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FORMAL MODELING AND VERIFICATION OF E-LEARNING BASED ADAPTIVE SYSTEM

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Abstract
E-learning plays an important role in today's education using digital media. In classrooms, teachers change their behaviors, techniques, and teaching methods according to the response they receive from students. E-Learning system in its entirety should be able to do so. However, to do this open communication is necessary and based on that decision-making from associated users should be driven by the system. Only then an e-learning system can be reliable and effective. The presented architecture uses Colored Petri-Nets, with the inclusion of a feedback module in the existing architecture for the reduction of a communication problem to enhance the system's efficiency. In this way, users communicate for optimizing the system and updating it with best learning practices and techniques. With the help of Simulation and its analysis report generated by the state space analysis tool, the users will be able to understand the behavior of the system more effectively and tackle faults before implementation.
KEYWORDS: Adaptive E-learning, Multi-agent systems, Colored Petri Nets, State-Space Analysis

1. Introduction

E-learning is the acquisition of information or knowledge in a formalized way with the help of an electronic medium. Communication technologies like electronic and digital devices can be used as a medium for e-learning [1]. One can get knowledge online, same as we gain in classrooms. E-learning share knowledge in all kind of formats such as videos, PowerPoint documents, portable document formats and so on. E-Learning may be considered as the style of learning [2]. E-learning is most desirable for busiest people who find it difficult to gain knowledge by attending regular classes at a specific place, as one can take advantage of e-learning by gaining knowledge at any time and place suitable for them [3]. There are a large number of online education systems that are useful for students [4]. In today's world learners are well aware of the use of computers, the internet, smartphones, and the latest technologies. So, it is easy for them to operate e-learning management systems.

The term "adaptive" can be used in different ways in e-learning environments. e.g. one can say that adaptive interaction can be considered as an interaction between the user and the system interface without modifying the course content, whereas adaptive content or course delivery can use the term adaptation to deliver a course to the user according to the user requirements and needs [5]. The adaptive e-learning systems provide content to the user according to the user's needs and requirements [6]. Most of the adaptive systems take into account the user's characteristics like their interests, knowledge level, learning style, objective, confidence, understanding, capability etc. These systems automatically change their content according to the user's goals and capability of understanding by analyzing the user's interest. The purpose of the adaptive feature is to maximize user satisfaction, efficiency, and effectiveness [7].

In section 2 literature review about e-learning systems and adaptive e-learning systems is presented. Preliminaries are discussed in section 3, Modeling of the system and analysis is discussed in sections 3 and 4 respectively and finally conclusion is discussed in section 5.

2. Related Work

There are several working adaptive e-learning systems [8] and there are different modules that are handled for the adaptiveness of the system. The major problem arises in the development of these systems is the interaction. Without interaction, it is impossible to design such systems that take into account the user's needs and goals and change accordingly. The interaction plays an important role in such systems where two-way communication is important [9]. So the concept of agents was used for the development of these systems in a more efficient way.

The depiction of a system in the form of a graphical structure is known as modeling. This is a crucial methodology for problem-solving and we can interpret the behavior of the system by using this methodology. The models of the systems are designed to check whether the system holds certain properties or not. It gives information about the behavior of the system before the actual development or implementation of the system. Different models give information about different modules of the system and their complex relationships with each other. Execution

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of these models is known as simulation. With the help of these models, we can perform an analysis of the system and interpret results from the analysis of each module of the system hence resulting in better decision making [10].

Several E-learning systems have been implemented using different technologies and methodologies with the collaboration of different agents. Yi-Hsing Chang et. al. [11] presented an adaptive E-learning system based on intelligent agents (IAELS). IAELS improves the ability of the learner to learn new things as learners were unable to get new knowledge from discussions in the past. Four intelligent agents are designed in IAELS: user agent, learning agent, data mining agents and feedback agent. M.U. Bokhari and S. Ahmad [12] proposed a new Interactive Multi-Agent Based Learning System (IMBLS) for distance learning on the web. Their architecture provides a highly interactive learning environment for the students and the teachers. Pham Quang Dung, Adina Magda Florea [13] proposed an architecture for developing a personalized multi-agent e-learning system. The system supports pre-defining students' learning styles and re-estimating them with the help of intelligent agents. Sadaf Ahmad and Mohammad Ubaidullah Bokhari [14] proposed a new architecture based on Multi-agent system for e-learning environment where the main focus is on the ease of the use of the system and to reduce the complex behavior of the interaction. The architecture takes into account other features like personalization, intelligence, accessibility, and security. Ville Karavirta and Petri Ihantola and Teemu Koskinen [15] have designed and implemented a system called A+ which can be thought of as a service-oriented approach to improve interoperability of e-learning systems.
Salah Hammami et.al [16] proposed architecture for Adaptive E-learning system based on agents and object petri nets (AELS-A/OPN) and used a blackboard agent technique to ensure the communication between agents. Adaptive e-learning systems is also proposed by Soukaina et. al. to overcome the weaknesses of traditional learning systems [17]. Agent based e-learning system is also proposed by Hammami, S., & Mathkour, H. [18]. In this research interaction between agents of e-learning system is formally verified through Object Petri nets. Tarus et. al. [19] represents a literature review about recommendation-based e-learning systems. Tarhini et. al. [20] developed a theoretical model for measuring cultural values based on e-learning system in developing countries. In [21] 12 different types of multimedia-based research principles are discussed to promote academic learning. Kolekar et al. proposed an algorithm about the learning behavior of the learner in the e-learning portal using Web Log Mining. In [22] adaptive e-learning system is briefly discussed. Drissi and Amirat have proposed an approach to integrate learning styles into adaptive e-learning hypermedia in [23].

