A COOPERATIVE INTELLIGENT SYSTEM FOR URBAN TRAFFIC PROBLEMS

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Abstract

This paper discusses urban traffic problems and their intelligent solutions. It firstly considers and analyzes the urban traffic problem itself. As a conclusion, a multi-agent paradigm and cooperation between humans and computers are necessary for solving the traffic problems. Such a model is presented to support the argument. Then the paper introduces a cooperative intelligent system for urban traffic problems (COTSCS). A testbed for COTSCS is also described in this paper.

1. Introduction

A working definition of artificial intelligence (AI) is that it studies and attempts to duplicate human problem solving [1]. One of the goals of AI is to develop systems that become part of our everyday life.

Everyday, people have to face traffic problems. Driving in heavy traffic is a highly interactive task. Various types of road users have to continuously adjust their actions in order to avoid collisions and to get on to their destinations. However, problems may arise when too many road users with various conflicting goals meet. This usually results in a traffic-jam or, in severe cases, a crash. Distributed artificial intelligence (DAI) technologies and cooperative problem solving approaches may help to handle this problem. They offer certain advantages for problem solving [2]: faster response, increased flexibility, robustness, resource sharing, graceful degradation, and better adaptability. Much of the power comes through cooperation and communication. It relates to how the elements of a loosely coupled network can work together to solve problems that are beyond their individual capacities. Each problem solving node in the network is capable of solving sophisticated problems and can work independently, but the problems faced by nodes can not be solved without cooperation.

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Some of the relative research in distributed, parallel or cooperative traffic problem solving includes: distributed vehicle monitoring [3]; distributed air traffic control [4] [5]; distributed control of street traffic lights [6]; distributed urban traffic control [7] [8]; PARAMICS microscopic traffic simulator [9]; and so on.

2. The Urban Traffic Problem

Currently, there are four means of catering for passenger travel [10], i.e., the urban railway, the tramway, the bus, and the private vehicle, which have provided the basis for passenger movement in urban areas. This paper only deals with the traffic problem of private vehicles, especially cars, in urban areas.

What's a Traffic Problem?

Generally speaking, a traffic problem is all the activities and installations concerned with the traffic affairs. It is very complex. In order to describe and discuss it easily in this paper, we will only introduce one of the many urban traffic problems: how to let cars drive, according to some reasonable routes, from their starting points to their destinations safely and efficiently.

Even in such a simplified urban traffic problem, there are two different views about a traffic problem, from road users and road managers: from the view of road users, a traffic problem is only the problem of choosing the direction at the junctions; from the view of road managers, it is the problem of controlling the traffic flows. But what is a good route for the road users, and what is a good traffic situation for the road managers? Some issues may be given in the following subsections:

What is a good route? There will be some different interpretations for various types of road users. But it may be evaluated by some factors: (1) distance; (2) time; (3) cost; (4) speed; (5) traffic situation (safety and easy to drive); and so on. The road users can select one or several of the above-mentioned factors as an evaluation function.

What is a good traffic situation? The judgment whether it is a good traffic situation in some cases do not depend on the quantity of cars, but on whether each car can be driven at its promised speed without any problem and difficulty, and whether the current traffic situation can give as much assistance as possible to neighbouring places.

How to Solve a Traffic Problem?

To solve a traffic problem, both the road users and the road managers should adopt two steps of solution: making out a driving or a management plan (even it only a draft plan); executing the plan. The constraint conditions are the physical conditions and the traffic rules [11].

In a normal situation, the road user(s) or the road manager(s) can execute the original traffic plan step by step, without any modification. However, in most situations, especially for the road user(s), the original plan has to be modified according to the current traffic situation. For example, when a road user is preparing to go straight ahead at a junction according the original driving plan, but the driver finds that there is a road works sign in the street that he will join, the driver must choose an alternative route. The subsequent steps in the plan must also be modified correspondingly. As another example, when a crash or a traffic jam happened in some place, the road manager(s) also has to change the original controlling plan to handle such situation.

