Expert Systems with Applications 41 (2014) 5030–5040

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Verifying soundness of business processes: A decision process Petri nets approach

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ARTICLE INFO

Keywords:
Soundness
Workflow nets
Decision-process Petri nets
Stability
Lyapunov methods
Optimization

ABSTRACT

This paper presents a trajectory-tracking approach for verifying soundness of workflow/Petri nets represented by a decision-process Petri net. Well-formed business processes correspond to sound workflow nets. The advantage of this approach is its ability to represent the dynamic behavior of the business process. We show that the problem of finding an optimum trajectory for validation of well-formed business processes is solvable. To prove our statement we use the Lyapunov stability theory to tackle the soundness verification problem for decision-process Petri nets. As a result, applying Lyapunov theory, the well-formed verification (soundness) property is solved showing that the workflow net representation using decision process Petri nets is uniformly practically stable. It is important to note that in a complexity-theoretic sense checking the soundness property is computationally tractable, we calculate the computational complexity for solving the problem. We show the connection between workflow nets and partially ordered decision-process Petri net used for business process representation and analysis. Our computational experiment of supply chains demonstrate the viability of the modeling and solution approaches for solving computer science problems.

1. Introduction

1.1. Brief review

Companies' success depends on the ability to evolve with the market, not just respond to it. In response to the competitive pressures applied by the customer demands and the constant changes on the conditions of the environment, many companies are re-thinking the way they do business (Hammer, 1990). The ambient turbulence has created a need for dynamic business processes and companies are looking for models that can evolve and adapt efficiently business processes to the changing conditions and the changing business strategies. As a consequence, research interest in business process modeling has increased dramatically over the past decades.

Organizations needs very complicated configuration and arrangements, it has been claimed that carefully developed models are necessary for describing, analyzing and/or enacting the underlying business processes (van Hee, Sidorova, & van der Werf, 2013). The most critical point in the development of a business process depends largely on the ability to choose a conceptual model to represent the problem domain in a coherent and natural fashion and, ensure validation ability (van der Aalst, 2013). Validation of well-formed business process models is very important in the context of business process re-engineering (BPR), because the task of BPR is to evaluate the current processes with the goal of radically revising them, in order to accommodate their improvement to new organizational needs or goals. Formal models that capture and organize knowledge about a business environment can facilitate solutions to this problem (Fahland & van der Aalst, 2012). Petri nets are used for business process representation, taking advantage of the well-known properties of this approach, namely, formal semantic, graphical display and wide acceptance by practitioners of workflow nets (Clempner & Retchkiman, 2005; Chen, Ha, & Zhang, 2013; Fahland & van der Aalst, 2012; van Hee et al., 2013; Li & Iijima, 2007; van der Aalst, 2011, 2013).

Loosely speaking, a workflow net is a Petri net with an initial place and a distinguished final place called sink. Well-formed business processes correspond to sound workflow nets (van der Aalst, 2007). Petri nets have been extensively studied since the mid nineties, as an abstraction of the workflow, to check the soundness property (van der Aalst, 1998, 2007, 2011; Bashkin & Lomazova, 2013; Barkaoui & Petrucci, 1998; Barkaoui & Ayed, 2011; Basu & Blanning, 2000; Basu & Kumar, 2002; Bi & Zhao, 2004; Clempner & Retchkiman, 2005; Clempner, 2014; Dehnert & Rittgen, 2001;

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http://dx.doi.org/10.1016/j.eswa.2014.03.005

van Dongen, van der Aalst, & Verbeek, 2005; Fu, Bultan, & Su, 2002, 2004; van Hee, Serebrenik, Sidorova, & Voorhoeve, 2005, 2004; Karamanolis, Giannakopoulou, Magee, & Wheater, 2000; Kindler, Martens, & Reisig, 2000; Liu, Du, & Yan, 2012; Liu, 2013; Lohmann, Massuthe, Stahl, & Weinberg, 2006; Martens, 2005a, 2005b; Mendling, Neumann, & van der Aalst, 2007; Sadiq & Orlowska, 2000; Salimifard & Wright, 2001; Vanhatalo, Völzer, & Leymann, 2007; Verbeek, Basten, & van der Aalst, 2001; Wombacher, 2006; Wynn, Edmond, van der Aalst, & ter Hofstede, 2005, 2006). In theses studies authors have proposed alternative notions of soundness and more sophisticated language, making these notions undecidable.

From a practical point of view, workflow nets became a standard way to analyze workflows. They are used to guarantee the soundness property. A workflow process determines a set of activities and the specific order they are to be performed to reach a common goal. Such processes apply in different application domains such as: manufacturing, finance, marketing, etc. Unfortunately, current commercial systems do not incorporate verification techniques of workflows (van der Aalst, 2011). Therefore, the need for an analytical method to verify the correctness of workflow specification is becoming a fundamental task. Designers have the propensity to make many errors in process modeling. For example, the report in Mendling et al. (2007) and van der Aalst (2011), based on more than 2000 process models, demonstrated that more than 10 percent of these models have errors. Moreover, many errors were discovered using workflow nets in the SAP reference model (Mendling et al., 2006, Mendling, Verbeek, van Dongen, van der Aalst, & Neumann, 2008; van der Aalst, 2011), and more than 20 percent have mistakes. Fixing such mistakes can be a process that implies time and high labor costs.

