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STECEQL: A Spatio-Temporal Constraint Event Query Language for Internet of Vehicles

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ABSTRACT

In recent years, the complex event technology has been widely used in the monitoring and real-time querying information of the internet of things. The internet of vehicles is a novel researching area of the intelligent transportation systems, which developed with the technology of internet of things. It is different from the traditional internet of things. There are a large number of moving objects and they will produce large amounts of temporal and spatial information in the internet of vehicles. It becomes the core issue of the complex event technology in the internet of vehicles, how to effectively represent and process these information of the moving objects. We propose a novel temporal and spatial constraint complex event query language STeCEQL for the internet of vehicles. In STeCEQL, we use time interval as temporal model and grid map as spatial models. We give the syntax and operational semantics of STeCEQL based on the temporal and spatial model. Finally, our experiments illustrate the effectiveness of the operational semantics.

Keywords: *Event Driven Architecture, Event Query Language, Internet of Things, Internet of Vehicles, Grid Map, Mobile Systems.*

1 INTRODUCTION

With the development of Internet of things (IoT)[1]and Cyber-Physical System(CPS)[2], many new methods and viewpoints were proposed to solved the problem in the research of Intelligent Transportation Systems (ITS). The Internet of Vehicles use the vehicle-mounted electronic sensing device[3], the mobile communication technology, the car navigation system, the information terminal device and the intelligent network platform to contact each other between the vehicles and the road, cars and trucks, cars and people, vehicles and urban. By these networks, we can effective monitor, schedule and management the time, space, speed and other information of vehicles, people and road.

Internet of Vehicles is performance crucial system and the system's time performance and spatio-temporal consistence are the key of the system [4,5]. So it is very important to real-time monitor the time, space and other context information of various components of the system during the running time. With the applications of the clock technology, position technology (e.g. RFID, GPS), orientation sensors, speed sensors and other sensors, users can very easily get the time, position, direction, speed and other information about the internet of vehicles. However, there are a lot of mobile objects are moving very fast in the system and they instantly generate large amounts of data in the moving process. It is a very big challenge to store and process these data using the traditional database. Meanwhile, the traditional data mining techniques cannot monitor the information in time.

To solve the above problems, many researchers have applied the complex event technology to sensor networks and the internet of things. The complex event technology can filter the amounts of data through the event query language into the events concerned by the users [6]. When a concerned event occurs, the event based system can real-time or near real-time process these information according to the pre-defined rules. In the event based system, it greatly reduces the processing and storing load since the system only need store the concerned event and discard unwanted data. So the complex event technology has a very wide range of applications in the internet of things.

Since the existing complex event query language cannot effectively express the events' mobile and spatio-temporal characteristics in the internet of vehicles. This paper presents a novel complex event query language to internet of vehicles: STeCEQL (spatio-temporal consistence event query language). The remainder of this paper is structured as follows: section 2 introduces the related works. Section 3 describes the temporal model and the spatial model of the internet of vehicles. Section 4 presents the syntax and operational semantics of STeCEQL. Section 5 gives some simulation data examples to reasoning complex event expresses. The last Section concludes this paper.

2 RELATED WORK

An event query language is a high level programming language. A simple event express is a specification of a certain kind of single events. A complex event express is a specification of a certain combination of events using multiple simple event describing the correlation of the events. The complex event technology has been successfully used in the research of internet of things. It is very important to use the appropriate spatial and temporal models in the complex event query language of internet of things.

Xchange is a complex event query language based on the complex event relational algebra [7]. The syntax of the language likes the SQL language and contains the time model and time event to support the computation of time. ETALIS is a complex Query language based on the rules and the time relationships include: during, starts, equals, finishes, meet etc. [8]. RCEDA can describe a series of sequential events and a series of events occurred in time intervals [9]. CE language can express a combination of continuous, parallel and repeated events and it allows users to use the interval show the relationship between events [10].

