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# ECA rule learning in dynamic environments

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ABSTRACT

Through the development of management and intelligent control systems, we can make useful decision by using incoming data. These systems are used commonly in dynamic environments that some of which are been rule-based architectures. Event–Condition–Action (ECA) rule is one of the types that are used in dynamic environments. ECA rules have been designed for the systems that need automatic response to certain conditions or events. Changes of environmental conditions during the time are important factors impacting a reduction of the effectiveness of these rules which are implied by changing users demands of the systems that vary over time. Also, the rate of the changes in the rules are not known which means we are faced with the lack of information about rate of occurrence of new unknown conditions as a result of dynamics environments. Therefore, an intelligent rule learning is required for ECA rules to maintain the efficiency of the system. To the best knowledge of the authors, ECA rule learning has not been investigated. An intelligent rule learning for ECA rules are studied in this paper and a method is presented by using a combination of multi flexible fuzzy tree (MFlexDT) algorithm and neural network. Hence data loss could be avoided by considering the uncertainty aspect. Owing to runtime, speed, and also stream data in dynamic environments, a hierarchical learning model is proposed. We evaluate the performance of the proposed method for resource management in the Grid and e-commerce as case studies by modeling and simulating. A case study is presented to show the applicability of the proposed method.

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## 1. Introduction

Today, extensive developments in many areas of information and communication technology have provided useful and valuable information to management systems. In most environments, using of dynamic and flexible decision-making system is necessary (Efendigil, Onut, & Kahraman, 2009). One of the important issues in dynamic systems is need to quick and almost immediate decision making in presence of different environmental conditions (Efendigil et al., 2009). In real-world problems, especially in engineering and manufacturing, complexity and dynamics of interactions with the environment requires sophisticated methods and tools for creating intelligent decision-making systems (Efendigil et al., 2009; Gonzalez, Lerch, & Lebiere, 2003). A convenient and efficient decision-making for dynamic environments has to clarify the meaning of information for decision-makers and acts based on communication with the user and learn from the environment to increase the quality of decisions (Gonzalez et al., 2003). The main advantages of these systems come with the concurrent control, quick processing, high security, reliability, predictability and ensure of necessary decisions in dynamic systems that realize critical tasks (Cimino, Lazzerini, Marcelloni, & Ciaramella, 2012; Mark, 2009).

In such environments, most systems use decision rules which at first are provided by experts after a review and analysis of the system. In most cases, rule-based systems have been used to decide on unstructured situations where expertise is needed (Cimino et al., 2012; Hong, Lin, Lin, & Wang, 2008; Im, Ras, & Wasyluk, 2010; Mark, 2009). Rules are one of the most important structures for presenting relationships and dependencies between the expression of a large set of data items (Tomczak & Gonczarek, 2012; Tsai, Lee, & Yang, 2009). Finding effective and efficient rules can be difficult in different areas of applications (Cimino et al., 2012; Hsu, Jao, & Chen, 2005; Trepos, Salleb-Aouissi, Cordier, Masson, & Gascuel-Odoux, 2013), for example, when we wish to explore the relationship between the large volumes of e-commerce transactions attending to many number of users (Im et al., 2010). Over time and environmental changes, the existing rules in the dynamics environment start losing their effectiveness in responding to all incoming data (this data is often a kind of stream

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data) (Cimino et al., 2012; Tomczak & Gonczarek, 2012; Tsai et al., 2009). To solve this problem and maintain the necessary adaptation of decision-making system, updating of rules is necessary that would require adding new rules or modify existing rules (Efendigil et al., 2009; Trepos et al., 2013). Therefore, to achieve above goals to maintain effective and useful rules in the system, we need rule learning system. Rule learning is faced with high complexity in dynamic environments due to the uncertainty and limitation of time. Intelligent techniques can be useful for achieving flexibility and adaptation in high speed and accuracy learning systems. Intelligent rule learning systems must be able to realize learning and exhibit high flexibility in environments exhibiting formats of various data and knowledge (Efendigil et al., 2009; Hong et al., 2008). The system must be capable to realize distributed data management, data mining on current data and the flexibility to adapt to frequent changes (Hong et al., 2008).

