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Research and Challenges in Complex Event Processing for CPS

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Abstract: Cyber-Physical System (CPS) has become a hot research area, because it is an emerging trend around the world for fundamental technological and economic forces. Event is a key element who transforms the physical data into the semantic model. The complex events in CPS have following characteristics: interactivity and dynamic feedback, context correlation, streaming events and the uncertainties in event composition rules which bring challenges to research. In this study, the notion, characteristics and research significance of the event in CPS are represented firstly. Then, the research development of event processing techniques of the CPS and its related research fields are summarized. Finally, as the most important part, the challenges to be dealt with for event processing in CPS and the future research contents are discussed.

Key words: Cyber-physical system, complex event processing, challenges

INTRODUCTION

Cyber-Physical Systems (CPS) are integrations of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa (Lee, 2008). In CPS, the interactions to physical elements are achieved by defining the human-computer interaction interfaces, with which the remote physical elements can be operated reliably and safely at real-time. As a new research field, CPS is developed based on the supporting of the mature techniques in Wireless Sensor Networks (WSNs) and RFID systems. It thus requires the system to have the abilities of "sensing", "communicating", "knowing" and "controlling". CPS will bring new vigor and vitality into the areas of process control, environmental control, aviation equipment development, basic equipments control, distributed robot technology, national defense system, manufacture and intelligent building. All these applications will make great impact to the national economy.

The computer processing system in CPS handles the information coming from the physical world in the form of 'events' (Talcott, 2008). Each physical element in CPS integrates the functionalities of sensing, computing and communicating. The CPS system aims to monitor the changes in the physical world, based on which the system will make intelligent reply and takes necessary actions following some established procedure. The interactions between the physical layer and the computing layer in CPS are achieved through the event middleware, so the CPS applications are called "event-driven". Since a great deal of equipments existed in CPS, "heterogeneity" becomes a key property of CPS. The heterogeneity comes from the differences between any two sensing devices or from the diversity in communication mode.

PROPERTIES OF EVENTS OF CEP SCHEMES IN CPS

The distinct properties of event processing schemes in CPS are summarized compared with that in traditional event-handling systems.

Interactivity and dynamic feedback: One important property of CPS is the interactions between the cyber world and the physical world. CPS monitors several sensing data which are then send to the event middleware to perform the composite event matching. To ensure the accuracy of composite event matching, the CPS requires more feedbacks from the physical world, e.g., asking the sensors to sample more data. Specifically, the local collecting sensing data in CPS can be compounded into some primary composite events which then act as new inputs to the system to refine the final event matching results.

Context correlation: A judgment towards an event is usually made by combining the concrete context of the event. Specifically, the semantic of events is highly correlated to the concrete applications which provide the context of those events. The information of where or when the event took place must be known by the system

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users. The context correlation is a vital property of CPS. It points out that objects in the same logic group have been embedded with the same context information.

Streaming events: The physical elements in CPS sense and collect data from the physical world and those sensing data generate the basic atomic events in CPS. For the sensing activities are really uninterrupted which produces a large amount of atomic events in a streaming pattern. We call this as the "event stream". The streaming events stream to local event detector on which the atomic events are compounded into composite events based on some predefined event composition rules. Due to the streaming properties of events in CPS, the event processing scheme in CPS needs to ensure the accuracy as well as the efficiency of the event detection.

The uncertainties in event composition rules: The time and space of an event are multi-scale variables that may be uncertain which leads to the uncertainties in event composition rules. For example, an aircraft may use different modes when it takes off, lands or cruises. When the aircraft lands on the airport, the air traffic control mode should be taken into account in the design of the event composition rules, so that event composition rules can correctly imitate and reflect the real condition of events in the physical world.

The before-mentioned properties of event processing schemes in CPS contain the event interactivity in the active databases. However, the event processing scheme in CPS differs from that in active databases. On one hand, event processing scheme in CPS needs to handle numerous data sources and a great deal of sensing data. On the other hand, the event composition model in CPS is uncertain. Moreover, events in CPS come in the form of a data stream which requires to be coped with by one-pass operations. All these determine that the event processing schemes in active databases cannot be directly employed under the context of CPS. To summarize, the event processing schemes in CPS have a demand of processing massive amounts of streaming events as that in the RFID systems. Nevertheless, it distinguishes from the event processing schemes in RFID systems in that the events in CPS own the properties of interactivity, dynamic feedback as well as the uncertainties in event composition rules. The new properties of event processing scheme in CPS asks for some new technologies which proposes a challenge to the research scientists.

