Towards Intelligent and User-Friendly Vehicle Navigation Systems

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Abstract: The article presents a new approach to vehicle route planning and navigation, called *robust route planning*. Until recently, inclusion of intelligence in route planning systems was limited to path determination algorithms. The presented approach tries to take intelligent navigation systems to a new level by supplying the driver with multiple options and letting them utilize their own intelligence when making decisions. The paper summarizes recent work and presents current and future research direction in this field.

Keywords: route planning, navigation, GIS

1. Introduction

Intelligent systems [8] find applications in numerous aspects of human lives. However, it must be noted that intelligence in these systems can manifest itself in many different ways.

One of the classical AI methods is solving problems by searching [7]. As the state space is often given as a graph, one obvious practical application of these methods is route planning for vehicles. Early systems relied on *a priori* planning, e.g. the route was calculated before the travel began. State-of-the-art route planners are usually combined with navigation systems and embedded in a mobile device which, by means of GPS positioning, can obtain its location and, to some extent, learn about the actions of the driver.

In route planning and navigation systems, AI methods are usually applied in the path determination process, e.g. by replacing "blind" search algorithms with "informed" methods which utilize heuristic functions, such as the A* search algorithm [3]. This tendency is supported by the ease of heuristic function determination in domains where each node is assigned to specific coordinates.

However, these systems include more potential for application of intelligence, e.g. by letting them *understand* the motivation behind the actions of the driver and *supply* the driver with knowledge to support their decisions. This paper summarizes the work conducted during preparation of a PhD dissertation regarding intelligent route planning [4] and presents the research being currently conducted, as well as future goals.

2. Motivation

Ordinary navigation systems operate according to a rather simple scheme. Given the start location, usually obtained from the GPS receiver, and the goal location provided by the user, the nearest nodes (junctions) are identified. Then, a path between these nodes is determined according to given optimality criteria (length, estimated travel time, etc.).

During travel, the software monitors the current location and tries to assess if the driver is following the initial route. If the driver, for some reason (map data error, blocked road, human mistake), is no longer able to follow that route, they have to arbitrarily choose another option. Only then a new route is being calculated.

There are several reasons why this behaviour is unfavourable. First of all, the arbitrary decision may not be optimal. Moreover, the delay before a new route is ready – during which the driver is left with no guidance – can be significant due to the time needed for the system to notice the detour (slight deviations can be interpreted as GPS signal disruption) and calculate the new route.

A real-life example of such situation is shown in Figure 1, where the commercial route planning system instructs the driver to make a U-turn at the nearest junction. As that maneuver is illegal, the driver, with no additional knowledge, decides to continue straight on, seeking the next possible turning point. However, the optimal action would be to turn left, as that would provide the opportunity to turn around. The resulting (non-optimal and optimal) routes are shown in Figure 2.

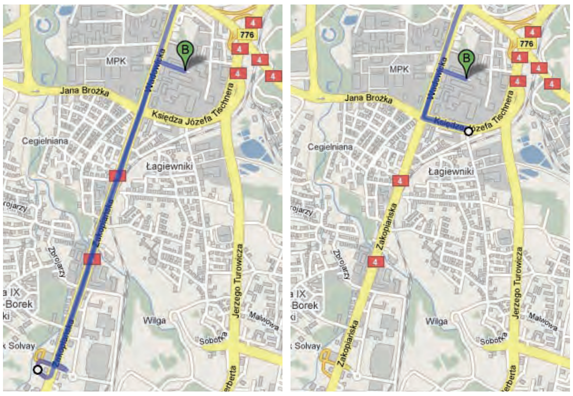
3. Solution Outline

The proposed solution is a new generation of navigation systems which would, at any point, supply the driver with all feasible maneuvers, thus providing them means of assessing alternative options if the original solution can no longer be followed.