From the point of view of individual drivers, the road users merely watch the environment and react appropriately in order to achieve their goals. These local goals are the driving forces that let the individual move and behave in certain ways. However, sometimes unintentional misbehavior (misguidedness) happens due to a lack of environmental information. In another words, no driver would voluntarily join a traffic-jam if drivers knew in advance that it will occur. Thus, anticipation is an important factor for the reactive behavior of road users. At present, the scope of anticipation is limited to the range of the human senses, in particular seeing and hearing.

The well known radio traffic services try to extend the "senses" of the individual by providing information about situations that lie beyond the individual's range. They are broadcasted on special frequencies. These can provide valuable real-time information to the users. Unfortunately, these services tend to be slow and misleading. They often provide information when it is too late to react appropriately. In some cases, the situation gets even worse due to outdated information or over-reactions of the receivers. So far, this method can be used in solving air traffic problems. However, it still does not meet the requirements of urban traffic problems.

If each road user could be embedded into a network of telecommunication links that spread all over the urban region and connect every relevant passive or active entity (agent), then significant improvements are conceivable. Each road user can plan a route, select a means of transport and calculate the estimated time needed, based on the information given by the network. Then if necessary, the driver can replan and come up with an alternative, more viable plan. On the other hand, the road managers can handle the traffic more easily. To achieve that, a multi-agent paradigm and cooperation between humans and computers are necessary.

3. A Multi-Agent Model

The notion of agents

At present, the multi-agent systems (MAS) researchers have not yet settled on concise and unopposed definitions. So the term *agent* is used in an intuitive fashion. An agent, like the respective real world entity, exhibits observable behavior. It is autonomous and often thought of as intelligent. It is comprised of logical components whose implementations may be neglected.

Agents stand for a wide variety of real world entities. In the traffic problems, agents may be vehicles, streets, junctions, traffic lights, and so on. So the model of agents has to fit a broad spectrum of relevant entities in the world of discourse.

Using agents to model traffic problems

A multi-agent model for the urban traffic problem may be viewed as three layers, as shown in Fig 1: the highest layer is the global urban traffic agent, executing the global planning; the middle layer is composed of some traffic flow control agents, executing the group planning; in the lowest layer, there are a lot of individual traffic agents, executing the individual planning.

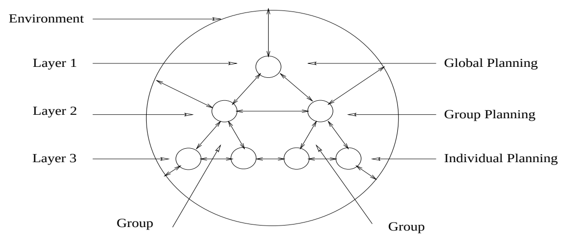

Fig. 1. The multi-agents environment

The global urban traffic agent is a central manager. It will supervise and control all the traffic agents in the urban region.

There are some middle layer managers, called traffic flow control agents. This kind of agent samples data about all mobile agents entering or leaving its control region. Each of them has to declare its origin, destination(s), preferred route(s), speed, estimated time of departure, constraint time if any (like office start time), etc.. The traffic flow control agents calculate a route for the approaching agent based on their current knowledge about the (estimated) traffic volume and parking space occupation, i.e., they will arrange routes for approaching mobile agents according to tested and predicted traffic conditions.

The most important individual traffic agents in this model are vehicles, streets, junctions, and traffic lights or signs. They can be divided into two types: mobile agents (vehicles) and immobile agents (others).

Vehicles, especially cars, are agents with necessary computational powers and telecommunication facilities model the advanced mobile traffic in the future. A street agent models the space between consecutive junctions. A junction agent models the space connecting some streets. A traffic light agent models a traffic flow control point at some junction.

In this model, the junctions are the decision points to solve a traffic problem. There are mainly two kinds of typical junctions in Britain: one with traffic lights; the other only with road signs or markings (with or without pedestrian lights). Or, they can be divided into pedestrian-crossing, T-junction, crossroad, branch and round-about.

Traffic at a junction with traffic lights is controlled by the cooperation of a group of traffic lights. All these traffic lights should negotiate, among them and those approaching cars, about the length and start time of the cycles of the next light-sequence in order to minimize waiting time for the cars.