Some events Query language focus on the spatial relationship between events. Xiaoyan Chen design an intelligent location-based service, which contains two spatial relationship predicates: Within and Distance [11]. Bamba discuss the issues about the region alerts [12]. For example, users firstly described a certain region and if there is any object moving into the region, the alarm will sound.

Recently, some researchers concern about the relationship between the spatial and temporal model of complex query language. Moody Ken presents a complex event Query language: SpaTec [13]. There are six base event operators: same location, remote, sequence, concurrency, conjunction, and disjunction. And four complex event operators: same location and sequence, remote and sequence, same location and concurrency, remote and concurrency. They have used SpaTec language in the monitoring system of London bus and propose the system architecture [14]. Jin Beihong has proposed a complex event Query language: CPSL [15]. The language can describe many temporal and spatial models and their relationships. In SpaTec language, the spatial model is a region with the central point. And in CPSL language, the spatial models are points set and convex polygons. These two complex event languages do not consider the direction information of the spatial model.

We think that each object of internet of vehicles can share the spatial information from geographic information systems and they can access to the global map. The direction information is important in the system. Based on the above considerations, we propose a complex event query language: STeCEQL. We main emphasis on the following three improvements:

(a) Using the grid map model as the spatial model of internet of vehicles.

(b) Based on the grid map model, give the method to judge the direction and the relationship between the locations.

(c) Proposed an effectively complex event query language STeCEQL.

3 THE EVENT INSTANCE AND THEIR TEMPORAL MODEL, SPATIAL MODEL

We look the objects in the internet of vehicles as agents (e.g. a traffic signal, a car or a traffic speed limit etc.). The agents' properties can be detected and sensed by several sensors. These properties include time, location, speed and many other values. In the event-based system, we associate these properties with agent and call these as base event instances.

Definition 1: The event instance of the internet of vehicles is that the various prosperities of the concerned agents in the system when they perform an action or during some states. For example: Event instance 1: the car C' speed is 124 km/h at 1300km of a highway during 14:38:30 and 14:38:40. Event instance 2: the traffic light L is red during 20:14:10 and 20:14:35. Assume that the general format of the event instance is: e=<ID, Attribute1, Attribute2, …, Attributen>.

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3.1 The Temporal Model of Internet of Vehicles

Time is continuous in the real world, but we consider it is discrete and orderly in internet of vehicles. Since the sensors periodically identify data, we cannot know the specific time point of the base event in the system and only know the interval time of it. According to the existing research results, we give the definition of the temporal model of the event as below.

Definition 2: The timestamp of the event instance is a time interval and it is a sequence composed of two time points. Time-stamp= (start-time, end-time), and the start-time is before the end-time. For example: time-stamp1= (20:14:10, 20:14:35).

There are a lot of research results about the relationship of the interval temporal model. Allen has defined seven relationship between the time intervals [16]. We simplified his model and the relationship of our model are BEFORE, AFTER, EQUAL, OVERLAP and DURING.

3.2 The Spatial Model of Internet of Vehicles

The following we discuss the spatial model of internet of vehicles. The internet of vehicles is an important part of the intelligent transport system and the smart city. Its spatial information generally comes from the geographic information system (GIS). In the geographic information system, the spatial model (or the map model) should be represented by vector map or grid map. The vector map model can occupy less storage space, but it spends a lot of time to calculate. Otherwise, the grid map model need less time to calculate, but it occupies more space. Since it is very important to rapidly detect the event and make decision in the event based system, we use the grid map to model the space of internet of vehicles.

In the grid map, we look the space as a whole continuous entirety and divided the space into array of uniform size grid. There is only one row and column number of each grid. The number of rows and columns depends on the characteristics and spatial resolution of the system. The grid is the basic unit of the grid map and the shape of a grid usually is square, triangular or hexagonal. In the square grid map, all grids have the same direction and it is widely used in the field of processing the map and the image.