3. Preliminaries

A few terminologies, mathematical and computational models have been described in this section that will help to build the understanding of the basic terms used in this work.

3.1 Multi-Agent System

A multi-agent system is one of the techniques of distributed artificial intelligence (AI). The interaction of a group of intelligent agents forms a multi-agent system (MAS). In MAS each agent works separately on its own task as every agent has a different task. If an agent needs help then they interact with each other in a system and perform the task as a group. They work together to achieve a goal that is difficult to achieve by an individual agent. Agents work together to solve a particular problem in an efficient way. There is cooperation exists between individual agents to work together for a goal. MAS play an important role in e-learning systems as multiple agents can work for different modules thus increasing the functionality of the system. There are several multi-agent systems that are used for adaptive e-learning [14][24].

3.2 Colored Petri Nets

Coloured Petri Nets [25] models can be described as formal models because CPN modeling language has a mathematical definition of both its syntax and its semantics.
A Coloured Petri Net is a 9-tuple
CPN = $(P, T, A, \Sigma, V, C, G, E, I)$ where:

- P is a set of places, i.e. $P = \{p_1, p_2 \ldots p_m\}$
- T is a set of transitions, i.e. $T = \{t_1, t_2 \ldots t_n\}$
- A is a set of arcs, i.e. $A \subseteq P \times T \cup T \times P$
- Σ is a set of color sets,
- V is a set of variables, i.e.
  $Type(v) \in \Sigma$ for all variables $v \in V$
- C is a color set function, $C: P \rightarrow \Sigma$
- G is a guard expression function, i.e.
  $Type[G(t)]$ = Bool for all $t \in T$
  $G(t)$ = true for all $t \in T$.

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A guard function is represented as: $G: T \rightarrow EXPR_v$

- E is an arc expression function, i.e. $E: A \rightarrow EXPR_v$
  $Type[E(a)] = C(p)$ for all $a \in A$.
- I is an initialization function, i.e. $I: P \rightarrow EXPR_\emptyset$

3.3 State Space Analysis

To verify the functional correctness of any system modeled in Colored Petri nets, the state space method is used. All the reachable states and the variation of the states in the model are computed with the help of this method. The state space generated at the end consists of several states and arcs. Different behavioral properties of the system are analyzed and verified through the output generated by the state space. The several properties include boundedness, liveness or deadlock freedom, fairness, and reachability property. The CPN model in the CPN tools has two different methods of the analysis which includes simulation and state space analysis.

The CPN simulator is responsible for the simulations of the CPN models. And the state space method is supported by CPN state space tool. The simulation method is useful for the simulations performed in the model i.e. the complete model is executed So for this purpose, the state space analysis method is used, in which the complete model and its behavior are analyzed and the results showed the presence or absence of the several formally specified properties. The state space analysis performed in CPN tools helps the user to understand the behavior of the system in detail by providing the detailed output of the system. The report generated by the CPN tool is useful in the identification of errors and for the correctness of the system.[26],[27].

4. System Architecture and Modeling

The adaptive E-learning system architecture developed in [16] has lack of information regarding the registration and login components of the system. So, in this research, the existing architecture for adaptive E-learning system based on agents is enhanced by the addition of different modules namely registration module and a feedback agent module. The registration module is added for the registration of the users of the system. This way we are making sure that the author is an authentic and reliable source of information and the course which he will create will be authentic as well. The enhanced architecture can easily verify the author and learner of the system efficiently as there is detailed information regarding the registration and login components of the system. The feedback agent enhances the feedback of the system. This agent helps in the enhancement of the system by providing the feedback of the user to the system and hence improves the functionality of the system in an efficient way over periods of time for continued enhancements and evaluation of the system.

The system starts with the registration module and ends at the feedback agent module. There is an e-learning information system attached to the e-traceability system. The information system contains the databases of the system and the e-traceability system is used for the evaluation of the e-learning system. The system diagram is shown in Figure 1.

The system is designed in the colored Petri nets tool to show the internal behavior of the modules and to model the system in an efficient way. The CPN representation of the system is represented in Figure 2.

The architecture has several modules consisting of different multi-agents. Each module is modeled in the colored Petri nets and all micro-level modules are combined to form a macro-level. The feedback agent module is added to enhance the functionality and efficiency of the system. For registration of author or learner two different modules are used. Through these modules different parameters are taken into account to register the author and learner into the system. After registration of the users, the user's profile is created, and the status is sent to a human agent.

4.1 Author Registration Module

Author registration module is presented in Figure 3. In this way system admins can create the number of authors for particular domains/subjects. Availability of diverse content covering different subjects/domain can therefore, be managed in the system.

