PSTeCEQL: A Novel Event Query Language for VANET's Uncertain Event Streams

Huiyong Li, Yixiang Chen and Baohua Wang

Software Engineering Institute, East China Normal University, Shanghai, P.R. China

ABSTRACT

In recent years, the complex event processing technology has been used to process the VANET's temporal and spatial event streams. However, we usually cannot get the accurate data because the device sensing accuracy limitations of the system. We only can get the uncertain data from the complex and limited environment of the VANET. Because the VANET's event streams are consist of the uncertain data, so they are also uncertain. How effective to express and process these uncertain event streams has become the core issue for the VANET system. To solve this problem, we propose a novel complex event query language PSTeCEQL (probabilistic spatio-temporal constraint event query language). Firstly, we give the definition of the possible world model of VANET's uncertain event streams. Secondly, we propose an event query language PSTeCEQL and give the syntax and the operational semantics of the language. Finally, we illustrate the validity of the PSTeCEQL by an example.

KEYWORDS

VANET, Internet of vehicles, Event stream, Event-driven Architecture, uncertain data, event query language， Mobile systems.

1. INTRODUCTION

In recent years, the VANET and Internet of Vehicles have made great achievements [1]. The VANET is a typical mobile system and Internet of Things' system. In VANET system, there are a lot of sensing devices in the vehicles and these sensing devices will produce a large number of temporal and spatial event streams when they are moving quickly.

Many scholars have processed the VANET's data steams by the complex event processing technology. Moody K has proposed a complex event query language SpaTec and this language can describe the spatial and temporal properties of the event streams of VANET [2,3]. Jin B has presented a event query language CPSL and this language can describe the relationship between the various temporal and spatial properties of the events [4]. Yixiang Chen has proposed a complex event query language STeCEQL and the language can describe the spatial and temporal relationships of the event streams in VANET [5,6].

The conventional data processing systems often assume that the data is accurate. However, with the rapid development of the sensor networks and the Internet of Things, the uncertain data of these systems causes the relevant researchers. According to statistics, the probability of the RFID tags, which can be correctly recognized by the sensors, is about 60% to 70%. The uncertain data in the sensor networks and the Internet of Things are ubiquitous and cannot be ignored. These uncertain data were produced by the following main reasons: 1) the original data is not accurate. The data collection devices' accuracy is limited, such as: various types of sensors, RFID scanning equipment, GPS equipment. In addition, the sensing device has different data precision in

DOI:10.5121/ijfcst.2015.5201

different working conditions. 2) In the data transmission process, the accuracy of the data was affected by the transmission bandwidth, transmission protocol and the other conditions.

Since the existing complex event processing language cannot effectively express the uncertain event in VANET. This paper presents a novel complex event processing language to VANET: PSTeCEQL (probabilistic spatio-temporal constraint event query language). The remainder of this paper is structured as follows: section 2 introduces the related works. Section 3 describes the possible world model of VANET'S uncertain event stream. Section 4 presents the syntax of PSTeCEQL. Section 5 gives operational semantics of PSTeCEQL. The last Section concludes this paper.

2. RELATED WORKS

In the event-driven architecture systems, data is abstracted as the event and the uncertain data is abstracted as the uncertain data. In the studies of the uncertain events, there are two types uncertain event model: Probability theory model [7-9] and the fuzzy set theory model [10-12]. Our uncertain event model: the possible world model which based on the probability theory, is very widely recognized now [13,14].

For the uncertain data processing problem, the current research results focus on the uncertain database fields. Many scholars have conducted in-depth research in the uncertain database's storage, indexing and query. Since the data streams arrive at very fast rate and are very large amount, the data stream processing system cannot directly use the methods and techniques of the conventional database processing system. Compared with the uncertain database's research, the studies of uncertain data stream processing system is still in its infancy. Cormode has proposed the uncertain data stream query system with probability parameters [15]. Zhang has designed the frequently query on uncertain data stream query method [16]. As an important uncertain data processing area, the uncertain event stream processing system has made these major achievements: Kanagal has extended the relational database system in order to be able to deal with uncertain event streams [17]. Christopher has proposed an uncertain event stream processing system which named Lahar [18].

In the VANET system, users usually only need query the events with specially trustworthiness. In view of this situation, we have proposed a novel uncertain VANET's event stream query language: PSTeCEQL (probabilistic spatio-temporal constraint event query language). Comparing with the other researches, ours mainly have the following improvements: the PSTeCEQL language can reduce the numbers of the uncertain event instances by setting the probability threshold manner, so to improve the efficiency of the event stream processing system.

3. POSSIBLE WORLD MODEL OF VANET'S UNCERTAIN EVENT STREAMS

In order to deal with the VANET's uncertain data, we should firstly establish the model of these uncertain data. The possible world model is the most common uncertain data model, which evolved many instances from the model and these instances called the possible world data instances. The types of the possible world model are: the relational data model, semi-structured data model and data flow models, etc.

The data flow's possible world model is as below:

Definition 1: Suppose each tuple can get more value in a discrete domain D, the trustworthiness of the data stream for each tuple is based on a probability density function of these discrete domains. For example, a tuple is described as (<I_1:P_1>,…,<I_m:P_m>), then $\forall s \in [1, m]$, there is $I_s \in$ D, Pr[Is]=Ps, and $\sum_{1}^{m} P_s \leq 1$, and said the probability density function data value Ps is the trustworthiness.

For example, a speed sensor has generated a data stream and the speed range is (0, 80], the possible data flow are: {(<25:0.7>,<28:0.2>), (<26:0.85>), (<35:0.6>, <40:0.13>),…}.

In the VANET system, we use this type uncertain data flow's possible world model. Because the VANET's uncertain data is a multi-source data, so we extended the above model to the VANET's possible world model as bellow:

Suppose a tuple can be represented $[(<I_{11}:P_{11}>, \cdots, <I_{1m}:P_{1m}>), \cdots, (<I_{n1}:P_{n1}>, \cdots, <I_{nm}:P_{nm}>)]$, then$\forall s \in [1, m]$, there is $I_s \in$ B, Pr[I_s]=P_s, and $\sum_{1}^{m} P_s \leq 1$.

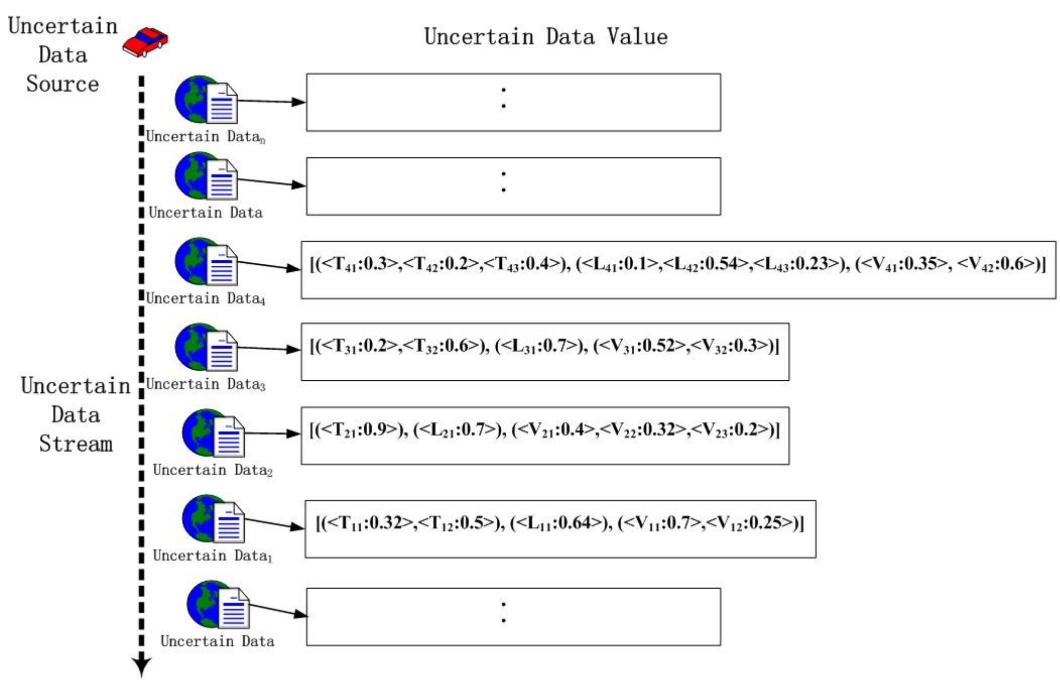

Figure1. The uncertain data flow of VANET

Example 1: As shown in Figure 1, assume that there are three type data of the data stream of the VANET: the time data, the position data and the speed data. We denoted these data as T, L,V: T represents a time data value, L represents a spatial data value and V represents a velocity value.

