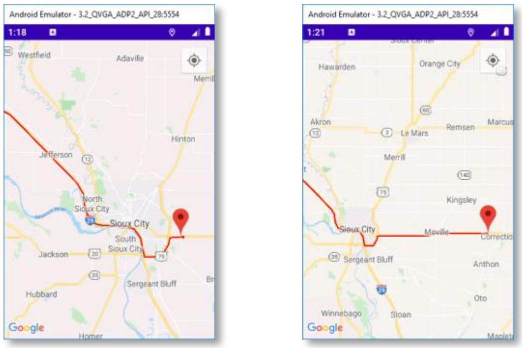
The subject keeps driving on the I-29 southbound before encountering a major intersection in Fargo where I-29 southbound is to Sioux Falls, South Dakota and I-94 westbound is to Minneapolis, a COVID-19 hotspot. The app recommends the I-29 southbound to avoid Minneapolis, and it is shown in Figure 6.a. The subject keeps driving on I-29 southbound and passes a major intersection in Sioux Falls after following a recommendation from the app as shown in Figure 6.b.



(a) (b)

Figure 6. (a) a current travel path shown and (b) the subject about to reach to a major intersection in Sioux City.

The subject keeps driving on I-29 southbound until it reaches to another major intersection in Sioux City, Iowa, where it could keep driving on I-29 southbound to Omaha, Nebraska or turn to US-20 to Dubuque, Iowa. The app recommends US-20 because the number of COVID cases is low comparing to the one from I-29 as shown in Figure 7.a. Figure 7.b shows the subject keeps driving on US-20.



(a) (b)

Figure 7. (a) our method suggesting to take the direction via US-20 and (b) the subject keeping moving on the US-20.

Evaluations

Table 2 shows the evaluation data of the three methods from Grand Forks, North Dakota to Columbus, Ohio. The first method uses Google Maps, and it is simple because it does not need development. It has the highest number of COVID-19 cases from the counties passed through by the route, but it also gives the shortest path and driving time. It is the route we take normally. The second method tries to avoid the hotspots like Minneapolis and Chicago and take the major highways to reach to the destination. It has the second highest number of COVID-19 cases because the counties passed through by the highways usually have many cases. Our method does show the lowest number of COVID-19 cases, but it also takes the longest driving time because it tends to take remote roads to stay away from coronavirus.

Table 2. Evaluation data from Grand Forks, ND to Columbus, OH by the three methods.

Method	Distance (miles)	Driving Time (hours)	COVID-19 Cases as of 06/03/20
Google Maps APIs (the shortest route)	1,078	16.0	108,837
Major route using highways (avoiding hotspots)	1,284	19.0	36,591
Our method (taking a "best" route)	1,259	20.6	29,694

Table 3 shows another evaluation data from Grand Forks, North Dakota to Thief River Falls, Minnesota. The three methods do not show dignificant differences because our method does not work well for short-distance travel. To solve this problem, we need more detailed data as the CDC (Center for Disease Control and Prevention) only provides the COVID-19 data by county [3].

Table 3. Evaluation data from Grand Forks, ND to Thief River Falls, MN by the three methods.

Method	Distance (miles)	Driving Time (hours)	COVID-19 Cases as of 06/03/20
Google Maps APIs (the shortest route)	52.5	1.0	401
Major route using highways (avoiding hotspots)	69.6	1.3	351
Our method (taking a "best" route)	51.4	1.0	401

Discussions

This is an innovative method to tackle the problems caused by the COVID-19. Preliminary results show the results are satisfactory, but they are not without problems. The proposed method has the following disadvantages:

- It only works well for long-distance travel because the CDC only provides the COVID-19 data county by county. For short-distance travel, the method requires the data in small areas.
- The testing is performed in remote upper Midwest, where the population and roads are not dense, and the results are acceptable. If the method is used in the areas with denser population and complicated traffic, the results may not be satisfactory because many more cases need to be considered.

5. CONCLUSIONS

The COVID-19 pandemic causes a world catastrophe and creates serious problems, but at the same time many research opportunities are created by it. Because of the COVID-19, people require to keep social distances and avoid the "hotspots" as possible as they could. However, it is easier said than done since the coronavirus is everywhere and people usually forget how easily they may be infected. Keeping the social distances is mainly based on our sense and vigilance, and not much we can help. On the other hand, avoiding the hotspots may be helped by computers. Either the computers can remind people where the hotspots are or the computers can help people stay away from the hotspots. In order to avoid the hotspots, this research uses incremental direction searches to find the "best" routes.

This research proposed incremental direction searches to avoid COVID-19 hotspots. Many contributions have been made by this project. Four of the major contributions are given as follows:

- Help users reach to the destination via a "best" route, which has a short distance or driving time, and passes through less infected areas.
- Instead of using exhaustive searches, this research proposes an innovative method, incremental direction searches, which suggests a "safe" direction to turn to when an intersection is encountered based on the number of COVID-19 cases of each direction.
- User privacy is enforced because the users do not need to share their information, other than the current location and destination, to the service provider.

- Finally, human travel behavior such as popular paths and prediction accuracy and effectiveness is also studied in this research. It may be applied to other research in the future.

Preliminary experiment results show this method is effective and efficient for finding a safe route during the COVID-19 pandemic, but have not yet been formally validated. For example, the system works well for a remote area, but how well does it do if it is applied to an area of more complicated traffic? Experiments and solid proofs need to be carried out to prove the effectiveness and robustness of the proposed system and method. The ideas and system will be further improved or revised based on users' feedbacks and testing data.

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