COLORED PETRI NETS, A MODERN TECHNOLOGY FOR SYSTEMS MODELING AND SIMULATION

Mariana POPA, Senior lect. Ph.D. candidat, *University of Bucharest*

Mihaita DRAGAN, Ing. Sis. Ph.D. candidat., *University of Bucharest*

Marin POPA, **Prof. Ph.D.**, *University of Bucharest*

ABSTRACT

This paper emphasizes a modern technology that can be used for modeling, simulating and analyzing systems, no matter how complex they'd be.

This technology is represented by Colored Petri nets class, networks that derive from the classic theory of Petri nets, theory initiated by Carl Adam Petri in order to develop a mathematical theory proper for studying information processing systems based on communication, synchronization, parallelism and competition.

Colored Petri Nets are Petri networks of high level, in which different types of tokens under a certain location are distinguished by different colors, and for which concepts of communication, synchronization and shared resources play a central role.

The success of CPN is given, actually, by the fact that they can develop simultaneously models in all three domains: theoretic, software processing, and practical industrial applications.

Keywords: location, transition, flow relation, arch inscriptions, Petri nets, Colored Petri Nets.

1. INTRODUCTION

The history of Petri nets started in 1962, with the emergence of doctoral work „Kommunikation mit Automaten" of Carl Adam Petri, a German-born mathematician, paper work presented at Technical University of Darmstadt, in July 1961, and the thesis was sustained in June 1962 [1].

The first class of Petri nets was called Condition/Event Petri nets (CE-net). This net model allows each location to contain at least a token. The location is considered to be represented by a booleana condition, which can take value of "true" or "false". In the next years, a big number of scientists have contributed in developing of new network models, basic concepts and analysis methods.

Petri nets came the focus of researchers shortly after they appeared, because they have a series of fundamental advantages: simplicity, generality and adaptability.

Over the years, the theory of Petri nets followed two directions of developing:

A. Formal theory of Petri nets- by which were developed methods, means and notions necessary for using Petri nets.

B. Applied theory of Petri nets- aimed at the development of certain instruments, so by using Petri nets, to make direct modeling systems, even more, the systems to be implemented, analyzed, validated and verified, involving the obtain of reference results.

For Petri nets, starting point is the transitional system, considered as the simplest model of distributed system possible.

By refining successively, it gets to Petri net concept.

Petri nets are an instrument for the research of systems using models.

In many research domains, the real system behavior is studied not directly on the system, but indirectly, using the model.

Classic theory of Petri nets allows to a system to be modeled by a Petri net, thus realizing a system mathematical representation. After that, Petri net analysis can give important information about the structure and the dynamic behavior of the modeled system, giving the possibility to be used for evaluating the modeled system and for suggesting improvements or changes.

The model is, basically, a representation, mostly trough mathematical terms, for what predicts to be the most important features of the object or the system that aims at studying. By studying the model of the wanted system, can be given information of certain value without involving costly expenses.

Modeling distributed systems using Petri nets is made at a level state: determine what actions occur in system, which states are prior to these actions and in which states the system will be after the actions occur. By simulating the model of states through Petri nets is obtained the description of system behavior.

Thereby, for an easier description and modeling of systems, there were developed the Colored Petri Nets, abbreviated CPN or CPNs, which have emerged as a promising theoretical model, doubled by a full-fledged programming language for design, specifications, simulation, validation and implementation of large software systems (and other systems in which human been and/or computers communicate through rules more or less formal).

Colored Petri nets stand are distinguished by developing a very useful soft, CPN-Tool, which is a variety of instruments such as editing, simulation, state space analysis and performance analysis of systems modeled by CPN.

CPN models are formal, in that the modeling language CPN has a mathematical definition for it's syntax, as for semantics. That means that they can be used for checking systems properties, namely , they prove the fact that certain wanted properties are met and that for some unwanted properties, the guarantee of their absence.

Checking properties of systems is supported by a number of methods played by the state space. The basic idea of state spaces is to calculate all the states accessible and the state changes of model CPN and is represented as an oriented graph where the nodes are states and the transitions that occur are events, the connection between states and locations or between transitions and states is made by arcs.