There are two type structures of algorithms for rule learning: compression and covering (Elaine Califf & Mooney, 2003). In the compression structure, system starts forming an initial set of specific rules that are built for each example. A more general rule is built to replace with subsumes rules at each repeat. It is considered to the greater compression of the rule set for evaluating new rules. When no new rules are found to compress the rule set, rule learning completes. Examples of such systems are DUCE, CIGOL and CHILLIN. The Covering systems use a set of positive examples and once a new rule has been created, all positive examples covering by this rule are removed. When all positive examples have been covered, rule learning is completed. Some of these structures falling in this category of techniques are: FOIL, GOLEM, PROGOL, CLAUDIEN and various systems based on FOIL such as FOCL, MFOIL and FOIDL (Elaine Califf & Mooney, 2003).

In this paper, we focus on ECA rule that is for reactive dynamic environments. In recent years, progress of ECA rule in applied terms are increased (Cimino et al., 2012; May, Alferes, & Amador, 2005; Khanli & Analoui, 2006; Patiniotakis, Papageorgiou, Verginadis, Apostolou, & Mentzas, 2013; Zoumboulakis, Roussos, & Poulovassilis, 2004), so we need learning according to their progress. To the best knowledge of the authors, in studies is not method that introduced learning for the ECA rules. In this work, we investigate ECA rule learning that consider dynamic environment with stream data of events. We present a method for ECA rule learning with combination of MFlexDT algorithm and neural network. Since sometimes each event has several rules with different conditions and features, we extend FlexDT (Hashemi & Yang, 2009) to multi partitioning as MFlexDT. It provides more flexibility and accurate with less tree depth and size. Also neural networks are used to find the dependency between features. In this paper, to evaluate performance of our method, we consider resource management in Grid computing and e-commerce as a case study. In follows, we elaborate on of the problem and formulate the key research objectives.

### 1.1. The problem

In dynamic environments, events occur such as end-open data stream without interruption that include valuable data for decision-making (Gonzalez et al., 2003; Patiniotakis et al., 2013). One of the problems in these systems is primary ECA rules that are not always effective because of dynamic nature. ECA rules should be accountable for all acceptable situations that occur in the environment (Cimino et al., 2012). So, primary rules can not be used continuously for several reasons:

1. Changing interval and critical values of features.
2. Variable number of entities, features and parameters in terms of the rules.
3. Changing the event part of rules.
4. Unresponsiveness of rules in some or all unknown conditions.

This problem could be resolved by rebuilding or modifying rules periodically. In this paper, the design of an intelligent ECA rule learning system is suggested for dynamic environment. In this way some problems are highlighted. Discovering variables and features for rule learning due to the large volume of received data has complexity because events occur uninterruptedly. Also, the main problem is the uncertainty in the presence or absence of features in some instances. Another challenge is set the range of continuous values of some features. Furthermore, environmental uncertainties increases complexity of learning approach because many effective variables are unknown that nonlinear relations between them are complicated.

### 1.2. Objective

The aim is to deliver an intelligent solution for learning ECA rules in dynamic decision making systems that provides high flexibility and support to make decisions for responding relevant requests. The rule learning concerns adding, extending and adapting of the rule based on incoming data (Mark, 2009; Ruckert & Kramer, 2006). In summary, the aims of designing a method for ECA rule learning in dynamic environments with data stream can be outlined as follows:

1. Determining the effective range of features in conditions part of rule to create the flexibility to respond events.
2. Efficiently forming new features extracted from incoming data and generate new rules by considering to the dependency between features.
3. Generating new rules based on new related events.
4. Management and considering all stream data in online learning.

Hence, we have designed an intelligent ECA rule learning that automatically changes the rules based on received data for decision making.

### 1.3. Organization

The paper is organized as follows. Section 2 covers related studies on ECA rules, rule learning and fuzzy decision tree. In Section 3, we describe the ECA rule learning process. In Section 4, we evaluate our approach. Finally, conclusions are covered in Section 5.

## 2. Related works

One type of the dynamic environments is the environments that is sensitive to events and their decisions should be based on occurrence of events (Behrends, Fritzen, May, Schenk, & Schubert, 2006; Dai & Huang, 2007; Khanli & Analoui, 2006, 2009; May et al., 2005; Zoumboulakis et al., 2004), for example resource management in Grid computing, Cloud computing and e-commerce. The purpose of this paper is to learn the event-based rules in dynamic environments. We review a number of related concepts.

### 2.1. ECA rule

ECA rule is one of the knowledge representation structures for events that are also called active rule. These rules can react automatically to the events according to the conditions and actions defined in the system (Behrends et al., 2006; Dai & Huang, 2007; Khanli & Analoui, 2009; Patiniotakis et al., 2013). Each ECA rule consists of three parts, namely event, condition and action (Dai & Huang, 2007; Patiniotakis et al., 2013):

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