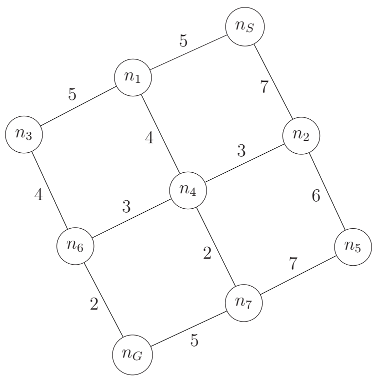
3.1. Robust Route Planning

The concept behind *robust route planning* is determination of the optimal route as well as suboptimal routes (possibly

Rys. 1. Trasa niezgodna z przepisami
Fig. 1. Illegal route



Rys. 2. Nieoptymalna i optymalna trasa alternatywna
Fig. 2. Non-optimal and optimal alternative route



Rys. 3. Przykładowy prosty graf
Fig. 3. A simple graph example

with a set maximum length/cost). The plan can be represented as a decision table, providing all possible decisions at a given node (junction) which ultimately lead to the goal node, as well as the predicted cost of routes available after a given maneuver.

Consider a simple graph shown in Figure 3, where n_S is the start node and n_G is the goal node. Table 1 presents part of the decision table for that graph.

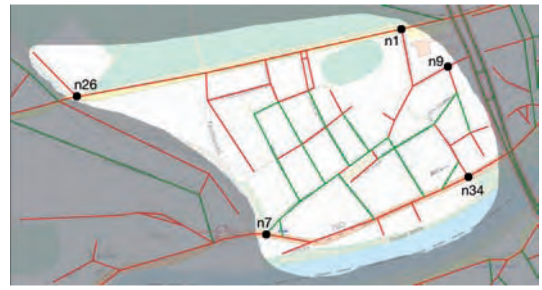
Tab. 1. Part of a decision table for graph shown in Fig. 3
Tab. 1. Część tabeli decyzyjnej dla grafu przedstawionego na Rys. 3

$n_{current}$	d	ρ	g_{min}	g_{max}
n_S	$n_S \rightarrow n_1$	6	14	38
n_S	$n_S \rightarrow n_2$	6	15	37
n_1	$n_1 \rightarrow n_3$	3	11	33
n_1	$n_1 \rightarrow n_4$	3	9	25
n_1	$n_1 \rightarrow n_S$	4	20	32
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

An obvious limitation of this basic robust planning method is its computational complexity and the size of the result output data. The following section presents an innovative way of partitioning the search domain to limit the number of plans which need to be generated.

3.2. Partitioning of the Planning Domain

Common map abstraction methods, i.e. based on omitting lower-grade roads and using main arteries whenever possible, are in contradiction to the motivation behind the development of robust planning methods as outlined in the previous section. The proposed idea for partitioning of the search domain involves the introduction of so-called *granules*, derived from the observation that the density of real-life environments, such as large cities, is not uniform. Specifically, there are regions, often surrounded by either natural or man-made boundaries (such as rivers or railways), with a relatively limited number of ways for traversing to another region, but with very dense and complicated (one-way streets, etc.) structures inside.



Rys. 4. Przykładowa granula na mapie Krakowa
Fig. 4. Example of a granule in the map of Krakow

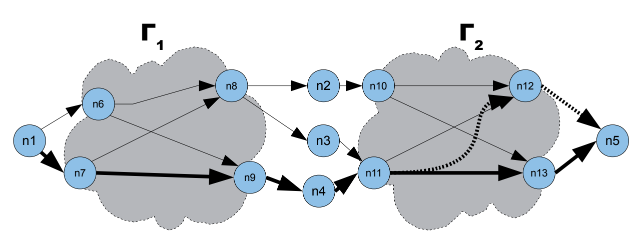
Therefore, a *granule* is a part of the planning domain, such that the number of inputs and outputs is maintained at a low level, while the inner structure is rather dense – in fact, inputs and outputs are often the source of 'bottlenecks' within the street network. An example of a granule within the map of Kraków is presented in Figure 4. Note th at the map can be either partially or entirely covered by granules.

The definition of granules is a difficult and domain-specific task: knowledge about the characteristics of the search space plays the key role for efficient determination of useful granules. Several methods (such as graph clustering and density analysis) exhibited only limited usability. Therefore, [4] concluded that automatic methods can only assist the human operator in the granule determination process.