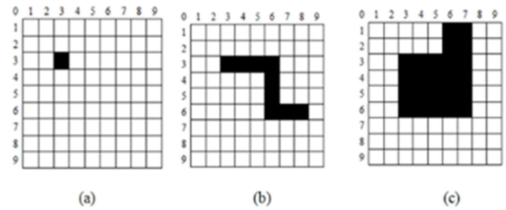

Fig. 1. Point, Line and Area of Grid Map

Base the grid map, we can define the location model in the internet of vehicles:

Definition 3: In internet of vehicles, the location is a set of grids which the base event occurred in. Its value is the set of sequence numbers of its rows and columns: location-stamp={(row1, column1), (row2, column2), (row3, column3), (row4, column4), (row5, column5), (row6, column6),…}.

In general spatial model, there are three kinds of model: point, line and area. We look the point and the line as a special location in our spatial model. It is shown as Figure 1.

The direction is an important attribute of the moving agents in internet of vehicles. We define the direction relationship based on the grid map as below:

Definition 4: As shown in figure 2, there are eight directions in the spatial model of internet of vehicles: direction-stamp={NORTH, SOUTH, WEST, EAST, NORTHEAST, SOUTHEAST, SOUTHWEST, NORTHWEST}.

We can judge the direction of the locations through the row and column numbers of the grid unit. For example: if A.row-number < B.row-number, we can say that agent A stayed at NORTH of agent B. On the other hand, the direction of a moving agent can be detected by its orientation sensors.

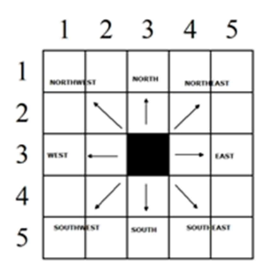

Fig. 2. Directions of STeCEQL

Based the above spatial model, we define eleven relationships: OUT-NORTH, OUT-SOUTH, OUT-WEST, OUT- EAST, OUT- NORTHEAST, OUT-SOUTHEAST, OUT-SOUTHWEST, OUT-NORTHWEST, EQ, OP, IN.

4 SYNTAX AND OPERATIONAL SEMANTIC OF STECEQL

4.1 Syntax of STeCEQL

In internet of vehicles, the complex event query language STeCEQL mainly involves the following syntax sets:

The agents set of the internet of vehicles: AGENT. The elements of AGENT are the objects which act events in the internet of vehicles. We call the element of AGENT as agent. Boolean value set: T={true, false}. The normal attributes of the agents may be an integer or a real number, e.g. temperature, speed etc. Assume the numbers set A= Z∪R, and we call its element as a.

In addition, the syntax sets also include the time sets and the space sets. The temporal stamps set is called TIME-STAMP and its element represented by t. The spatial stamps set: LOACATION= {POINT-STAMP, AREA-STAMP }. And its element represented by l. The direction set: DISTANCE= {NORTH, SOUTH, WEST, EAST, NORTHEAST, SOUTHEAST, SOUTHWEST, NORTHWEST}. Its element called d.

We call the storage unit sets X, and x is its element. The storage unit can store a variety of base event instance properties. The numerical attributes Boolean expressions set: ABexp and its element b. The temporal expressions set: TBexp and its element time. The spatial expressions set: LBexp and its element location. The base event expressions set: EBexp and its element e. The complex event expressions set: CEexp and its element ce.

The syntax of the STeCEQL rules are as following:

ABexp:

$b ::= true \mid false \mid x_a = a \mid x_a \mathrel{!}= a$

$\mid x_a > a \mid x_a >= a \mid x_a < a \mid x_a <= a$

TBexp:

$time ::= true \mid false \mid x_t\ BEFORE\ \ t \mid x_t\ AFTER\ \ t$

$\mid x_t\ EQUAL\ t \mid x_t\ OVERLAP\ t \mid x_t\ DURING\ t$

LBexp:

$location ::= true \mid false \mid x_l\ EQ\ l \mid x_l\ OP\ l \mid x_l\ IN\ l$

$\mid x_l\ NORTH\ l \mid x_l\ SOURTH\ l \mid x_l\ EAST\ l\ \mid x_l\ WEST\ l$

$\mid x_l\ NORTHWEST\ l \mid x_l\ NORTHEAST\ l$

$\mid x_l\ SOURTHWEST\ l \mid x_l\ SOURTHEAST\ l$

DBexp:

