Events driven approach for supporting real-time management of complex systems

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ABSTRACT

Management and modeling of complex systems is challenging area of research. There are various approaches for modeling of these systems. In this paper we will present a comprehensive framework for events driven approach for modeling and management of complex system. The concept of application of event to systems modeling is not a new one. It has been applied for modeling of the discrete systems, stochastic systems etc. However, most of the existing modeling approaches use only information about type of event and the time when an event occurs. The information systems store much richer information about events. This information might be structured as well as unstructured. The structured information is stored in databases in the form of tables. The unstructured information is stored in various forms of textual information. It can be considered and used more information about the events what advance events driven modeling approaches.

Keywords: event mining, temporal data mining, on-line knowledge delivery and decision support

1. INTRODUCTION

There are well established approaches for building *models* of the systems that apply concept of the events. The most often used modeling approaches:

- Petri nets
  Definition 1 [1]
  A Petri net N is a tuple (B,E,F) where B is a set of conditions, E is a set of events, $F \subset (B \times E) \cup (E \times B)$ is the causal dependency relation satisfying several conditions.

  There is well developed theory of discrete event systems. Winskel [2] has shown in his PhD thesis how general and fundamental is the notion of event in the theory of computation as well as he has developed the theory of events structures. Baccelli at al. [3] present the algebra for discrete event systems.

- stochastic processes:
  survival processes, birth processes, recurrent events, discrete-time Markov chains, hidden Markov models etc.

The above modeling approaches use very limited information about the events. In this paper we will assume that the event might be described by several attributes. The events can be defined as follows.

Definition 2
An event e_i is something that happens in the system or its environment and can be described by a set of attributes.

Let us consider the finite set of events $E = \{e_1, e_2, ...e_n\}$. We can distinguish external E_e and internal E_i events:

$$E = E_e \cup E_i$$

$$E_e = \{e_1, e_2, ..., e_e\} \quad \text{and} \quad E_i = \{e_1, e_2, ...e_i\}$$

The second definition of event considers that an event is characterized by a set of attributes.

Definition 3
Let us $A_{e_i} = \{a_{1,e_i}, a_{2,e_i}, ...a_{m_{e_i},e_i}\}$ will be the set of attributes for an event e_i and $V_{a_{j,e_i}}$ is the domain of attribute a_{j,e_i}.
An event is defined as $(m+2)$ tuple $(a_{1,e_i}, a_{2,e_i}, ...a_{m_{e_i},e_i}, t, \Delta t)$, where $a_{j,e_i} \in V_{a_{j,e_i}}$, t is a time of occurring an event, Δt is duration of an event.

2. MODELING FRAMEWORK

Figure 1 shows the basic components of the event driven modeling framework: the system that is influenced by external as well as internal events, data and textual information about the system as well as about the events, models, algorithms, event detection algorithms, knowledge representation, description of decision maker behavior and actions.

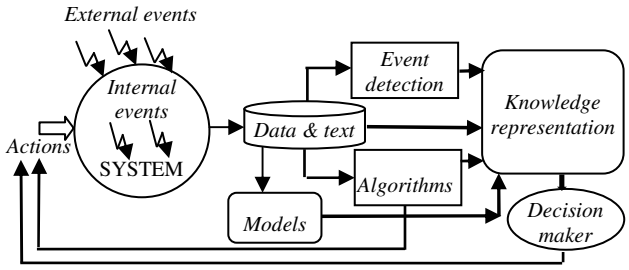

Figure 1 Basic components of the modeling framework

In order to build models or algorithms we have to store *the data* about the system and the events. The existence and the proper quality of data are crucial to any further steps. We can distinguish primary data that are stored in relational databases and preprocessed data that are prepared for specific modeling tasks. The data can be stored in one central database or can be stored in distributed databases. Moreover, the designers apply event based system design approach which leads to well structured databases that contain information about events. There is also increased importance of using textual information about events. Recently, the video sequences are becoming important source of data for event discovery [4].

