

Monographic lectures: “Modeling with Petri and Sleptsov nets”

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Lectures:

Lecture 1: "Verification of protocols with Petri nets"

The operation of computer networks is based on protocols - sets of rules for the interaction of systems. The questions of the correctness of network protocols, in particular, the absence of deadlocks, are considered. Protocol correctness is the foundation of cybersecurity. Links to the main organizations developing modern network protocols are provided. On the example of the TCP protocol - the main protocol of the Internet - a review of the standard descriptions of the RFC protocols is made. To check the correctness (verification) of the protocols, the language of Petri nets was used. On the example of building and analyzing a model of a simplified protocol for transferring messages with confirmations, reminiscent of TCP, the basics of protocol verification by Petri nets are studied. Deadlock found in protocol. Several methods for modifying (improving) the protocol in order to avoid deadlocks have been proposed: based on collision detection, similar to Ethernet; using cyclic retransmission of the permission to transmit, similar to Token Ring; and others. The necessity of developing effective formal methods for analyzing the properties of Petri nets for verifying real protocols represented by large-size models is substantiated. An example of a model of one of the transactions of the IOTP e-commerce protocol is given.

Lecture 2: "Methods of model analysis. Composition of clans"

On the example of previously constructed models of network protocols, the main methods for analyzing the properties of Petri nets are studied. Verification of network protocols was chosen as the main area of application. A review of other areas of application, such as proof of correctness of parallel and distributed programs, production automation, organization of business processes, controller programming, traffic control, and others, is made. The analysis of the properties of Petri nets is carried out by the methods of graph theory in the process of constructing a graph of reachable (covering) markings, as well as by the methods of linear algebra in the process of solving systems of linear Diophantine equations for finding network invariants. The modeling system Tina of the Systems Architecture Laboratories, Toulouse, France was used. The fundamentals of the theory of clans of linear

systems developed by the author are presented. The composition of clans is used to speed up the solution of large systems in the process of verifying real protocols. Varieties of clan composition in the process of simultaneous, sequential and parallel-sequential collapse of the system decomposition graph are studied. A review of the Adriana and Deborah software for system decomposition into clans and the solution of systems in the process of clan composition, implemented in the form of plug-in modules of the Tina system, was carried out. A new joint development with the Laboratory of Innovative Computing (Jack Dongarra), USA - the ParAd system (Parallel Adriana) for the compositional solution of systems on modern parallel and distributed architectures is presented.

Lecture 3: "Analysis of computational grids and clouds by infinite Petri nets"

A review of the development processes of such applied areas as: communication systems of supercomputers and computing clusters; networks on chips for connecting processor cores and other components; modern numerical methods widely used in computer-aided design; particle accelerators and means of providing a controlled thermonuclear reaction and others. Among modern challenges to modeling methodology, the connection of an unlimited number of systems with a certain spatial structure, for example, toroidal, is noted. For example, the communication subsystem of the most productive computer in the world, Fugaku, is a 6-dimensional hypertorus. The fundamentals of the new theory of infinite Petri nets proposed by the author and his research team are studied. As an example, the problem of model composition and the study of the properties of a square commutation lattice on a plane is chosen. A model of a lattice node is constructed, the rules for composition of a structure of unlimited size and its parametric description are considered. To construct realistic lattices, a number of boundary conditions are considered, such as connection of subscriber devices at the boundary, truncated switching devices at the boundary, and closure of opposite boundaries, leading to toroidal structures. To study the properties of the model, infinite systems of linear Diophantine equations are constructed and solved in a parametric form, and methods of graph theory are also used. Complex impasses in multidimensional lattices are found and classified. Deadlocks can be induced by malicious traffic, which is a threat to cybersecurity. The results are generalized to lattices of arbitrary size with an arbitrary number of dimensions. As additional sections, the application of infinite Petri nets for modeling cellular automata is studied, in particular, with the generalized neighborhood proposed by the author, which fills the gap between the known neighborhoods of von Neumann and Moore.