$direction ::= true \mid false \mid x_d = d \mid x_d \mathrel{!}= d$

EBexp:

$e ::= agent^{time}(b1;b2;b3\cdots)$

$\mid agent_{location}(b1;b2;b3\cdots) \mid agent_{location}^{time}(b1;b2;b3\cdots)$

$\mid agent_{(location,\ direction)}^{time}(b1;b2;b3\cdots)$

CEexp:

$ce ::= e1\ AND\ e2 \mid e1\ OR\ e2 \mid e1\ BEFORE\ e2$

$\mid e1\ EQUAL\ e2 \mid e1\ OVERLAP\ e2 \mid e1\ DURING\ e2$

$\mid e1\ EQ\ e2 \mid e1\ OP\ e2 \mid e1\ IN\ e2 \mid e1\ NORTH * e2$

In the above syntax rules, the operators of the temporal and spatial relationship are same as section 3. In the base event expression, the mobile agents' event expression include: temporal, spatial and direction expression. The other agents' event expression may include: temporal and spatial expression or only temporal expression. In addition, the elements of the complex event expression can be base events and complex events.

4.2 Opreational Semantics of STeCEQL

In order to accurately explain the meaning of complex event expressions of STeCEQL language, we describe the operational semantics of the STeCEQL language:

Assume the state set Σ consist of the function σ from the storage unit set to the attributes set. So σ(X) is the value of storage unit X under stateσ. The ordered pair $< n, \sigma > \rightarrow n$ represents that the evaluation result of any numeric attribute is itself. The ordered pair $< b, \sigma > \rightarrow true$ represents that the evaluation result of expression b is true, under state σ . The Boolean value of the complex event expression is true or false and the rules are following:

ABexp:

$\langle x_a = a, \sigma \rangle \rightarrow true, \quad if\ \sigma(x_a) = a$

$\langle x_a = a, \sigma \rangle \rightarrow false, \quad if\ \sigma(x_a) \neq a$

$\langle x_a \mathrel{!}= a, \sigma \rangle \rightarrow true, \quad if\ \sigma(x_a) \neq a$

$\langle x_a \mathrel{!}= a, \sigma \rangle \rightarrow false, if\ \sigma(x_a) = a$

$\langle x_a > a, \sigma \rangle \rightarrow true, \quad if\ \sigma(x_a) > a$

$\langle x_a > a, \sigma \rangle \rightarrow false, \quad if\ \sigma(x_a) \leq a$

$\langle x_a >= a, \sigma \rangle \rightarrow true, \quad if\ \sigma(x_a) \geq a$

$\langle x_a >= a, \sigma \rangle \rightarrow false, \quad if\ \sigma(x_a) < a$

$\langle x_a < a, \sigma \rangle \rightarrow true, \quad if\ \sigma(x_a) < a$

$\langle x_a < a, \sigma \rangle \to false, \quad if\ \sigma(x_a) \ge a$

$\langle x_a <= a, \sigma \rangle \to true, \quad if\ \sigma(x_a) \le a$

$\langle x_a <= a, \sigma \rangle \to false, \quad if\ \sigma(x_a) > a$

TBexp:

$\langle x_t\ BEFORET\ t, \sigma \rangle \to true, \quad if\ \sigma(x_t).endn < t.start1$

$\langle x_t\ AFTER\ t, \sigma \rangle \to true, \quad if\ \sigma(x_t).start1 > t.endn$

$\langle x_t\ AFTER\ t, \sigma \rangle \to false, \quad if\ \sigma(x_t).start1 \le t.endn$

$\langle x_t\ EQUAL\ t, \sigma \rangle \to true, \quad if\ (\forall \sigma(x_t).starti = t.starti$
$and\ \forall \sigma(x_t).endi = t.endi), i = 1, 2 \cdots n$