In the event-driven architecture, a set of meaningful data were looked as a based event instance.

Therefore, in the event-driven architecture VANET system, the uncertain data have caused the event is also uncertain. Based on the above possible world model of the uncertain data of VANET system, we give the definition of the possible world model of the event stream of VANET.

The uncertain based event stream is shown as Figure 2, and the definition is as below:

Definition 2: A based event tuple is described as (<E_1:P_1>,…,<E_m:P_m>), then $\forall s \in [1, m]$, there is $Pr[I_s]=P_s$, and $\sum_{1}^{m} P_s \le 1$, and said the probability density function data value P_s is the trustworthiness.

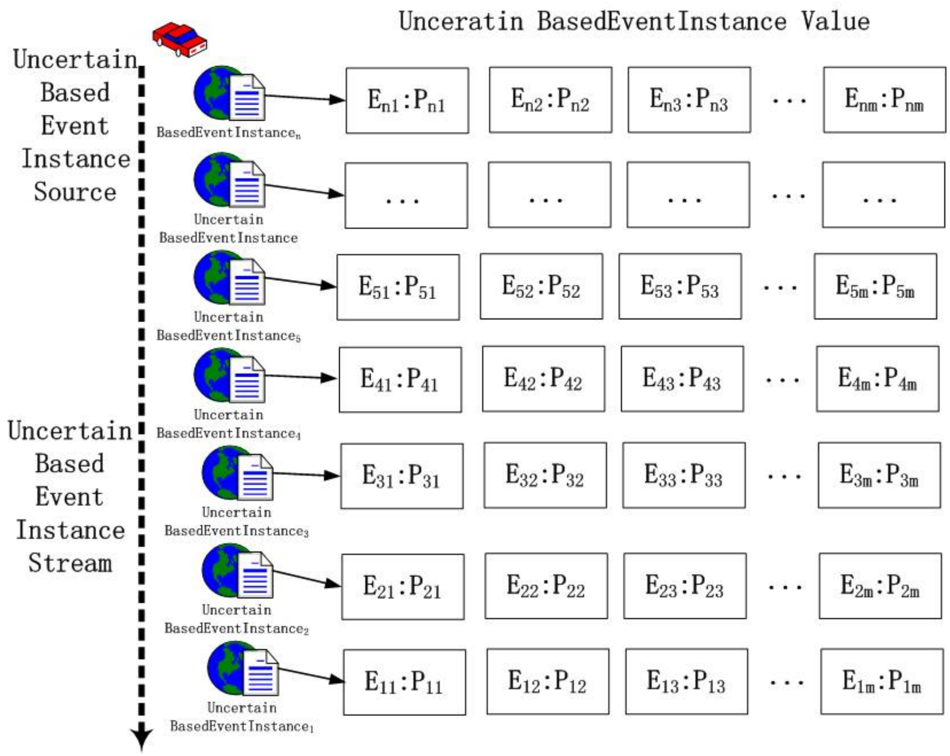

Figure2. The uncertain based event flow of VANET

According to this definition, the fourth data of the Example 1's data stream: [(<T_{41}:0.3>,<T_{42}:0.2>,<T_{43}:0.4>,), (<L_{41}:0.1>,<L_{42}:0.54>,<L_{43}:0.23>), (<V_{41}:0.35>, <V_{42}:0.6>)] represents a uncertain based event instance:

(< E_1: P_1>, < E_2:P_2>, < E_3: P_3>, < E_4: P_4>, < E_5:P_5>, < E_6:P_6>, < E_7: P_7>, < E_8: P_8>, < E_9:P_9>,< E_{10}:P_{10}>, < E_{11}: P_{11}>, < E_{12}:P_{12}>, < E_{13}: P_{13}>, <E_{14}:P_{14}>, < E_{15}:P_{15}>, < E_{16}:P_{16}>, < E_{17}: P_{17}>, < E_{18}: P_{18}>).

Among them, E_1= (T_{41}, L_{41}, V_{41}), E_2= (T_{42}, L_{41}, V_{41}), E_3= (T_{43}, L_{41}, V_{41}), E_4= (T_{41}, L_{42}, V_{41}), E_5= (T_{42}, L_{42}, V_{41}), E_6= (T_{43}, L_{42}, V_{41}), E_7= (T_{41}, L_{43}, V_{41}), E_8= (T_{42}, L_{43}, V_{41}), E_9= (T_{43}, L_{43}, V_{41}),E_{10}= (T_{41}, L_{41}, V_{42}), E_{11}= (T_{42}, L_{41}, V_{42}), E_{12}= (T_{43}, L_{41}, V_{42}), E_{13}= (T_{41}, L_{42}, V_{42}), E_{14}= (T_{42}, L_{42}, V_{42}), E_{15}= (T_{43}, L_{42}, V_{42}), E_{16}= (T_{41}, L_{43}, V_{42}), E_{17}= (T_{42}, L_{43}, V_{42}), E_{18}= (T_{43}, L_{43}, V_{42}).

There are 3 × 3 × 2=18 based event instances in the possible world model of the event and the trustworthiness of each instance can be calculated according to the probability theory's formula Pr[E]=Pr[T] × Pr[L] × Pr[V]. For example: P_1=0.3 × 0.1 × 0.35=0.0105.

The complex event instance can be calculated by the based event instances; therefore, we can define the uncertain complex event possible world model by the based event possible world model.

Definition 3: A complex event tuple is described as (<CE_1:P_1>,…,<CE_m:P_m>), then $\forall s \in [1, m]$, there is Pr[CE_s]=P_s, and $\sum_{1}^{m} P_s \leq 1$, and said the probability density function data value P_s is the trustworthiness.

Example 2: $CE_1 = (E_1 \vee E_2) \wedge E_3$
Which, E_1's possible events: (<E_{11}: 0.35>, <E_{12}: 0.42>, <E_{13}: 0.13>),
E_2's possible events: (<E_{21}:0.26>, <E_{22}:0.58>),
E_3's possible events: (<E_{31}:0.35>, <E_{32}:0.42>,<E_{33}:0.13>),

And the CE_1 possible events are:

(<($(E_{11} \vee E_{21}) \wedge E_{31}$):$P_1$>,<($(E_{12} \vee E_{21}) \wedge E_{31}$):$P_2$>,<($(E_{13} \vee E_{21}) \wedge E_{31}$):$P_3$>,
<($(E_{11} \vee E_{22}) \wedge E_{31}$):$P_4$>,<($(E_{12} \vee E_{22}) \wedge E_{31}$):$P_5$>,<($(E_{13} \vee E_{22}) \wedge E_{31}$):$P_6$>,
<($(E_{11} \vee E_{21}) \wedge E_{32}$):$P_7$>,<($(E_{12} \vee E_{21}) \wedge E_{32}$):$P_8$>,<($(E_{13} \vee E_{21}) \wedge E_{32}$):$P_9$>,
<($(E_{11} \vee E_{22}) \wedge E_{32}$):$P_{10}$>,<($(E_{12} \vee E_{22}) \wedge E_{32}$):$P_{11}$>,<($(E_{13} \vee E_{22}) \wedge E_{32}$):$P_{12}$>,
<($(E_{11} \vee E_{21}) \wedge E_{33}$):$P_{13}$>,<($(E_{12} \vee E_{21}) \wedge E_{33}$):$P_{14}$>,<($(E_{13} \vee E_{21}) \wedge E_{33}$):$P_{15}$>,
<($(E_{11} \vee E_{22}) \wedge E_{33}$):$P_{16}$>,<($(E_{12} \vee E_{22}) \wedge E_{33}$):$P_{17}$>,<($(E_{13} \vee E_{22}) \wedge E_{33}$):$P_{18}$>,
…)

As shown in the possible world model of the based event instance and the complex event instance, the numbers of the event instance will increase quickly with the event's complex level increasing and the computing system will be difficult to accomplish the processing task. How to efficient processing the huge collection of instances of the possible world is the main difference between the normal event processing system and the uncertain event processing system.

