A Petri net-based simulation of synchronized curriculum for IT-specialists' training

Lyudmyla I. Bilousova[1], Liudmyla E. Gryzun[2]

[1]*Independent researcher, Professor, Kharkiv, Ukraine*
[2]*Simon Kuznets Kharkiv National University of Economics, 9A Nauky Ave., Kharkiv, Ukraine*

Abstract

The problems of synchronized curriculum shaping are discussed in the paper in the context of the challenges of contemporary IT specialists' training in terms of permanent evolution and rapid expansion of computing. The authors' technique of the curriculum simulation based on Petri net applying is presented. The theoretical framework which allowed us to elaborate the technique includes some didactical fundamentals of curriculum design and academic disciplines structuring as well as the theoretical basics of Petri nets in terms of their significant facilities for different processes synchronization. The technique of academic disciplines structuring based on frame model of knowledge representation is covered as a chain of stages which results in the net of disciplines modules (frames) including the proper learning elements along with preserving and spreading links between them. In order to solve the problem of synchronization of the learning elements mastering throughout the academic disciplines with regard of the established links in the frames, it is offered the practically-driven approach to curriculum modeling based on Petri nets simulation. The different types of the precedence relations for the learning elements (inputs and outputs of the frames) were distinguished. Using these precedence relations, we managed to simulate through Petri nets a learning element itself and the process of its mastering. Using the operations of Petri nets modifications and learning elements' connections of different types, we could obtain a model of a curriculum discipline module and finally – a curriculum discipline model. Built Petri nets models represent all the evolution of the learning elements mastering by students in the curriculum courses. Synchronization of their mastering is guaranteed by the rules of Petri net execution and modifications. The peculiarities of the offered technique are analyzed. The benefits in terms of applying such a simulation to the building of synchronized curriculum for IT-specialists training are formulated. The prospects of the research are outlined in the lines of using the obtained results for special software development.

Keywords

IT-specialists' training, synchronized curriculum, Petri net-based simulation, curriculum simulation

1. Introduction

Rapid development of IT industries and their penetration in all branches of social life as well as the modern shifts in the demand for computing throughout a global economy cause growing requirements to potential IT-specialists' training. Consequently, this needs changes in

computing education and demands innovative approaches to university curriculum building for training high level professionals in computing sphere.

In the international guidelines shaping the modern paradigms of global IT education, it is emphasized the transformation of computing which nowadays is not just a profession or a single knowledge domain [1, 2, 3, 4, 5, 6]. According to the current state of IT education covered in the latest Computing Curricula Series Report [5, 6], we can conclude that computing area (as a result of rapid evolution) is not an isolated domain, but rather a family of knowledge domains which embraces a set of fundamental and applied study areas. They go on their developing that leads to emerging of new study areas which represent intersection of fundamental science, applied branches of science and traditional computer disciplines.

In particular, it is mentioned that during recent decades the essential changes in IT industry have happened that led to the important changes in the disciplines [1, 2, 3, 4, 5, 6]:

(1) Computer science has evolved into a more developed academic subject;
(2) Computer engineering has raised from electrical engineering;
(3) Software engineering as a discipline has emerged based on Computer science and Computer engineering;
(4) Information systems has expanded throughout economic and organizational processes;
(5) Information technology has appeared as a new discipline that encouraged building computing infrastructures and others.

The study areas continued to evolve, at the same time, increasing the range of study opportunities for pre-service IT-specialists and educational establishments. Additionally, many jobs emerged which concentrated on software use rather than on its development that accelerated the study areas and disciplines maturation.

It is also emphasized that in terms of globalization processes and permanent changes in computing, building of worldwide curricula is getting really urgent. Its development, on the one hand, has expanded the scope of the traditional computing disciplines. On the other hand, it raises the task of preserving the natural links between the disciplines, integrating of the newly-appeared disciplines into the existing curriculum, synchronization of their mastering.

Thus, it seems to be necessary not only to develop a proper approach to university curriculum building for potential computing specialists, but also to elaborate practically-driven means for its efficient modeling.

The *aim* of the paper is to represent authors' Petri nets-based approach to the building of synchronized curriculum for IT-specialists training.