4.2 Learner Registration Module

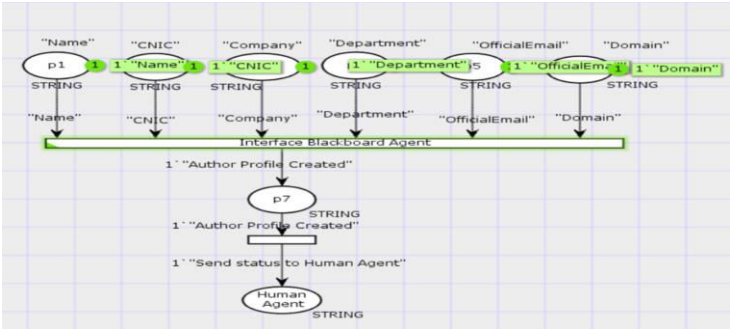

Figure 3 – Author Registration Module

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The module given in Figure 4 is represented a learner registration process, this will help the system to present relevant Subjects/Domains courses to learners. Hence, increasing usability and engagement of the system.

4.3 Human Agent Module

In the human agent module, the users of the system request to Interface Blackboard Agent to login into the system.

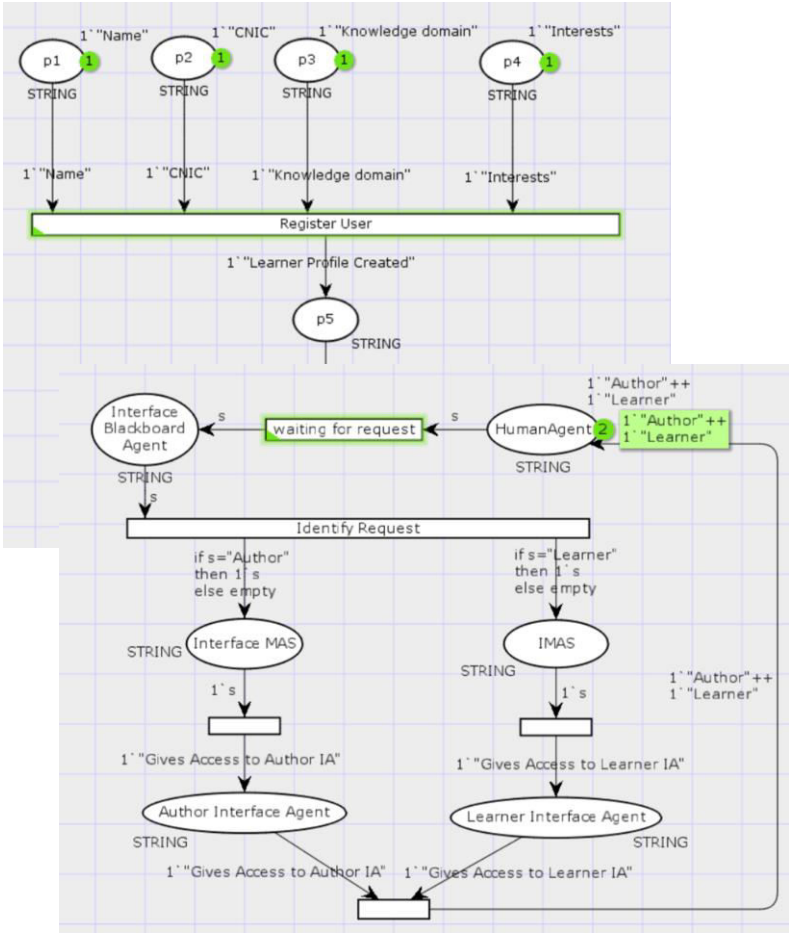

Figure 5 – Human Agent Module

Firstly, the users are identified, and the actions are performed accordingly. Blackboard is a shared working environment where different agents communicate with each other to perform a task efficiently. Different agents share their problems and can be facilitated with a suitable solution to their problems. Multiple blackboard agents are used so that the system can work effectively and efficiently, and the system load can be distributed among different blackboard agents. Blackboard Agent is used for the interaction of the human agent with the system. It also stores information of the users to the storage module of the system. This agent receives requests from the users or from the human agent module and distributes them through interface multi-agent system to the author or learner interface agents as shown in Figure 5.