However, in the practical application of VANET's, not all events are useful to the user's making decision. Users usually will limit the trustworthiness of the event during the querying. For example: an user requires the trustworthiness of a based event instance is greater than 0.5, another user requires the trustworthiness of a complex event instance is greater than 0.3, etc.

According the above ideas, we proposed a novel event query language: PSTeCEQL.

4. SYNTAX OF PSTECEQL

It is assumed that the syntax structure of the constants and the variables are known. For example: the variable is a collection of the non-null letters. So, the syntax of the PSTeCEQL is as follows:

1. The uncertain object identifier expressions **POBEXP**:

$$pob\exp ::= TRUE : P | FALSE : P | x_{id} = ID : P | x_{id}! = ID : P$$

$$| pob\exp_1 \wedge pob\exp_2 : P | pob\exp_1 \vee pob\exp_2 : P$$

2. The general uncertain numerical attribute expressions **PABEXP**:

$$pab\exp ::= TRUE : P | FALSE : P | x_a = A : P | x_a! = A : P$$

$$| x_a > A : P | x_a \geq A : P | x_a < A : P | x_a \leq A : P$$

$$|pab\exp_1 \wedge pab\exp_2 : P|pab\exp_1 \vee pab\exp_2 : P$$

3. The uncertain temporal attribute expressions **PTBEXP**:

$$ptb\exp ::= TRUE : P|FALSE : P|x_t\ BEFORE\ T : P|x_t\ EQUAL\ T : P$$

$$|x_t\ OVERLAP\ T : P|x_t\ DURING\ T : P$$

$$|ptb\exp_1 \wedge ptb\exp_2 : P|ptb\exp_1 \vee ptb\exp_2 : P$$

4. The uncertain spatial attribute expressions **PLBEXP**:

$$plb\exp ::= TRUE : P|FALSE : P|x_{loc}\ EQ\ LOC : P|x_{loc}\ OP\ LOC : P$$

$$|x_{loc}\ IN\ LOC : P|x_{loc}\ NORTH\ LOC : P|x_{loc}\ EAST\ LOC : P$$

$$|x_{loc}\ NORTHEAST\ LOC : P|x_{loc}\ NORTHWEAST\ LOC : P$$

$$|plb\exp_1 \wedge plb\exp_2 : P|plb\exp_1 \vee plb\exp_2 : P$$

5. The uncertain event expressions **PEBEXP**:

$$peb\exp ::= TRUE : P|FALSE : P|pob\exp; ptb\exp; plb\exp; pab\exp : P$$

$$|peb\exp_1 \wedge peb\exp_2 : P|peb\exp_1 \vee peb\exp_2 : P$$

$$|peb\exp_1\ BEFORE\ peb\exp_2 : P|peb\exp_1\ EQUAL\ peb\exp_2 : P$$

$$|peb\exp_1\ OVERLAP\ peb\exp_2 : P|peb\exp_1\ DURING\ peb\exp_2 : P$$

$$|peb\exp_1\ EQ\ peb\exp_2 : P|peb\exp_1\ OP\ peb\exp_2 : P|peb\exp_1\ IN\ peb\exp_2 : P$$

$$|peb\exp_1\ NORTH\ peb\exp_2 : P|peb\exp_1\ EAST\ peb\exp_2 : P$$

$$|peb\exp_1\ NORTHEAST\ peb\exp_2 : P|peb\exp_1\ NORTHWEST\ peb\exp_2 : P$$

For example: e_1=((CarId=10584:0.89); (CarTime DURING (19:18:20, 19:19:10):0.93); (CarLoc NORTH {(1052,306), (1052,307), (1052,308)}:0.94); ((V<100):0.96);((Acceleration <30):0.94):0.6);
e_2=(((LightId=63254:0.95); (LightTime DURING (19:18:20, 19:18:40):0.93); (Signal=GREEN:0.99)):0.87);
e_3=($e_1 \wedge e_2$:0.5);
The syntax of the PSTeCEQL language listed above and the following are the operational semantics of the language.

5. OPERATIONAL SEMANTIC OF PSTECEQL

Each expression's value was decided by the current environmental of the variable storage. In VANET system, the subscribers have received event instances and stored the event instance in the memory firstly. Then the event instances will be processed by the system following the principle of first-come, first-served (FCFS). Finally, the PSTeCEQL expressions' value will be calculated.

Based on the above setting, the operational semantics of the PSTeCEQL as below:

1. The operational semantics of the **POBEXP**:

(1) $\frac{\langle x_{pid},\delta_{id}\rangle\rightarrow P_0}{\langle(TRUE:P),\delta_{id}\rangle\rightarrow\langle(TRUE:P_0),\delta_{id}\rangle}, if\ (P_0 \geq P)$;

(2) $\frac{\langle x_{pid},\delta_{id}\rangle\rightarrow P_0}{\langle(FALSE:P),\delta_{id}\rangle\rightarrow\langle(FALSE:P_0),\delta_{id}[\emptyset/x_{id},0/x_{pid}]\rangle}, if\ (P_0 < P)$;

(3) $\frac{\frac{\langle x_{pid},\delta_{id}\rangle\rightarrow P_0}{\langle x_{id},\delta_{id}\rangle\rightarrow ID_0}}{\langle(x_{id}=ID:P),\delta_{id}\rangle\rightarrow\langle(TRUE:P_0),\delta_{id}\rangle}, if\ (P_0 \geq P)\ and\ (ID_0 = ID)$;

$\frac{\frac{\langle x_{pid},\delta_{id}\rangle\rightarrow P_0}{\langle x_{id},\delta_{id}\rangle\rightarrow ID_0}}{\langle(x_{id}=ID:P),\delta_{id}\rangle\rightarrow\langle(FALSE:P_0),\delta_{id}[\emptyset/x_{id},0/x_{pid}]\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, ID_0 \neq ID)$;

(4) $\frac{\frac{\langle x_{id},\delta_{id}\rangle\rightarrow P_0}{\langle x_{id},\delta_{id}\rangle\rightarrow ID_0}}{\langle(x_{id}!=ID:P),\delta_{id}\rangle\rightarrow\langle(TRUE:P_0),\delta_{id}\rangle}, if\ (P_0 \geq P)\ and\ (ID_0 \neq ID)$;

$\frac{\frac{\langle x_{id},\delta_{id}\rangle\rightarrow P_0}{\langle x_{id},\delta_{id}\rangle\rightarrow ID_0}}{\langle(x_{id}!=ID:P),\delta_{id}\rangle\rightarrow\langle(FALSE:P_0),\delta_{id}[\emptyset/x_{id},0/x_{pid}]\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, ID_0 = ID)$;

