Google Maps

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ABSTRACT
This paper gives a perspective about how Google Maps, one of the world's most influential application works. Google Maps was initially coded in C++ programming language by its founders - Lars and Jens Eilstrup Rasmussen. Formerly it was named 'Where 2 Technologies', which was later acquired by Google Inc. in 2004, which renamed this web-application to Google Maps. Earlier it had limited features restricted to navigation, but today it provides overwhelming features like street-view, ETA and other such intriguing features.

It gives an overview about the algorithms and procedures employed by Google Maps to carry out analysis and enable users to carry out desired operations. Various features provided by Google Maps are portrayed in this paper. It describes the algorithms and procedures used by Google Maps to find the shortest path, locate one's position, geocoding and other such elegant features it provides its users.

Keywords
Heuristics, A* algorithm, Dijkstra's algorithm, Street View, Rosette, Optical flow, Ceres Solver, Geocoding, Triangulation, Trilateration, WAAS, GNSS, Geo-Positioning System [GPS].

1. INTRODUCTION
Google Maps is one of the most sought after innovation in the history of technology. The advent of this feature by the tech-giant Google Inc. Google Map enables people to navigate and find the shortest and most convenient route to their desired destination. According to a recent survey, Google Maps has acquired almost 64 million users. Moreover, it has included new features like street-view, location of hospitals, cafes, police-stations and many more helpful features. The algorithms, techniques and technology used by Google Maps is cutting-edge and highly advanced. The team of engineers at Google, preserve and analyze myriad datasets including historic and real-time data, which is what makes Google Maps so progressive and accurate. The prediction models continuous valued functions i.e., predicts new values. Also ML models can be used and applied on traditional computing techniques to improve the existing accuracies [1-5].

2. GOOGLE MAPS: ALGORITHMS AND TECHNIQUES

1.1 Dijikstra's Algorithm
Google maps employs Graph data structures for calculation of the shortest path from the source (point A) to the destination (point B). Graph data structure comprises of various nodes and multiple edges connecting these nodes. Dijkstra's algorithm is an effective and proficient algorithm proposed by Edsger.W. Dijkstra to navigate the shortest distance and path to reach a given destination. The nodes of the graph are connected by weighted edges, which represent the distance to be traversed to reach there. Thus Dijkstra devised an algorithm to find the shortest route from the source to the destination.

ALGORITHM:-

1.1.1 Choose an initial node in the weighted graph which serves as a source node.

1.1.2 The distance of the other nodes is intialised as infinity with respect to the source node.

1.1.3 An empty set N containns the nodes to which the shortest path has been found.

1.1.4 The distance of the source node with respect to itself is zero. It is added to N and thus termed as 'active node'.

1.1.5 Consider the neighbouring nodes of the active node which are connected to it by a weighted edge. Sum up the distance with the weight of the edge.

1.1.6 If the neighbouring nodes already have some distnace assigned, then update the distance if the newly obtained distance in step 5 is less than the current value.

1.1.7 Now, choose the node which has the minimum distance assigned to it and insert it into N. The newly inserted node is now the 'active node'.

1.1.8 Repeat steps 5 to 7 until the destination node is included in the set N or if there are no more labelled nodes in N.

PSEUDO CODE:-

```
function dijkstra_algorithm (graph, S)  // S represents source
for each node N in graph:
distance[N] :=  infinity
prev[N] := NULL
if (node N != S),  add node N to the set Q
distance[S] := 0
Q:= set of all nodes in graph
while Q is not empty:
Z := node in Q with minimum distance
for each unvisited neighbour N of Z:
dist := distance[Z]+ edge_weight(Z,N)
if dist<distance[N] // new value less than previous distance
distance[N] := distprev := Z
return distance[ ] , prev[ ]   ……[6]
```

The time complexity of Dijkstra's original algorithm is given by O(| V^2V^2 |) , but when it is implemented based on minimum-priority queue implemented by Fibonacci Heaps, then the time complexity reduces to O (|E| + |V|log|V|).

Google maps deals with a mammoth of data, thus the number of nodes in the graph are myriad. Thus, graph algorithms like Dijkstra's algorithm may fail due to the increased time and space complexity. The drastic increase in the size of the graph limits the efficiency of the algorithm. Heuristic algorithms like A* algortihm prove to be implementable.