In essence, the application of formal methods denotes mathematical approaches in software / hardware development activities, such as specifications, design, validation, verification and implementation. Thus, formal methods, characterized by mathematical techniques, provide a rigorous foundation for systems development. Although formal methods are rarely considered applicable, they are just beginning to become widespread in industrial scale. This change was mainly produced in recent years.

Formal methods are usually introduced in development when critical conditions occur, such as safety or life critical systems, and where systematic testing is difficult.

Typical applications of CP Nets are communication protocols [6], data networks [7], distribution algorithms [8] and embedded systems [9]. CP Nets are also applicable more generally to model systems where concurrency and communication are key characteristics. Examples of these are business processes and workflow modeling, production systems, agent systems.

Stressed that it is necessary for practical use of CP Nets and tools for computer support is sufficient an intuitive understanding of syntax and semantics of CPN modeling language.

This is analogous to using common programming languages like Java, which are successfully implemented by developers, even those who are not usually familiar with formal definitions of languages.

This feature underlies some important properties of CP Nets that can be taught and learned without studying the related formal definitions. Practical application of CPN modeling and analysis rely heavily on the existence of tools that support creating and manipulating models.

CPN Tools [10] is a suite of editing tools, simulation, state space analysis and performance analysis of CPN models. CPN Tools utility works directly on the graphical representation of the CPN model. (GUI) of CPN Tools is based on interaction techniques, such as tool palettes, etc. A license for CPN Tools can be obtained free via web pages CPN Tools [10]. CPN Tools is available for MS Windows and Linux.

2 THEORETICAL CONSIDERATIONS

The aim of mathematical methods is to study the evolution and properties of modeling system, and these properties are modeled by mathematical objects or properties of the mathematical model, which means finding ways of calculation (decision algorithms) of these properties.

Such a mathematical object can be represented by structures cover for Colored Petri nets, with which can solve some problems of decision(that is: the cover issue, the limit issue, pseudo-viability issue, finite graph accessibility problem, the problem finite-accessibility needle shaft, etc.) and can measure the degree of network competition.

Colored Petri nets are based on the observation that the labeled transition systems, but also in distributed systems, concepts of state and transition are very important.

Definition1. It's called Petri net, abbreviated PN, $\Sigma = (S, T, F)$ where:

$S \cup T \neq \varnothing$.

$S \cap T = \varnothing$.

$F \in (S \times T) \cup (T \times S)$ so that dom $F \cup$ imag $F = S \cup T$.

Items of crowd S are usually called locations and represent states which may find the system at a certain time. They can score a variable number of data. The location plan can be represented by: circles, ellipses.

Fig. 1

T crowd elements are usually called transitions. These are elementary changes to data distribution over the network locations. Transitions can be represented by: rectangles, squares.

Fig. 2

F is called flow relation of the network.

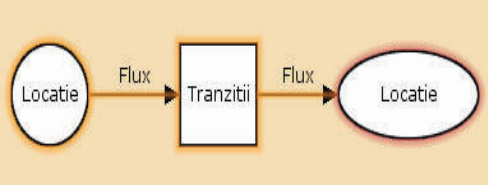

Fig. 3

Colored Petri nets were made in 1979 by Kurt Jensen [2, 3, 4, 5], and are a graphic language with the general purpose of building models and modeling, simulation and analysis of their properties.

Derived from classical theory of Petri nets, Colored Petri Nets theory maintains the basic syntactic elements - which are essentially locations, transitions, arcs - but also introduces the concept of "inscriptions" and if the first three concepts can be expressed graphically, the fourth concept can be expressed only verbatim.

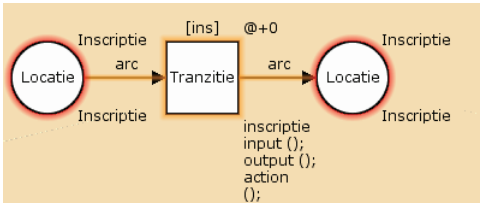

Fig. 4

Inscriptions on the arch are given by functions and are used to determine the quantity of tokens that can move between states. The role of "guards" is to filter and restrict possible events. Sets of colors are specified on locations and the initial marking determine the initial configuration states of a CP net. Also CP Nets include support for modeling widely through hierarchical decomposition of transitions. For this reason, CP Nets became known and have been applied in many fields such as government, military, education, latest technologies, listing only the general areas that have purchased a license from the University Working Group CPN Aarhus.