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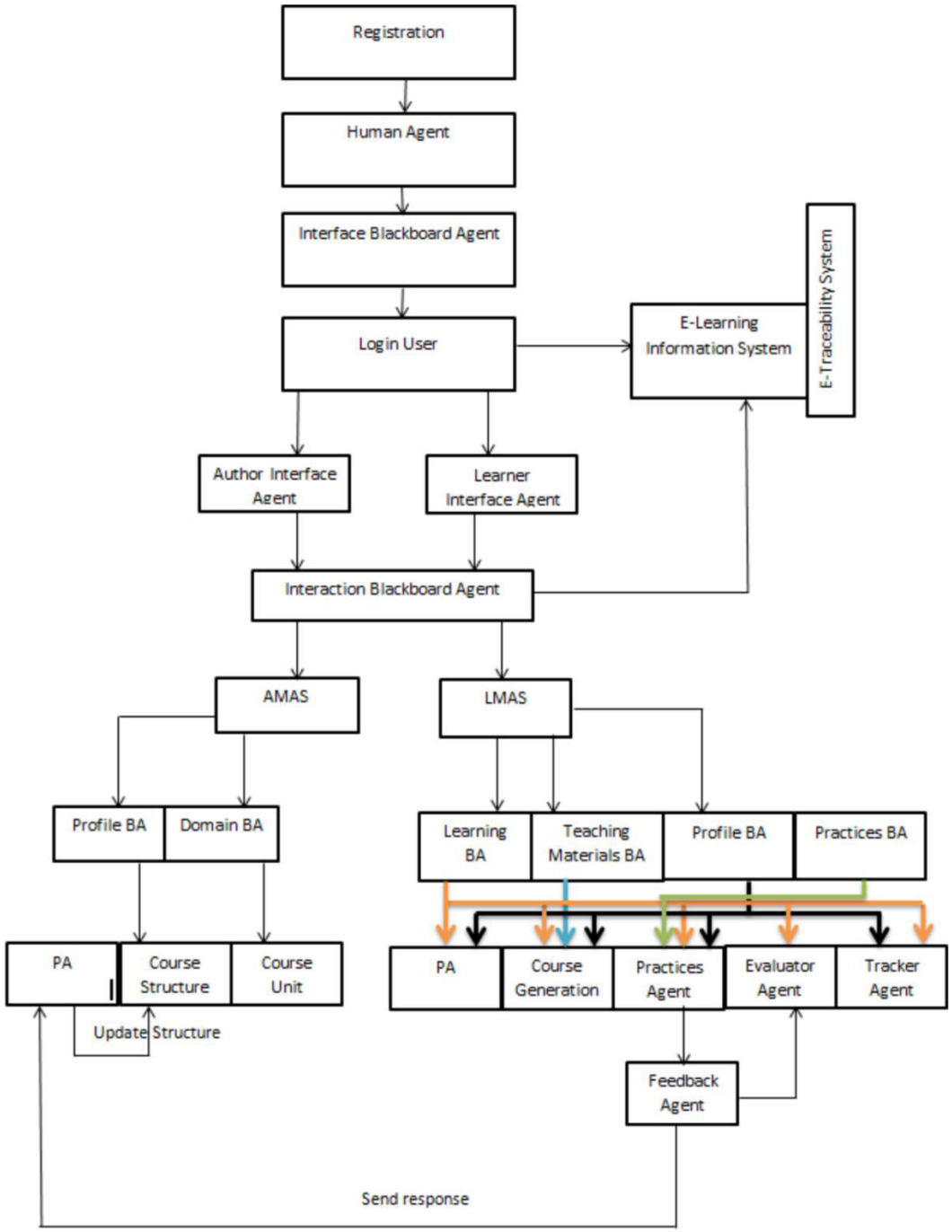

Figure 1 – E-learning System Architecture

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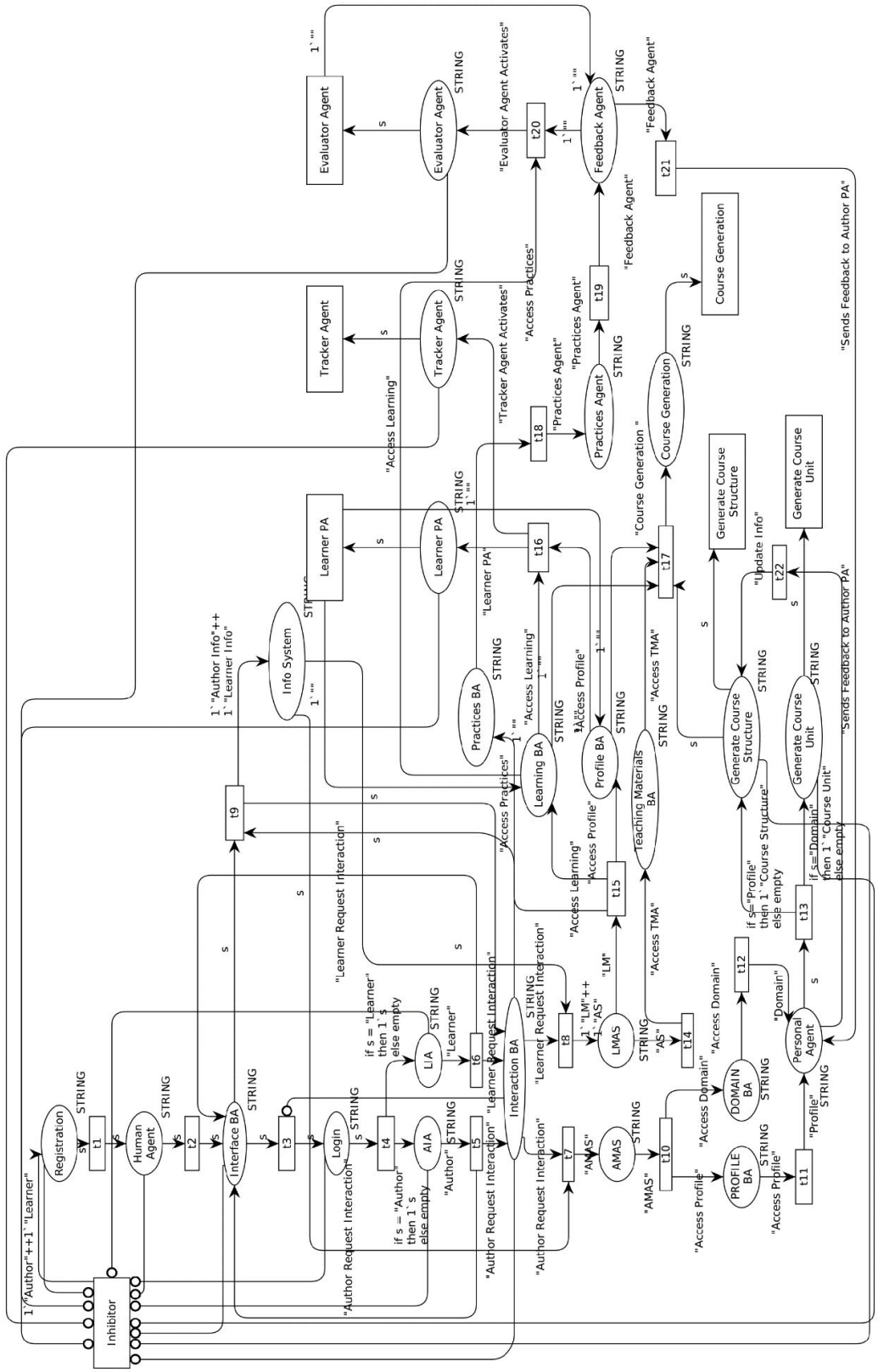

