A 'MAP' OF SHORTEST PATH ALGORITHMS

Presentation by:
Aryaan Bazaz, Vedika Agarwal

PROBLEM STATEMENT

When you are lost and have no idea how to get to your destination, what unfolds?

Ever picked a path only to realize the other road was the shortcut to dodge that pesky traffic jam? Any regrets?


GOOGLE MAPS
NAVIGATES
THE WORLD
rch Google Maps
Restaurants
Hotels
Things to do
Museums
Transit
la Industrial Estate
24°
Heavy traffic in this area
Typical conditions

INTRODUCTION

In 2005, Google Maps transformed navigation with features like Street View and real-time updates. This journey unfolds from a simple idea to a global innovation, reshaping how we explore and navigate our world today.

The focus of this presentation is how Google Maps leverages the principles of discrete mathematics to optimise its route searching algorithm.

ALGORITHM TIMELINE

201
3

PIGEON

Considers the distance of the business from the user's location, the relevance of the business to search query

Learns from behavior of users to identify patterns and provide relevant results

RANK BRAIN

201
5

2018

MEDIC

Improves quality of search results for health-related queries. Takes into account the expertise of the author etc.

Uses machine learning to improve the understanding of natural language and context of search

BERT

201
9

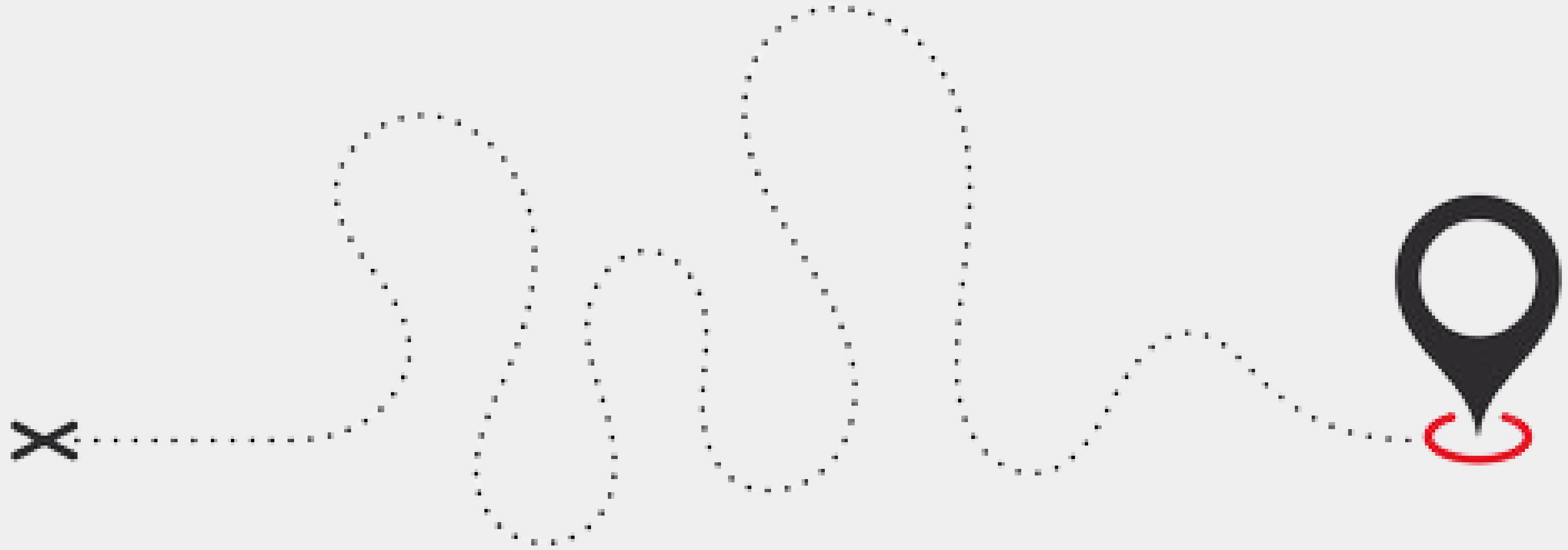
2021

MUM

Performs multiple tasks at once, such as translation, question answering, and text generation