2. Theoretical framework

Developing the approach to the simulation of synchronized curriculum, we addressed to the didactical fundamentals of curriculum design and academic disciplines structuring as well as the theoretical basics of Petri nets which have significant facilities for different processes synchronization.

According to a number of studies, in the process of curriculum design, one of the essential steps is made by the modular structuring of the disciplines which at the same time have to

reflect the content of proper scientific branches. The main challenge here is seen by the researchers in the proper shaping disciplines from modules, which would allow to keep existing links between the portions of knowledge (learning elements). It is pointed out, that building modular structure of disciplines without saving the links and desynchronized mastering of knowledge (skills) will cause the set of negative consequences and educational drawbacks (such as destroying the logic and wholeness of the accepting of the set of curriculum disciplines, shaping uncoordinated system of students' knowledge, inability to use them flexibly in related areas, and other [7, 8, 9, 10]. It is also emphasized in the studies (in particular, [6, 7, 8, 11, 12]) that nowadays it is urgent to find out the ways to build coordinated university curriculum in order to overcome the exposed problems, to cultivate interdisciplinary understanding of knowledge nature, to focus pre-service specialists on holistic mastering of learning content and forming their compound skills.

There are some special challenges in the sphere of IT university education and, subsequently, in curriculum building for IT-specialists' training (partially highlighted above). Among the principles of building global computing curriculum followed by the [6], it is essential to mention the set of important pillars which may become the guidelines for curriculum building in national university education:

(1) it has to preserve the concept of computing throughout the world and in time, as well as to support existing, emerging and future computing disciplines both for the today and potential students;
(2) it has to mind future trends and achievements from industry, research, and the entire spectrum of society;
(3) it has to be flexible to get global enduring acceptance and be adaptable within multiple educational contexts.

Thus, trying to overcome the problems of disconnection between the curriculum disciplines, taking into consideration the main pillars of the building curriculum for IT-specialists training, and meeting the requirements of creation of holistic system of students' knowledge and skills, the authors has developed and implemented the technique of the module disciplines structuring based on the knowledge penetration. The said technique (that was covered in details in our earlier papers [12, 13]) can be represented in brief as follows.

This technique was elaborated by the authors basing on the concepts of the multilevel approach to the formation of learning content in the correspondence with different levels of knowledge generalization minding its AI sense [13]. In particular, there were applied such models of knowledge representation as semantic networks and frame-based models due to their relevant facilities to spread determined connections between knowledge units [14, 15].

Thus, the said technique of the curriculum building based on the knowledge penetration, embraces some stages matching the levels of the educational content building (which, in turn, match the levels of knowledge generalization).

The first stage of curriculum building corresponds to the so called "Super-Subject" level where the content is represented as a network of the concentrated units of knowledge (KPs shown in the figure 1). These units are preliminary defined basing on the analysis of the system of professional functions of the specialists, their job scope, current requirements to their expertise,

typical vocational tasks etc. Thus, these KPs include real elements the subject domain which are to be mastered by per-service specialists in the process of their training.
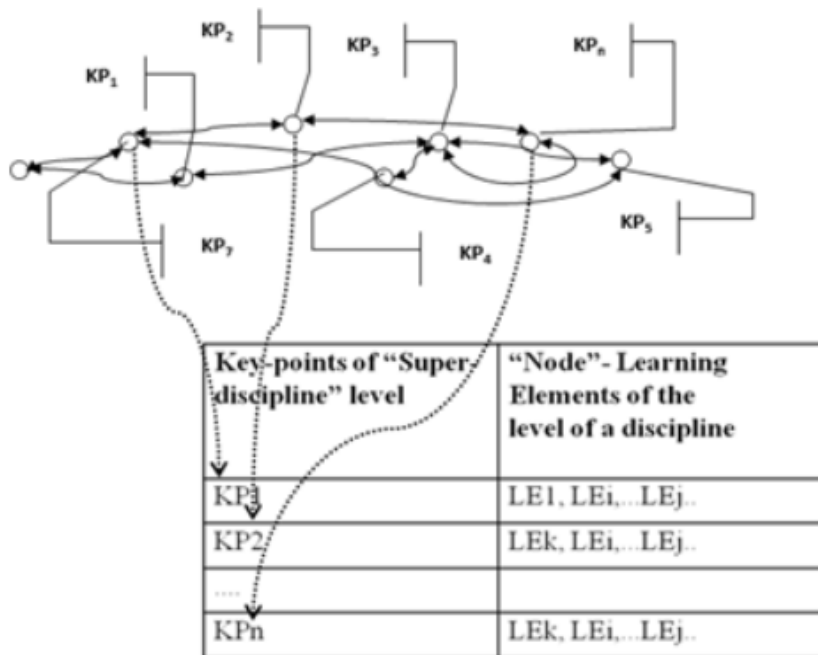