The task of a singleton traffic light is rather simple. It has to recognize (i.e. count) approaching vehicles (and pedestrians, if needed). Based on their estimated arrival times the timing of the light sequence at the junctions can be adjusted appropriately. Since, in most cases, a traffic light belongs to a group it can not alter the light sequence timing on its own but has to negotiate with its partners. Each traffic light agent knows about the traffic volume approaching from the direction it is controlling. The integration of the knowledge of all members of the group allows to calculate the timing of light sequences that is optimal with respect to overall throughput.

Unfortunately, the local optimizations at each junction will not lead to globally optimal results. Therefore, the dependencies that exist between sequences of junctions (lined up along streets) have to be taken into consideration. It is beyond the discussion scope of this paper.

Limited by space, only a formal definition for the traffic light agent will be given as follows:

A traffic light agent models a traffic flow control point at some junction, and can be written as:

$$T = (NAME, DIR, PRED, SUC, LENGTH, START, ACTIVE$$
$$CHANGE, SPLIT, ARRIVE, NEXT, OTHER)$$

in which, $NAME$ is the name of the traffic light; DIR is the traffic-light's controlling direction; $PRED$ is the predecessor of traffic light in some direction,

$$PRED_{Tname}(dir_i)$$

represents the traffic light which is the predecessor of traffic light $Tname$ in direction dir_i; SUC is the successor of traffic light in some direction,

$$SUC_{Tname}(dir_i)$$

represents the traffic light which is the successor of traffic light $Tname$ in direction dir_i; $LENGTH$ is the cycle length of the traffic light; $START$ is the start time of the cycle (the point of time in the cycle when the light goes green in some direction; $ACTIVE$ is the time period when the traffic light is active (i.e., green or yellow in some direction); $SPLIT$ is the split of the traffic light (the fraction of cycle time for the light in some direction); $CHANGE$ is the change time of the cycle (the point of time in the cycle when the light goes red in some direction,

$$T-CHANGE_{Tname}(dir_i) =$$
$$T-START_{Tname}(dir_i)+$$
$$T-ACTIVE_{Tname}(dir_i)\ mod\ T-LENGTH_{Tname}$$

represents the traffic light $Tname$ will turns red in direction dir_i, after the active period $T-ACTIVE$ from the start time $T-START$ in this direction; $ARRIVE$ is the the time point when the first car arrive at the traffic light in some direction. $NEXT$ is the average time it takes the first car stopped at the traffic light to get to the next successor traffic light, after this traffic light turns green,

$$NEXT_{Tname,SUC_{Tname}}(dir_i)$$

represents the average time it takes a car coming through the green and uncongested traffic light $Tname$ to reach its successor SUC_{Tname}, in direction dir_i,

$$NEXT_{PRED_{Tname},Tname}(dir_i)$$

represents the average time it takes a car to reach the traffic light SUC_{Tname} from coming through its green and uncongested predecessor traffic light $PRED_{Tname}$, in direction dir_i; $OTHER$ may represent other properties of the traffic light.

4. A Cooperative Traffic Scheduling and Controlling System

According to the multi-agent model for urban traffic problems, a cooperative traffic scheduling and controlling system (COTSCS) has been designed. The overall scheme of the system is composed of three layers (Fig 2): the central manager (Scheduling & Planning); the traffic control points (Communicating & Coordinating); and the individual traffic entities (Controlling & Executing). From the view of scheduling and controlling, only mobile vehicles are mentioned in Fig 2.

COTSCS consists of many functional components: the central manager module will take the role of master functional component to achieve centralized control. On the other hand, the traffic control point

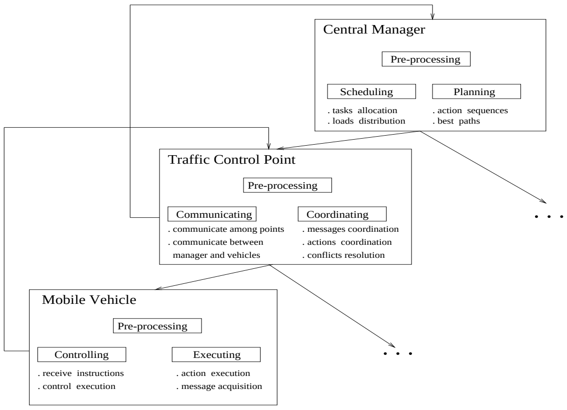

Fig. 2. Design scheme of COTSCS

modules and the mobile vehicle modules will achieve decentralized coordination. In addition, a traffic control point module can be viewed as a master functional component of some mobile vehicle modules in its control region.

