Infinite Petri Nets as Models of Grids

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INTRODUCTION

The present article represents an overview of works where basic methods of infinite Petri nets investigation were presented; moreover, it reveals directions of prospective future research. Peculiar practical concern represents the result on deadlocks disclosure within mentioned structures, their classification and revealing possibilities of the network blocking via ill-intended traffic of special form.

The research technique was described in detail and approved on a series of tasks (Zaitsev, 2013; Zaitsev & Shmeleva, 2010; Shmeleva, Zaitsev, & Zaitsev, 2009; Zaitsev & Shmeleva, 2008; Shmeleva, 2007); the obtained theoretic results were formulated as theorems for definite structures.

BACKGROUND

Components, used for composition of infinite structures, are functional subnets (clans) of Petri nets (Zaitsev, 2006; Zaitsev, 2005) which are well studied when investigating usual (finite) models, for instance, in the process of protocol TCP verification. Input places of a clan have only outgoing arcs and output place – only incoming arcs. Composition of protocol TCP model from its clans is represented in Figure 1.

Compositional analysis allowed speed-up of the verification processes of complex networking protocols because of solving a sequence of linear systems with lesser dimension which is essential when finding solutions in nonnegative domain (monoid) for Diophantine systems (ring).

ISSUES, CONTROVERSIES, PROBLEMS

The first problem which researchers encountered, when verifying networking protocols via Petri nets, was the problem of exponential computation complexity of the majority known analysis methods.

To solve this problem, the compositional analysis of Petri nets (Zaitsev, 2006; Zaitsev, 2005) was offered based on the decomposition of a net into the set of its functional subnets (clans), solving tasks for each clan and then fulfilling, either simultaneously or sequentially, composition of functional subnets. Solving a few systems with considerably lesser dimension, under the condition of exponential complexity, allowed an exponential speed-up of computations and verification of known protocols, such as ECMA, BGP, TCP, and IOTP, in reasonable time.

The second problem arose when investigating protocols of the network Ethernet with common bus architecture. It was rather simple to construct a model of a single device. The majority of protocols stipulates interaction of two systems, for example, as protocol TCP. Electronic commerce protocol IOTP considers a few interacting systems but their number is constant: Customer, Merchant, Payment Handler, Delivery Handler, Merchant Customer Care Provider. A segment of Ethernet with common bus architecture could contain a priory unknown number of computers which is reasonable to not limit in research in spite of definite physical limitations stated in standards.

To solve this problem, infinite Petri nets with regular structure were introduced for the first time as a linear composition of the workstation models. The further

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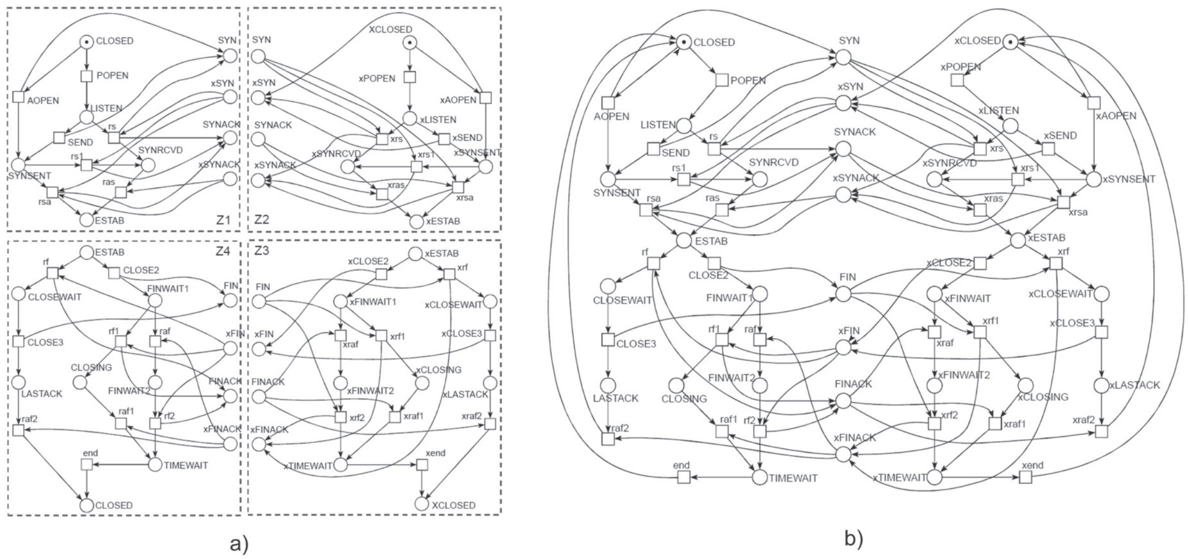
Figure 1. Composition of protocol TCP model



progress of research was indicated by the number of dimensions and the structure of devices' connections: tree-like structures for analysis of switched Ethernet (Shmeleva, 2007), triangular, rectangular, and hexangular grids for analysis of distributed computations, radio and television broadcasting, cellular communications (Zaitsev, 2013; Shmeleva, Zaitsev & Zaitsev, 2009) as well as various edge conditions. In the most general form, results were obtained for a hypercube with an arbitrary size and an arbitrary number of dimensions (Zaitsev & Shmeleva, 2010; Zaitsev & Shmeleva, 2008).

BASIC NOTIONS AND DEFINITIONS

Petri net (PN) is a bipartite directed graph on which a discrete dynamic process is defined. The first part of vertices, named places, is depicted by circles; the second part of vertices, named transitions, is depicted by bars (rectangles); dynamic elements, named tokens, are depicted by dots situated inside places. Tokens are consumed and produced by transitions as result of their firing. A transition is firable if each its input place contains at least a token. The behavior of a net is a step-by-step process; on each step, an arbitrary firable transition fires. When firing, a transition consumes a token from each its input place and puts a token into each its output place. In Figure 2, an example of the transition firing is shown and also a graph of reachable markings (GRM) of Petri net which is a complete formal description of its behavior. In general case GRM is infinite which requires developing special methods of Petri net analysis.

A Petri net occupies a unique position within hierarchy of discrete systems: it is more powerful than a finite automaton and less powerful than a Turing machine. Thus, it provides facilities of the systems' behavior specification inaccessible is the formalism of finite automata and, besides, a series of the systems' properties analysis tasks are algorithmically solvable problem, in contrast to Turing machines.

Figure 2. Behavior of a Petri net