A* is similar to Dijkstra's algorithm, which uses a heurisitc function to navigate a better and more efficient path. A* algorithm assigns higher priority to the nodes which are supposed to be better (checks for parameters like time requirement, distance and other such parameters) than the others, while Dijkstra explores all the nodes. Therefore it is meant to be faster than Dijkstra's algorithm, even if the memory requirement and operations per node are more, since it explores a lot less nodes and the gain is good in any case. [7]

1.2 A* (A-star) Algorithm

A* algortihm is a flexible, more efficient and cutting-edge algorithm which Google Maps currently utilises to find the shortest path between a given source and destination. It has a wider range of contexts hence, it can deal with larger graphs which is preferable over Dijkstra's algorithm.A* is like Greedy Best-First-Search. A* algorithm is widely used since its mechanism involves combining the pieces of information that Dijkstra algorithm uses (It favours the vertices close to the source) and information that Greedy Best-First-Search uses (choosing nodes close to the goal).[8]

One of the difference between A* and Dijkstra's algorithm is that A* algorithm, being a heuristic algorithm, has two cost functions :

g(x) :- The actual cost to reach a vertex (same applies to Dijkstra)

h(x) :- Approximate cost to reach goal node from node n. (This is the heuristic part of the cost function)

f(x) :- Total estimated cost of each node

The cost calculated by A* algorithm shouldn't be overestimated, since it is a heuristic algorithm. Hence, the actual cost to reach the destination node, from any given node n should be either greater than or equal to h(x). This is called Admissible Heuristic.

Hence, one can represent the estimated total cost of each node by :

$f(x) = g(x) + h(x)$.

A node is expanded by A* search, only if it is considered to be promising. This algorithm focuses solely on reaching the goal node from the node which is currently under consideration. It does not try to reach other nodes.

Thus, if the heuristic function taken into consideration approximates the future cost accurately, then one needs to explore considerably less nodes as compared to Dijkstra's algorithm. [9]

A* algorithm terminates when the destination node has been reached ensuring that the total cost of reaching the destination node is the minimum compared to all the other paths. It can also terminate if the destination node has not been reached despite all the nodes being explored. Unlike, Dijkstra's algorithm, it does not explore all nodes possible, thus A* proves to be more proficient.

Owing to the high accuracy, flexibilty, ability to deal with mammoth graphs and its stark advantages over Dijkstra's algorithm, Google Maps has shifted to deploying A* algorithm for obtaining the shortest path between the source and destination.

ALGORITHM:-

1) Initialise two lists -

   a) Open_list

   b)Closed_list

2) Insert the source node into the open_list

3) Keep the total cost of the source node as zero

4) While open_list is not NULL:

   a) Check the node with minimum total cost (least f(x)) present in the open_list

   b) Rename the above node as X

   c) Pop X out of the open_list

   d) Generate the successors to X

   e) Set X as the parent node of all these successors

5) for each successor:

   a) if successor is same as the destination:stop

   b) else:

   successor.g(x) = X.g(x) + distance between successor and X

   successor.h(x) = distance from destination [goal] to successor (using heuristics)

   successor.f(X) = successor.g(x) + suucessor.h(x)

   c) if a node with same position as successor is present in open_list, but having a lower cost [f(x)] than successor, then skip the successor

   d) if a node with the same position as the successor is present in the closed_list , but having a lower cost [f(x)], then skip this successor, else insert the node into the open_list

   end for loop

6) Add X into the closed list

7) End the while loop

8) The route is obtained by the closed_list

9) Stop.

PSEUDO CODE:-

function A_star_algorithm (start, goal)

open_list = Initialised set contains start //Initialisation of the open list closed_list = NULL set //Initialisation of the closed list

start.g = 0

start.f = start.g + h(start, goal) // f(x)= g(x) + h(x) where h is the heuristic function

while open_list is not empty:

node = element in open list with lowest cost //f(x) should be minimum if node = goal// when destination is reached, current node = goal return route(goal) // route found

remove node from open_list

insert node into closed_list

for neighbour in neighbours(node):

if neighbour not in closed_list:

neighbour.f = neighbour.g + h(neighbour, goal) //f(x)= g(x) + h(x) where h is the heuristic function

if neighbour is not in open_list:

insert neighbour into open_list

else:

x = neighbour node already present in open_list

if neighbour.g < x.g:

x.g = neighbour.g

x.parent = neighbour.parent

return False // no path exists

function neighbours(node)

neighbours = set of valid neighbours to node // check for obstacles here

for neighbour in neighbours: if neighbour is diagonal:

neighbour.g = node.g + diagonal_cost // Pythagoras Theorem eg. 5^2 = 3^2 + 4^2 -> here 5 is the diagnol

else:

neighbour.g = node.g + normal_cost // eg. 3

neighbour.parent = node

return neighbours

function route(node) / Displays the route

path = the set which contains the current node

while node.parent exists:

node = node.parent

add node to path

return path

3. STREET VIEW – GOOGLE MAPS

In 2007, the Google Maps team introduced an outstanding feature called Street View. This brilliant innovation proved to be a milestone in the history of navigation and GPS. Street View, the newly introduced feature, provided a 3-dimensional, HD, Panaromic view of many neighbourhoods, streets, avenues, and other such areas merely from one's mobile phone or computer. Surprisingly, these images are manually taken by Google Maps team using a car specially fitted with multi-camera rig and other necessary equipments for actually taking pictures of the neighbourhoods they drive by. The following images depict the cars and cameras used to generate the street view.

Fig.1. Cars and Camera Rig used.

The development and creation of these panoramic views is a strenuous task, involving image capturing from multi-camera setup called Rosette. Subsequently, the manually captured images are blended and stitched using various computer editing and blending algorithms and softwares. However, impediments like parallax, miscaliberation of the Rosette camera geometry, time difference can destroy or adversely affect the image-processing and blending.

Despite such cautious procedure/steps, visible seams in overlap-region can still occur. In order to provide more seamless images and to overcome the above drawbacks, the team at Google has developed a new algorithm based on Optical-Flow. The concept behind this is to warp/adjust each image in a way such that the content aligns with the region of overlap. To eliminate/avoid any chance of distortion or drawback the process is to be carried out meticulously. A robust and potent approach is required to counteract adverse lighting conditions, varying scene geometry, calibration and parallax distortion, and other inevitable conditions.[10]

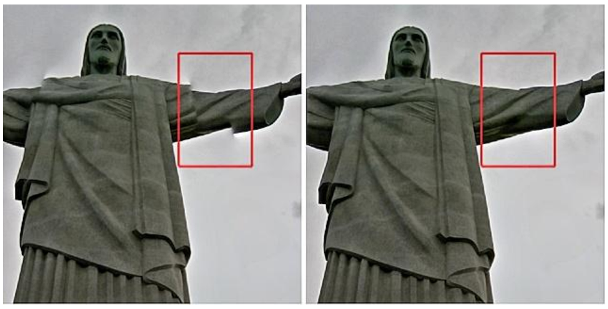

Fig.2. Parallax distortion due to miscalibration.

Moreover, the images captured by rosettes are aligned and adjusted corresponding to all the points from the overlap region. These images are then stitched using softwares to obtain desired panoramic, 3-D views. To generate the final results, the warping is formulated as a spline-based flow field with spatial regularization. Google's open source Ceres Solver is used to compute the spline parameters. [10]

Therefore, after carrying out such complicated procedures, the images can be corrected, aligned and warped as pleased.
Google Maps' street-view feature is being drastically refined and remodeled since their team is exploring more and new places every day. The expanse of street-view coverage is almost fully completed in numerous developed countries and is dramatically increasing in the developing countries. Statistically, the Government of India reported that 14 miles are being covered each day by the Google Maps' Street View team. The implementation of such a 3-D, Panoramic feature which enables the users to view and virtually travel along the extreme corners of the world is truly a technological breakthrough. [11]

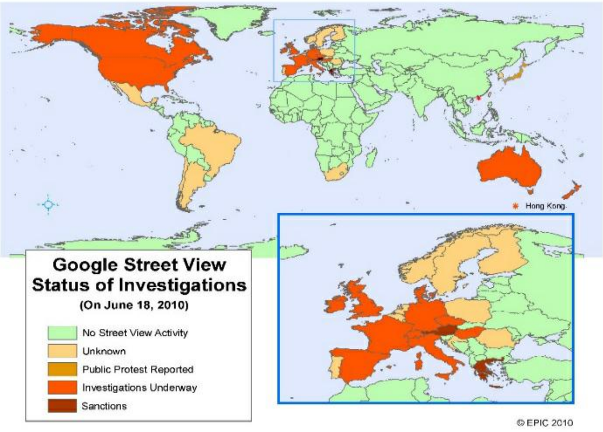

Fig.3. Status of Street View compatibility in the world.