(5) $\frac{\frac{\langle x_{pid1},\delta_{id1}\rangle\rightarrow P_1\ and\ \langle x_{pid2},\delta_{id2}\rangle\rightarrow P_2}{\langle(obexp_1:P'),\delta_{id1}\rangle\rightarrow\langle(TRUE:P_1),\delta_{id1}\rangle\ and\langle(obexp_2:P''),\delta_{id2}\rangle\rightarrow\langle(TRUE:P_2),\delta_{id2}\rangle}}{\langle(pobexp_1\wedge pobexp_2:P),(\delta_{id1},\delta_{id2})\rangle\rightarrow\langle(TRUE:P_1\times P_2),(\delta_{id1},\delta_{id2})\rangle}$,

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P$;

$\frac{\frac{\langle x_{pid1},\delta_{id1}\rangle\rightarrow P_1\ and\ \langle x_{pid2},\delta_{id2}\rangle\rightarrow P_2}{\langle(obexp_1:P'),\delta_{id1}\rangle\rightarrow\langle(FALSE:P_1),\delta_{id1}[\emptyset/x_{id1},0/x_{pid1}]\rangle\ or\langle(obexp_2:P''),\delta_{id2}\rangle\rightarrow\langle(FALSE:P_2),\delta_{id2}[\emptyset/x_{id2},0/x_{pid2}]\rangle}}{\langle(pobexp_1\wedge pobexp_2:P),(\delta_{id1},\delta_{id2})\rangle\rightarrow\langle(FALSE:P_1\times P_2),(\delta_{id1}[\emptyset/x_{id1},0/x_{pid1}],\delta_{id2}[\emptyset/x_{id2},0/x_{pid2}])\rangle}$,
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P$;

(6) $\frac{\frac{\langle x_{pid1},\delta_{id1}\rangle\rightarrow P_1\ and\ \langle x_{pid2},\delta_{id2}\rangle\rightarrow P_2}{\langle(obexp_1:P'),\delta_{id1}\rangle\rightarrow\langle(TRUE:P_1),\delta_{id1}\rangle\ or\langle(obexp_2:P''),\delta_{id2}\rangle\rightarrow\langle(TRUE:P_2),\delta_{id2}\rangle}}{\langle(pobexp_1\vee pobexp_2:P),(\delta_{id1},\delta_{id2})\rangle\rightarrow\langle(TRUE:P_1+P_2-P_1\times P_2),(\delta_{id1},\delta_{id2})\rangle}$,

$if\ (P_1 \geq P'\ or\ P_2 \geq P'')\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P$;

$\frac{\frac{\langle x_{pid1},\delta_{id1}\rangle\rightarrow P_1\ and\ \langle x_{pid2},\delta_{id2}\rangle\rightarrow P_2}{\langle(obexp_1:P'),\delta_{id1}\rangle\rightarrow\langle(FALSE:P_1),\delta_{id1}[\emptyset/x_{id1},0/x_{pid1}]\rangle\ and\langle(obexp_2:P''),\delta_{id2}\rangle\rightarrow\langle(FALSE:P_2),\delta_{id2}[\emptyset/x_{id2},0/x_{pid2}]\rangle}}{\langle(pobexp_1\wedge pobexp_2:P),(\delta_{id1},\delta_{id2})\rangle\rightarrow\langle(FALSE:P_1+P_2-P_1\times P),(\delta_{id1}[\emptyset/x_{id1},0/x_{pid1}],\delta_{id2}[\emptyset/x_{id2},0/x_{pid2}])\rangle}$,
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P$;

2. The operational semantics of the **PABEXP**

(1) $\frac{\langle x_{pa},\delta_{a}\rangle\rightarrow P_0}{\langle(TRUE:P),\delta_{a}\rangle\rightarrow\langle(TRUE:P_0),\delta_{a}\rangle}, if\ (P_0 \geq P)$;

(2) $\frac{\langle x_{pa},\delta_{a}\rangle\rightarrow P_0}{\langle(FALSE:P),\delta_{a}\rangle\rightarrow\langle(FALSE:P_0),\delta_{a}[\emptyset/x_{a},0/x_{pa}]\rangle}, if\ (P_0 < P)$;

(3) $\frac{\frac{\langle x_{pa},\delta_{a}\rangle\rightarrow P_0}{\langle x_{a},\delta_{a}\rangle\rightarrow A_0}}{\langle(x_{a}=A:P),\delta_{a}\rangle\rightarrow\langle(TRUE:P_0),\delta_{a}\rangle}, if\ (P_0 \geq P)\ and\ (A_0 = A)$;

$\frac{\frac{\langle x_{pa},\delta_{a}\rangle\rightarrow P_0}{\langle x_{a},\delta_{a}\rangle\rightarrow A_0}}{\langle(x_{a}=A:P),\delta_{a}\rangle\rightarrow\langle(FALSE:P_0),\delta_{a}[\emptyset/x_{a},0/x_{pa}]\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, A_0 \neq A)$;

(4) $\frac{\frac{\langle x_a,\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a != A:P),\delta_a\rangle \rightarrow \langle (TRUE:P_0),\delta_a\rangle}, if\ (P_0 \geq P)\ and\ (A_0 \neq A)$;

$\frac{\frac{\langle x_a,\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a != A:P),\delta_a\rangle \rightarrow \left\langle (FALSE:P_0),\delta_a[\emptyset/x_a,0/x_{pa}]\right\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, A_0 = A)$;

(5) $\frac{\frac{\langle x_{pa},\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a > A:P),\delta_a\rangle \rightarrow \langle (TRUE:P_0),\delta_a\rangle}, if\ (P_0 \geq P)\ and\ (A_0 > A)$;

$\frac{\frac{\langle x_{pa},\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a > A:P),\delta_a\rangle \rightarrow \left\langle (FALSE:P_0),\delta_a[\emptyset/x_a,0/x_{pa}]\right\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, A_0 \leq A)$;

(6) $\frac{\frac{\langle x_a,\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a >= A:P),\delta_a\rangle \rightarrow \langle (TRUE:P_0),\delta_a\rangle}, if\ (P_0 \geq P)\ and\ (A_0 \geq A)$;

$\frac{\frac{\langle x_a,\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a >= A:P),\delta_a\rangle \rightarrow \left\langle (FALSE:P_0),\delta_a[\emptyset/x_a,0/x_{pa}]\right\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, A_0 < A)$;

(7) $\frac{\frac{\langle x_{pa},\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a < A:P),\delta_a\rangle \rightarrow \langle (TRUE:P_0),\delta_a\rangle}, if\ (P_0 \geq P)\ and\ (A_0 < A)$;

$\frac{\frac{\langle x_{pa},\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a < A:P),\delta_a\rangle \rightarrow \left\langle (FALSE:P_0),\delta_a[\emptyset/x_a,0/x_{pa}]\right\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, A_0 \geq A)$;

(8) $\frac{\frac{\langle x_a,\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a >= A:P),\delta_a\rangle \rightarrow \langle (TRUE:P_0),\delta_a\rangle}, if\ (P_0 \geq P)\ and\ (A_0 \geq A)$;

$\frac{\frac{\langle x_a,\delta_a\rangle \rightarrow P_0}{\langle x_a,\delta_a\rangle \rightarrow A_0}}{\langle (x_a >= A:P),\delta_a\rangle \rightarrow \left\langle (FALSE:P_0),\delta_a[\emptyset/x_a,0/x_{pa}]\right\rangle}, if\ P_0 < P\ or\ (P_0 \geq P, A_0 < A)$;

(9) $\frac{\frac{\left\langle x_{pa1},\delta_{a1}\right\rangle \rightarrow P_1\ and\ \left\langle x_{pa2},\delta_{a2}\right\rangle \rightarrow P_2}{\langle (abexp_1:P'),\delta_{a1}\rangle \rightarrow \langle (TRUE:P_1),\delta_{a1}\rangle\ and \langle (abexp_2:P''),\delta_{a2}\rangle \rightarrow \langle (TRUE:P_2),\delta_{a2}\rangle}}{\langle (pabexp_1 \wedge pabexp_2:P),(\delta_{a1},\delta_{a2})\rangle \rightarrow \langle (TRUE:P_1 \times P_2),(\delta_{a1},\delta_{a2})\rangle}$,