Key-points of "Super-discipline" level	"Node"- Learning Elements of the level of a discipline
KP3	LE1, LEi,…LEj…
KP2	LEk, LEi,…LEj…
…..	
KPn	LEk, LEi,…LEj…

Figure 1: Grouping LEs of a subject domain around proper KPs of the Super-Subject level.

On the subsequent stages of the curriculum building, the content of discipline modules is concentrated around the KPs of the Super-Subject level.

At the next stage of the curriculum building (Subject level and the level of learning material) it is provided the deep analysis of the subject domain regarding its double essence: any curriculum subject is both a part of the educational content and the reflection of a scientific branch. The result of such an analysis (usually made with software like Trope, Text Analist etc) is the system of the interconnected knowledge portions (Learning Elements, or LEs) that are grouped around proper KPs of the Super-Subject level (figure 1).

Then typical procedures for frame-based model of knowledge representation are implemented [14]. In particular, the frames-prototypes are built and filled in with the revealed LEs minding the links, determined at the previous stage. The links between LEs are able to be spread around other frames due to embedded facilities of frame based model. Applying similar procedures to all the curriculum subjects, we obtain the coordinated system of the disciplines which is sensitive to the changes happening on the highest level of education content and at the same time provide students with holistic system of knowledge and skills.

Schematically, the result of the curriculum building may be depicted as a diagram (figure 2) where each frame represents a curriculum subject with nested frames (modules) and connections between revealed LEs grouped around the KPs. Thus, the curriculum can be simulated as a net of modules modeled by the system of frames involving the LEs.

It is important to emphasize that the presented authors' technique of university curriculum
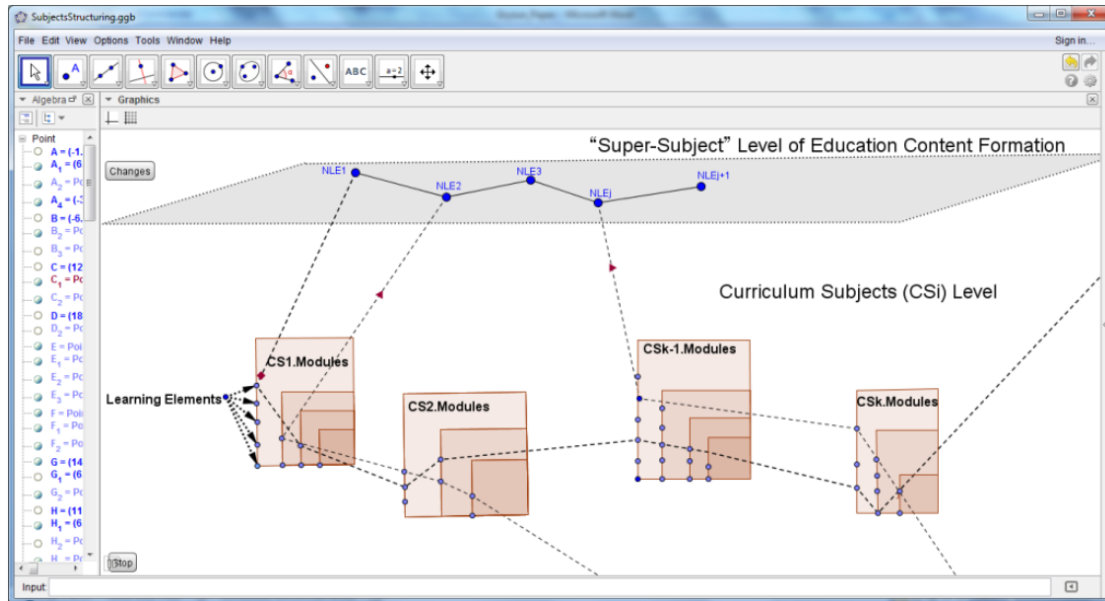
Figure 2: The result of the curriculum building where each frame represents a curriculum subject with nested frames (modules).

building which makes the theoretical and practical framework of our current research was based on the revealed mechanisms of knowledge integration in scientific branches and in curriculum disciplines and allows to trig the integration mechanisms realization. The technique of the disciplines structuring and coherent curriculum shaping was implemented and verified with the help of special expertise.