Figure 2 – CPN Model for E-learning System

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4.4 User Login Module

This module is designed for the users of the system to login to the system by entering their username and password as shown in Figure 6. The author and learner both required their username and password to login to the system. After the user's login, they request the interaction blackboard agent module to access the rest of the system.

4.5 Authoring and Learning MAS Module

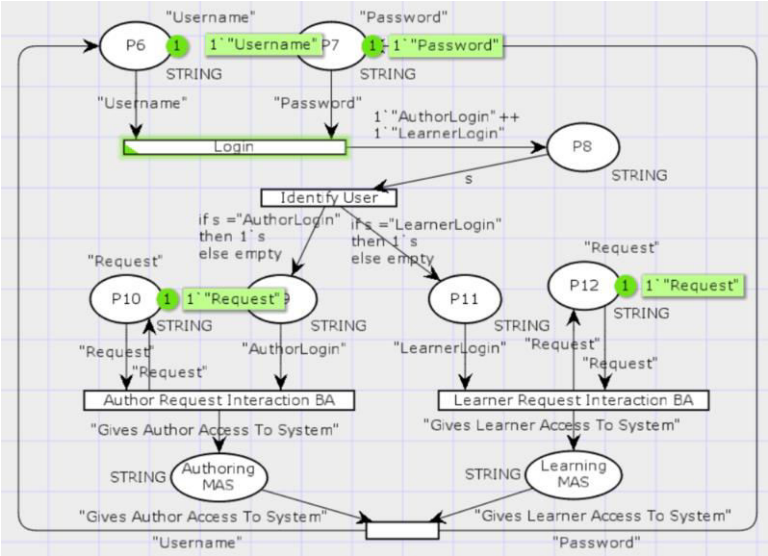

Figure 6 – User Login Module

If the request is generated from the author, then the author will be provided with the authoring MAS access and if the learner request to access the system then the learner will be given access to the learning MAS. The authoring MAS consists of three different agents: author personal agent; course structure generator agent and course unit generator agent. These help the author for the creation of the electronic content for the learner of the system as shown in Figure 7. The author personal assistant agent helps the author in the creation of the course structure and course unit and give suggestions to the author to update the teaching content after receiving a response from the feedback agent module. Course structure generator agent is responsible for the creation of the course structure. If an author wants to access the course structure generator agent or to create a course structure, then the authoring MAS will retrieve the initial information of the author from the interaction blackboard agent and sends the request to the author personal assistant agent. The author personal assistant agent gains information from the profile blackboard agent and the domain blackboard agent that contains the different learning styles and retrieves author profile which contains author skills and hence allows the author to generate a course structure. Course unit generator agent generates course units according to different learning styles and selects information from domain blackboard and profile blackboard.

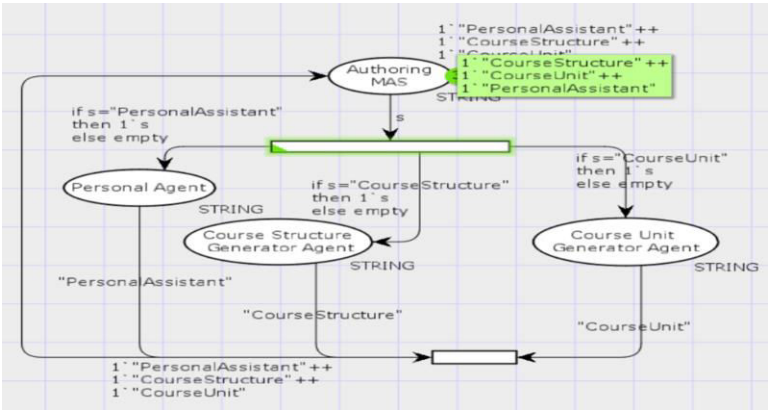

Figure 7 – Authoring MAS Module

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The learning MAS module consists of five different agents: learner personal agent, course generation agent, practices generator agent, evaluator agent and learner tracker agent. These agents help the learner for accessing the electronic content by the system and provide the functionality that is necessary for the learner in the learning process as shown in Figure 8.