Formal definition is the one that made possible the development of formal methods of analysis that can prove whether a particular network CP has certain properties (for example, absence of deadlock, marking trap, components associated countries, etc.).

Definition 2.Is called Colored Petri Net a tuple $CPN = (P,T,A,\Sigma,V,C,G,E,I)$ where :

1. S – represents a finite crowd, whose elements are named locations.
2. T –represents a finite crowd, whose elements are called transitions.

The two crowds must meet the conditions: $S \cup T \neq \varnothing$ and $S \cap T = \varnothing$.

3. $A \subseteq S \times T \cup T \times S$ –represents the crowd of arcs that connect locations with transitions and transitions with locations.
4. Σ -represents a finite crowd of color sets, different of the empty crowd.
5. V –represents a finite crowd made of variable types, so that Type[v]∈Σ for all v∈V variables.
6. C : S→ Σ -represents the color set function that assigns a color set to each location.
7. G : T →EXPRV –represents guard function that assigns a guard to each transition *t* so that Type[G(t)] = Bool.
8. E : A→EXPRV - represents the function of arch expression, which assigns an arc expression to each arch so that Type[E(a)] =$C(s)_{MS}$, where s is the location connected to arch “a”.
9. I : P→EXPR –represents initializing function that assigns an initializing expression to each location s so that Type[I(s)] =$C(s)_{MS}$.

For example we present a model system using Colored Petri nets together with a suite of related tools.

3 MODELING THROUGH A COLORED PETRI NET A COMMUNICATION PROTOCOL BETWEEN TWO SERVERS ON THE INTERNET.

System model is taken from everyday activity, namely a communication protocol between two or more locations. Consider the announcement by the University Titu Maiorescu "Titu Maiorescu University invites to the fourth edition of the international conference held under the auspices <Education and Creativity based on knowledge! >".

Ad is placed on the UTM server, and from here through the use of dedicated services, it goes on the Internet. After its appearance on the Internet, those interested to attend the conference require different explanations, so they can comply with the requirements of writing and time of the organizers.

3.1 Model description

Suppose that University Titu Maiorescu launches on the Internet the invitation to the 4th international conference which organizes in the university. Also assume that the Information Technology Faculty of Bucharest University see the invitation and wants to participate with work in field <Education and Creativity based on knowledge!> discussed to the conference, and so announces the organizing committee its intention to participate, but requires additional clarification and participation regarding conditions of participation and the time period.

For this purpose we use a Colored Petri net [2,3,4] made of 13 locations and 7 transitions.

The locations are following:

SEU –location where it's believed that server of University Titu Maiorescu is, from where is launched on the Internet the invitation to the conference.

GAT – location which represents the server that translates the packages from local network to the Internet

RU1 – location where are routed the packages from local network to the Internet.

RU2 – location where can be routed the packages from local network to the Internet, if the first router isn't available.

RU3 – location where can be routed packages from local network to the Internet, if the other routers don't allow it.

SEI – is an internet server where the initial message is recomposed, from the packages that passed through routers RU1, RU2 and RU3.

INT – represents an Internet server where will be placed the University Titu Maiorescu invitation.

SEC – represents a client server from where the organizing committee is announced about intentions to participate.

UTM – represents a server of organizing committee on which is received the participating work.

A, B, C, D – are helping locations that allow ordering and reordering the packaged containing messages between the two universities.

The transitions are:

t1 – indicates action of sending the data packages from location SEU to GAT.

t2 – indicates action of distributing the packages to the 3 routers.

t3, t4, t5 – transitions which indicates actions of transferring the packages, respectively from routers RU1, RU2, RU3 to SEI server where the original message is recomposed.

t6 – represents action of placing the initial message on the Internet server INT.

t7 –represents action of sending to server UTM the intention of participating through server SEC.

We use the color family F= { INT, DATA, INTxDATA, M, Q }.

Color the locations SEU, GAT, RU1, RU2, RU3, SEI and SEC using the set of colors INTxDATA, locations UTM and INT using the set of colors DATA=string and locations A, B, D using the set INT =int and location C with the set of colors M = {m }.

Inscriptions on arcs allow data packets travel between different locations.