$\langle x_t\ EQUAL\ t, \sigma \rangle \to false, \quad if\ (\exists \sigma(x_t).starti \ne t.starti$

$\langle x_t\ OVERLAP\ t, \sigma \rangle \to true, \quad if\ (\sigma(x_t).endn \ge t.start1$
$and\ \sigma(x_t).endn \le t.endn)$

$\langle x_t\ OVERLAP\ t, \sigma \rangle \to false,$
$if\ \sigma(x_t).endn < t.start1\ or\ \sigma(x_t).start1 > t.endn$

$\langle x_t\ DURING\ t, \sigma \rangle \to true,$
$if\ \sigma(x_t).start1 \ge t.start1\ and\ \sigma(x_t).end1 \le t.endn$

$\langle x_t\ DURING\ t, \sigma \rangle \to false,$
$if\ \sigma(x_t).start1 < t.start1\ or\ \sigma(x_t).end1 > t.endn$

Lexp:

$\langle x_l\ EQ\ l, \sigma \rangle \to true, \quad if\ (\forall \sigma(x_l).rowi = l.rowi$
$and\ \forall \sigma(x_l).columni = l.endi), i = 1, 2 \cdots n$

$\langle x_l\ EQ\ l, \sigma \rangle \to false, \quad if\ (\exists \sigma(x_l).rowi \ne l.rowi$
$or\ \exists \sigma(x_l).columni \ne l.endi), i = 1, 2 \cdots n$

$\langle x_l\ OP\ l, \sigma \rangle \to true, \quad if\ (\exists \sigma(x_l).rowi = l.rowj$
$and\ \exists \sigma(x_l).columni = l.columnj), (i, j = 1, 2 \cdots n)$

$\langle x_l\ OP\ l, \sigma \rangle \to false, \quad if\ (\forall \sigma(x_l).rowi = l.rowj$
$and\ \forall \sigma(x_l).columni = l.columnj), (i, j = 1, 2 \cdots n)$

$\langle x_l\ IN\ l, \sigma \rangle \to true, \quad if\ \sigma(x_l) \subset l$

$\langle x_l\ IN\ l, \sigma \rangle \to false, \quad if\ \sigma(x_l) \not\subset l$

$\langle x_l\ NORTH\ l, \sigma \rangle \to true, \quad if\ (\forall \sigma(x_l).rowi < l.rowj$
$and\ \forall \sigma(x_l).columnj = l.columnj), (i, j = 1, 2 \cdots n)$

$\langle x_l\ NORTH\ l, \sigma \rangle \to false, if\ (\exists \sigma(x_l).rowi \ge l.rowj$
$or\ \exists \sigma(x_l).columnj \ne l.columnj), (i, j = 1, 2 \cdots n)$

DBexp:

$\langle x_d = d1, \sigma \rangle \to true, \quad if\ \sigma(x_d) = d1$

$\langle x_d = d1, \sigma \rangle \to false, \quad if\ \sigma(x_d) \ne d1$

$\langle x_d != d1, \sigma \rangle \to true, \quad if\ \sigma(x_d) \ne d1$

$\langle x_d != d1, \sigma \rangle \to false, \quad if\ \sigma(x_d) = d1$

EBexp:

$$\frac{\langle time, \sigma \rangle \to s1 \quad \langle b1, \sigma \rangle \to s2 \quad \langle b2, \sigma \rangle \to s3 \quad \cdots}{\langle agent^{time}(b1; b2; b3 \cdots), \sigma \rangle \to true},$$
$if\ \forall s \in (s1, s2, s3, \cdots), s = true$

$$\frac{\langle time, \sigma \rangle \to s1 \quad \langle b1, \sigma \rangle \to s2 \quad \langle b2, \sigma \rangle \to s3 \quad \cdots}{\langle agent^{time}(b1; b2; b3 \cdots), \sigma \rangle \to false},$$
$if\ \exists t \in (s1, s2, s3, \cdots), s = false$