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P$;

$\frac{\frac{\left\langle x_{pa1},\delta_{a1}\right\rangle \rightarrow P_1\ and\ \left\langle x_{pa2},\delta_{a2}\right\rangle \rightarrow P_2}{\langle (abexp_1:P'),\delta_{a1}\rangle \rightarrow \left\langle (FALSE:P_1),\delta_{a1}[\emptyset/x_{a1},0/x_{pa1}]\right\rangle\ or \langle (abexp_2:P''),\delta_{a2}\rangle \rightarrow \left\langle (FALSE:P_2),\delta_{a2}[\emptyset/x_{a2},0/x_{pa2}]\right\rangle}}{\langle (pabexp_1 \wedge pabexp_2:P),(\delta_{id1},\delta_{id2})\rangle \rightarrow \left\langle (FALSE:P_1 \times P_2),(\delta_{id1}[\emptyset/x_{id1},0/x_{pid1}],\delta_{id2}[\emptyset/x_{id2},0/x_{pid2}])\right\rangle}$,

$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P$;

(10) $\frac{\frac{\left\langle x_{pa1},\delta_{a1}\right\rangle \rightarrow P_1\ and\ \left\langle x_{pa2},\delta_{a2}\right\rangle \rightarrow P_2}{\langle (abexp_1:P'),\delta_{a1}\rangle \rightarrow \langle (TRUE:P_1),\delta_{a1}\rangle\ or \langle (abexp_2:P''),\delta_{a2}\rangle \rightarrow \langle (TRUE:P_2),\delta_{a2}\rangle}}{\langle (pabexp_1 \vee pabexp_2:P),(\delta_{a1},\delta_{a2})\rangle \rightarrow \langle (TRUE:P_1+P_2-P_1 \times P_2),(\delta_{a1},\delta_{a2})\rangle}$,

$if\ (P_1 \geq P'\ or\ P_2 \geq P'')\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P$;

$\frac{\frac{\left\langle x_{pa1},\delta_{a1}\right\rangle \rightarrow P_1\ and\ \left\langle x_{pa2},\delta_{a2}\right\rangle \rightarrow P_2}{\langle (abexp_1:P'),\delta_{a1}\rangle \rightarrow \left\langle (FALSE:P_1),\delta_{a1}[\emptyset/x_{a1},0/x_{pa1}]\right\rangle\ and \langle (abexp_2:P''),\delta_{a2}\rangle \rightarrow \left\langle (FALSE:P_2),\delta_{a2}[\emptyset/x_{a2},0/x_{pa2}]\right\rangle}}{\langle (pabexp_1 \vee pabexp_2:P),(\delta_{a1},\delta_{a2})\rangle \rightarrow \left\langle (FALSE:P_1+P_2-P_1 \times P),(\delta_{a1}[\emptyset/x_{a1},0/x_{pa1}],\delta_{a2}[\emptyset/x_{a2},0/x_{pa2}])\right\rangle}$,

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P$;

3. The operational semantics of the **PTBEXP**

(1) $\frac{\left\langle x_{pt},\delta_t\right\rangle \rightarrow P_0}{\langle (TRUE:P),\delta_t\rangle \rightarrow \langle (TRUE:P_0),\delta_t\rangle}, if\ (P_0 \geq P)$;

(2) $\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle (FALSE{:}P),\delta_t\rangle\to\langle (FALSE{:}P_0),\delta_t[\emptyset/x_t,0/x_{pt}]\rangle}, if(P_0<P);$

(3) $\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ BEFORE\ T{:}P),\delta_t\rangle\to\langle (TRUE{:}P_0),\delta_t\rangle}, if\ (P_0\geq P)\ and\ (T_0\ BEFORE\ T);$

$\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ BEFORE\ T{:}P),\delta_t\rangle\to\langle (FALSE{:}P_0),\delta_t[\emptyset/x_t,0/x_{pt}]\rangle}, if\ P_0<P\ or\ (P_0\geq P, T_0\ \overline{BEOFRE}\ T);$

(4) $\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ EQUAL\ T{:}P),\delta_t\rangle\to\langle (TRUE{:}P_0),\delta_t\rangle}, if\ (P_0\geq P)\ and\ (T_0\ EQUAL\ T);$

$\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ EQUAL\ T{:}P),\delta_t\rangle\to\langle (FALSE{:}P_0),\delta_t[\emptyset/x_t,0/x_{pt}]\rangle}, if\ P_0<P\ or\ (P_0\geq P, T_0\ \overline{EQUAL}\ T);$

(5) $\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ OVERLAP\ T{:}P),\delta_t\rangle\to\langle (TRUE{:}P_0),\delta_t\rangle}, if\ (P_0\geq P)\ and\ (T_0\ OVERLAP\ T);$

$\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ OVERLAP\ T{:}P),\delta_t\rangle\to\langle (FALSE{:}P_0),\delta_t[\emptyset/x_t,0/x_{pt}]\rangle}, if\ P_0<P\ or\ (P_0\geq P, T_0\ \overline{OVERLAP}\ T);$

(6) $\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ DURING\ T{:}P),\delta_t\rangle\to\langle (TRUE{:}P_0),\delta_t\rangle}, if\ (P_0\geq P)\ and\ (T_0\ DURING\ T);$

$\frac{\frac{\langle x_{pt},\delta_t\rangle\to P_0}{\langle x_t,\delta_t\rangle\to T_0}}{\langle (x_t\ DURING\ T{:}P),\delta_t\rangle\to\langle (FALSE{:}P_0),\delta_t[\emptyset/x_t,0/x_{pt}]\rangle}, if\ P_0<P\ or\ (P_0\geq P, T_0\ \overline{DURING}\ T);$

(7) $\frac{\frac{\langle x_{pt1},\delta_{t1}\rangle\to P_1\ and\ \langle x_{pt2},\delta_{t2}\rangle\to P_2}{\langle (tb\exp_1{:}P'),\delta_{t1}\rangle\to\langle (TRUE{:}P_1),\delta_{t1}\rangle\ and\langle (tb\exp_2{:}P''),\delta_{t2}\rangle\to\langle (TRUE{:}P_2),\delta_{t2}\rangle}}{\langle (ptb\exp_1\wedge ptb\exp_2{:}P),(\delta_{t1},\delta_{t2})\rangle\to\langle (TRUE{:}P_1\times P_2),(\delta_{t1},\delta_{t2})\rangle},$

$if\ P_1\geq P'\ and\ P_2\geq P''\ and\ P_1\times P_2\geq P;$

$\frac{\frac{\langle x_{pt1},\delta_{t1}\rangle\to P_1\ and\ \langle x_{pt2},\delta_{t2}\rangle\to P_2}{\langle (tb\exp_1{:}P'),\delta_{t1}\rangle\to\langle (FALSE{:}P_1),\delta_{t1}[\emptyset/x_{t1},0/x_{pt1}]\rangle\ or\langle (tb\exp_2{:}P''),\delta_{t2}\rangle\to\langle (FALSE{:}P_2),\delta_{t2}[\emptyset/x_{t2},0/x_{pt2}]\rangle}}{\langle (ptb\exp_1\wedge ptb\exp_2{:}P),(\delta_{t1},\delta_{t2})\rangle\to\langle (FALSE{:}P_1\times P_2),(\delta_{t1}[\emptyset/x_{t1},0/x_{pt1}],\delta_{t2}[\emptyset/x_{t2},0/x_{pt2}])\rangle},$