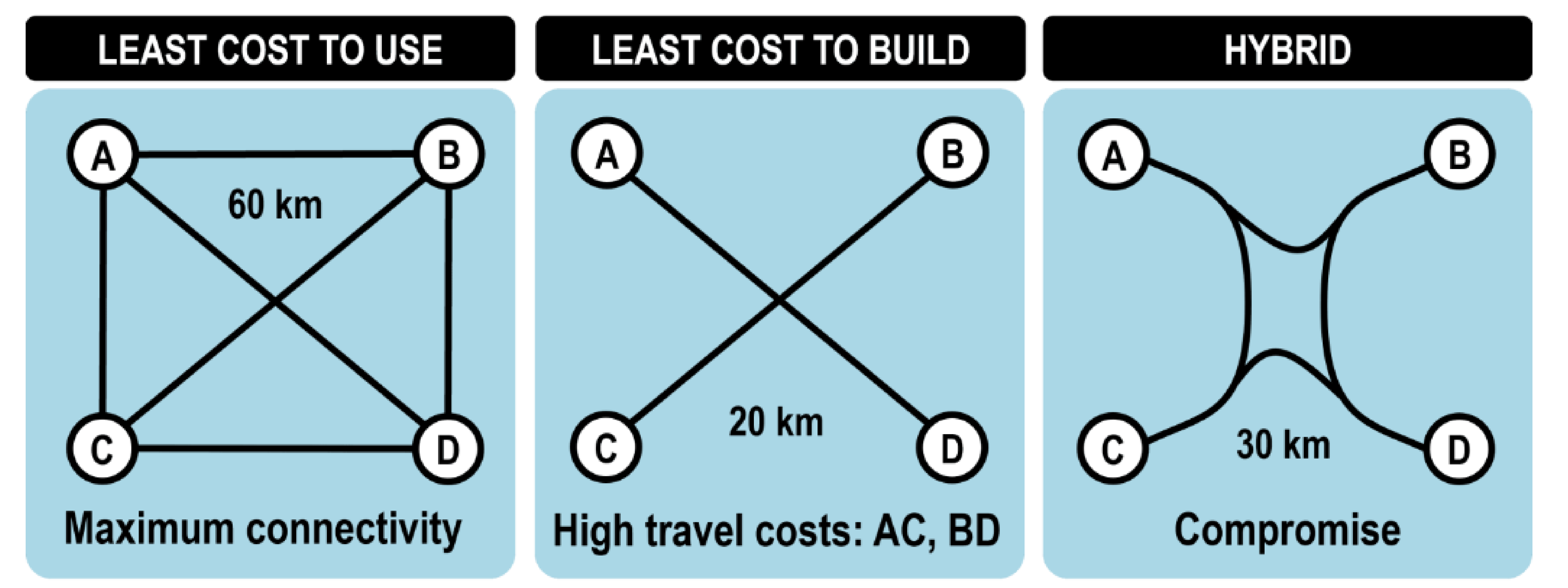
BUT HOW DOES ONE KEEP TRACK OF SO MANY ROADS?

An efficient data structure, that could accommodate all major intersections and road networks, along with data regarding traffic and road conditions, and reduce it to a simple computational problem...



GRAPH THEORY TO THE RESCUE!

A graph is a data structure built with a set of nodes and a collection of edges that connect pairs of nodes. Nodes represent distinct entities, and edges draw relationships between the connected nodes.

