Chapter 3: Approaches to modeling of complex systems

Approaches to the modelling of complex systems using Petri Nets

There have been many papers/publications in the past modeling complex systems using Petri Nets, each proposing a different approach [50][38][61][40]. Not many have attempted the area of performance monitoring of complex systems especially from the perspective of arriving at a set of steps resulting in an architecture/framework that could make easy the common challenges faced during the modeling of such systems. In this chapter, the focus is on some of the interesting papers that have proposed/demonstrated modeling of a complex system using Petri Net and/or its extensions and some papers on Petri Nets in general. A deeper understanding of this will help to understand the subject and the proposed architecture and its unique approach towards performance monitoring of complex systems.

Understanding of Petri Nets is a fundamental requirement for understanding their applications to complex systems. Towards this, Richard Zurawski and MengChu Zhou [50] have come up with a work that discusses the fundamentals of Petri Nets and their application in the industrial scenarios. This work introduces the fundamentals of Petri Nets from an industrial application perspective and is well suited for both researchers and practitioners. Then it goes on to introduce the properties of Petri Nets and analysis techniques using an example of a simple robotic assembly system. Both deterministic and stochastic Petri Nets are discussed. The work discusses the limitations of ordinary Petri Nets and goes on to discuss the need for high-level Petri Nets and then introduces high-level Petri Nets like fuzzy Petri Nets and temporal Petri Nets. This work also discusses why Petri Net is largely confined to academic and research purposes and also highlights
the lack of proper availability of inexpensive tools for building complex industrial level models.

One of the key aspects of performance monitoring is continuously reading the current performance information from the monitored system. This has to be done periodically to reflect the most recent state. Various approaches are used to do this; one such approach was used to model the updating of the location of a continuously moving object into the database with its current location. One of the common strategies called the distance updating strategy was used and modeled by Hatem Abdul-Kader and Warda El-Kholy using timed Petri Nets [21]. This work also used the minimum cycle time concept to arrive at a method for estimating the time needed to update the moving object location database.

While modeling of complex systems where there are many interacting components each of them by itself may be a complex system, there are many possibilities that the resulting system may result in a deadlock or may not be bounded. To avoid such situations, some strategies needed to be followed while modeling of complex systems. A paper by Jose R. Celaya, Alan A. Desrochers, and Robert J. Graves [26] discusses strategies about the modeling and analysis of multi-agent systems and the avoidance of deadlocks in such systems. A methodology consisting of definition of a simple multi-agent system based on the abstract architecture for intelligent systems has been defined using Petri Nets. Analysis has been done using the structural properties of the net to assess the interaction properties of the multi-agent system. Deadlock avoidance in the multi-agent system has been considered and is evaluated using the various properties of the Petri Net model.

Verification and validation of the model plays an important role in the successful building and evaluation of complex models. Various techniques are followed towards doing these when a model is built. One such case of
modeling of complex systems and doing verification by Percy I. Kaneshiro, Emilia Villani, Paulo E. Miyagi[40], where they have taken up the area of modeling of Fire Protection Systems (FPS) in Intelligent Buildings. In their work, they have modeled the FPS and the controlled plant and also their integration with the other building systems. A hierarchical structure of the system activities are defined and described. The model has been developed, and was used for the verification and validation of the system. Hence verification and validation of the developed model proves to be an important step in the success of the model that has been built.

Designing, modeling and evaluation of real time systems has been a challenge for many situations. The choice of approach and modeling tool has been of critical importance in the success of the model building. Armin Zimmermann, Jorn Freiheit and Gunter Hommel. [63] in their work have used Petri Net models with Discrete time for the modeling and analysis of real-time systems. They have discussed the advantages of using such an approach and have used a simple application example using the software tool TimeNET.

Modeling has been used in diverse areas to detect, rectify problems in design, development and deployment of systems. This results in huge saving for the organization. Also, the ability of tools like Petri Nets allows the modeler to study the dynamic behavior of the system and their interacting components. H. Motameni and A. Golpur [37] have discussed in their work how complexity in network management can be reduced by the usage of the mobile agent technology. Also, they have discussed how Petri Net based analysis helps in the early detection of problems and hindrances in the area of network management systems will be easily detected and can be avoided from occurring. Juraj Puksec, Darije Ramljak and Darko Huljenic [28] have
also taken up the area of usage of Petri Net for the simulation and analysis of Network Management based on Mobile Agent Technology.