The learner personal agent shown in Figure 9, helps the learner in the most suitable way as it gives suggestions to the learner that is useful for the learner. This agent communicates with all the other agents in the learning MAS and presents the learner's profile, knowledge level and interests to communicate with them and in turn get results from those agents accordingly and presents the learning content to the learner. The learner tracker agent activates as the learner communicates with the personal agent and all the information is stored in the learning blackboard agent. The course generation agent generates teaching materials for the individual learners by obtaining the information that is stored in the interaction blackboard agent. The practices agent generates the practices for different users according to their knowledge level and interests.

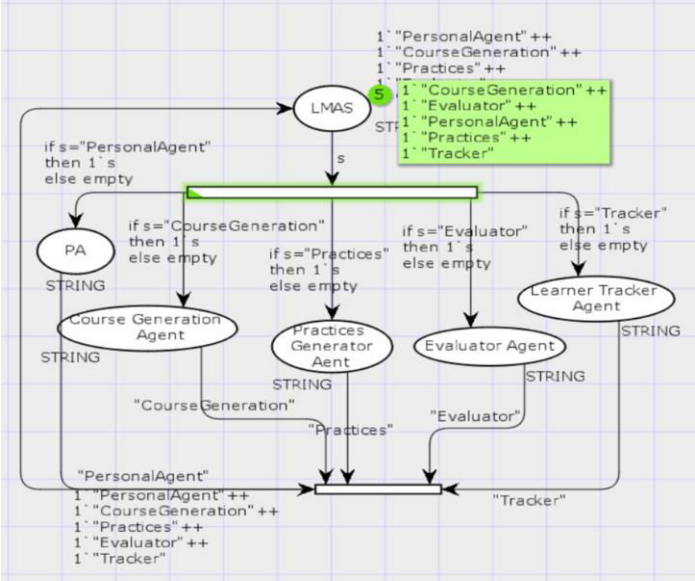

Figure 8 – Learning MAS Module

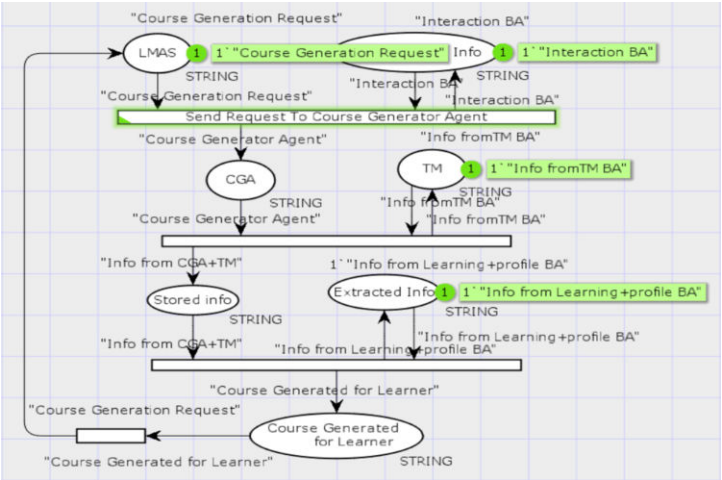

Figure 9 – Course Generation Agent Module

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The practices generator agent shown in Figure 10, generates the practices for different users according to their knowledge level and interests. These practices will be presented to the learner in the course unit. i.e. when the course is generated for the learner it includes course structure and course unit. When the learner accesses the course unit a practice is proposed to the learner according to his interests and knowledge level. The practices agent retrieves information from the practice blackboard agent (which includes the different questions with different difficulty level according to the different users), profile blackboard agent and learning blackboard agent and stores this information at a place. After reflecting upon the information obtained from these blackboard agents the different practices are generated for different learners. After the completion of the practice, the learner will give feedback about the practice and the results are stored in the learning blackboard agent and hence the evaluator agent will be requested for the evaluation of the learner. The practices agent generates the practices for different users according to their knowledge level and interests. These practices will be presented to the learner in the course unit. The evaluator agent will retrieve the results of the practice from the learning blackboard agent and generates the evaluation results. After evaluation, the evaluation results will also be stored in the learning blackboard agent and will be presented to the learner personal assistant agent.