$if\ P_1<P'\ or\ P_2<P''\ or\ P_1\times P_2<P;$

(8) $\frac{\frac{\langle x_{pt1},\delta_{t1}\rangle\to P_1\ and\ \langle x_{pt2},\delta_{t2}\rangle\to P_2}{\langle (tb\exp_1{:}P'),\delta_{t1}\rangle\to\langle (TRUE{:}P_1),\delta_{t1}\rangle\ or\langle (tb\exp_2{:}P''),\delta_{t2}\rangle\to\langle (TRUE{:}P_2),\delta_{t2}\rangle}}{\langle (ptb\exp_1\vee ptb\exp_2{:}P),(\delta_{t1},\delta_{t2})\rangle\to\langle (TRUE{:}P_1+P_2-P_1\times P_2),(\delta_{t1},\delta_{t2})\rangle},$

$if\ (P_1\geq P'\ or\ P_2\geq P'')\ and\ (P_1+P_2-P_1\times P_2)\geq P;$

$\frac{\frac{\langle x_{pt1},\delta_{t1}\rangle\to P_1\ and\ \langle x_{pt2},\delta_{t2}\rangle\to P_2}{\langle (tb\exp_1{:}P'),\delta_{t1}\rangle\to\langle (FALSE{:}P_1),\delta_{t1}[\emptyset/x_{t1},0/x_{pt1}]\rangle\ and\langle (tb\exp_2{:}P''),\delta_{t2}\rangle\to\langle (FALSE{:}P_2),\delta_{t2}[\emptyset/x_{t2},0/x_{pt2}]\rangle}}{\langle (ptb\exp_1\vee ptb\exp_2{:}P),(\delta_{t1},\delta_{t2})\rangle\to\langle (FALSE{:}P_1+P_2-P_1\times P),(\delta_{t1}[\emptyset/x_{t1},0/x_{pt1}],\delta_{t2}[\emptyset/x_{t2},0/x_{pt2}])\rangle},$

$if\ P_1\geq P'\ and\ P_2\geq P''\ and\ (P_1+P_2-P_1\times P_2)\geq P;$

4. The operational semantics of the **PLBEXP**:

(1) $\frac{\langle x_{ploc},\delta_{loc}\rangle\to P_0}{\langle (TRUE{:}P),\delta_{loc}\rangle\to\langle (TRUE{:}P_0),\delta_{loc}\rangle}, if\ (P_0\geq P);$

(2) $\frac{\langle x_{ploc},\delta_{loc}\rangle\to P_0}{\langle (FALSE{:}P),\delta_{loc}\rangle\to\langle (FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle}, if\ (P_0<P);$

(3) $\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\to P_0}{\langle x_{loc},\delta_{loc}\rangle\to LOC_0}}{\langle (x_{loc}\ EQ\ LOC{:}P),\delta_{loc}\rangle\to\langle (TRUE{:}P_0),\delta_{loc}\rangle}, if\ (P_0\geq P)\ and\ (LOC_0\ EQ\ LOC);$

$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\to P_0}{\langle x_{loc},\delta_{loc}\rangle\to LOC_0}}{\langle (x_{loc}\ EQ\ LOC{:}P),\delta_t\rangle\to\langle (FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle}, if\ P_0<P\ or\ (P_0\geq P, LOC_0\ \overline{EQ}\ LOC);$

(4) $\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\to P_0}{\langle x_{loc},\delta_{loc}\rangle\to LOC_0}}{\langle (x_{loc}\ OP\ LOC{:}P),\delta_{loc}\rangle\to\langle (TRUE{:}P_0),\delta_{loc}\rangle}, if\ (P_0\geq P)\ and\ (LOC_0\ OP\ LOC);$

$$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ OP\ LOC{:}P),\delta_t\rangle\rightarrow\langle(FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle},\ if\ P_0<P\ or\ (P_0\geq P,LOC_0\ \overline{OP}\ LOC);$$

(5) $$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ IN\ LOC{:}P),\delta_{loc}\rangle\rightarrow\langle(TRUE{:}P_0),\delta_{loc}\rangle},\ if\ (P_0\geq P)\ and\ (LOC_0\ IN\ LOC);$$

$$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ IN\ LOC{:}P),\delta_t\rangle\rightarrow\langle(FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle},\ if\ P_0<P\ or\ (P_0\geq P,LOC_0\ \overline{IN}\ LOC);$$

(6) $$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ NORTH\ LOC{:}P),\delta_{loc}\rangle\rightarrow\langle(TRUE{:}P_0),\delta_{loc}\rangle},\ if\ (P_0\geq P)\ and\ (LOC_0\ NORTH\ LOC);$$

$$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ NORTH\ LOC{:}P),\delta_t\rangle\rightarrow\langle(FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle},$$
$if\ P_0<P\ or\ (P_0\geq P,LOC_0\ \overline{NORTH}\ LOC);$

(7) $$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ EAST\ LOC{:}P),\delta_{loc}\rangle\rightarrow\langle(TRUE{:}P_0),\delta_{loc}\rangle},\ if\ (P_0\geq P)\ and\ (LOC_0\ EAST\ LOC);$$

$$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ EAST\ LOC{:}P),\delta_t\rangle\rightarrow\langle(FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle},$$
$if\ P_0<P\ or\ (P_0\geq P,LOC_0\ \overline{EAST}\ LOC);$

(8) $$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ NORTHEAST\ LOC{:}P),\delta_{loc}\rangle\rightarrow\langle(TRUE{:}P_0),\delta_{loc}\rangle},$$
$if\ (P_0\geq P)\ and\ (LOC_0\ NORTHEAST\ LOC);$

$$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ NORTHEAST\ LOC{:}P),\delta_t\rangle\rightarrow\langle(FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle},$$
$if\ P_0<P\ or\ (P_0\geq P,LOC_0\ \overline{NORTHEAST}\ LOC);$

(9) $$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ NORTHWEST\ LOC{:}P),\delta_{loc}\rangle\rightarrow\langle(TRUE{:}P_0),\delta_{loc}\rangle},$$
$if\ (P_0\geq P)\ and\ (LOC_0\ NORTHWEST\ LOC);$

$$\frac{\frac{\langle x_{ploc},\delta_{loc}\rangle\rightarrow P_0}{\langle x_{loc},\delta_{loc}\rangle\rightarrow LOC_0}}{\langle(x_{loc}\ NORTHWEST\ LOC{:}P),\delta_t\rangle\rightarrow\langle(FALSE{:}P_0),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle},$$
$if\ P_0<P\ or\ (P_0\geq P,LOC_0\ \overline{NORTHWEST}\ LOC);$

(10) $$\frac{\frac{\langle x_{ploc1},\delta_{loc1}\rangle\rightarrow P_1\ and\ \langle x_{ploc2},\delta_{loc2}\rangle\rightarrow P_2}{\langle(lb\mathrm{exp}_1{:}P'),\delta_{loc1}\rangle\rightarrow\langle(TRUE{:}P_1),\delta_{loc1}\rangle\ and\langle(lb\mathrm{exp}_2{:}P''),\delta_{loc2}\rangle\rightarrow\langle(TRUE{:}P_2),\delta_{loc2}\rangle}}{\langle(plb\mathrm{exp}_1\wedge plb\mathrm{exp}_2{:}P),(\delta_{loc1},\delta_{loc2})\rangle\rightarrow\langle(TRUE{:}P_1\times P_2),(\delta_{loc1},\delta_{loc2})\rangle},$$
$if\ P_1\geq P'\ and\ P_2\geq P''\ and\ P_1\times P_2\geq P;$

$$\frac{\frac{\langle x_{ploc1},\delta_{loc1}\rangle\rightarrow P_1\ and\ \langle x_{ploc2},\delta_{loc2}\rangle\rightarrow P_2}{\langle(lb\mathrm{exp}_1{:}P'),\delta_{loc1}\rangle\rightarrow\langle(FALSE{:}P_1),\delta_{loc1}[\emptyset/x_{loc1},0/x_{ploc1}]\rangle\ or\langle(lb\mathrm{exp}_2{:}P''),\delta_{loc2}\rangle\rightarrow\langle(FALSE{:}P_2),\delta_{loc2}[\emptyset/x_{loc2},0/x_{ploc2}]\rangle}}{\langle(plb\mathrm{exp}_1\wedge plb\mathrm{exp}_2{:}P),(\delta_{loc1},\delta_{loc2})\rangle\rightarrow\langle(FALSE{:}P_1\times P_2),(\delta_{loc1}[\emptyset/x_{loc1},0/x_{ploc1}],\delta_{loc2}[\emptyset/x_{loc2},0/x_{ploc2}])\rangle},$$
$if\ P_1<P'\ or\ P_2<P''\ or\ P_1\times P_2<P;$