However, its analysis made us improve some of its steps. In particular, in the process of real curriculum building it became clear that it is necessary to elaborate the issue of the grouping learning elements into the modules. The problem is that the links between the LEs are reserved and spread thanks to the frames facilities. At the same time, it would be beneficial to take into account also the sequence and order of their learning within the modules and disciplines, and to make their mastering not only holistic, but also synchronized.

In this context it is relevant to use the simulation advantages of Petri nets apparatus as for the processes synchronization. Thus, it is necessary to cover in brief basics of Petri nets theory as a framework for our approach to curriculum synchronization.

According to Murata [16], Barros and Gomes [17], Petri nets make a simulation formalism with a graphical visualization and a determined syntax and semantics.

According to Murata [16], a Petri is defined as a two-partite oriented graph N=$\langle P, T, R \rangle$, where P=$\{Pi\}$ is a set of graph vertices which are places and T=$\{Ti\}$ is a set of vertices which are transitions. R component determines a relationship between the vertices corresponding to the arcs.

In a graphical representation of a Petri net, places (P) are indicated with circles, whereas transitions (T) are indicated with bars. According to the rules of Petri nets theory, vertices of the same type cannot be connected. In terms of real processes simulation, places usually

simulate various states (conditions) of the process, whereas the transitions imitate the events which happen within it.

The places can accept tokens which can move around the net via transitions. Disposition of tokens in places is determined by the marking set M which assigns an integer number to each place: M=⟨M(p_1), ..., M(p_i)⟩, where i is a number of places of the net, and M(p_i) is the number of tokens in the place p_i. Thus, the amount of tokens and their disposition around the net control the net execution [16].

Various markings of the Petri net characterize the states of the corresponding dynamic system (process), and the dynamics of state changes is simulated by the movement of the tokens around places. Net marking may be changed as its transitions are triggered. When a transition is triggered, one token is deleted from each input place and is added to each output place.

The main facilities of Petri nets covered in a number of studies [16, 18], testify their advantages to be effectively used for modeling of parallel and consequent processes.

In the context of educational processes simulation, we would like to emphasize some essential Petri nets facilities which were used by the researchers in their works. In particular, the Petri nets were applied for courses structuring in e-learning platforms which allowed to build optimal learning paths for students [19, 20].

In addition, there were done the attempts to apply Petri nets simulation to synchronization in automatic measurement systems [18]; to model students' learning processes in e-learning [21, 22] etc.

The techniques used in said research also made the theoretical framework of our Petri nets-based approach to the modeling of synchronized curriculum.

3. Petri nets-based approach to the building of synchronized curriculum

Basing on the covered theoretical framework, let us focus on key issues, starting with the representation of the frames-based curriculum structure and its Petri nets-based modeling, and ending with the characterization of obtained model of curriculum.

In our approach, the disciplines are composed by the frames uniting the LEs and represented at the charts that specify the precedence between the LEs. As it is shown in figure 2 above, any frame has inputs and outputs. Inputs can be interpreted as the LEs necessary for the student to master in order to be able to learn the LEs of the frame. In similar way the outputs can be interpreted regarding the other frames.

We can distinguish different types of the precedence relations for the inputs:

- 1 LE to 1 LE relation: the only requirement of the LE's learning is the accomplishment of one previous LE's learning (within the frame or between the frames);
- 1 LE of K LEs of frame N to 1 LE of different frame M relation: a LE of the frame M has as requirement the accomplishment of learning of one of K LEs of previous frame N (OR precedence relation);
- The whole set of K LEs to 1: a LE of the frame M has as requirement the accomplishment of learning of the set of K LEs of previous frame N (AND precedence relation).

