# Chapter 25
# An Enhanced Petri Net Model to Verify and Validate a Neural– Symbolic Hybrid System

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## ABSTRACT

*As the Neural-Symbolic Hybrid Systems (NSHS) gain acceptance, it increases the necessity to guarantee the automatic validation and verification of the knowledge contained in them. In the past, such processes were made manually. In this article, an enhanced Petri net model is presented to the detection and elimination of structural anomalies in the knowledge base of the NSHS. In addition, a reachability model is proposed to evaluate the obtained results of the system versus the expected results by the user. The validation and verification method is divided in two stages: 1) it consists of three phases: rule normalization, rule modeling and rule verification. 2) It consists of three phases: rule modeling, dynamic modeling and evaluation of results. Such method is useful to ensure that the results of a NSHS are correct. Examples are presented to demonstrate the effectiveness of the results obtained with the method.*

## INTRODUCTION

Neural-Symbolic Hybrid Systems have received great attention and they have been used in application areas where the existence of faults can be expensive, such as engineering, manufacturing, science, business (Cruz, Reyes, Vergara, Perez, & Montes, 2005; Cruz, Reyes, Vergara, & Pinto, 2006; Santos, 1998) and cognitive informatics and cognitive computing (Wang, 2003, 2008). The NSHS combine symbolic knowledge (rules or frames, mainly) and connectionist (neural networks). The knowledge contained in a NSHS comes from practical and theoretical sources

and may contain errors. Errors occur due to data nature and to integration results from different representations (Cruz, Reyes, Vergara, Perez, & Montes, 2005; Villanueva, Cruz, Reyes, & Benítez, 2006). The previous statement is due to Rule-Based Systems (RBS) whose use is made consulting with several experts and may have conflicting experiences; on the other hand the examples of connectionist approach might be redundant due to a wrong selection. Therefore, verification and validation of extracted knowledge from a NSHS allows the knowledge engineer to make decisions in the construction of the same one (Cruz, 2004; Cruz, Reyes, Vergara, Perez, & Montes, 2005; Santos, 1998).

The validation and verification works of production rule bases have been based on the comparison of rule pairs. However, recent proposals use techniques such as Petri nets, directed graphs and directed hipergraphs (He, Chu, & Yang, 2003). In these approaches, nodes are used to represent simple clauses of a rule and directed arcs to represent causal relations.

Petri nets have been used in the study of RBS due to the possibility of capturing dynamics and structural aspects of the system. Its rule base can be verified by Petri net analysis techniques. Those techniques have been used in several works. In Yang, Lee, Chu, & Yang (1998) an error verification method in a Rule Base (RB) based in an incidence matrix is proposed. This method does not admit negated propositions. It makes a previous ordering of the RB for the verification and it does not need an initial marking of the net for the verification. In He, Chu, & Yang (2003) a reachability graph of a Petri net (PN) for structural anomalies detection in a knowledge base (KB) is presented. This technique is known as *w*-Net, where *w* indicates the amount of tokens existing in each place. Nevertheless, in this technique it is necessary to know the initial marking of the net to detect errors. In Wu & Lee (1997) a variant of classic Petri net named high level extended Petri net is proposed. This model allows the logical

negation and the use of variables and constants in the antecedent as well as consequence of the rules. Execution of the model is made by means of input conditions. It uses a reachability approach based on a color scheme for validation.

We present an enhanced Petri net model in this article. Negative relations in the rules are properly represented in this model. Errors on RB can be detected by means of an analysis of the mathematical representation of the enhanced Petri net (EPN) and the type of relation that exists between places and transitions. In validation, the inference of rules is properly represented and it considers aspects of a RBS, such as conservation of facts, refraction and closed world assumption. A color scheme for validation of the knowledge base is presented, which is raised in terms of a reachability problem.

In the following section, Neural-Symbolic Hybrid Systems are introduced. Stages of a NSHS including the validation and verification phase are presented.

## NEURAL-SYMBOLIC HYBRID SYSTEMS

Neural-Symbolic Hybrid Systems are systems based on artificial neural networks that also interact with symbolic components (Cloete & Zurada, 2000). These types of systems integrate the connectionist and symbolic knowledge, in such a way that the knowledge contained in each one of these is complemented (Cruz, Reyes, Vergara, Perez, & Montes, 2005; Cruz, Reyes, Vergara, & Pinto, 2006; Negnevitsky, 2005; Santos, 1998).

NSHS transfers knowledge represented by a set of symbolic rules toward a connectionist module. The obtained neural network permits a supervised training starting from a base of examples. In the next step, an extraction algorithm is developed to obtain the knowledge of a neural network into production rule form. Finally, the rules extracted must be verified and validated to be sure that the

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