

# Chapter 15

## Modeling With Colored Petri Nets: Specification, Verification, and Performance Evaluation of Systems

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### ABSTRACT

*Aviation and aerospace systems are complex and concurrent and require special tools for their specification, verification, and performance evaluation. The tool in demand should be easily integrated into the standard loop of model-driven development. Colored Petri nets represent a combination of a Petri net graph and a functional programming language ML that makes it powerful and convenient tool for specification of real-life system and solving both tasks: correctness proof i.e. verification and performance evaluation. This chapter studies basic and advanced features of CPN Tools – a powerful modeling system which uses graphical language of colored Petri nets. Starting with a concept of colored hierarchical timed Petri net, it goes through declaration of color sets and functions to peculiarities of hierarchical design of complex models and specification of timed characteristics. The authors accomplish the chapter with a real-life case study of performance evaluation for switched Ethernet network.*

### INTRODUCTION

Automated systems in the aviation and aerospace industries represent concurrent systems which behavior correctness should be verified in a formal way as well as its performance, on average and in the worst case, carefully estimated. Thus, a model-driven development is an appropriate approach to the design of such systems. Petri nets family represents an appropriate choice of the corresponding modeling para-

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digm since Petri nets specify concurrent processes and allow their formal verification via state space and algebraic methods as well as their statistical analysis for the performance evaluation.

A colored Petri net represents a combination of a Petri net graph with a functional programming language ML (Meta Language) which constructs load nodes, arcs, and tokens of a Petri net. It offers facilities for the modular approach application via the creation of hierarchical nets via the transition substitution. Besides, it allows simulating timed characteristics of a system using a wide range of random value distribution functions. Special ergonomic interface that allows work even with two mouse manipulators makes the process of models (programs) development fast, convenient, and more reliable.

For the correctness proof, we use a model-checking approach via creation and analysis of the model state space, while for the performance evaluation, a classic simulation approach is applied. To avoid storing bulky raw statistical data, we offer our technique of measuring fragments when certain parts of a colored Petri net calculate statistical characteristics “on flight” directly in the process of simulation.

Thus the chapter offers a new powerful and convenient toolset for the development of automated systems in the aviation and aerospace industries which applicability is acknowledged by a few successful examples of application described in recent publications. The chapter is accomplished with a case study where ARINC-429 and switched Ethernet (a prototype for AFDX) applications are modeled.

## **BACKGROUND**

Petri nets represent a unification of a graphical language introduced by Frank and Lillian Gilbreth for production processes specification. Their most significant advantage consists in the possibility of applying formal methods for their analysis. Though, general Petri nets are too abstract to be a convenient tool for a specialist in some application area. Developed by Jensen and Kristensen (2009) colored Petri nets are loaded by a functional programming language that makes their application less laborious and more concise. A colored Petri net represents a computationally universal system that allows their wide application not only for specification and modeling but for programming and control as well.

Dodd (2006) started a professional application of colored Petri nets for modeling in an avionics mission computer. Then a few works appeared which develop the application of colored Petri nets in the aviation and aerospace industries with modeling a landing detector (Kordon, 2016), auto flight control system (Bourdil et al, 2016) and others.

The authors of this chapter have gained a strong experience in colored Petri nets with teaching them for more than a decade, developing enterprise-level models, and applying them in research projects. The first paper (Zaitsev, 2004) that develops a switched Ethernet model represents a personal record of citation. Note that, the modern avionics protocol AFDX (ARINC, 2009) represents a specialization of a general switched Ethernet technology. Then a series of papers have been published which present models of MPLS networks (Zaitsev & Sakun, 2008), develop a new parametric modeling paradigm (Zaitsev & Shmeleva, 2009), and analyze threats in modern computing grids (Zaitsev et al, 2014) and (Zaitsev et al, 2016). Supplied with the measuring fragments, the technique was presented for the first time in (Zaitsev, 2004) and further developed with recent works, our library of models represents a condensed experience and is distributed via official site of CPN Tools <http://cpntools.org>.

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