For the outputs, it is possible to set these kinds of relations:

- 1 LE to 1 LE relation: the LE is requirement to learning only one of the LE's learning (within the frame or between the frames);
- 1 LE to K LEs relation: the LE's learning is precedent to a set of K LE's learning.

Using these precedence relations, we can simulate LEs, frames (composed by the LEs) and curriculum disciplines (composed by the frames) through Petri nets.

Each LE can be represented with a common Petri net, and can be considered as the basic component to construct the discipline model. Petri net which simulates a LE mastering by the student is given in the figure 3.
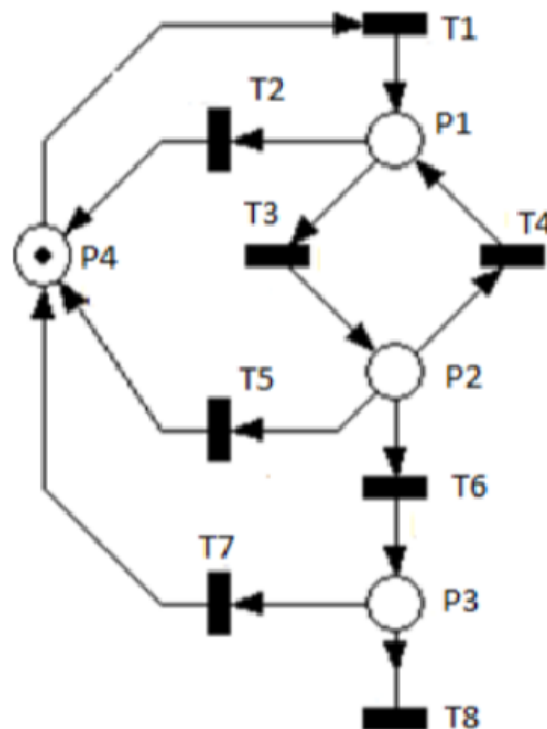

Figure 3: Petri net which simulates a LE mastering by the student.

The places **P1–P4** of the Petri net (figure 3) represent here the states of LEs as for their readiness to be learnt by students due to their precedence relations:

- the place **P1** represents the state that LE is ready (available) to be mastered by a student, according to its precedence relations;
- the place **P2** represents the state while the student is mastering of the LE;
- the place **P3** represents the accomplishment of the LE mastering;
- the place **P4** represents the state when the LE is unavailable student not being able to start the module.

The transitions **T1–T8** (figure 3) simulate the events of start of LE's mastering; the process of its learning, regarding the academic time and its availability due to its precedence relations; and accomplishing the LE's mastering.

There is always the only token in the net, which means that only one of the LEs states is true, so only one of the places can be marked at a time (in the situation shown in figure 3, it is in **P4**).

At the next step of modeling, such Petri nets which simulate a LE mastering were used to create a frame (course module) model. It was composed by a set of LEs' models connected, depending on their precedence relations determined above. This models (Petri nets) composition was done by merging transitions **T1** (LE is available to learn) of the dependent LE and **T8** (LE is ready to be continued) of the previous LE's model.

Figure 4, a – c demonstrates three situations of adding the LEs models to compose a frame (module) with regard to the said precedence relations:

- figure 4, a illustrates a 1 to 1 precedence relations where the fusion of the transition **T1** of the previous LE with the transition **T8** of the next LE is expected;
- figure 4, b presents a K to 1 precedence (AND precedence relation) where all the transitions **T8** of all previous modules and the transition **T1** of the next LE will be merged;
- figure 4, c demonstrates a 1 of K to 1 precedence (OR precedence relation) where each transition **T8** of each previous LE will be merged with the transition **T1** of the next LE.

Using the operations of Petri nets modifications (in particular, their fusion) defined in [17, 23] and LEs connections of different types (depicted above), we could obtain a model of a curriculum discipline module and finally – a curriculum discipline model.

These Petri nets models represent all the evolution of the LEs mastering by students in the curriculum courses. It is essential to note that output transitions of each LE's model can trig the subsequent LE's model only if the previous (in terms of precedence relation) one is accomplished. It is guaranteed by the rules of Petri net execution and modifications.

We would like to remind here that in our technique of curriculum building (depicted in figure 2) each discipline is represented by a frame with the nested other frames, which simulate the disciplines modules involving the LEs along with their connections.