(11) $$\frac{\frac{\langle x_{ploc1},\delta_{loc1}\rangle\rightarrow P_1\ and\ \langle x_{ploc2},\delta_{loc2}\rangle\rightarrow P_2}{\langle(lb\mathrm{exp}_1{:}P'),\delta_{loc1}\rangle\rightarrow\langle(TRUE{:}P_1),\delta_{loc1}\rangle\ or\langle(lb\mathrm{exp}_2{:}P''),\delta_{loc2}\rangle\rightarrow\langle(TRUE{:}P_2),\delta_{loc2}\rangle}}{\langle(plb\mathrm{exp}_1\vee plb\mathrm{exp}_2{:}P),(\delta_{loc1},\delta_{loc2})\rangle\rightarrow\langle(TRUE{:}P_1+P_2-P_1\times P_2),(\delta_{loc1},\delta_{loc2})\rangle},$$
$if\ (P_1\geq P'\ or\ P_2\geq P'')\ and\ (P_1+P_2-P_1\times P_2)\geq P;$

$$\frac{\frac{\langle x_{ploc1},\delta_{loc1}\rangle\rightarrow P_1\ and\ \langle x_{ploc2},\delta_{loc2}\rangle\rightarrow P_2}{\langle(lb\mathrm{exp}_1{:}P'),\delta_{loc1}\rangle\rightarrow\langle(FALSE{:}P_1),\delta_{loc1}[\emptyset/x_{loc1},0/x_{ploc1}]\rangle\ and\langle(lb\mathrm{exp}_2{:}P''),\delta_{loc2}\rangle\rightarrow\langle(FALSE{:}P_2),\delta_{loc2}[\emptyset/x_{loc2},0/x_{ploc2}]\rangle}}{\langle(plb\mathrm{exp}_1\vee plb\mathrm{exp}_2{:}P),(\delta_{loc1},\delta_{loc2})\rangle\rightarrow\langle(FALSE{:}P_1+P_2-P_1\times P),(\delta_{loc1}[\emptyset/x_{loc1},0/x_{ploc1}],\delta_{loc2}[\emptyset/x_{loc2},0/x_{ploc2}])\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P;$

5. The operational semantics of the **PEBEXP**:

(1) $\frac{\langle x,\delta\rangle \to P_0}{\langle (TRUE:P),\delta\rangle \to \langle (TRUE:P_0),\delta\rangle}, if\ (P_0 \geq P);$

(2) $\frac{\langle x,\delta\rangle \to P_0}{\langle (FALSE:P),\delta\rangle \to \langle (FALSE:P_0),\delta[\emptyset/x,0/x_p]\rangle}, if\ (P_0 < P);$

(3) $$\frac{\dfrac{\langle x_{pid},\delta_{id}\rangle \to P_1\ and\ \langle x_{pt},\delta_t\rangle \to P_2\ and\ \langle x_{ploc},\delta_{loc}\rangle \to P_3\ and\ \langle x_{pa},\delta_a\rangle \to P_4}{\begin{pmatrix} \langle (ob\exp : P'),\delta_{id}\rangle \to \langle (TRUE : P_1),\delta_{id}\rangle\ and\ \langle (tb\exp : P''),\delta_t\rangle \to \langle (TRUE : P_2),\delta_t\rangle \\ and\ \langle (lb\exp : P'''),\delta_{loc}\rangle \to \langle (TRUE : P_3),\delta_{loc}\rangle\ and\ \langle (ab\exp : P''''),\delta_a\rangle \to \langle (TRUE : P_4),\delta_a\rangle \end{pmatrix}}}{\langle (pob\exp;ptb\exp;plb\exp;pab\exp:P),\delta\rangle \to \langle (TRUE:P_1\times P_2\times P_3\times P_4),\delta\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''and\ P_3 \geq P'''and\ P_4 \geq P''''\ and\ P_1 \times P_2 \times P_3 \times P_4 \geq P;$

$$\frac{\dfrac{\langle x_{pid},\delta_{id}\rangle \to P_1\ and\ \langle x_{pt},\delta_t\rangle \to P_2\ and\ \langle x_{ploc},\delta_{loc}\rangle \to P_3\ and\ \langle x_{pa},\delta_a\rangle \to P_4}{\begin{pmatrix} \langle (ob\exp : P'),\delta_{id}\rangle \to \langle (FALSE : P_1),\delta_{id}[\emptyset/x_{id},0/x_{pid}]\rangle\ and\ \langle (tb\exp : P''),\delta_t\rangle \to \langle (FALSE : P_2),\delta_t[\emptyset/x_t,0/x_{pt}]\rangle \\ and\ \langle (lb\exp : P'''),\delta_{loc}\rangle \to \langle (FALSE : P_3),\delta_{loc}[\emptyset/x_{loc},0/x_{ploc}]\rangle\ and\ \langle (ab\exp : P''''),\delta_a\rangle \to \langle (FALSE : P_4),\delta_a[\emptyset/x_a,0/x_{pa}]\rangle \end{pmatrix}}}{\langle (pob\exp;ptb\exp;plb\exp;pab\exp:P),\delta\rangle \to \langle (FALSE:P_1\times P_2\times P_3\times P_4),\delta[\emptyset/x,0/x_p]\rangle},$$

$if\ P_1 < P'\ or\ P_2 < P''or\ P_3 < P'''or\ P_4 < P''''\ or\ P_1 \times P_2 \times P_3 \times P_4 < P;$

(4) $$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 \wedge ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P;$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 \wedge pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$

$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P;$

(5) $$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (pebexp_1 \vee pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1+P_2-P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1+P_2-P_1\times P_2/x_p])\rangle},$$

$if\ (P_1 \geq P'\ or\ P_2 \geq P'')\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P;$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ and \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 \vee pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1+P_2-P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ (P_1 + P_2 - P_1 \times P_2) \geq P;$

(6) $$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 BEFORE\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (T_1\ BEFORE\ T_2);$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 BEFORE\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$

$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (T_1\ \overline{BEFORE}\ T_2);$

(7) $$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 EQUAL\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (T_1\ EQUAL\ T_2);$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 EQUAL\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$

$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (T_1\ \overline{EQUAL}\ T_2);$

(8) $$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 OVERLAP\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$

$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (T_1\ OVERLAP\ T_2)$;

$$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 OVERLAP\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (T_1\ \overline{OVERLAP}\ T_2)$;

(9) $$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 DURING\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (T_1\ DURING\ T_2)$;

$$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 DURING\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (T_1\ \overline{DURING}\ T_2)$;

(10) $$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 EQ\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ EQ\ LOC_2)$;

$$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 EQ\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{EQ}\ LOC_2)$;

(11) $$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 OP\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ OP\ LOC_2)$;

$$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 OP\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{OP}\ LOC_2)$;

(12) $$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 IN\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ IN\ LOC_2)$;

$$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 IN\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{IN}\ LOC_2)$;

(13) $$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 NORTH\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ NORTH\ LOC_2)$;

$$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or \langle (ebexp_2:P''),\delta_2\rangle \to \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1 NORTH\ pebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{NORTH}\ LOC_2)$;

(14) $$\frac{\frac{\langle x_{p1},\delta_1\rangle \to P_1\ and\ \langle x_{p2},\delta_2\rangle \to P_2}{\langle (ebexp_1:P'),\delta_1\rangle \to \langle (TRUE:P_1),\delta_1\rangle\ and \langle (lbexp_2:P''),\delta_2\rangle \to \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1 EAST\ ebexp_2:P),(\delta_1,\delta_2)\rangle \to \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle},$$
$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ EAST\ LOC_2)$;