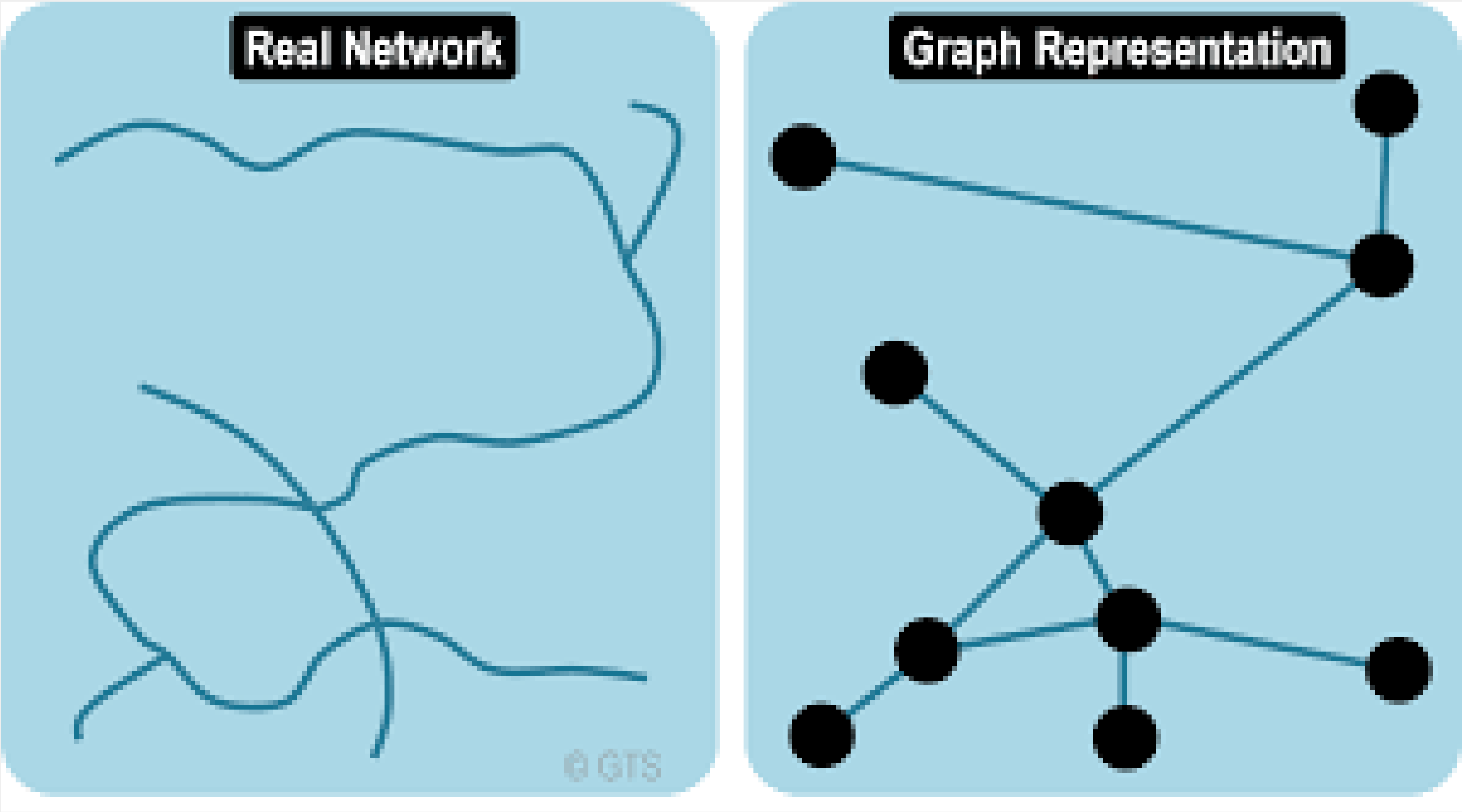


Source: transportgeography.org

Here is how a graph simplifies a complex road network:

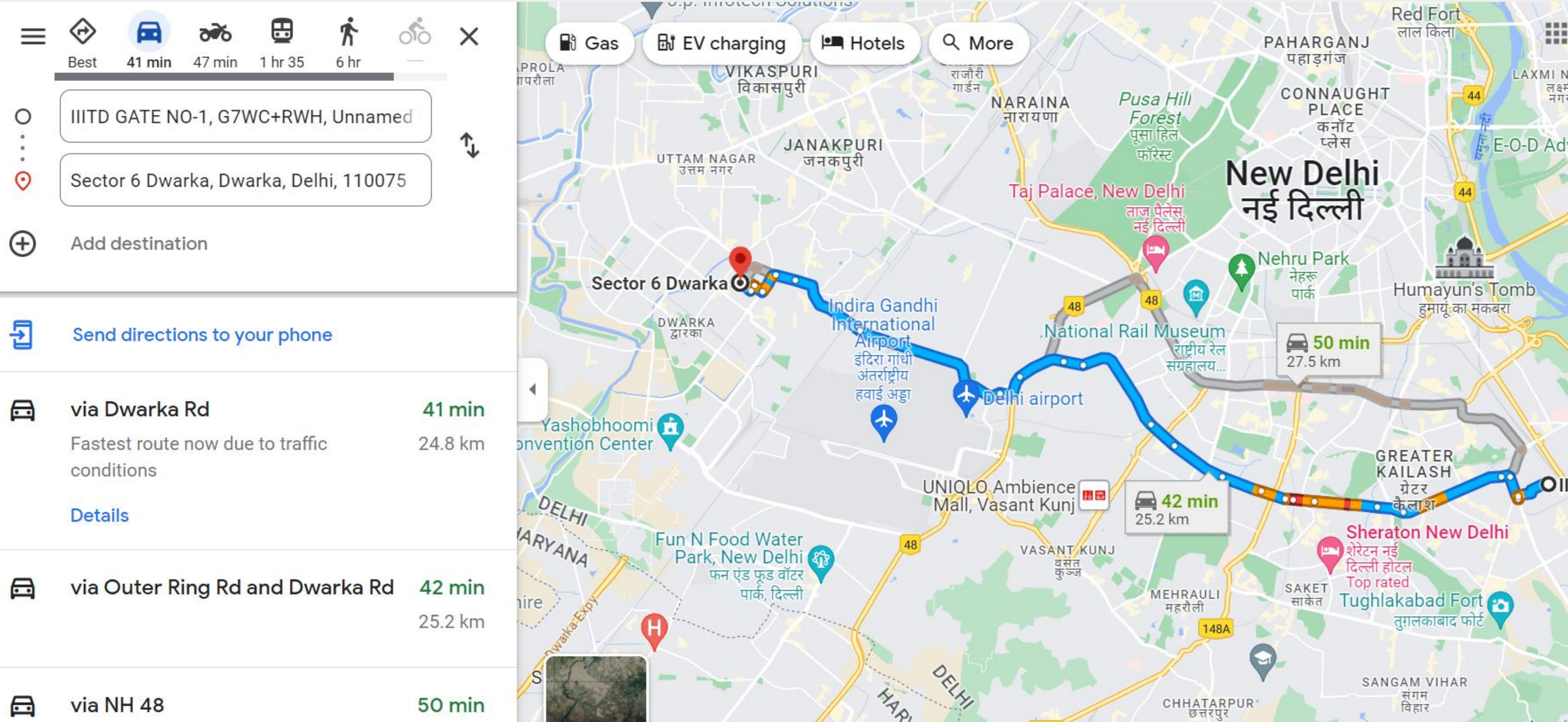
- Nodes represent intersections
- Edges represent roads
- Each edge carries weights such as distance and traffic conditions.

Thus, Graph Theory abstracts and models intricate road systems, providing a crucial mathematical framework for optimal routing solutions



Source: transportgeography.org

CONVERTS REAL WORLD PATHS INTO AN ABSTARCT NETWORK FOR EASY COMPUTATION



AN IDEAL ALGORITHM CHARACTERISES:

1 ACCURACY IN RESULTS

2 TIME EFFICENCY

3 RESOURCE UTILISATION

DIJKSTRA'S ALGORITHM

Manages a set S of vertices for which the final shortest-path distances from the source s are known

Iteratively chooses the vertex u from the set V-S with the smallest current shortest-path estimate

Put S = S U {u}

Updates shortest-path estimates for all edges departing from u

Follows a greedy approach

Time Complexity = O(|E| log|V|)

THE CONCEPT OF HEURISTICS

Type of function used in problem-solving and decision-making

Provides an approximate solution when an exact solution is either impractical

Allows algorithm to prioritize exploring states that are likely to be closer to the goal

Assigns a numerical value to each potential solution, indicating its desirability or estimated cost
(In this case it is time and distance)

The search algorithm then uses this information to prioritize which solutions to explore first

A* ALGORITHM

Navigates a grid with obstacles from a start to a target cell

Selects nodes based on the sum of g (cost of reaching the cell from the start) and h (estimated cost to the destination)

'h serves as a heuristic

Chooses nodes with the lowest f value (combined cost function)