Lecture 4: "Performance evaluation of systems by colored Petri nets"

The correctness established during the verification process is an important property of the system. Efficiency is a property that determines the success of the practical application of a system or technology. Evaluation of the effectiveness of systems acquires a special role in the conditions of widespread use of a model-driven development (design) of systems, during which the initial draft model is converted into a specification of a system with specified characteristics. The colored net is a special case of the loaded Petri net presented in the works of Anatoly Ilyich Sleptsov. The colored network of

the CPN Tools modeling system is a combination of a Petri net graph and the ML functional programming language, whose constructions load positions, transitions, tokens and arcs. To study the properties of models, the construction and analysis of the state space will be used. To assess the performance and quality of service (the main characteristics of technical efficiency), simulation modeling is used - simulating the behavior of the system over long time intervals with the collection and processing of statistical information. The study was carried out on the example of estimating the response time of the Ethernet local network of the railway dispatch center. According to the block diagram of the network, the model is assembled from such components as the switch, workstation and server models, the model parameters are configured according to the characteristics of the equipment and software used. The use of special measuring components of the model makes it possible to evaluate the efficiency directly in the simulation process. A review of the library of models of the main modern network technologies IP, MPLS, PBB, Bluetooth, computational grids and others, developed by the author and members of his scientific group, is carried out. The model repository is hosted on the website of the CPN Tools system (Technical University of Eindhoven, the Netherlands). The studied modeling technology is recommended for the development of real-time systems and new network technologies.

Lecture 5: "Organization of calculations on Sleptsov nets"

Modern parallel architectures have a common drawback - the memory-processor bottleneck. Multi-level caches smooth out the difference in operating speeds without radically correcting the situation. On the other hand, the modern technology of parallel and distributed programming is a complex heterogeneous system. Multi-core processors with shared memory form nodes running OpenMP. The nodes are connected using high-performance network subsystems to a distributed MPI messaging system. In addition, graphics cards are devices for massively parallel computing, with thousands of threads organized in multidimensional structures, their operation is organized using CUDA and OpenCL systems. Efficient parallelization of processes for solving practically significant problems for such heterogeneous structures is a difficult task. On the other hand, modern supercomputers have millions of cores, and practically getting close to peak performance is possible only with the maximum possible load of each of the cores.

The inhibitory or priority Petri net is a universal algorithmic system, which allows it to be used as a graphical parallel programming language. The dilemma - to write a program or to draw a program - has been discussed for decades with the practical use of such well-known systems as P-programming technology, Dragon, Scratch, MVPL and others. The block diagrams used in the Draco system initially do not contain means for describing parallel processes. Long before Carl Petri's 1962 doctoral dissertation, the parallel process description schemes introduced by Frank and Lillian Gilbreth in 1921 were used in manufacturing. Gill was the first to use bipartite graphs to specify parallel processes in 1958. Currently, Petri nets are part of the UML standard for describing activity diagrams. Sleptsov nets, which execute exponentially faster than Petri nets, open up prospects for their application as a single homogeneous graphical language for programming parallel processes with fine granulation. The implementation of the

computer of Sleptsov networks in the form of computing memory does not have a processor-memory bottleneck, which leads to the achievement of hyper-performance today, opening up the possibility of solving intractable tasks. The features of programming technology on Sleptsov networks are studied, networks that implement basic arithmetic and logical operations, operators of programming languages are presented. The universal Sleptsov network, which represents the prototype of the corresponding processor, is considered. Examples of programs in the language of Sleptsov networks for fast encryption/decryption with the RSA public key, solution of the Laplace equation, calculation of the fuzzy logic function, two-cycle linear control with the speed required to control hypersonic objects and other super-high-speed processes are considered. An additional advantage of using Petri and Sleptsov nets is the possibility of using formal methods for proving the correctness of programs, which is especially important for special-purpose applications.

Tools:

Modeling system Tina, Laboratory for Analysis and Architecture of Systems, France:

<https://projects.laas.fr/tina/index.php>

Modeling system CPN Tools, Eindhoven University of Technology, The Netherlands:

<https://cpntools.org/>

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