RESEARCH STATUS

Presently, the study of the CPS is at the beginning stage. The research of the CPS event processing is also at the discussion and embryonic stage. In 2008, the CPSweek arranges the workshops of the CPS event processing, in which the content of discussion includes the semantic of events and the challenges. Some projects are being studied.

The architecture of cyber-physical space: (Kim *et al*., 2008) describes the Information Cyber-Physical System (ICPS) that uses calculating interaction and bases on the event semantic. They establish a two layer "observation-analysis-adjustment" framework. It satisfies the basic structure of ICPS and uses modeling, standardization and reasoning of multidimensional QoS. SATWare System (Hore *et al*., 2007): University of California, Irvine, carries the rescuing and responding project. Using semantic model, the high level semantic events are mapped to the low level physical events that can be detected by sensors. The study includes privacy, trust and judgment of semantic, self monitoring and adaptive.

Multi-dimension Analysis of Atypical Events (Tang *et al*., 2012) gets the events from large amount of data and analyzes them with spatio-temporal and multi-dimensional information. Therefore, they put forward a new atypical cluster model to express the events and get the events from large amount of data. The micro-cluster is designed to summarize a single event and the macro-cluster is used to get information by integrating multiple events.

Nowadays, many work of the event processing are progressed in related fields such as WSNs, RFID systems. The typical event streaming processing system includes: (1) University of California, Berkeley, develops the SASE system (Wu *et al*., 2006). SASE provides the extended event language, event query processor and operating optimization strategy. The system realizes functions, including the collection and cleaning of RFID data, generation of basic events, processing of complex events, archiving of events and the query of events. (2) Cornell University develops the Cayuga system (Brenna *et al*., 2007): This system provides the extended query language and it can detect complex events efficiently through the defined automata model and internal naming methods. The automata of Cayuga defines a set of rules to maintain the circulation of the transition and also defines a variety of internal naming rules which make the mapping and transforming between different statuses be completed successfully. (3) University of California, Berkeley, develops the HiFi system (Cooper *et al*., 2004): This system provides the functions of generating application level's simple events in heterogeneous EDGE equipment and processing complex events in simple event streaming. It cleans and processes dirty data and meaningless data for the application that are generated by EDGE equipment through constructing "virtual equipment" and the data are

converted into the form that the system can use directly. (4) University of Washington develops the Cascadia system (Welbourne *et al*., 2008): According to the integrity and ambiguity of RFID data, this system establishes a probability model that can transform RFID data into probability events. In this way, the RFID application is established on probability model not on RFID original data. (5) University of Massachusetts develops real-time medical monitoring prototype system based on active CEP (Wang *et al*., 2011): This system designs the active CEP model and related rules language and establishes the event processing architecture. In the process of the continuous query processing, it allows to trigger rules according to the state of the CEP system. In the CEP kernel, it integrates active rule components and the rules can be processed optimally in fine grit. It proposes processing methods of the active CEP in event streaming. (6) University of Worcester Polytechnic develops the complex event query language called NEEL: To assure real-time responsiveness and scalability for pattern detection on high-speed streams, Liu *et al*. (2011a) analyzes the existing methods and there exists two shortcomings. First, a lot of sequences constructed previously are discarded. Second, sharing embedded subsequences are ignored. (7) Liu *et al*. (2011b) puts forward a new E-Cube model: This model combines the CEP and OLAP to conduct multi-dimension event pattern analysis in different abstract levels. Given a group of queries, based on the relationships of the query concept and the query hierarchy, E-Cube arranges an event pattern query rank for the query.

CHALLENGES OF EVENT PROCESSING SCHEMES IN CPS

As the most important part, in this section, the challenges to be dealt with for event processing in CPS are discussed in detail.

Event processing model: Interactive event processing model: The concept of event detecting in CPS is most similar to the event detecting model in active database and event stream processing in the prototype system. But these research works are only suitable for known and constant semantic rules and aim to detect composite event instead of post-processing. Due to the interactivity of event in CPS, partial composite event usually can be used as the input of producing new event composition rules. For example, the frequency of event A is higher than event B and event C during a period of time, dynamic modification of frequency threshold and so on. Through the analysis of the partial event results and calculation of the feedback by relevant factors to revise the rule set. Therefore, solving the interactivity in CPS needs to build a feedback control model instead of utilizing the existing models for CPS running in real time and more accurately. Extension of the event instance consuming strategies: Physical phenomenon in real world can map into basic events and composite events in logical world. So the existing operation on events can be utilized to composite events in CPS. But in event processing of CPS, the abstracts of events need some additional constraints to reflect the relationship of context semantic in the real world better. When detecting composite event, there may be some instances with the same event type. According to the strategies of event instance consuming, it can choose the exact instance. There are some existing strategies of event instance consuming, such as Recent, First, Chronicle, Cumulative and Continuous and so on. Every strategy of event instance consuming has its own background and rules. Due to many types of objects and complex semantic, it is not suitable for utilizing some simple strategies of event instance consuming. So there is a need of researching the expansion of strategies of event instance consuming to express the full context semantics and support mixed-mode applications.