One of the inherent characteristics of complex systems is optimal resource utilization. Scheduling is a technique used in many industries, especially manufacturing / production lines to ensure maximum/optimal utilization of resources, in terms of machines, workstations etc. Scheduling is one of the most challenging areas that has to be addressed while modeling complex systems. In his work W. M. P. Van der Aalst [61] discusses how Timed Petri Nets can be used to model scheduling problems. He provides ways to map the various components of the scheduling problem onto timed Petri Nets. By providing a way to map scheduling problems onto timed Petri Nets he opens up ways to use standard techniques to analyze the scheduling problems. He has broken down the scheduling problem into simple task, resource with some precedence constraints among them. He also shows how we can use Petri Net based tools and techniques to find conflicting and redundant precedence’s, upper and lower bounds for the makespan, etc.

Applying Petri Nets to modern day manufacturing systems bring in a new set of challenges. M. D. Jeng [24] puts forth a theory that uses Petri Nets for modeling Flexible Manufacturing Systems(FMS). The work uses a bottom-up or modular-composition approach to build the Petri Net models of FMS modules/components. The modules are modeled as a resource control net (RCN), each representing a subsystem that controls a resource in a FMS. Interactions between the modules are given as common transition and transition subnets. Modules with a minimum of two restrictions can be merged and formed as a net that is conservative and bounded. An algorithm to detect two sufficient conditions (It examines only the net’s structure and the initial marking) for structural liveness of the net was developed. This appears to be a more efficient way that state enumeration techniques such as
the reachability tree method. The sufficient conditions for liveness are shown to be related to some structural objects called siphons. An FMS has been modeled and analyzed using the proposed approach.

Modern day software systems are also very complex in nature and fit in the definition of complex systems where different components/sub-systems (in this case software component) works together towards achieving a single/common goal. One of the key challenges today faced by software developers is to do more with fewer resources; multi-threaded programming is a way of achieving this. Today, programming languages like Java has brought multi-threaded programs to the common usage. Modeling of such software is a serious challenge which Hongwei Liao, Hao Zhou, Stephane Lafortune [22] has tried to address in their work. In this work, they have used a novel technique for deadlock-avoidance control. The programs were modeled using a special class of Petri Nets called the Gadara nets. Also the authors have proposed a formal simulation methodology for Gadara Nets. Simulations of two deadlock prone programs were done and their performance studied before and after the application of the deadlock-avoidance control.

Modeling of communications amongst the various interacting components of a complex system brings about a series of challenges different in nature. This necessitates a set of rules, hierarchies, relationships and interaction between the various components. Ali A. Pouyan, Steve Reeves, Ali Hassan Beigi [6] in their work have addressed the area of a Petri Net based approach to modeling communications of mobile software agents in multi-agent systems. This has been achieved by formalizing the basic agent template with a set of rules and actions that govern the communication between the different agents. They have presented a formal model for designing, describing the communications of mobile software agents in a distributed asynchronous
network system. This way of mapping allows a Petri Net based evaluation of the agent and their interaction dynamics.

Complex systems sometimes may necessitate some abstraction in order to maintain the readability/understandability of the model. One of the ways of achieving this is usage of sub-nets or hierarchical nets. Usage of sub-nets/hierarchical nets brings in a set of new challenges to the modeler like maintaining the integrity of the net and maintaining the structural properties of the net. I. Suzuki and T. Murata have addressed this specific area in their work that puts forth a way of expanding or contracting Petri Net model to the needed level of detail using step-by-step refinement of transitions and places [53] (or abstraction of subnets to transitions). They present a set of conditions under which a subnet can be substituted for a single transition while preserving their structural properties (like liveness and boundedness) [54]. They present the refinement technique as a top-down approach for building Petri Net model of concurrent system. They present the abstraction technique as a divide-and-conquer approach to the analysis of Petri Nets.

Checking the properties of the built nets is one of the important aspects of the analysis and validation of the built model. Various approaches has been taken towards this, G. Berthelot, Lri Lie [11] in their work proposes a way of checking properties of nets using transformations. This work proposes a set of transformations that does not affect the classical properties of the underlying nets. Another work of Hierarchical reduction and decomposition of a model by transforming sub-nets into macro-places and macro-transitions is proposed by Kwang-Hyung Lee and Joel Favrel [30]. This hierarchical bottom-up approach also preserves the properties like boundedness and liveness of the underlying nets.

Even though extensive research has been carried out in the areas of Petri Nets and various approaches, diverse in nature exist in the literature, the possible
extensions of these model architectures to accommodate continuously evolving modern day systems and the inherent complexities arising in these, especially relating to the area of performance monitoring of such complex infrastructure, alerting performance issues Alert Management are the subject area of this research work.

Though many papers of importance are discussed in this chapter, this by no means is exhaustive as there are literally too many papers to present within this dissertation. Some important papers that are of relevance to our area of work have been presented above. This area is continuously evolving and the readers/researchers are advised to be in constant touch with the current work in these areas and go through leading publications in this area to keep up with the latest trends in this area of research.