Open Fuzzy Synchronized Petri Net: 
Formal Specification Model for Multi-agent Systems

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ABSTRACT
Designing Multi agent systems needs a high-level specification model which supports abstraction, dynamicity, openness and enables fuzziness. Since the model of Synchronized Petri Nets supports dynamicity and abstraction, we extend it by fuzziness, openness and interaction with environment. The proposed model called Open Fuzzy Synchronized Petri Nets (OFSyPN for short) associates action name with transitions and enables openness feature and interaction with environment. Each action has an uncertainty degree and places are typed. The authors give an operational semantics for OFSyPN in terms of Fuzzy Labeled Transition System (FLTS for short). FLTS is a semantics model, which allows a concise action refinement representation and deals with incomplete information through its fuzziness representation. Furthermore the structure can be used to produce a tree of potential concurrent design trajectories, named fuzzy labeled transition refinement tree (FLTRT for short). We exemplify the OFSyPN model thought a case study.

KEYWORDS:
Dynamicity, Formal Model, Fuzzy Set, Multi Agent System, Openness, Petri Net, Refinement

INTRODUCTION
Multi-agent system (MAS) can be viewed as a group of sophisticated entities (i.e. agents) that cohabit and interact together in order to achieve a common goal. This paradigm forms an attractive way for conceptualizing, designing and implementing software systems (Sycara, 1998; Nugraheni, 2011). This capacity arises from the diversity characteristics of MAS, among others distribution, openness, dynamicity, autonomy, complex forms of interaction, etc.

While current multi-agent applications are promising, there are still many efforts remains to conceive these systems since they are more complex than conventional object oriented applications (Gómez-Sanz & Pavón, 2002). In fact, the formal stepwise refinement method is a powerful fashion to design such systems. It postulates MAS engineering gradually by starting from initial abstract specification and follows a rigorous refinement process to establish final specification. This later could be translated to code execution.

Thereby, an efficient refinement process relies on formal specification model that should support abstraction, dynamicity, openness, interaction with environment, handle an approximate and uncertain behaviors over steps and converge to code (i.e. decrease uncertainty).
Thus, the paper focuses on formal specification model, where we intend to provide a complete framework in which an incremental MAS design is supported and MAS modeling characteristics are enabled.

A large scale number of formal specification models has been proposed in the literature, among others Z-language (Regayeg, Kacem & Jmaiel, 2005), Petri nets (Celaya, Desrochers & Graves, 2007), colored Petri nets (El Fallah-Seghrouchni, Haddad & Mazouzi, 1999) (Mazouzi, Seghrouchni, & Haddad, 2002), Recursive Petri Nets (RPN for short) (El Fallah-Seghrouchni & Haddad, 1996), Maude (Mokhati, Boudiaf, Badri & Badri, 2007), Logic (Lomuscio & Sergot, 2003 ; Lomuscio & Michaliszyn, 2015), Synchronized Recursive Petri nets (SyPN for short) (Kouah, Saïdouni & Ilié, 2013). A full description of these models have already tackled in (Kouah, Saïdouni & Ilié, 2013). This study has revealed the inability of these specification models behind modeling of at least one of the following characteristics: abstraction and refinement, asynchronous aspects, synchronization between several processes. Such challenge motivates our work.

Literature Review

Since refinement is a key stone for designing MASs, we recall some other related works which are based on refinement paradigm:

- The authors in (Pereverzeva, Troubitsyna & Laibinis, 2012a) have proposed an approach for formal modeling critical MAS which aims to derive a secure system implementation. This approach is based on Event B language and its related principle of refinement.
- Similarly, authors in (Pereverzeva, Troubitsyna, & Laibinis, 2012b) have introduced an approach for modeling fault tolerant MAS. Its refinement strategy starts by specifying the global MAS goal, defines the set of agents to carry out this goal, identifies agents’ failures and introduces communication model and errors recovery mechanisms.
- Alike, by means of Event B specification language, authors in (Graja et al., 2013) have proposed a formal approach for self-organizing MAS where two abstraction levels are considered:
  - **Micro Level**: It corresponds to agent local behavior.
  - **Macro Level**: It corresponds to the global behavior of MAS.

Firstly, the refinement strategy starts by building the local behavior of agents. Then it is extended to the global properties. Unlike to previous approaches which are top-down, this approach is bottom-up.

- Corchuelo et al. (Corchuelo & Arjona, 2003) have proposed a top-down approach for MAS protocol description. This approach uses Finite State Automata (FSA for short) and multi-Role Interaction (mRI) abstraction. The refinement process relies on analyzing the knowledge used by each role in mRI and using this information to transform mRI into many simpler mRIs. Based on the sequence of mRIs after refinement, the corresponding FSA is built and analyzed.
- An incremental development approach of MAS by means of object Z formalism, has proposed in (Smith & Winter, 2012). In this methodology, the notion of action refinement has been introduced for object Z. It allows agent decision-making procedures and inter-agent negotiation mechanism to be introduced through refinements steps (Smith & Winter, 2012).

We observe that the presented approaches, dedicated to MAS development, are based on stepwise refinement enabling incremental development in well-structured manners. They use formal models which allow rigorous development and enable checking desired properties. Despite the important contribution of these works, they lack from:
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