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \rightarrow P_1\ and\ \langle x_{p2},\delta_2\rangle \rightarrow P_2}{\langle (ebexp_1:P'),\delta_1\rangle \rightarrow \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or\langle (ebexp_2:P''),\delta_2\rangle \rightarrow \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1\ EAST\ pebexp_2:P),(\delta_1,\delta_2)\rangle \rightarrow \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{EAST}\ LOC_2);$$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \rightarrow P_1\ and\ \langle x_{p2},\delta_2\rangle \rightarrow P_2}{\langle (ebexp_1:P'),\delta_1\rangle \rightarrow \langle (TRUE:P_1),\delta_1\rangle\ and\langle (lbexp_2:P''),\delta_2\rangle \rightarrow \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1\ NORTHEAST\ ebexp_2:P),(\delta_1,\delta_2)\rangle \rightarrow \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle}, \tag{15}$$
$$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ NORTHEAST\ LOC_2);$$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \rightarrow P_1\ and\ \langle x_{p2},\delta_2\rangle \rightarrow P_2}{\langle (ebexp_1:P'),\delta_1\rangle \rightarrow \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or\langle (ebexp_2:P''),\delta_2\rangle \rightarrow \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1\ NORTHEAST\ pebexp_2:P),(\delta_1,\delta_2)\rangle \rightarrow \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{NORTHEAST}\ LOC_2);$$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \rightarrow P_1\ and\ \langle x_{p2},\delta_2\rangle \rightarrow P_2}{\langle (ebexp_1:P'),\delta_1\rangle \rightarrow \langle (TRUE:P_1),\delta_1\rangle\ and\langle (lbexp_2:P''),\delta_2\rangle \rightarrow \langle (TRUE:P_2),\delta_2\rangle}}{\langle (ebexp_1\ NORTHWEST\ ebexp_2:P),(\delta_1,\delta_2)\rangle \rightarrow \langle (TRUE:P_1\times P_2),(\delta_1,\delta_2,\delta_3[E_1\otimes E_2/x,P_1\times P_2/x_p])\rangle}, \tag{16}$$
$$if\ P_1 \geq P'\ and\ P_2 \geq P''\ and\ P_1 \times P_2 \geq P\ and\ (LOC_1\ NORTHWEST\ LOC_2);$$

$$\frac{\dfrac{\langle x_{p1},\delta_1\rangle \rightarrow P_1\ and\ \langle x_{p2},\delta_2\rangle \rightarrow P_2}{\langle (ebexp_1:P'),\delta_1\rangle \rightarrow \langle (FALSE:P_1),\delta_1[\emptyset/x_1,0/x_{p1}]\rangle\ or\langle (ebexp_2:P''),\delta_2\rangle \rightarrow \langle (FALSE:P_2),\delta_2[\emptyset/x_2,0/x_{p2}]\rangle}}{\langle (pebexp_1\ NORTHWEST\ pebexp_2:P),(\delta_1,\delta_2)\rangle \rightarrow \langle (FALSE:P_1\times P_2),(\delta_1[\emptyset/x_1,0/x_{p1}],\delta_2[\emptyset/x_2,0/x_{p2}])\rangle},$$
$$if\ P_1 < P'\ or\ P_2 < P''\ or\ P_1 \times P_2 < P\ or\ (LOC_1\ \overline{NORTHWEST}\ LOC_2);$$

6. CONCLUSIONS

Focusing on VANET's uncertain event stream's processing problem, we have proposed a novel event query language PSTeCEQL in this paper. In this event query language, we have used possible world models to model the uncertain event instances of VANET and called the event's probability is its trustworthiness. Based on the VANET's event model, we have proposed the event query language PSTeCEQL. Then we give the syntax and operational semantics of PSTeCEQL. Finally, we illustrate the validity of the PSTeCEQL by an example.

ACKNOWLEDGEMENTS

This work is supported by the National Basic Research Program of China (No. 2011CB302802) , the National Natural Science Foundation of China (No.61370100 and No.61021004) and Shanghai Knowledge Service Platform Project (No. ZF1213).

REFERENCES

[1] Calandriello G, Papadimitratos P, Hubaux J P, et al. Efficient and robust pseudonymous authentication in VANET[C]//Proceedings of the fourth ACM international workshop on Vehicular ad hoc networks. ACM, 2007: 19-28.

[2] Schwiderski-Grosche S, Moody K. The SpaTeC composite event language for spatio-temporal reasoning in mobile systems[C]//Proceedings of the Third ACM International Conference on Distributed Event-Based Systems. ACM, 2009: 11.

[3] Moody K, Bacon J, Evans D, et al. Implementing a practical spatio-temporal composite event language[M]//From active data management to event-based systems and more. Springer Berlin Heidelberg, 2010: 108-123.

[4] Jin B, Zhuo W, Hu J, et al. Specifying and detecting spatio-temporal events in the internet of things[J]. Decision Support Systems, 2013, 55(1): 256-269.

[5] Huiyong Li,Yixiang Chen, Yujing Ma. A Spatio-Temporal Constraint Event Query Language for Internet of Vehicles[J].International Journal of Computer Networks and Communications Security,2014,2(12):448-455.

[6] Huiyong Li,Yixiang Chen. On denotational semantics of the complex event query language STeCEQL[J].Computer Modelling & New Technologies,2014,18(6):15-23.
[7] Kanazawa K. A Logic and Time Nets for Probabilistic Inference[C]//AAAI. 1991: 360-365.
[8] Kjaerulff U. A computational scheme for reasoning in dynamic probabilistic networks[C]//Proceedings of the Eighth international conference on Uncertainty in artificial intelligence. Morgan Kaufmann Publishers Inc., 1992: 121-129.
[9] Pearl J. Probabilistic reasoning in intelligent systems: networks of plausible inference[M]. Morgan Kaufmann, 1988.
[10] Gal A, Anaby-Tavor A, Trombetta A, et al. A framework for modeling and evaluating automatic semantic reconciliation[J]. The VLDB Journal—The International Journal on Very Large Data Bases, 2005, 14(1): 50-67.
[11] Liu H, Jacobsen H A. Modeling uncertainties in publish/subscribe systems[C]//Data Engineering, 2004. Proceedings. 20th International Conference on. IEEE, 2004: 510-521.
[12] Zadeh L A. Fuzzy sets[J]. Information and control, 1965, 8(3): 338-353.
[13] Boulos J, Dalvi N, Mandhani B, et al. MYSTIQ: a system for finding more answers by using probabilities[C]//Proceedings of the 2005 ACM SIGMOD international conference on Management of data. ACM, 2005: 891-893.
[14] Antova L, Koch C, Olteanu D. MayBMS: Managing incomplete information with probabilistic world-set decompositions[C]//Data Engineering, 2007. ICDE 2007. IEEE 23rd International Conference on. IEEE, 2007: 1479-1480.
[15] Cormode G, Garofalakis M. Sketching probabilistic data streams[C]//Proceedings of the 2007 ACM SIGMOD international conference on Management of data. ACM, 2007: 281-292.
[16] Zhang Q, Li F, Yi K. Finding frequent items in probabilistic data[C]//Proceedings of the 2008 ACM SIGMOD international conference on Management of data. ACM, 2008: 819-832.
[17] Kanagal B, Deshpande A. Online filtering, smoothing and probabilistic modeling of streaming data[C]//Data Engineering, 2008. ICDE 2008. IEEE 24th International Conference on. IEEE, 2008: 1160-1169.
[18] Ré C, Letchner J, Balazinksa M, et al. Event queries on correlated probabilistic streams[C]//Proceedings of the 2008 ACM SIGMOD international conference on Management of data. ACM, 2008: 715-728.