$$\frac{\langle time, \sigma \rangle \to s1 \quad \langle location, \sigma \rangle \to s2 \quad \langle b1, \sigma \rangle \to s3 \cdots}{\langle agent^{time}_{location}(b1; b2; b3 \cdots), \sigma \rangle \to true},$$
$if\ \forall s \in (s1, s2, s3, s4 \cdots), s = true$

$$\frac{\langle time, \sigma \rangle \to s1 \quad \langle location, \sigma \rangle \to s2 \quad \langle b1, \sigma \rangle \to s3 \cdots}{\langle agent^{time}_{location}(b1; b2; b3 \cdots), \sigma \rangle \to false},$$
$if\ \exists s \in (s1, s2, s3, s4 \cdots), s = false$

$$\frac{\langle time, \sigma \rangle \to s1 \quad \langle location, \sigma \rangle \to s2 \quad \langle direction, \sigma \rangle \to s3 \cdots}{\langle agent^{time}_{(location, direction)}(b1; b2; b3 \cdots), \sigma \rangle \to true},$$
$if\ \forall s \in (s1, s2, s3, s4, s5 \cdots), s = true$

In the above operational semantics, In the complex event expressions of CEexp, we only express the semantics of the expressions which composed by the base event. The semantics of complex events are similar. If a complex event expression includes AND, the spatial and temporal sets of the complex event will be the union of the sub-events' spatial and temporal set. If a complex event expression includes OR, the spatial and temporal sets of the complex event are the sub-events' spatial and temporal set, which Meets the conditions.

5 SIMULATION AND RESULTS

There are a bus system and the bus lines as shown below. In the grid maps, the length of each grid is 600m. The bus will ply from the place START={(25,10)} to the place END={(10,24)}. There are two bus stations in the bus lines: BusStation1={(18,9)} and BusStation2={(10,8)}. And there are two corners of the bus lines: CORNER1={(25,16)} and CORNER2={(10,1)}.

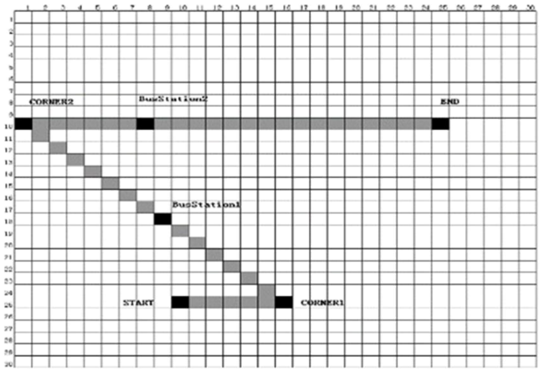

Fig. 3. The Grid Map of the Bus Line

The running schedule of the bus is as follows:

Table 1: The Schedule of Two Buses

Start Time	BusStaion1Time	BusStaion2 Time
9:10:00	9:29:00	9:49:00
9:15:00	9:34:00	9:54:00

There are two buses BusA and BusB start at 9:10 and 9:15 respectively. Their velocity curve shown as figure 4 and their distance curve shown as figure 5. The sampling frequency of the speed is 60 seconds.

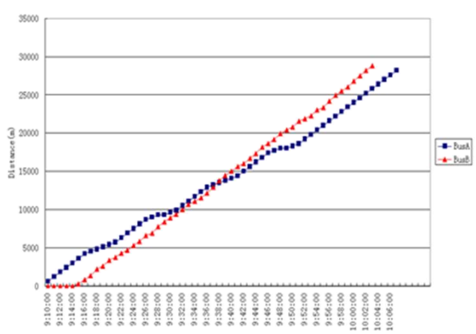

Fig. 4. The Velocity of Two Buses

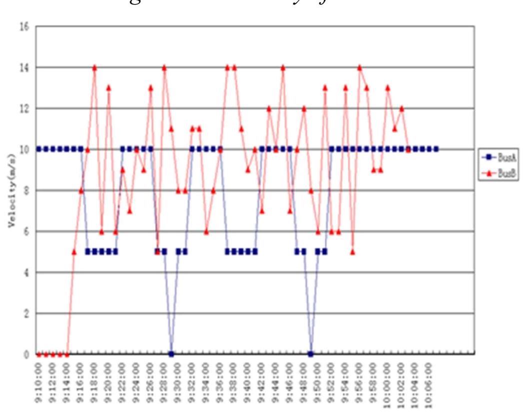

Fig. 5. The Distance of Two Buses

In order to monitor the irregularities in the bus running, we query the complex event as bellow:

(a) Buses are punctual arrival: the buses run according to the schedule and the time error does not exceed 30 seconds.

$$e1 = BusA_{x_l\ EQ\ \{(18,9)\}}^{x_t\ DURING\ \{(9:28:30,9:29:30)\}}$$

$$e2 = BusA_{x_l\ EQ\ \{(10,8)\}}^{x_t\ DURING\ \{(9:48:30,9:49:30)\}}$$

$$e3 = BusB_{x_l\ EQ\ \{(18,9)\}}^{x_t\ DURING\ \{(9:33:30,9:34:30)\}}$$

$$e4 = BusB_{x_l\ EQ\ \{(10,8)\}}^{x_t\ DURING\ \{(9:53:30,9:54:30)\}}$$

(b) Buses are overdrive: the corner speed is not greater than 6m/s and other sections can not be more than 12m/s.

$$e5 = BusA_{x_l\ IN\ L}(x_v > 12)$$

$$e6 = BusA_{x_l\ EQ\ CORNER1}(x_v > 6)$$

$$e7 = BusA_{x_l\ EQ\ CORNER2}(x_v > 6)$$

$$e8 = BusB_{x_l\ IN\ L}(x_v > 12)$$

$$e9 = BusB_{x_l\ EQ\ CORNER1}(x_v > 6)$$

$$e10 = BusB_{x_l\ EQ\ CORNER2}(x_v > 6)$$

(c) Buses are overtaking: the buses can not exceed the first departure of the bus.

$$e11 = (BusB_{x_l\ IN\ L1})\ EAST\ (BusA_{x_l\ IN\ L1})$$

$$e12 = (BusB_{x_l\ IN\ L2})\ NORTHWEST\ (BusA_{x_l\ IN\ L2})$$

$$e13 = (BusB_{x_l\ IN\ L3})\ EAST\ (BusA_{x_l\ IN\ L3})$$

According to the operational semantics of STeCEQL, we reason the above complex event expresses and the results shown in the following table:

Table 2: The Values of Complex Event Expresses

Event	True	False
e1	√	
e2	√	
e3		√
e4		√
e5		√
e6		√
e7		√
e8	√	
e9	√	
e10	√	
e11		√
e12		√
e13	√	

The values of the event e8 and ce3 are True in many times. The value of complex event ce3 is True after time interval (9:39:30,9:40:30). The value of event e8 is True in these time intervals:

(9:17:30,9:18:30), (9:19:30,9:20:30), (9:25:30, 9:26:30), (9:27:30,9:28:30), (9:36:30,9:37:30), (9 :37: 30,9:38: 30), (9:44: 30,9:45: 30), (9:50: 30,9:51: 30), (9:53: 30,9:54: 30), (9:55: 30,9:56: 30), (9:56: 30,9:57: 30), (10:00: 30,10:00: 30).

From the above results, we can conclude that BusA run more standardized, BusB run more mistaken and has the overtaking behavior. These results illustrate the effectiveness of the operational semantics of the STeCEQL language.

6 CONCLUSION

For the current complex event query language cannot be effectively expressed the spatio-temporal information of the internet of vehicles. In this paper, we introduce a temporal model, a novel spatial model based on the grid map and give a method to determine the relationship between the spatial position and orientation relations. Based on the temporal and spatial model, we give the syntax and operational semantics of STeCEQL. Finally, we describe the language is expressive and its operational semantics is valid by the reasoning of the data of a simulation of the bus system.

As the internet of vehicles is a typical distributed real-time system, we will further study their performance analysis in the distributed real-time system.

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