Scheduling and planning in COTSCS

The scheduling and planning for the central manager will be based on a scheduling function:

$$S(Sit, Rou, Req)$$

in which, Sit represents traffic situation, Rou represents routes, Req represents requests.

The central manager will use the scheduling function to produce the traffic scheduling plans for those traffic control points, based on the messages of the current traffic situation in the urban area (the variable Sit), the possible vehicle routes (the variable Rou), and the requests from the traffic control points (the variable Req).

Communicating and coordinating in COTSCS

The communicating and coordinating for a traffic control point will be based on a evaluation function:

$$E(Tim, Imp, Sit, Env, Com)$$

in which, Tim represents time, Imp represents importance, Sit represents traffic situation, Env represents environment, and Com represents commands.

Each traffic control point will use the evaluation function to produce the traffic control plans for those individual traffic agents, based on the messages of the current time (the variable Tim), the traffic importance (the variable Imp), the current traffic situation in the control region (the variable Sit), the traffic environment conditions in the control region (the variable Env), and the scheduling commands from the central manager.

Controlling and executing in COTSCS

The control and execution for an individual mobile vehicle will be based on a cost function:

$$C(Tim, Exp, Dis, Saf, Con, Jam, Com)$$

in which, Tim represents time, Exp represents expenses, Dis represents distance, Saf represents safety, Cov represents convenience, Jam represent jam. and Com represents commands.

Each individual mobile vehicle will use the cost function to produce a driving plan for itself, based on the messages of the current time (the variable Tim), the driving expenses (the variable Exp), the driving distance (the variable Dis), the driving safety (the variable Saf), the driving convenience (the variable Cov), the traffic jam messages (the variable Jam), and the control commands from the current traffic control point.

As most traffic scheduling and control are achieved by means of traffic lights, this section will only discuss the traffic light control strategies in detail.

The control goal of the traffic light at a junction can be abstracted as a decision problem, i.e., a car approaching the junction will be allowed to cross or be asked to wait behind the white line. Both of them are controlled by the colour of the traffic light. The colour of the traffic light depends on its control strategies. The control variables for the traffic light are [12]: (1) the length of the cycle; (2) the length of "active time" (sum of the periods of yellow and green lights in one or the other direction); (3) the point of time when the cycle starts.

There are four basic strategies for traffic light control (the first three strategies are based on [12]). For simplicity, we will assume all the relative junctions are crossroad intersected by two streets.

<u>The semiactuated strategy:</u> This strategy is to be used when the traffic flow in both directions of one street is extremely small. The light stays green in the busier direction(s) of the other street until one or more cars approach the junction in the less busy street. Then the light turns green in the latter directions as needed, up to a predetermined maximum time.

What should be noted is the light in the busier directions will not keep green continuously, even there is no car approaching from the less busy street. If so, a traffic jam may result at the successor junctions. That is just one of the reasons why a distributed and cooperative intelligent traffic control strategy is needed.

<u>The platooning strategy:</u> The word of "platoons" in traffic problems means the traffic flow in one street can be divided into some small groups separated by gaps. Ideally, the light should be green when the cars are approaching the junction, and red when the gaps

appear, passing the messages to the successor junction at the same time. If this strategy can be used to coordinate the traffic flow in both directions at a junction, it is possible for most of the cars to cross the junction quickly. Of course, some of the control messages should be given by the traffic control point in this region.

The strategy to control individual characteristics separately: This strategy can be divided into three future categories, depending on which type of the three above-mentioned control variables is used: (1) modify cycle length: longer cycle lengths given in the directions with heavier traffic flow can speed traffic; (2) change cycle splits: longer lengths of "active time" in the directions with heavier traffic flow will also speed traffic; (3) change cycle start time: a suitable cycle start time will reduce the waiting time.

The emergency strategy: The fourth strategy mentioned is a special case: i.e., if there are oncoming emergency vehicles such as fire engine, ambulance, police vehicles and so on, in some direction at a junction, the traffic light in this direction should turn to green as soon as possible, or keep on green, irrespective of the colour before.