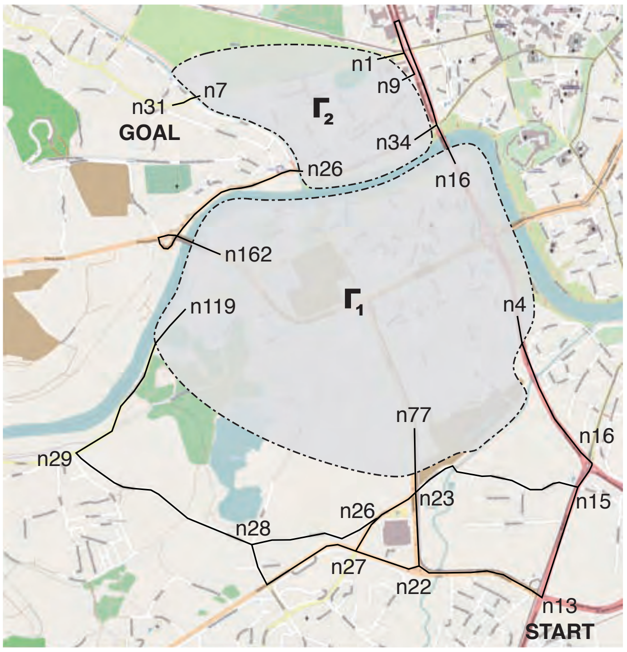
However, new methods of granule determination are currently being researched. These include spatial data analysis in a distributed architecture using Google's map/reduce paradigm [2] and the Apache Hadoop framework, as well as georeferenced data mining using tools such as Apache Mahout.

3.3. Robust Granular Planning and Navigation

Route planning in the partitioned map is performed as follows. For each granule, a *robust traversal plan* is generated. Such a plan consists of paths from *every inner node*



Rys. 5. Graf uogólniony w prostej dziedzinie
Fig. 5. A generalized graph in a simple domain



Rys. 6. Graf uogólniony na mapie Krakowa
Fig. 6. A generalized graph in the map of Krakow

to *each output node* within a granule. This allows quick determination of paths for traversing granules.

Then, a *generalized graph* is generated, by omitting all *inner nodes* in all granules and substituting them with generalized traversal edges (using lengths of the traversal paths). A simple generalized graph consisting of two granules is shown in 5.

Planning involves determination of a path in the *general graph*. Upon execution, when the driver reaches a granule *input*, precompiled traversal instructions are used to reach the *output node* according to the general plan. A generalized graph for a route planning task in Kraków is shown in Figure 6.

4. Conclusions and Future Work

Until recently, inclusion of intelligence in route planning systems was limited to path determination algorithms. Robust granular route planning tries to take intelligent navigation systems to a new level by supplying the driver with multiple options and letting them utilize their own intelligence when making decisions, as well as deducing the motivation between the driver's actions.

The article outlines the concept as presented in [4], and shows the current research directions in this field.

Currently investigated and future research directions include:

– generalization of the presented concepts to solve general AI planning problems [5],

– utilization of domain-independent methods [6] to determine granules in non-graph plamnning domains,

– development of data mining-based map partitioning methods,

– extension of the concept towards flexible multi-criteria route planning systems [1].

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Inteligentne i przyjazne dla użytkownika systemy nawigacji pojazdów

Streszczenie: Artykuł przedstawia nowe podejście do planowania tras przejazdu i nawigacji – *odporne granularne planowanie tras*. Do niedawna, elementy sztucznej inteligencji w systemach planowania trasy występowały przede wszystkim w algorytmach używanych do wytyczania ścieżki. Prezentowane podejście ma na celu wytworzenie inteligentnych systemów nawigacyjnych, przedstawiających kierowcy wiele wariantów i pozwalających mu użyć inteligencji i obserwacji do podejmowania decyzji.

Słowa kluczowe: planowanie tras, nawigacja, GIS

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