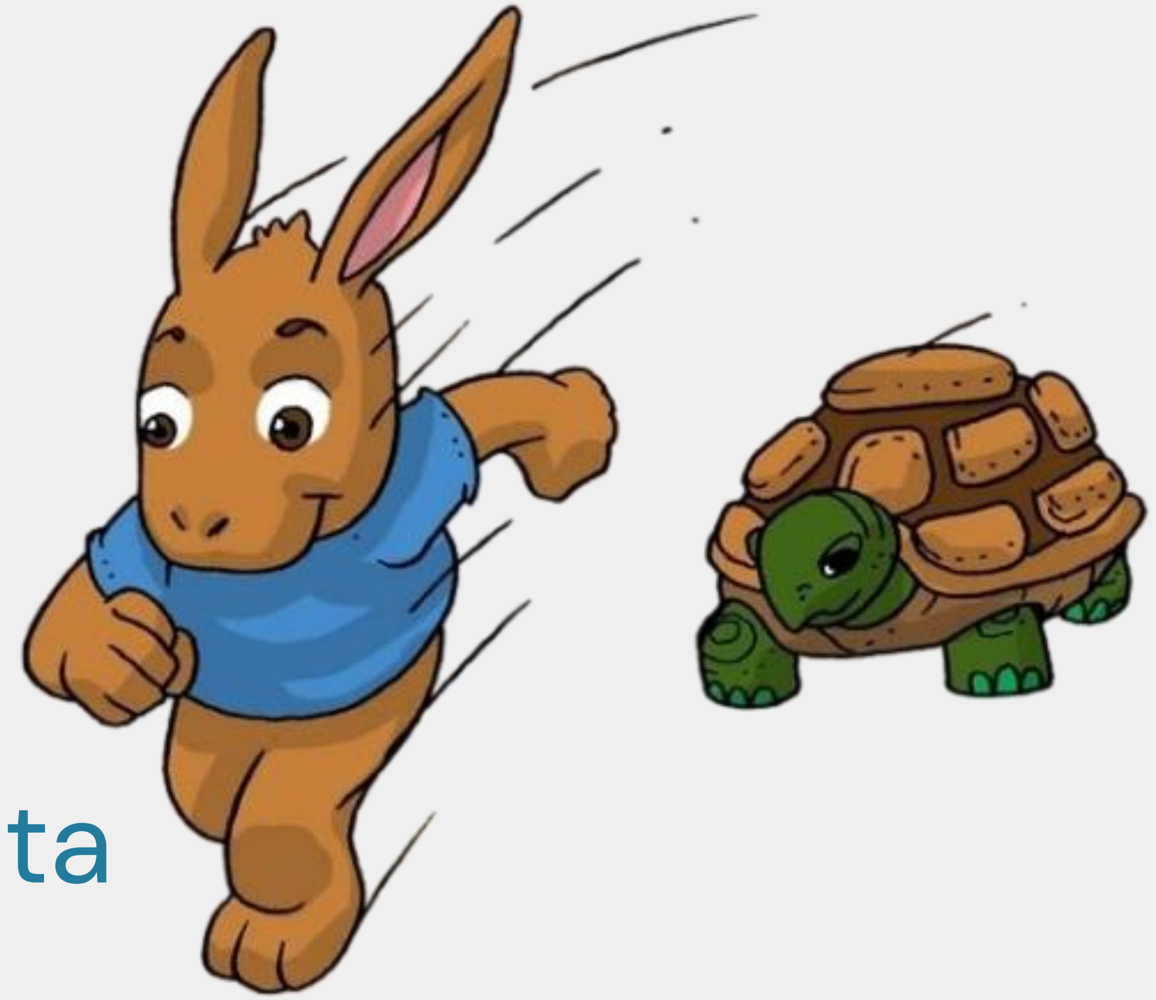
f(n) = g(n) + h(n)

Guides the pathfinding process toward the target cell

Makes use of a heuristic function to limit searching towards the goal, instead of traversing entire graph

SO WHAT WORKS FOR GOOGLE MAPS?

The Dijkstra's algorithm...