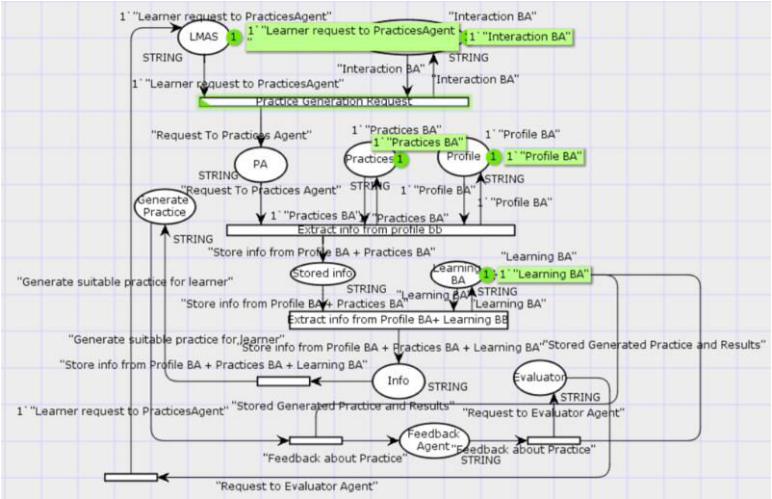

Figure 10 –Practice Generator Agent Module

4.6 Feedback Agent Module

The feedback agent module shown in Figure 11, is the most important module in the system. As feedback is an important component for the progress of any system and organization. Feedback is necessary for the improvement of any system to validate the system's performance and functionality [28]. It is a two-way communication phenomenon, as we can take feedback from the system and can give feedback about it. We can give and take feedback in different forms. It can be positive or negative feedback. From educational perspectives, feedback is considered as an important component for both the teachers and students. It helps students and teachers to improve their performance [29]. We can give and take feedback in so many different forms; it can be formal or informal. The internal behavior of the feedback module represents that after receiving feedback about the practices the feedback

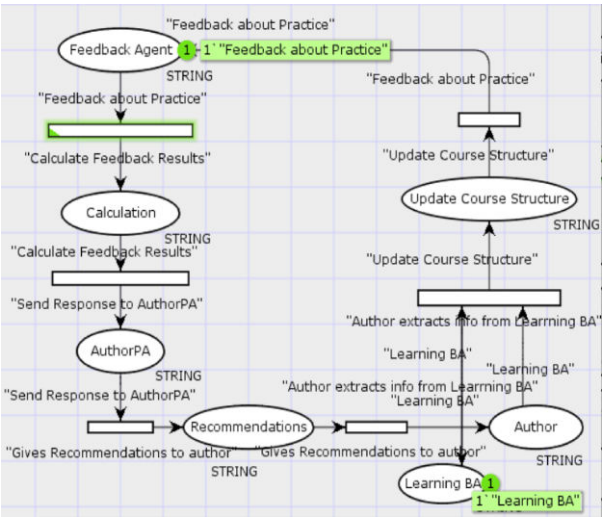

Figure 11 –Feedback Agent Module

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results will be calculated and then the response will be sent to the author personal assistant agent. The author personal assistant agent will give recommendations to the author after receiving a response from the feedback agent module. The author then extracts information from the learning blackboard agent as there is complete updated information regarding learner is present. After the extraction of the updated information, the author will update the course structures according to the different user's needs and requirements.

5. Verification and Analysis of the System

Two types of properties can be studied through Petri nets; structural and behavioral proerties. The behavioral properties depend on the initial marking of a system and can be referred to as marking-dependent. The structural properties are the properties which are independent of the initial marking of a system [30]. Reachability is a behavioral property describes the behavior of the system in the form of firing sequences or marking. A marking is said to be reachable from the initial marking if there exists a path from the firing transitions that result in a particular place or marking. A reachable marking from initial marking is represented as:

$R(M_0)$ = set of markings reachable from the initial marking M_0.

The most important behavioral property of a Petri net is the boundedness property. This property can be described by the number of tokens in each place. We can say that a PN is bounded or k-bounded for some $k > 0$.

$M(p) \leq k$, $\forall p$ & $M \in R(M_0)$ **(K-bounded net)** (1)

A PN is consider safe if it is 1-bounded i.e. $k = 1$.

$M(p) \leq 1$, $\forall p$ & $M \in R(M_0)$ **(Safe net)** (2)

A PN is said to be deadlock-free or live if at least one transition is enabled at every reachable marking. A transition t is said live if it is always enabled at a marking M' from any reachable marking M_0 i.e.

$\forall M \in R(M_0), \exists M' \in R(M)$ such that $M'[t >$ (3)

A transition is said to be L-1 live, if it can be fired at least once, i.e.

$\exists M \in R(M_0)$ such that $M[t >$ (4)

Similarly, the model is verified through structural properties. Our model is structurally live due to the existence of initial marking during analysis. Also, the model is structurally bounded as number of tokens remain finite and each place is reachable from initial marking. The state space analysis is represented through Tables 1-4. According this analysis there are 65222 nodes and 267858 arcs and it is impossible to represents state space graph. The bounded property tables represent that there is no any place having infinite number of tokens.