4. LOCATING THE POSITION (OF AN OBJECT, PERSON OR PLACE) USING GPS AND GEOCODING:-

Global Position System (GPS) is an outstanding innovation used for tracking an object using satellite systems currently present in the space. This type of tracking can be used for military as well as civilian purposes. Google Maps uses the civil GPS tracking and locates people and places. The tracking system used by the Global Positioning System is the GNSS network (Global Navigation Satellite System Network). This system not only stores the location, but also has the memory to store the speed, direction, time and other parameters.

The Global Positioning System comprises of 27 GPS satellites orbiting around the Earth, out of which 24 are operational and 3 are spare (To be used in case of failure). These revolve around the Earth each 12 hours and emit civilian and military navigation data signals, on two L-band frequencies. These signal are emitted in space and are gathered by the GPS receiver. Five monitoring stations along with four ground antennas comprise the control of the Global Positioning System. These are located across the globe which gathers the data about the satellite's position which is further relayed to the master control station at Schriever Air Force Base in Colorado, USA [12]. Passive tracking by GPS involves storage of the data obtained during tracking, while in active tracking some information is relayed regularly through a modem within the GPS system unit (2-way GPS) to a centralized database. [13]

The location tracking is based on a mathematical principle called Trilateration. There are 2 types of trilateration - 2-D trilateration and 3-D trilateration. This requires two parameters –

- ✔ First, the location of the place is required to be known, which will subsequently be traced by atleast 3 satellites. The range of these satellites should be able to cover the specific position.
- ✔ Next, the distance between the object (eg. a vehicle) and one of the satellites is required to be known.

Hence, for this, a miniature receiver/device is installed on the vehicles/phones to capture the radio (electro-magnetic signals) emitted by the satellite. This helps to compute the distance between the vehicle and satellite as well as the satellite's location. Thus, by locking the signals onto 3 satellites, the location of the vehicle can be gauged by using Triangulation technique, which can be extended to the mathematical principle of Trilateration.To achieve 3-D trilateration, one need to take consider spheres instead of two dimensional circles. Unlike 2-D trilateration, the radii of the sphere is said to spread in all directions, thus forming imaginary 3-dimensional spheres around a given point. Thus the intersection of these three sphere, gives the location of the object. In case of 3-D trilateration, two intersection points are obtained because of the 3 spheres. The Earth helps by eliminating one of the points by acting as the fourth sphere. This enhances the search and makes it possible to locate the exact position of the given object, place or person. [14]The concept of Trilateration is echoed better by the following diagrams:-

This is a system comprising of satellites as well as ground stations which works with GPS to refine and improve the quality of the system and also helps in error detection and correction. A GPS receiver is capable of gauging any given position accurately within three meters, with the assistance of WAAS. It has been developed by the Federal Aviation Administration (FAA) and the Department of Transport (DOT) to counteract the signal errors caused as a result of disturbances in the ionosphere, time errors and satellite orbit errors. WAAS is essential for obtaining the knowledge about the conditions of each satellite of the GPS network. [15]

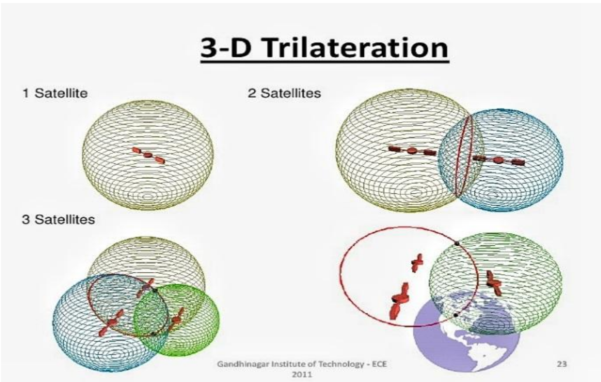

Fig.4. Three Dimensional Trilateration

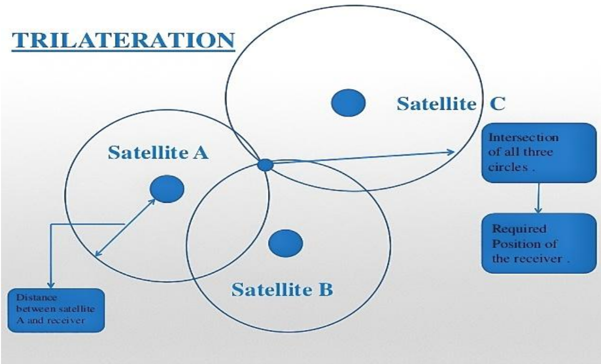

Fig.5. Two Dimensional Trilateration

WAAS (Wide Area Augmentation System):-

With the help of the satellites, the receiver can now compute and detect the latitude, longitude and altitude of the vehicle which are supposed to comprise the hypothetical geometrical co-ordinates of the vehicle. Thus, assigning and accessing the following values is termed 'Geocoding', where the location of a particular object is accessed using a hypothetical grid system, and then locating/plotting the specific co-ordinates (latitude, longitude, altitude) to obtain the required location of the object on a given map.