Cannot handle the large dataset alone

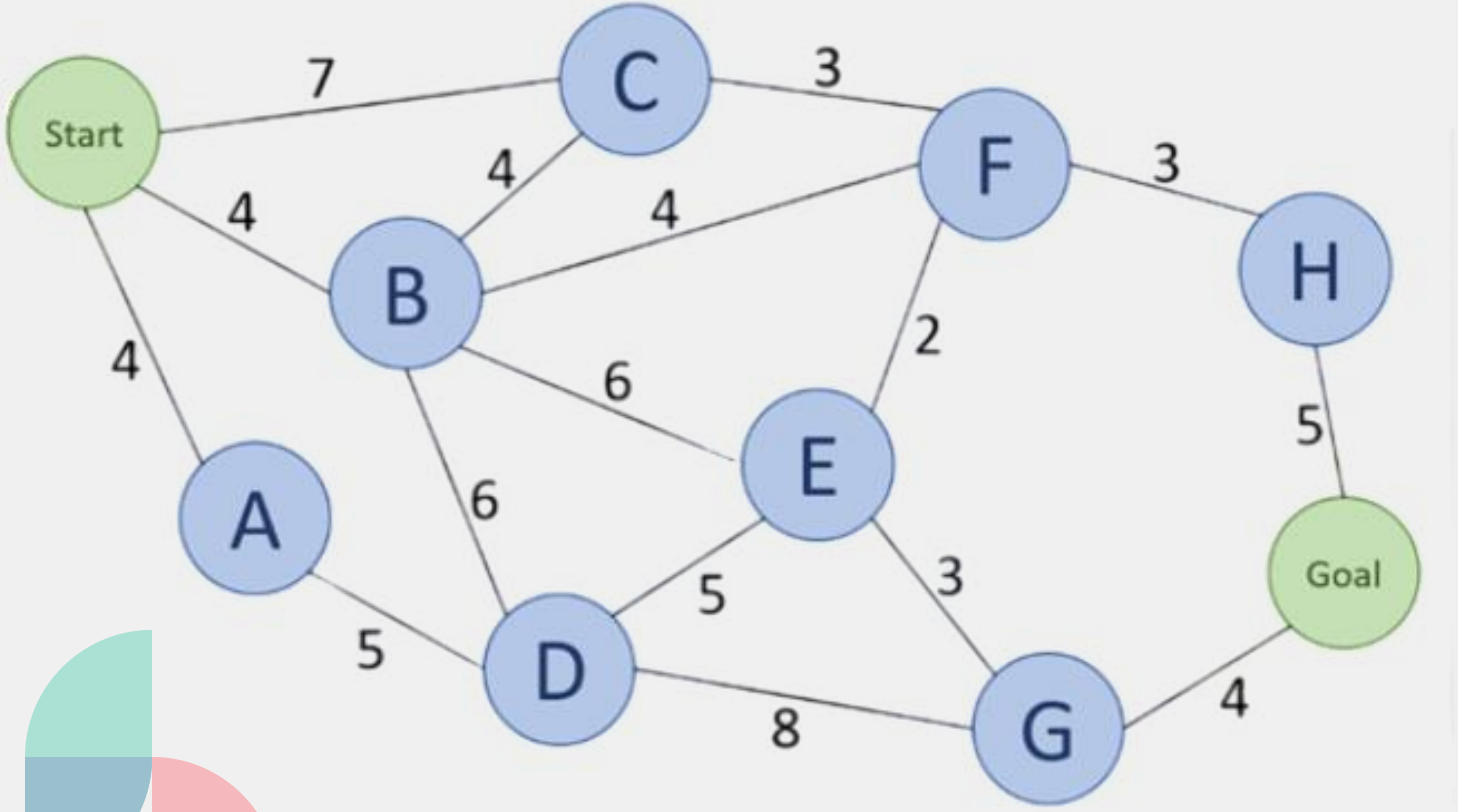
More or less for general purpose

Does not exploit the properties of its data structure efficiently to speed things up