5. A Testbed for COTSCS

The principal goal of the testbed is to build an experimental environment or platform which can be used to develop a distributed intelligent system for urban traffic problems. In order to develop systems that will be useful in this area it is necessary to be able to test them. Clearly real-world testing is impossible: a testbed is needed. The testbed must be able to simulate real-world problems and provide interfaces to allow the systems that will manage the traffic to influence the evolution of the traffic problems.

It will involve building a simulator that can handle the problem of driving from Forrest Hill to Waverley station. The simulator will have the following capabilities: (1) Mobile agents that simulate cars. (2) Immobile agents that simulate streets, junctions, traffic lights etc. (3) Allowing these agents to interact with each other. The simulator should be designed in an extensible and modular way (e.g. using object-oriented techniques).

An urban traffic problem example

This problem is presented from the view of a car driver. Suppose a driver in the Department of Artificial Intelligence wants to go to the station to meet someone. The traffic problem is how to drive the car, according to a reasonable route, from the Departmental Building (5 Forrest Hill) to Edinburgh Waverley Station. Fig 3 shows a traffic sketch map.

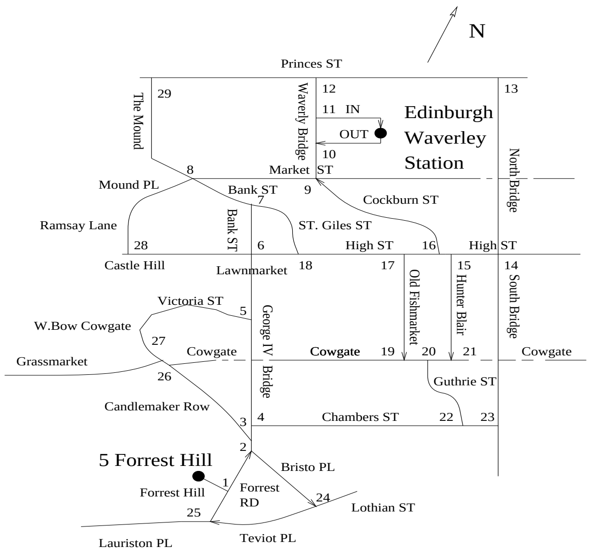

Fig. 3. An urban traffic sketch map

In Fig 3, a line with a name represents a street; a point with a number, which is the intersection of two or more lines represents a junction; a line with an arrow represents an one-way street; the two medicine dots represent the starting point and the destination, respectively. There are thirty-one streets and twenty-nine junctions in all in Fig 3.

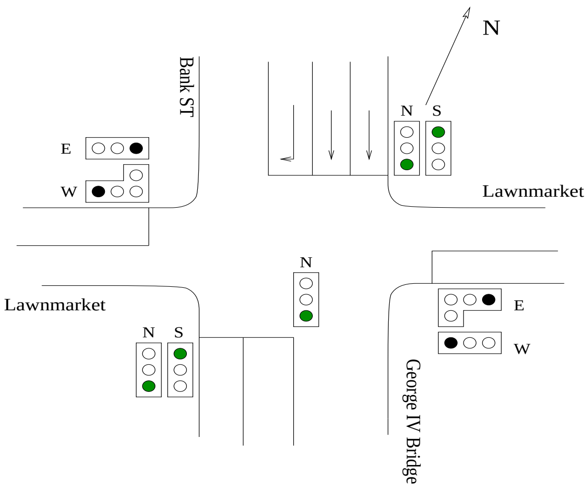

Fig. 4. A junction with traffic lights

Fig 4 shows a typical crossroad in Britain (it is just the junction No.6 in Fig 3).

In Fig 4, the names are the street names. The frames with three or more circles are the traffic lights, in which the black medicine circles represent the red lights, the mesh circles represent the green lights. The capital letters N (North), S (South), E (East), W (West) on the traffic lights represent the views of the traffic lights. For example, a traffic light with the letter 'N' means it can be seen by, and used to control, the traffic flows from south to north. The road markings are referred to the traffic rules. Any vehicles must pass through according to the indication signals of the traffic lights.

