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Computers & Operations Research 33 (2006) 3324–3343
computers & operations research
www.elsevier.com/locate/cor

Heuristic shortest path algorithms for transportation applications: State of the art

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Available online 3 May 2005

Abstract

There are a number of transportation applications that require the use of a heuristic shortest path algorithm rather than one of the standard, optimal algorithms. This is primarily due to the requirements of some transportation applications where shortest paths need to be quickly identified either because an immediate response is required (e.g., in-vehicle route guidance systems) or because the shortest paths need to be recalculated repeatedly (e.g., vehicle routing and scheduling). For this reason a number of heuristic approaches have been advocated for decreasing the computation time of the shortest path algorithm. This paper presents a survey review of various heuristic shortest path algorithms that have been developed in the past. The goal is to identify the main features of different heuristic strategies, develop a unifying classification framework, and summarize relevant computational experience.

Keywords: Artificial intelligence; Traffic network; Shortest path algorithm; Heuristics; Heuristic shortest path algorithm; In-vehicle route guidance system (RGS); Intelligent transportation systems (ITS)

1. Introduction

In recent years there has been a resurgence of interest in the shortest path problem for use in various transportation engineering applications. This is directly attributed to the recent developments in Intelligent Transportation Systems (ITS), particularly in the field of in-vehicle Route Guidance System (RGS) and

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doi:10.1016/j.cor.2005.03.027

real time Automated Vehicle Dispatching System (AVDS) where there is a definite need to find the shortest paths from an origin to a destination in a quick and accurate manner. In a distributed RGS, an in-vehicle computer is commonly used to calculate the optimal route in a large traffic network. Typically the recommended routes must be found within a very short time period (e.g., a few seconds). In a real-time AVDS new routes and schedules must be identified within a reasonable time after a customer requests a service. Because the travel times are the basic input to the real-time routing and scheduling process and are dynamic in most urban traffic environments, there is an implicit requirement to use a minimum path algorithm repeatedly during the optimization procedure.

In the above applications, the traditional optimal shortest path algorithms often cannot be used because they are too computationally intensive to be feasible for real-time operations. A number of heuristic search strategies have been developed for increasing the computational efficiency of shortest path search. Most of these heuristic search strategies originated in the artificial intelligence (AI) field [1–4], where the shortest path problem is often used as a testing mechanism to demonstrate the effectiveness of these heuristics.

The current RGS field tests in North America, Europe and Japan have generated renewed interest in using heuristic algorithms to find shortest paths in a traffic network for real-time vehicle routing operations. Guzolek and Koch [5] discussed how heuristic search methods could be used in a vehicle navigation system. Kuznetsov [6] discussed applications of an A* algorithm (called the force driven method in his paper), a bi-directional search method, and a hierarchical search method used for identifying paths in the TravTek project. Since then, many researchers have followed the same track and tried to develop a universal strategy for improving the efficiency of the shortest path search process. These efforts have resulted in a large body of literature including a wide spectrum of search strategies and mechanisms. But to date, there has not been a comprehensive review examining the implementation and performance of these heuristic algorithms.

This paper first provides a brief overview of the optimal shortest path algorithms, which are often considered as the starting point for the development of many heuristic shortest path algorithms. The paper then examines four heuristic search strategies: (i) limit the area searched, (ii) decompose the search problem, (iii) limit the links searched, and (iv) some combination of above. The review summarizes the distinguishing idea of each search strategy and its algorithmic variations.

2. The shortest path problem and optimal algorithms

A road traffic network is represented by a digraph $G(N, A)$ that consists of a set of nodes N and a set of arcs A (or links used in this paper). Denote the number of nodes $|N| = n$ and the number of links $|A| = m$. A link $a = (i, j) \in A$ is directed from node i to node j and has an associated generalized cost c_{ij}. The generalized cost represents the impedance of an individual vehicle going through that link and is usually described by link travel time, link length, tolls, etc. Without losing generality, the term link travel time is used mostly in this paper. A path from an origin(o) to destination(d) may be defined as a sequential list of links: $(o, j), \ldots, (i, d)$ and the travel time of the path is the sum of travel times on the individual links. The problem is to find the path that has the minimum total travel time from the origin node to the destination node.