Consider the locations in the order given by the vector:

(SEU, GAT, RU1, RU2, RU3, SEI, B, INT, SEC, UTM, C, D, A).

Using the tool CPN-Tools we obtained the Colored Petri Net from fig. 1, where can be noticed the elements described above.

3.2. Network functioning

Network evolution starts from initial marking μ_0 given by :

$\mu_0 = ((1,"Universitatea....),0,0,0,0,0,10,"",(1,"Dorim.....),"",0,4,1)$, where 0 is the empty multiset and " " is the empty string, marking, containing the two messages sent between Universities. This marking is shown in Fig.1.

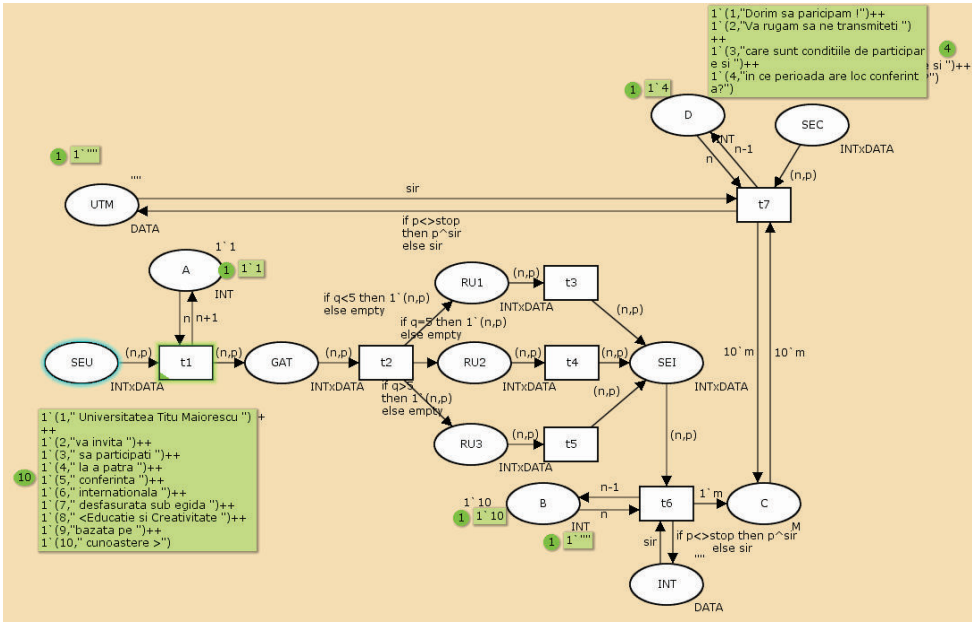

Fig. 1

After this network operates, it gets to the final marking μ given by:

$$\mu = (0,0,0,0,0,0,0,"Universtitatea\ Titu....",0,"Dorim\ sa...",10,0,11)$$

On this marking, that can be seen in fig.2, we find the two messages that amrks location INT and UTM.