Thus, summarizing our approaches to the university courses modeling based on the frames properties and Petri nets facilities, we would like to underline the following benefits in terms of applying such a simulation to the building of synchronized curriculum for IT-specialists training:

1. The built Petri nets allow to model the process of the LEs mastering by students in the frames (discipline modules) and between them.
2. Petri nets facilities provide grouping LEs into the frames (modules) taking into account precedence of their learning.
3. Facilities of frame-based model of knowledge representation provide spreading the set links between the LEs within the module and between the modules of different curriculum disciplines.

Thus, combining the applied properties of Petri nets modeling and AI models of knowledge representation allow to obtain both holistic and synchronized university curriculum.
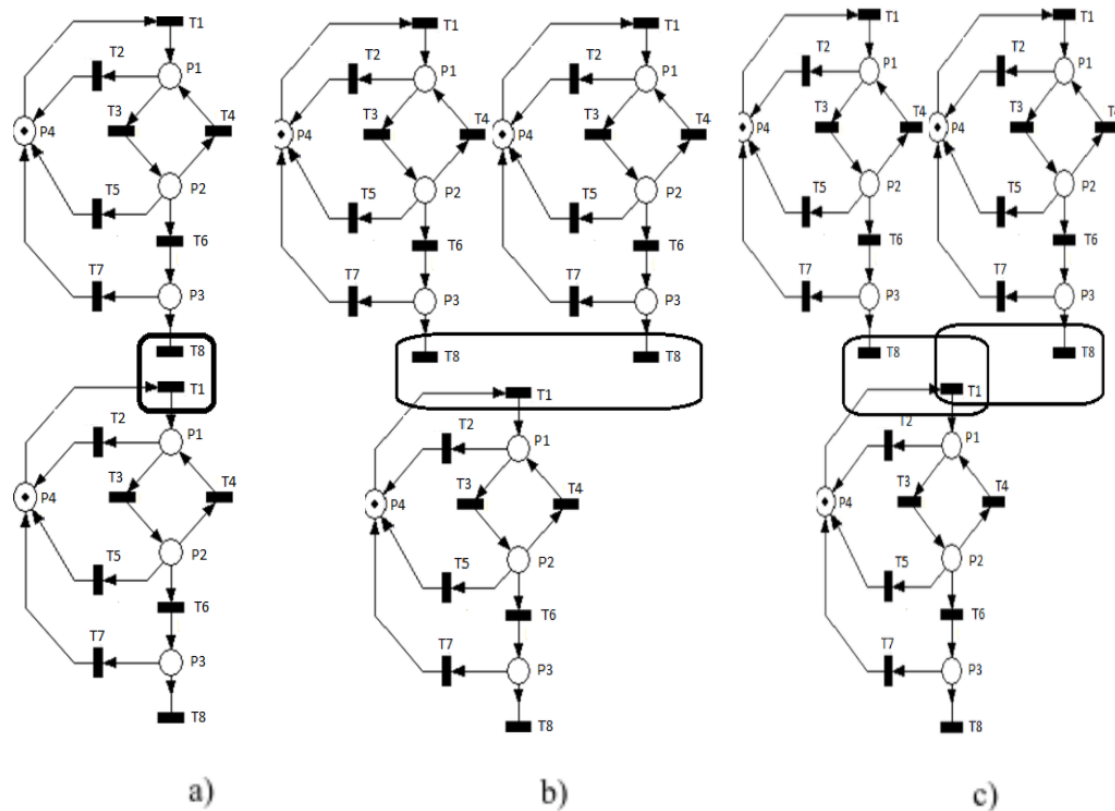
Figure 4: LEs connections, according to different types of precedence relations.

We would like to emphasize special importance of such modeling of curriculum exactly for pre-service IT-specialists' training. The built and realized model allows to shape the family of disciplines which are sensitive to the rapid changes in IT industry with immediate spreading of renewed requirements to the specialists in these sphere throughout all of the modules and with simultaneous preserving of the proper links. It is also provided the opportunity to mind the disciplines evolution and appearing new ones with their including into the flexible curriculum excluding the unnecessary repetition and academic time saving. The obtained curriculum with our simulation is flexible to account both global acceptance and national educational contexts. Thus, elaborated Petri nets-based mean for the curriculum simulation matches main guidelines for building contemporary computing curriculum.