CONSTRUCTION AND OPTIMIZATION OF ADAPTIVE RULE SETS

Building the dynamic rule sets: In CPS, every complex semantic can be expressed as a composite event. It collects and pre-processes the basic event stream to detect a composite event which users care about, according to the existing rule sets. That is the uncertain and complex semantic information. By the statistical analysis and logical judgment, mining the potential and significant semantic information to modify, optimize and expand the limited rule set. In order to improve the efficiency, it discards some atomic events which have nothing to do with composite events on the basis of rules. Match the composite events based on the context information and then utilize the information to improve the event patterns. Therefore, building and adjusting uncertain rules set dynamically are the bases of composite event detection.

Rule adjustment based on context information: Event patterns in CPS are changed by outside factors and individual differences, so context correlation is a factor of affecting event patterns. Context correlation is a logical grouping of the related information with particular purpose which includes the semantic relations. Context correlation is the important characteristics in CPS. When

detecting events, it is usually necessary to combine the specific conditions and background. It means that the semantic of events has a relationship with applications.

- Different context can map different semantics of events. Space, time, object and other related information are all the context information of events. Changing related elements can decide the event whether happen or not
- Causal relationship among events is implicit in atomic event stream. If there is no causal model, the relationship will be ignored after the accomplishment of complex event processing. Comparing to event processing in RFID system, the causal relationship in CPS is very complex and hard to give an exact definition. But it is significant for complex event processing
- In distributed environment, according to context information can get the local logic of events and then achieve a unique global logic of events. The process of forming the final events, namely events blending, is to build the relationship between the original event and one or more context

Context correlations should be taken as the important feedback information in the designing of event model which are used to improve the composite event rules. It also ensures suit for the changes of physical world

Elimination of event pattern conflicts: According to event rules, create the corresponding physical objects. Those objects may meet some other rules again and then create objects again. Therefore, the interactive event processing system is feedback-driven. In the process of feedback-driven system, there are some rules improved or created at the same time which may cause the confliction between the original rules and new rules or among the new rules. It will not make the system terminate in a state at a time. Thus, event conflict resolution should be one of the researches.

Elimination of redundant rules: Some additional rules can be redundant rules though deduced in adding event rules dynamically of CEP. Because redundant rules lead to low efficiency of event matching, they should be eliminated. Due to interactive event in CEP, local and global events will update rules continuously. It is necessary to take considerations about the affecting of specific context factors, such as time, location, local results and global results.

Event detection schemes

Event detection based on context semantics: In the process of compositing in CPS, atomic events may meet different semantics at the same time which introduce detecting events method in an interactive way based on context semantics. It is a two-way interactivity between physical world and digital world. Previous system, such as E-C-A rule in active database, only considered the judgment and operation of digital world about physical world. But it ignored that the interaction between objects in the physical world can lead to concept drifting, the variation of attributes and so on. It is reflected abstracted context semantics rules in the digital world. For example intelligent medical system, there is the spread of virus between observation objects. It not only creates the relationship of events in different scenarios, but also contacts the corresponding rules. Therefore, introducing the detecting events method in an interactive way based on context semantics is one of the researches.

Adjustment of event pattern utilizing feedback control strategy: Due to a large scale events and strong interactivity in CPS, it usually needs to adjust the complex event pattern according to the demands. Feedback control is an important characteristic which is different from other IOT systems. If rebuild the complex event detecting models and use them every time, it will cost much time and produce some delay. So events can't be processed in real time. Thus, utilizing the method based on feedback control, designing the appropriate feedback function, adjusting event composition pattern in time are the necessary research to improve the efficiency of event processing.

Optimized event composition method based on shared semantic segments: A basic event can meet several queries because of the causal relationship among events and complex semantic. Furthermore, the result of one query can be used as the new input several times. So some queries have the same semantic segments. If there are no shared semantic segments among some queries, it will waste a lot of resources. Therefore, shared semantic segments is very necessary which includes data sharing and operation sharing.

CONCLUSIONS

CPS has become a hot research area for its pervasive application. Event is the key element between the cyber world and the physical world. This study introduces

properties of events in CPS and makes an overview over some related research areas. As the most important part, the challenges for event processing schemes in CPS are pointed out.

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