Google Maps uses this algorithm of Global Positioning System to detect and locate places on the map. Thus the signals obtained from satellites in space and other such ground networks, towers and other such facilities help in accurately locating the position of an object, place or person using algorithms like Triangulation, Trilateration and other such complex algorithms.

5. ESTIMATED TIME OF ARRIVAL (ETA):-

The most basic and important criterion for Google Maps to estimate the time taken to reach a particular destination is based on the route taken to reach the given destination from the source. This is calculated using the A-star (A*) algorithm, which helps in obtaining the shortest route from the starting point to the desired destination. This would be the shortest path recommended by Google Maps without taking into consideration the real-time traffic, which was a major drawback. To overcome this drawback, Google collects continuous data from all cellular devices on that particular way and other routes possible. Manipulating this data, the average speed of any user can be determined and the shortest path can then be decided. A user can find a route adding a few halts, avoid freeways, avoid bridges and choose a location according to their desire, despite the shortest path recommended by Google Maps.

Before 2007, Google Maps was only able to calculate the estimated time of arrival (ETA) by taking into consideration the distance between two given points and the average speed of the object or person between the source and destination. The flaw with this was that a very important criterion of traffic was overlooked. Today, Google Maps considers the current traffic condition on the selected route, which often prove to increase the commute time. It provides the user with two ETA – one is at the average optimal conditions and the other is under current traffic conditions, which helps the user estimate the time required to reach any particular destination. [16]

A former Google engineer Richard Russell wrote, answering a question on Quora - "These things range from official speed limits and recommended speeds, likely speed derived from road types, historical average speed data over certain time periods (sometimes just averages, sometimes at particular times of day), actual travel times from previous users and real-time traffic information. They mix data from whichever sources they have and come up with the best predictions they can make."[17]

Moreover, the collection of the data like average speed of users travelling on the same paths, officially recommended speeds, comparison between optimum average speed and the current real-time speed due to traffic conditions help the engineers and analysts at Google to calculate the estimated time of arrival (ETA) from point A to point B. Historic data also helps the engineers analyze the current traffic scenarios at a certain point between two places, which contribute towards the fluctuation of the ETA. As rightly stated by former Google engineer Richard Russell, the companies who have the best, most accurate and highly advanced real-time data usage tend to come up with best forecasts in the medium and long term. [18]

Thus, in the modern time, myriad factors apart from average speed of the user on a specific route, the shortest path and distance between two points have to be taken into consideration in order to determine and compute the estimated time of arrival.

However, Google Maps cannot take into consideration a user's personal speed [16], but can only determine the approximate time of arrival by taking into consideration factors like distance remaining, average speed due to real-time traffic conditions, historic data and officially recommended speed. They can thus predict the approximate time needed to reach the destination using any desired mode of transport (car, walking, train, cycle and other available modes). The average speed of a person in each of these modes are recorded and used for determining the ETA.

The technology giant Google is one of the best company at collecting, manipulating, analyzing data and drawing very accurate conclusions about ETA, shortest path and other such real-time data. Since it has so much access to data through cellular devices and the data signals emitted by them, Google Maps can almost correctly and efficiently predict the time taken by the user to reach his destination.

6. CONCLUSION

Therefore, the algorithms, techniques, procedures and technology used by Google Maps in order to render accurate and real-time information and data on their app, is understood. Obsolete algorithms like Dijkstra's algorithm may not work since the time complexity would increase drastically and hence a more efficient, accurate and faster algorithm like A* has helped replaced it. Features like street view need a splendid level of image processing, editing and stitching. Mathematical concepts like Trilateration, Triangulation and Geocoding are required to locate any position with the help of imaginary geographical co-ordinates. Aerial imagery also helps design the frontend of the app. The pictures captured by aerial imagery are processed and thereafter used to give the map layout which is seen when one opens the application. Thus, Google Maps constantly keeps updating the old features and introduces new ones for the benefit and convenience of its users. Hence, Google Maps is one of the most helpful and reliable application.

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