Multi-agent modeling of the learning process using nested colored Petri nets

I M Gorbachenko
Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russian Federation

Abstract. A model of the educational process of the university in the form of a two-level multi-agent system is implemented in the form of an embedded colored Petri nets using the CPN Tools software. The system allows a statistical modeling of the development of the educational program as a single student or group of students by evaluating the success of training. The average grade point and dropout rate are assessed both for passing one academic subject and the entire educational program. The initial data for modeling are taken on the basis of the experience of teaching students with a close profile of training and expert assessments of specialists. The structure of the system and the functioning of Petri nets are considered. An example is given illustrating the operation of the system.

1. Introduction
The process of "learning" - a classic example of a controlled process, which provides the achievement of goals phased gradual transfer system from the initial state to a final [1]. In teaching process, the teacher acts as a management subsystem, a group of students acts as controlled ones.

Learning itself includes: model teaching model of emotional and intellectual interaction teaching model [2 - 4]. Before modern pedagogy task of creating effective teaching technologies that contribute to the high quality of education. To attain these objectives, various models of the educational process. For example, commonly used representation of the learning process in the form of directed graphs which are called learning paths, learning strategies, situational learning patterns [2 - 6].

In this paper, we propose a model of the learning process based on the fact that this process is probabilistic in nature, and under certain assumptions this process can be represented as a certain graph (for example, Petri net, Markov chain [7 - 9]). Many studies have shown that, using the Petri net, one can describe discrete dynamical systems [9 - 11].

However, this approach does not take into account the behavior of the active participants in the learning process. In this paper we use a different approach that focuses on modeling systems, consisting of independently operating entities, called agent-based modeling [12 - 14]. An effective tool for implementing this approach is nested Petri nets describing the interaction of independently acting agents [7 - 10]. The use of nested Petri nets allows you to create realistic models of the dynamics of educational systems by modeling and analysis of parallel and distributed systems, which is the learning process. The first work in this direction [12, 15 - 17] have shown the advantage of agent-based approach, but they are not used special software to enable practical to build such a model the real dimension.

In this paper, first suggested to use a software package CPN TOOLS to construct hierarchical models of the learning process as a system of interacting agents. The types of agents are considered; their interaction is described. In this paper, a model of development of subjects as a single student or student...
The comparison of simulation results with the results of a real educational process is also made. As a result of this work shows good agreement of results.

2. The process model of learning

Proposed model learning process is a two-level colored Petri net created via special program CPN Tools [18 - 21].

A distinctive feature of this program is to have a rich tool that allows to analyze various aspects of the models based on Petri nets (safety and limited positions, level of transition activity, the presence of dead-end markings). CPN Tools is used in a variety of real-world projects in the field of telecommunications, in the simulation of networks and network devices, as well as verification of communication protocols.

This model involves many resources, each of which relates to a particular type - the color set. To operate with these resources, appropriate variables are introduced, sometimes called chips. So, the color set STUDENT contains variables of type string, which denote the names of students; the MARK color set contains possible grades for mastering items - excellent, good, well, bad. Full list of color sets and their elements are shown in figure 1.

![Figure 1. Description of the color system of sets.](image)

The created model contains two types of agents: a learning structure whose behavior is simulated by a lower level network (figure 2), and a group of students whose behavior is simulated by a variety of lower level Petri nets (figure 3).

Each Petri net contains many positions, graphic symbols and resources, and controls the redistribution of resources. Transitions indicated by double-line rectangles mean a separate subnet of the lower level.

Consider the position of the top-level network for students:

- **stud position** contains the STUDENT type chips, indicating the names of the students,
- **kurs position** contains chips type PREDMET, indicating studied subjects,
- **position 1** contains a list of the students and offered to study the disciplines,
- **START position** contains a list of selected students and to study disciplines
- **END position** contains a list of students and studying the discipline of evaluation,
- **second position** contains a list of the students and the disciplines they study again
- **DIPLOM position** contains a list of student studied disciplines with estimations (this information is displayed in the diploma).

Description of transitions:

- **transition ready** to generate a list of students with proposed for the study of disciplines,
it represents a transition start subnet, which verifies whether student data discipline studied previously or not,
transitions course1 course and 2 represent subnet describing particular student study subjects under number 1 and 2 respectively,
transition report identifies the need for re-examination of certain student discipline or information can be entered into the diploma.

Figure 2. The top-level Petri net.

In this version of the model, students only study two courses, but the model can easily be extended to the required number of disciplines.

When the network is working, a student is randomly selected and the training course that he must take, after which it is checked whether this student took this training course or not. If the student has not yet taken the course, then the student's learning process begins, as a result of which there is a certain assessment of the student's knowledge in the chosen discipline. If a student has studied this subject for a positive assessment, then re-studying the course is blocked, the assessment is entered in the "diploma" (the corresponding chips appear in the DIPLOM position) and the student and course are selected again for passing. If the grade after completing the course is unsatisfactory, then the student returns to the study of the chosen course.

Network start works as follows:

creates a list of students indicating the courses taken earlier (if it is the first training for the first time a student is triggered inhibitory arc to start a list of consciousness)
as soon as a regular student, indicating the discipline, then there is a check for the presence of this information in the list,
if the information is not available, the student is sent to the training, otherwise there is a return to the selection of a new student and curriculum.

Network 1 course is presented in figure 3 and simulates the passage of a student of the course.
Figure 3. Network course 1.

In this network transition course 1 checks what students learn discipline. In this case - it is a discipline of "1". If this transition is triggered, then remembered who of the students studying the discipline (chip is placed in the position of the student), and begins a course of study (chip placed in position 11).

Next the triggering of transitions 11 or 12, transition 13 come. In the proposed model, these transitions reflect the logic of the course. Thus transition 11 denotes the use of a tutorial in the study of the theoretical course material and a transition 12 - reading material from the textbook another poster. As a result, the student receives some knowledge and counter indicating the student is in the position 12 or 13, respectively. Triggering the transition means 13 case studies. As a result, the student masters the skills and abilities (the chip indicating the student is in position 14 or 15, depending on the volume of completed tasks).

Transition 14 is the scoring students on the results of the study course.

Reduced learning course diagram deliberately simplified and can be expanded and / or verified (e.g., based on models [13 - 16]).

Subnet 2 is similar to the construction of course. Since the subnet, describing the process of the study subjects, is set separately, the learning process can be detailed with the required accuracy, set the probability of obtaining a particular mark, the number of points obtained in the training, and more.

Network performs verification report described above.

3. Checking model
To check the model fit the actual process of learning were taken data from 40 examination sheets on various subjects. With a single attempt to pass the exam average percentage of students who received
an exam as "excellent" - 32% of that received "good" - 26%, received "satisfactory" - 20%. These numbers are used as in the simulation probabilities. The proposed model assumes that all students must pass all the exams - without limiting the number of attempts. If we limit the number of re-sit it at 4-5 attempts to "retake" the exam data roughly correspond to the actual figures, "excellent" - 38% "good" - 23% "satisfactory" - 18%.

4. Conclusion
We see that the proposed agent-based model of the educational process, implemented using SPN Tools systems provide realistic results and enable with the necessary information to assess, predict and plan the learning outcomes of both individual students and groups:

- both for individual subjects, and the educational program as a whole;
- determine the average scores on academic achievement and the percentage of students dropping out;
- to identify the most difficult to study subjects and themes;

In addition, modeling can be useful in the development of education in new directions of training programs.

Improvement of the proposed models and methods can be both more complete simulation of the learning process (for example, time recording student responses), and in connection to the proposed model educational institution information process control system.

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