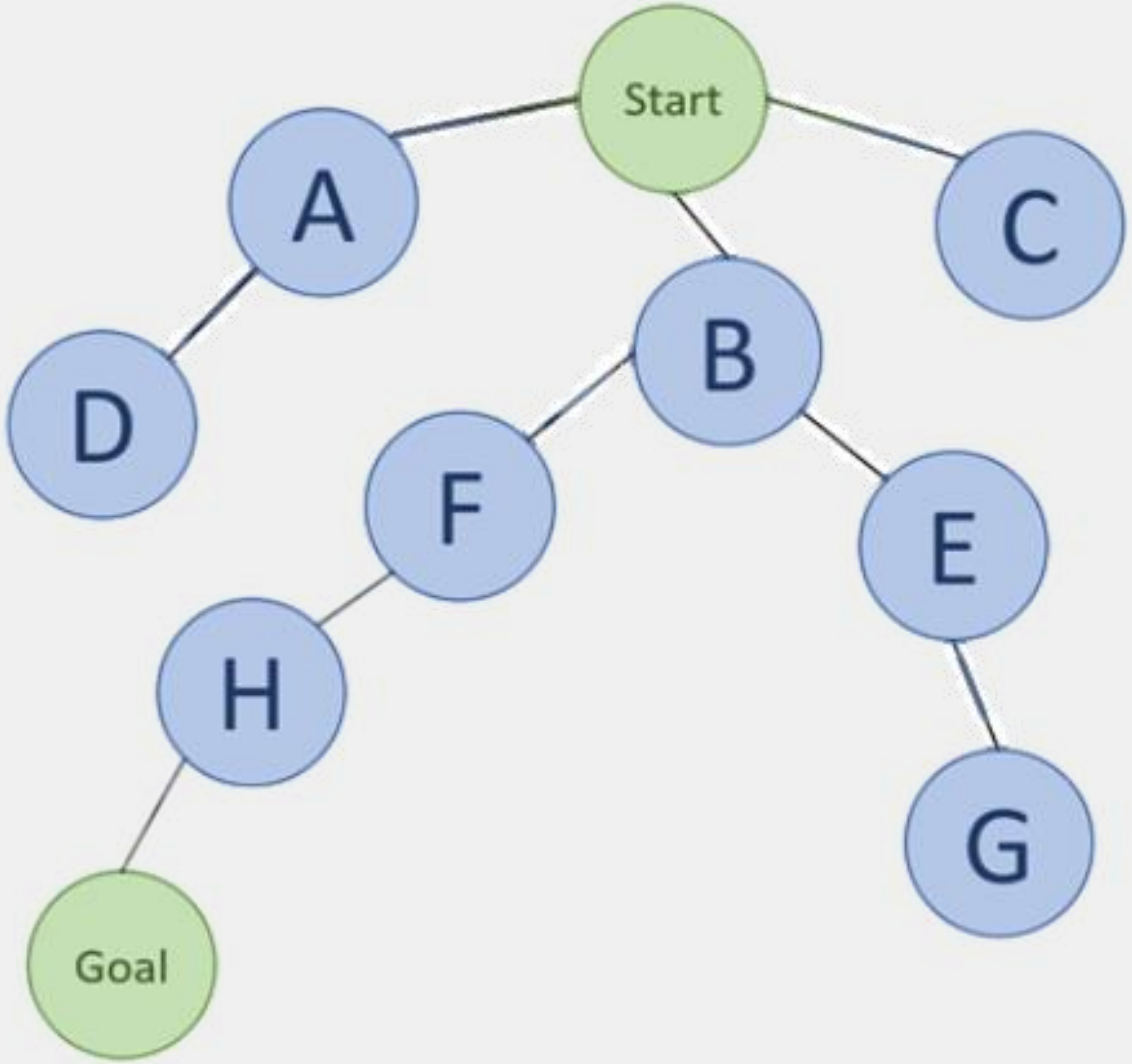
Alternative?

Google Maps is used to compute routes in the two-dimensional Euclidian plane and thus could achieve a significant speedup by incorporating the A* algorithm

CONSIDER THE FOLLOWING GRAPH:



Dijkstra's traversal:



A traverses fewer nodes, and thus is more efficient*

A*'s traversal:

A* IS NOT AN A+ ALGORITHM

Efficiency depends on the heuristic function.

Optimal path is not guaranteed if the heuristic is not admissible.

The space complexity can be more challenging to analyze.

Not capable of optimizing a route with preferred stops enroute.

Might have to recalculate if the user wants to consider a different route.

HOW TO IMPROVE?

Adaptive Heuristics

Heuristics that can adapt during runtime based on the characteristics of the problem space.

Memory-Efficient A* Variants

Use memory-efficient variants of A* for situations where space complexity is a concern, such as Memory-Bounded A* (MBA*), which trades optimality for reduced memory usage.

Incremental Search

Utilize incremental search algorithms that can update the existing path when preferences change, instead of recalculating the entire path.

CONCLUSION

To cater to the needs of millions diverse users, a simple algorithm alone will not suffice. While the A* algorithm appears to be more efficient that Dijkstra's algorithm, it is not the ultimate solution to all the problems and there is a lot of scope of improvement in the years to come. This is a journey, to dig deeper into your companion on all journeys – The Map!

THANK YOU