The models use mathematical formulas to describe behavior of the system. In case of the presented framework the models describe dependencies between events and observable variables. Various models can be considered like stochastic models, temporal relationships, temporal sequence associations etc.

The algorithms on Figure 1 are understood as algorithms that work with analytical models as well as algorithms for event mining or event processing. A key to understanding events is knowledge of what might have caused them and having that knowledge at the time the events happen. Event mining is one of key approaches. Event mining can be defined as a process of finding

- the frequent events,
- the rare events,
- the unknown event (it occurrence can be deduced from observation of the system),
- the correlation between events,
- the consequences of event,
- and what caused the event.

There is a special class of algorithms for *event detection.* We distinguish two classes of algorithms. Events detection based on numerical and categorical data analysis and event detection by analysis the textual information.

The results of algorithms, data and textual information and results of algorithms go to the block called *Knowledge representation.* In this block there is unifying representation of the results. However, the results are very simple form of the knowledge. Here, there is a place for introducing contextual knowledge and more advanced algorithms that support knowledge creation and management. There will be also represented the knowledge about the consequences of events. The ability to track event causality and consequences is an essential step toward on-line decision support and important challenge for new algorithms for event mining.

The models and algorithms as well as data provides *the decision maker* important knowledge about the system. Then decision maker can specify various *actions* that will be applied in the system and reduce the influence of events on the system. The information about actions should be stored in computerized form. That will help later the evaluation of consequences of the chosen actions. In some cases the results of the algorithms can be directly applied to the system (for example the event based control algorithms).

Recently, the focus is on real-time decision support what requires a new class of the data processing, the analytical algorithms as well as modeling approaches. The actions have to be taken immediately after the event occurred. The delay may cause the fault of the system or significant loses.

It should be stressed that we can distinguish a broad spectrum of various types of events. It will often require dedicated algorithms and approaches. However, the framework will help in generalization of the specified methods and algorithms. Moreover, this framework may help in integration of achievements in event based modeling in different scientific disciplines. At this time there are separate developments in temporal data mining, stochastic systems, event based control etc. The combination of these approaches might significantly improve the results of new algorithms.

3. EVENTS DRIVEN MODELING

The presented approach has various applications in business monitoring, network management, intrusion detection, fault detection etc. In this section we will present selected examples of event driven modeling: events monitoring, event processing networks, events in environmental scanning, event based control, temporal sequence associations for rare events, event mining and events in alerting systems.

3. 1. Events monitoring

There is research on events monitoring in given environment [5]. The sensor networks are applied for events monitoring. Sensor networks are systems of many sensing elements endowed with computation, communication and motion that can work together to provide information about events in an environment. In this case we have information about the type of event, the time and location of events. The control algorithms are used for positioning mobile sensors in response to a series of events.

Many monitoring problems can be also stated as the problem of detecting a change in the parameters of a system called *event detection*. The overview of the methods of detecting the abrupt changes can be found in [6].

3. 2. Event processing networks

Another important concept is an EPN (Event Processing Networks) [7], [8]. Such networks consist of Event Processing Agents called event sources, event processors and event viewers. EPN have been applied for computer network monitoring. The events sources were middleware sniffers. The aggregated information about events has been displayed by viewers and additionally has been used for event mining. This concept has been also applied for solving business problems.

3. 3. Events in environmental scanning

The organizations are working on improvement of the analysis of the external environment and influence of this environment on the performance of the organization. Environmental scanning is a new term and it means the acquisition and use of the information about events, trends, and relationships in an external environment. In this case the methods of dealing with unstructured information about events are especially important [9].

3. 4. Events based control

In event based control the sampling is event-triggered instead time-triggered. The event-based PID controller has been presented in [10]. In this paper it has been shown that this approach reduces CPU utilization. The event-triggered PID controller is nonlinear system of hybrid nature.