Such an approach to the curriculum modeling can be used in the software for automatic creation of a holistic and synchronized curriculum, which makes prospects of our research. Such a software will allow:

(1) to detect which proper LE and where has to be mastered;
(2) to trace the LEs which have been mastered and will be necessary for mastering other set of LEs;
(3) to build individual study plan for students etc.

4. Conclusions

The problems of synchronized curriculum shaping are discussed in the paper in the context of the challenges of contemporary IT specialists' training in terms of permanent evolution and rapid expansion of computing.

The authors' technique of the curriculum simulation based on Petri net applying is presented.

The theoretical framework which allowed us to elaborate the technique includes some didactical fundamentals of curriculum design and academic disciplines structuring as well as the theoretical basics of Petri nets in terms of their significant facilities for different processes synchronization. The technique of academic disciplines structuring based on frame model of knowledge representation is covered as a chain of stages which results in the net of disciplines modules (frames) including the proper learning elements along with preserving and spreading links between them.

In order to solve the problem of synchronization of the learning elements mastering throughout the academic disciplines with regard of the established links in the frames, it is offered the practically-driven approach to curriculum modeling based on Petri nets simulation.

The different types of the precedence relations for the learning elements (inputs and outputs of the frames) were distinguished. Using these precedence relations, we managed to simulate through Petri nets a learning element itself and the process of its mastering. Using the operations of Petri nets modifications and learning elements' connections of different types, we could obtain a model of a curriculum discipline module and finally – a curriculum discipline model.

Built Petri nets models represent all the evolution of the learning elements mastering by students in the curriculum courses. Synchronization of their mastering is guaranteed by the rules of Petri net execution and modifications.

The peculiarities of the offered technique are analyzed. The benefits in terms of applying such a simulation to the building of synchronized curriculum for IT-specialists training are formulated.

The prospects of the research are outlined in the lines of using the obtained results for special software development.

References

[1] M. Ardis, D. Budgen, G. W. Hislop, J. Offutt, M. Sebern, W. Visser, SE 2014: Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering, Computer 48 (2015) 106–109. URL: https://doi.org/10.1109/MC.2015.345. doi:10.1109/MC.2015.345.

[2] Computer Engineering Curricula 2016: Curriculum Guidelines for Undergraduate Degree Programs in Computer Engineering, 2016. URL: https://www.acm.org/binaries/content/assets/education/ce2016-final-report.pdf.

[3] Task Group on Information Technology Curricula, Information Technology Curricula 2017: Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology, Association for Computing Machinery, New York, NY, USA, 2017.

[4] Joint Task Force on Cybersecurity Education, Cybersecurity Curricula 2017: Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity, Association for Computing Machinery, New York, NY, USA, 2018.

[5] Information Technology Transfer Curricula 2020: Curriculum Guidelines for Two-Year Transfer Programs in Information Technology, 2020. URL: https://ccecc.acm.org/files/publications/IT-Transfer2020.pdf.

[6] CC2020 Task Force, Computing Curricula 2020: Paradigms for Global Computing Education, Association for Computing Machinery, New York, NY, USA, 2020.

[7] D. B. Clark, M. C. Linn, The knowledge integration perspective: Connections across research and education, in: S. Vosniadou (Ed.), International Handbook of Research on Conceptual Change, 2nd ed., Routledge, New York, 2013. doi:10.4324/9780203154472.

[8] D. B. Clark, C. M. D'Angelo, S. P. Schleigh, Comparison of Students' Knowledge Structure Coherence and Understanding of Force in the Philippines, Turkey, China, Mexico, and the United States, Journal of the Learning Sciences 20 (2011) 207–261. doi:10.1080/10508406.2010.508028.

[9] A. A. diSessa, N. M. Gillespie, J. B. Esterly, Coherence versus fragmentation in the development of the concept of force, Cognitive Science 28 (2004) 843–900. URL: https://onlinelibrary.wiley.com/doi/pdf/10.1207/s15516709cog2806_1.

[10] M. Renzi, F. Sangiorgio, G. Carrada, A. Basset, Didactic of scientific disciplines in school: a possible role for LaguNet, Transitional Waters Bulletin 7 (2013). doi:10.1285/i1825229Xv7n2p13.