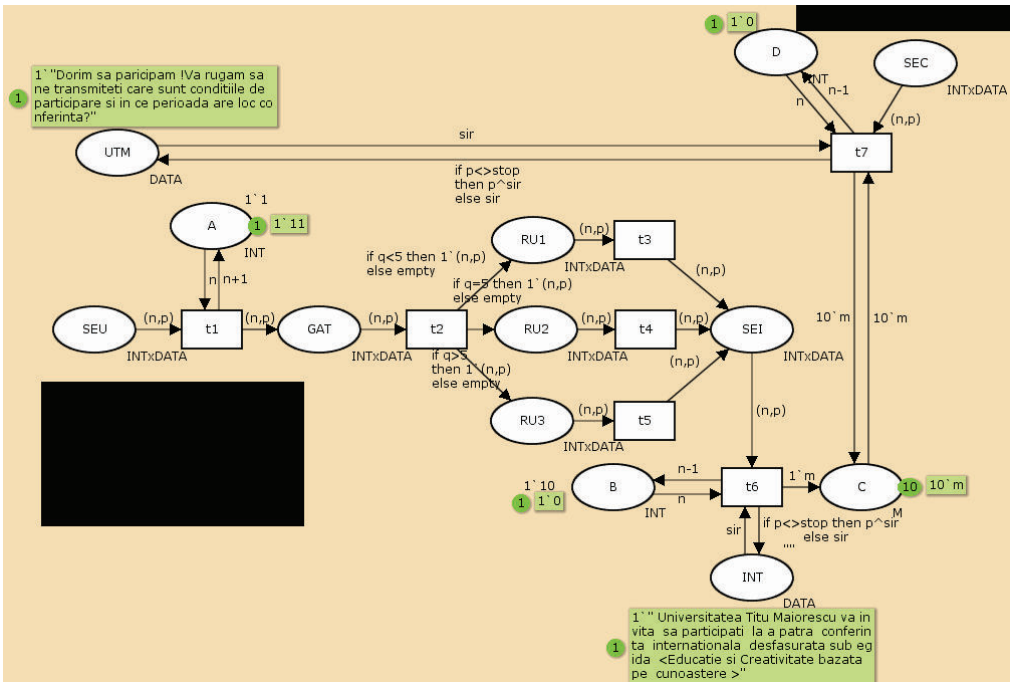

Fig. 2

In going from marking μ_0 to marking μ by successive producers of signal transitions, we have an intermediary marking μ_i which represents the network state at a certain moment of it's functioning.

The marking μ_i, that can be seen in fig. 3, has the next form:

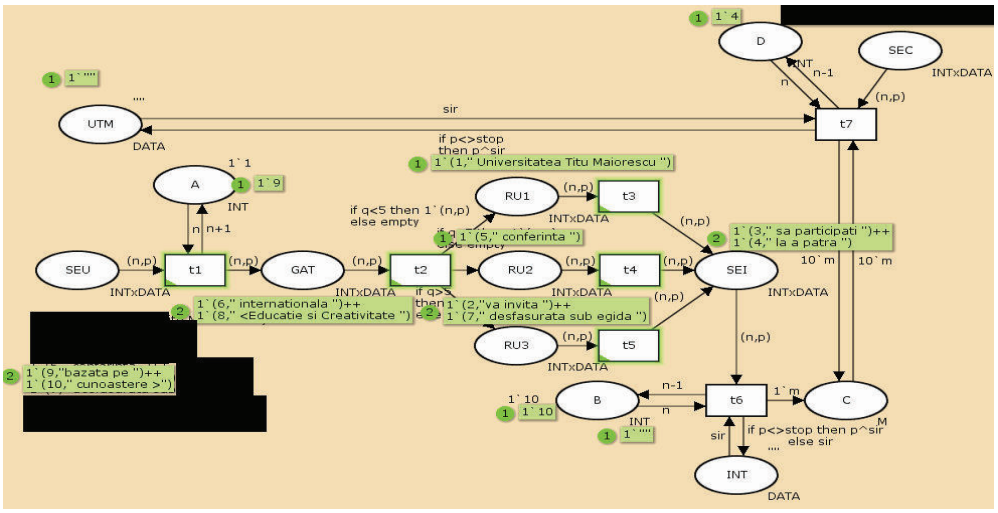

Fig. 3

$$\mu_i = \begin{pmatrix} (9, bazata\ \ pe)+(10, cunoastere),(6, \text{int}\, ernationala)+(8, educatie\ \ si\ \ creativitate), \\ (1, Universitatea\ \ Titu\ \ Maiorescu)+(5, confer\,\text{int}\, a),(2, va\ \ invita)+(desfasurata\ \ sub\ \ egida), \\ (3, sa\ \ participati)+(4, la\ \ a\ \ patra), 10,0,"",(Dorim\ \ sa\ \ participam)+.....,"",0,4,9 \end{pmatrix}$$

On this marking can be seen the data packages to different servers and routers, in their way to location INT from the Internet.

In the process of sending the data packages to servers and routers waiting tails are composed, whose order is both FIFO, such as for SET,GAT,RU1,RU2,RU3 and SEC, and LIFO, such as INT and UTM.

4. CONCLUSIONS

This article emphasizes both the modeling power of Colored Petri nets and the utility of instrument CPN-Tool, which comes to support the scientists, not only for designing the network that models a certain economic system, social or politic, but also for obtaining the cover tree associated to a concrete network evolution, starting from a given initial marking.

In addition, the instrument provides the researchers with a report that gives information obtained during the modeled network evolution.

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