Information Sciences 180 (2010) 995–1009

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Applying learning behavioral Petri nets to the analysis of learning behavior in web-based learning environments

Yi-Chun Chang *, Chih-Ping Chu

Department of Computer Science and Information Engineering, National Cheng-Kung University, Tainan, Taiwan

ARTICLE INFO

Article history:
Received 19 May 2008
Received in revised form 5 October 2009
Accepted 13 November 2009

Keywords:
Learning behaviors
Learning behavioral Petri nets
Intelligent tutoring systems
Web-based learning environments

ABSTRACT

This paper proposes the learning behavioral Petri nets (LBPN) to model learning behavior in web-based environments. Fully useful records of learning behaviors must contain their expended time and corresponding contents. Therefore, the LBPN extends the colored tokens of colored Petri nets to identify learners and learning contents, and raises the time variable to represent diverse learning times for individual learners. To verify the viability of the LBPN, this paper also proposes a LBPN-based learning behavioral model to simulate a situation in which many learners participate in an e-learning course, and then to generate their behavioral patterns. The experimental results illustrated in this paper confirm that (1) the generated behavioral pattern based on the LBPN-based model is very close to actual data, (2) the time and cost spent to verify the effectiveness of an ITS is substantially reduced, (3) adequate testing data for estimating the performance and accuracy of an ITS is easily acquired, and (4) the LBPN-based model can be built to recommend appropriate learning contents and to accomplish adaptive learning.

1. Introduction

Web-based learning highly depends on information and communication technologies [14], while adaptive learning is one of the important benefits for web-based learning environments, as it can take many kinds of learning styles into account to provide specific learning contents for individual users [3,4,12,14,20]. Numerous researchers have developed intelligent tutoring systems (ITSs) to achieve adaptive learning. Johnson et al. [21] proposed a microcomputer intelligence for technical training (MITT) which allows instructors to build ITSs for technical training. Gonzalez and Ingraham [16] designed an ITS which can automatically determine exercise progression and remediation during a training session, based on learners' previous performances. Cheung et al. [11] proposed the SmartTutor, an ITS that supports distance learning in Hong Kong. The SmartTutor contains two crucial elements, i.e., personalization and intelligent tutoring, both of which are important for continuing and adult education [11]. Huang et al. [17] proposed a framework, called the standardized course generation process (SCGP), which includes an e-learning portal, an authoring tool technique, and a material arrangement agent to provide learning suggestions for individual learners. Obviously, the developments of ITSs in web-based learning environments will be continued and become an extremely important trend in education for the seeing future [7,18,29,32].

To verify the availability and accuracy of an ITS, most researchers use questionnaires to measure the experiences and performances of learners [15]. However, asking learners to be test targets is troublesome and collecting learners' behaviors generally require a relative huge amount of processing time and efforts. Fully useful records of learning behaviors must contain their expended time and corresponding contents; such as, the time-point when a learner enters an ITS, the time length that

* Corresponding author. Tel.: +886 6 2757575x62527; fax: +886 6 2747076.
E-mail addresses: changyc@livemail.tw (Y.-C. Chang), chucp@csie.ncku.edu.tw (C.-P. Chu).

0020-0255/$ - see front matter
doi:10.1016/j.ins.2009.11.022

she/he spends on reading a specific unit, and the timing that a learner undertakes a test. Since Petri nets (PN) possess capabilities for system modeling and analyzing, and for knowledge presentation [22], we apply the PN to model learning behaviors in web-based environments. Furthermore, the high-level Petri nets (HLPN) extended the PN with color to model kinds of data, with time to simulate executing time, and with hierarchy to construct larger models [22,24,25]. Among these HLPN, the colored tokens of colored Petri nets (CPN) [19] can identify and separate learners and their learning contents. Although the time Petri nets (TPN) [31,34] utilize the concepts of time, the time-related parameters in TPN is lack of flexibility to keep tracking the dynamical reading times required by various learners for a specific learning unit.

In order to tackle all mentioned drawbacks above, this paper proposes a novel PN to accurately model and precisely analyze learning behaviors in web-based environments, which is called the learning behavioral Petri nets (LBPN). The LBPN extends the concept of colored tokens in CPN to identify learners and learning contents, and raises the time variable to represent diverse learning times for individual learners. Furthermore, in order to validate the viability of the LBPN, this paper proposes a LBPN-based learning behavioral model to simulate a situation in which many learners participate in an e-learning course, and then to generate their behavioral patterns. Behavioral patterns are defined as the data describing learning records, while the learning records contain the duration for which a learner reads a learning unit or undertakes assessments, the score that a learner receives from an assessment, and so on. In this paper, the generated behavioral patterns based on the LBPN-based learning behavioral model are also compared with actual data collected from elementary school students. The compared results emphatically confirm that the LBPN facilitates the research with respect to web-based learning environments. The advantages of approaches proposed in this paper include that, (1) the time and cost spent to verify the effectiveness of an ITS is substantially reduced, (2) adequate testing data for estimating the performance and accuracy of an ITS is easily acquired, and (3) the LBPN-based model closely approximates actual learning behavior in a web-based learning environment. As a result, the LBPN-based model can be used to recommend appropriate learning contents for individual learners automatically and efficiently.

The remainder of this paper is organized as follows: Section 2 briefly reviews the basic concepts of the CPN and relevant literature. Section 3 presents the details of the LBPN, and Section 4 illustrates the LBPN-based learning behavioral model. Section 5 evaluates the generated behavioral patterns based on the proposed model. Finally, Section 6 concludes this paper.

2. Background

This section briefly summarizes the definitions of the CPN and related applications of the HLPN.

2.1. Definition of colored Petri net

CPN denotes a 9-tuple [19]:

$$\mathrm{CPN} = (\Sigma, P, T, R, N, O, G, F, I), \quad (1)$$

which satisfies the following definitions and requirements [19]:

(1) Σ: is a finite set of non-empty types, called color set, in which dots describe data types.
(2) P: is a finite set of places, in which circles describe the states of a system.
(3) T: is a finite set of transitions, in which bars describe the actions of a system.
(4) R: is a finite set of arcs such that $P \cap T = P \cap R = T \cap R = \emptyset$.
(5) $N: R \rightarrow P \times T \cup T \times P$ is a finite set of node functions.
(6) $O: P \rightarrow \Sigma$ is a finite set of color functions.
(7) G: is a finite set of guard functions. It is defined from T into expressions such that $\forall t \in T:$ $[\mathrm{Type}(G(t)) = \mathrm{Bool} \wedge \mathrm{Type}(\mathrm{Var}(G(t))) \subseteq \sum]$.
(8) F: is a finite set of firing condition functions. The arc with an expression function describes how the state of the system changes when the transitions occur.
(9) I: is an initialization function.

2.2. Relevant literature

The HLPN is an extension of PN to help users handling highly detailed and relatively large descriptions. In 2002, Liu et al. proposed a CPN-based teaching net that uses a formal description to edit an e-learning course, to navigate learning paths, and to allow reuse and aggregate learning resources [22]. In [10], Chen et al. proposed a dynamic fuzzy Petri net (DFPN) for modeling a tutoring agent's knowledge and dynamically determining the order that learning content is to be accessed in an ITS. The method proposed by Chen et al. also provides individual learners with particular learning content structures [10]. Su et al. [33] proposed the object-oriented course modeling (OOCM) scheme to construct a course authoring tool by which an instructor can easily edit an e-learning course. In [6], Cai et al. used the hierarchy colored Petri nets (HCPN) to model multi-agent task-planning behaviors in an interactive intelligent virtual training system to perform safety training in underground coal mines.