[11] P. K. Singh, M. Kumar, A study on infrastructure and organizational learning: Rethinking knowledge performance perspective, PEOPLE: International Journal of Social Sciences 3 (2017) 61–77. URL: https://grdspublishing.org/index.php/people/article/view/513. doi:10.20319/pijss.2017.32.6177.

[12] L. Gryzun, Integrative technology of academic subjects structuring and its applications to practical didactic issues, Aktualni pytannia humanitarnykh nauk: mizhvuzivskyi zbirnyk naukovykh prats molodykh vchenykh Drohobytskoho derzhavnoho pedahohichnoho universytetu imeni Ivana Franka 16 (2016) 309–315. URL: http://dspu.edu.ua/sites/youngsc/AQGS/2016_16/309-_%D0%93%D1%80%D0%B8%D0%B7%D1%83%D0%BD.pdf.

[13] L. Gryzun, Integrative approach to the curriculum and content design for the pre-service teachers' training, PEOPLE: International Journal of Social Sciences 4 (2018) 1446–1462. URL: https://grdspublishing.org/index.php/people/article/view/1572. doi:10.20319/pijss.2018.42.14461462.

[14] M. Minsky, A framework for representing knowledge, in: Readings in Cognitive Science: A Perspective from Psychology and Artificial Intelligence, 2013, pp. 156–289. doi:10.1016/B978-1-4832-1446-7.50018-2.

[15] C. Ramirez (Ed.), Advances in Knowledge Representation, IntechOpen, 2012. URL: https://www.intechopen.com/books/1932. doi:10.5772/2351.

[16] T. Murata, Petri nets: Properties, analysis and applications, Proceedings of the IEEE 77 (1989) 541–580. doi:10.1109/5.24143.

[17] J. Barros, L. Gomes, Modifying Petri net models by means of crosscutting operations, in: Third International Conference on Application of Concurrency to System Design, 2003. Proceedings, 2003, pp. 177–186. doi:10.1109/CSD.2003.1207712.

[18] P. Arpaia, M. L. Bernardi, G. Di Lucca, V. Inglese, G. Spiezia, An Aspect Oriented-based Architectural Framework for Synchronization in Measurement Systems, in: 16th IMEKO TC4 Symposium. Exploring New Frontiers of Instrumentation and Methods for Electrical and Electronic Measurements. Sept. 22-24, 2008, Florence, Italy, 2008. URL: https://www.academia.edu/21866608/An_aspect_oriented_based_architectural_framework_for_synchronization_in_measurement_systems.

[19] R. Campos-Rebelo, A. Costa, L. Gomes, Finding Learning Paths Using Petri Nets Modeling Applicable to E-Learning Platforms, in: L. M. Camarinha-Matos, E. Shahamatnia, G. Nunes (Eds.), Technological Innovation for Value Creation, Springer Berlin Heidelberg, Berlin, Heidelberg, 2012, pp. 151–160. doi:10.1007/978-3-642-28255-3_17.

[20] D. C. Borges, H. B. Neto, J. N. de Souza, Work in progress — Petri Nets as applied to the modeling of E-learning cooperative systems, in: 2010 IEEE Frontiers in Education Conference (FIE), 2010, pp. F1D–1–F1D–3. doi:10.1109/FIE.2010.5673186.

[21] M. Kuchárik, Z. Balogh, Student learning simulation process with petri nets, in: S. Patnaik, V. Jain (Eds.), Recent Developments in Intelligent Computing, Communication and Devices, Springer Singapore, Singapore, 2019, pp. 1115–1124. doi:10.1007/978-981-10-8944-2_130.

[22] T. V. Shestakevych, V. V. Pasichnyk, The use of Petri Nets for inclusive education IT-support, ECONTECHMOD : An International Quarterly Journal on Economics of Technology and Modelling Processes 4 (2015) 33–38. URL: https://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-f4c8f26a-c76f-471c-8563-ca39a54ae112.

[23] J. Barros, L. Gomes, Net model composition and modification by net operations: a pragmatic approach, in: 2nd IEEE International Conference on Industrial Informatics, 2004. INDIN '04. 2004, 2004, pp. 309–314. doi:10.1109/INDIN.2004.1417350.