Planning and Executing

Firstly, the driver can receive some reasonable routes from the traffic information network. In some cases, there may be an infinite number of routes which can reach the Station from the Department. But in fact, there are only five reasonable routes. We can use a street name to represent the direction selected by the driver at each junction. Thus, the five routes can be shown as follows (the number in each bracket corresponds to a junction in Fig 3):

1 : *The Department* → *Forrest RD.*(1) → *George IV BR.*(2) → *George IV BR.*(3) → *George IV BR.*(4) → *George IV BR.*(5) → *Bank ST.*(6) → *Bank ST.*(7) → *Market ST.*(8) → *Waverley BR.*(9) → *Waverley BR.*(10) → *IN*(11) → *The Station*

2 : *The Department* → *Forrest RD.*(1) → *George IV BR.*(2) → *Candlemaker Row*(3) → *Candlemaker Row*(26) → *W.Bow Cowgate*(27) → *George IV BR.*(5) → *Bank ST.*(6) → *Bank ST.*(7) → *Market ST.*(8) → *Waverley BR.*(9) → *Waverley BR.*(10) → *IN*(11) → *The Station*

3 : *The Department* → *Forrest RD.*(1) → *George IV BR.*(2) → *George IV BR.*(3) → *George IV BR.*(4) → *George IV BR.*(5) → *Castle Hill*(6) → *Ramsay La.*(28) → *Market ST.*(8) → *Waverley BR.*(9) → *Waverley BR.*(10) → *IN*(11) → *The Station*

4 : *The Department* → *Forrest RD.*(1) → *George IV BR.*(2) → *George IV BR.*(3) → *Chambers ST.*(4) → *Chambers ST.*(22) → *South BR.*(23) → *High ST.*(14) → *Cockburn ST.*(16) → *Waverley BR.*(9) → *Waverley BR.*(10) → *IN*(11) → *The Station*

5 : *The Department* → *Forrest RD.*(1) → *George IV BR.*(2) → *George IV BR.*(3) → *Chambers ST.*(4) → *Chambers ST.*(22) → *South BR.*(23) → *North BR.*(14) → *Prince ST.*(13) → *Waverley BR.*(12) → *IN*(11) → *The Station*

To find a good route, some analysis messages about the above-mentioned five routes should also be received at the same time: *route* 1 is the shortest, but there are some traffic jams in Bank Street or George IV Bridge sometimes; *route* 2 and *route* 3 can be viewed as the branches of *route* 1, but there are fewer vehicles and pedestrians on the two routes; the streets on *route* 4 are wider and there is a one-way street, it is easier to drive; the streets on *route* 5 are also wider and there many left turning, but it is the longest. Then, for example, to save time, the driver should choose *route* 1 as a driving plan; if the driver is a new one and want to find a route for easily driving, *route* 5 should be chose as a driving plan.

Thus, the driver can execute the driving plan. Firstly, it is clear that the driver has to turn left (because it is an one-way street) at junction 1 and should also turn left to get George IV Bridge. Then, if executing *route* 1, the driver should go straight on junction 3 and 4 to keep George IV Bridge; if executing *route* 5, the driver should go straight at junction 3 and turn right at junction 4; and so on. A special example can be given as follows: when approaching junction 6 while executing *route* 1 or 2, if the driver receives a traffic situation message from the nearby traffic control point, a traffic jam or crash is happening on Bank Street, the driver can change the driving plan to *route* 3, i.e., turning left at junction 6 and going straight at junction 8 to get Market Street.

So the driver can get to the destination step by step.

6. Conclusion

The full traffic problems are more complex than that described in this paper. For example, even if a reasonable route has been chosen, when two cars meet in a street with parked cars on both sides and only one car may pass through, if both of them want to go and not give way to the other one, a traffic jam will happen unavoidably.

Due to the problem complexity, it is not easy to give a complete solution. This paper only gave some ideas for solving a kind of urban traffic problem. It presented a multi-agent model to formally describe the urban traffic problem, and introduced a cooperative traffic scheduling and controlling system and its proposed testbed to build an experimental environment simulating intelligent traffic problem solving in real world. An urban traffic problem example was discussed following the approaches suggested in this paper. Of course, a lot of work in cooperative and coordinated traffic control mechanisms need to be done.

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