3. 5. Temporal sequence associations for rare events

In many cases we have to monitor and analyze rare events like credit card frauds, network faults etc. However, if we store the data about the system in the database it is very difficult to identify rare events. In this case the events are characterized by type of event and the time of occurrence of the event. The sequence of event is analyzed. The detailed description of this type of algorithms can be found in [11].

3. 6. Event mining

There are new opportunities that come from the large amount of data that is stored in various databases (see [12]). Event mining becomes challenging area of research. In this subsection we will focus on formulating the event mining tasks that considers observations of the system as well as internal and external events.

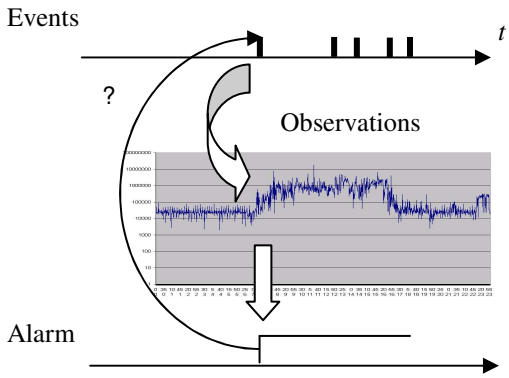

Figure 2 Events and observations

Figure 2 shows interrelations between events, observation of the system that is given in form of time series and alarms. Sometimes, it is impossible to observe the events directly. In such cases the data are stored in databases in form of time series. This data represents observations of the system in selected points. The observations are analyzed by the system and alarms are generated in case of abrupt changes in the values of observations. In the next step another algorithms finds the events that caused changes in the system.

The following algorithms can be considered:

- For significant change of observation find events that are the reasons of this change
- Prediction of future events by analyzing the changes of observations
- Prediction of changes of observations after the event occurs

To solve this tasks event mining table (Table 1) should be build. This table has the following columns: time, events and observations. In column *time* contains the timestamp. The column event contains identification of the event. The observations columns contain observations values in the given time.

time	events	observations			
t_1	-	$o_{1,t1}$	$o_{2,t1}$	$o_{3,t1}$	...
t_2	-	$o_{1,t2}$	$o_{2,t2}$	$o_{3,t2}$	...
t_3	E_{t3}	$o_{1,t3}$	$o_{2,t3}$	$o_{3,t3}$	...
...	...	...	...	...	...

Table 1 Event mining table

The event mining table is a source of data for event mining algorithms that identifies the changes in observations and correlate it with events.

3. 7. Events in alerting systems

Figure 3 shows the prototype of alerting system that was designed under the supervision of the author of the paper.

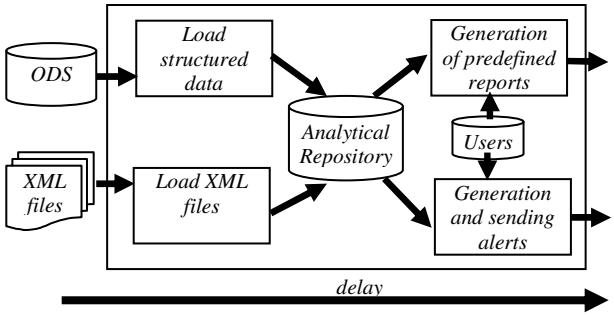

Figure 3 Alerting system

There are two source of data: ODS (Operational Data Store) and XML files with textual information about the event. The source data are loaded to analytical repository. At this step data are preprocessed. Then the analytical repository can be used as a source of data for generation of predefined reports that describes the behavior of the system as well as for algorithms that detects changes and correlates events with those changes. In this system the essential problem to be solved is the reduction of the delay between the event and alarm generation. This system can be applied for supporting decisions in real time.

4. CONCLUSIONS

It has been shown that there are various applications of event based modeling. This approaches use various methodologies. Presented modeling framework might help in developing future event driven modeling. We have stressed the new direction of research called event mining.

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