Table 1 – Statistics

State Space	
Nodes	65222
Arcs	267858
Secs	3000
Status	Total
SCC Graph	
Nodes	65222
Arcs	267858
Secs	5

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Table 2 – Bounded Properties

Best Integer Bounds	Upper	Lower
Systemdiagram'AIA 1	1	0
Systemdiagram'AMAS 1	2	0
Systemdiagram'Course_Generation 1	1	0
Systemdiagram'DOMAIN_BA 1	2	0
Systemdiagram'Evaluator_Agent 1	1	0
Systemdiagram'Feedback_Agent 1	2	0
Systemdiagram'Generate_Course_Structure 1	2	0
Systemdiagram'Generate_Course_Unit 1	1	0
Systemdiagram'Human_Agent 1	2	0
Systemdiagram'Info_System 1	4	0
Systemdiagram'Interaction_BA 1	2	0
Systemdiagram'Interface_BA 1	2	0
Systemdiagram'LIA 1	1	0
Systemdiagram'LMAS 1	4	0
Systemdiagram'Learner_PA 1	2	0
Systemdiagram'Learning_BA 1	3	0
Systemdiagram'Login 1	2	0
Systemdiagram'PROFILE_BA 1	2	0
Systemdiagram'Personal_Agent 1	3	0
Systemdiagram'Practices_Agent 1	2	0
Systemdiagram'Practices_BA 1	2	0
Systemdiagram'Profile_BA 1	3	0
Systemdiagram'Registration 1	2	0
Systemdiagram'Teaching_Materials_BA 1	2	0
Systemdiagram'Tracker_Agent 1	2	0

Table 3 – Bounded Properties

Home Properties	
Home Markings	All
Liveness Properties	
Dead Markings	None
Dead Transition Instances	None
Live Transition Instances	None
Fairness Properties	
No infinite occurrence sequences.	

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Table 4 – Best Upper and Lower Bounds

	Best Upper Multi-set Bounds	**Best Lower Multi-set Bounds**
Systemdiagram'AIA 1	1`"Author"	Empty
Systemdiagram'AMAS 1	2`"AMAS"	Empty
Systemdiagram'Course_Generation 1	1`"Course Generation "	Empty
Systemdiagram'DOMAIN_BA 1	2`"Access Domain"	Empty
Systemdiagram'Evaluator_Agent 1	1`"Evaluator Agent Activates"	Empty
Systemdiagram'Feedback_Agent 1	1`""++1`"Feedback Agent"	Empty
Systemdiagram'Generate_Course_Structure 1	1`"Course Structure"++1`"Update Info"	Empty
Systemdiagram'Generate_Course_Unit 1	1`"Course Unit"	Empty
Systemdiagram'Human_Agent 1	1`"Author"++1`"Learner"	Empty
Systemdiagram'Info_System 1	3`"Author Info"++3`"Learner Info"	Empty
Systemdiagram'Interaction_BA 1	1`"Author Request Interaction"++	Empty
	1`"Learner Request Interaction"	Empty
Systemdiagram'Interface_BA 1	1`"Author"++1`"Author Request Interaction"++ 1`"Learner"++1`"Learner Request Interaction"	Empty
Systemdiagram'LIA 1	1`"Learner"	Empty
Systemdiagram'LMAS 1	2`"AS"++2`"LM"	Empty
Systemdiagram'Learner_PA 1	2`"Learner PA"	Empty
Systemdiagram'Learning_BA 1	2`""++2`"Access Learning"	Empty
Systemdiagram'Login 1	1`"Author"++1`"Author Request Interaction" ++1`"Learner"++1`"Learner Request Interaction"	Empty
Systemdiagram'PROFILE_BA 1	2`"Access Profile"	Empty
Systemdiagram'Personal_Agent 1	2`"Domain"++2`"Profile"++ 1`"Sends Feedback to Author PA"	Empty
Systemdiagram'Practices_Agent 1	2`"Practices Agent"	Empty
Systemdiagram'Practices_BA 1	2`"Access Practices"	Empty
Systemdiagram'Profile_BA 1	2`""++2`"Access Profile"	Empty
Systemdiagram'Registration 1	1`"Author"++1`"Learner"	Empty
Systemdiagram'Teaching_Materials_BA 1	2`"Access TMA"	Empty
Systemdiagram'Tracker_Agent 1	2`"Tracker Agent Activates"	Empty

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6. Conclusion

In this research work, the existing architecture for adaptive E-learning systems based on agents is enhanced by the addition of several agents namely registration module and another agent namely feedback agent module. The communication gap is reduced to some extent by the inclusion of feedback module. The features like Usability, Effectiveness, Quality, and Diversity of Content are enhanced by Feedback and the Authenticity and Reliability is ensured by the help of the registration module. The graphical model of the architecture is also presented. We have modeled the architecture by using a class of Petri nets, known as colored Petri nets. The modules of the architecture at the micro-level are represented in the colored Petri nets and then these micro-level modules are integrated to form a macro level to ensure the internal behavior of agents. The macro level is also modeled in colored Petri nets. In the end, the model is evaluated by the help of simulation. This enables agility of the system and its scalability. Exact guidelines and behavior of the system can be easily judged based on colored Petri-nets simulation. This is useful for the developers of the system to maintain the system with less hassle and in development of the well-designed and well-documented system. The system efficiency is increased and the system became more reliable. The state space analysis is performed on the modeled system and it states that the model has 224 states and there is no deadlock condition occurred in any of the states and the proposed model is working efficiently without any error or deadlock. This is increasing the efficiency of the system and making the system more reliable. Our proposed model achieved the boundedness and liveness properties of the Petri nets and the reachability property is verified by the presence of the home marking states in the net. There is no dead state or marking in the net and the net is live. There are 65222 nodes and 267858 arcs are present in the net and it takes 3000 seconds to perform complete analysis on the net.

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