Therefore, a challenging problem for Petri nets is to provide analytical methods able to develop useful procedures for showing the soundness of the workflow nets. To our knowledge, there are only two analytical methods reported in the literature. Barkaoui and Ayed (2011) show the ability of structure theory of Petri nets to conduct a uniform verification for large subclasses of parameterized workflow nets modeling control flow patterns associated with complex synchronization mechanisms, routing constructs and resource allocation constraints. Clempner (2014) solves the classical soundness property for workflow nets from a structural point of view applying the Lyapunov theory of stability, showing that a finite and nonblocking workflow net satisfies the sound property if and only if its corresponding PN is stable, i.e., given the incidence matrix A of the corresponding Petri Net there exists a Φ strictly positive vector such that $A\Phi \leqslant 0$. In this work, we present a complete different method from a trajectory-tracking approach, showing that a finite and nonblocking Decision Process Petri net (DPPN) validate a well-formed business process if and only if its corresponding DPPN is uniformly practically stable, i.e. the Petri net is tracked forward from its source place and a natural form of termination is ensured by a sink.

DPPN allows a dynamical model representation to be expressed in terms of difference equations. The advantage of this approach is its ability to represent the dynamic behavior of the business process. A decision-process Petri net model of a workflow net gives a specific and unambiguous description of the behavior of the business process. Its solid mathematical foundation has resulted in different analysis methods and tools. In spite of the formal background, DPPN models are easy to understand. DPPN corresponds to a series of strategies which guide the selection of actions that lead to a final (decision) state. By taking into account different possible courses of action, the overall utility of each strategy is considered. The utility function of each business process is represented by a Lyapunov-like function. Conditions of equilibrium and stability for the DPPN are analyzed.

In this contribution DPPN theory is used as an abstraction of the workflow to check the soundness property. We present an analytical method and its theoretical limits for workflow verification:

- We use the Lyapunov stability theory to tackle the soundness verification problem for decision-process Petri nets: the well-formed verification (soundness) property is solved showing that the workflow net representation using decision-process Petri nets is uniformly practically stable.
- We show that the problem of finding an optimum trajectory for validation of well-formed business processes is solvable: given a workflow net the computation can always be completed, that is, it is possible to show that a process initiated in the source place and regardless of how the computation proceeds at the beginning, the DPPN has always a trajectory able to reach the sink place of the Petri net.
- We demonstrate that checking the soundness property is computationally tractable, calculating the computational complexity of finding an optimum trajectory for solving the problem.
- We prove the connection between workflow nets and partially ordered decision-process Petri nets used for business process representation and analysis.
- We validate the proposed method successfully, by a numerical example related with supply chains

1.2. Main results

This paper presents a trajectory-tracking approach for verifying soundness of workflow/Petri nets represented by a DPPN (Clempner, 2010). Well-formed business processes correspond to sound workflow nets (van der Aalst, 2011, 2013). The advantage of this approach is its ability to represent the dynamic behavior of the business process. It is important to note that in a complexity-theoretic sense checking the soundness property is computationally tractable and the use of a Lyapunov-like function U guarantee a convergence in a time step bounded by $O(U_0/\epsilon)$ where $\epsilon = \min\{\epsilon_i\}$ equals the length of the shortest-path. The results are summarized as follows:

Theorem. *Let DPPN* $= \{P, Q, F, W, M_0, \pi, U\}$ *be a finite and nonblocking workflow net. Then, the DPPN satisfies the soundness property iff* $U(p_{i+1}) - U(p_i) \leqslant 0$ *, i.e. it is uniformly practically stable.*

Theorem. *Let DPPN* $= \{P, Q, F, W, M_0, \pi, U\}$ *be a finite an nonblocking workflow net. The problem of finding an optimum trajectory for validation of soundness of a workflow net is solvable.*

Theorem. *Let DPPN* $= \{P, Q, F, W, M_0, \pi, U\}$ *be a Decision Process Petri net and let* $(p_0, p_1 \ldots, p_n)$ *be a realized trajectory which converges to* p^* *such that* $\exists \epsilon_i : |U_{i+1} - U_i| > \epsilon_i$ *(with* $\epsilon_i > 0$*). Let* $\epsilon = \min\{\epsilon_i\}$*, then an optimum point* p^* *is reached in a time step bounded by* $O(U_0/\epsilon)$*.*

1.3. Organization of the paper

The rest of the paper is structured in the following manner. The next section presents the necessary mathematical background and terminology on Petri nets needed to understand the rest of the paper. In Section 3, we motivate the need for the soundness workflow verification technique, the goal is not to formally present the method but to provide a high-level overview of how it works. We present the basic notion of a workflow net and soundness followed by the definition of soundness. We also describe and exemplify the