

A Survey on Workflow Verifications of Petri Nets based Service Process Management

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Abstract

Service process management is a cross-discipline research topic, including computer science, management technology and economics. How to effectively integrate service resources to meet customer demands becomes a key problem to service-oriented software development. Most of existing works are in the early research stage. The scope of process management consists of process design, process execution, process mining, and process intelligence. However, it requires process modeling, which is a crucial precondition in the lifecycle of service process management. In this paper, it reviews workflow verifications of Petri Nets based service process management. First, the workflow and description supporting tools are introduced. Then, considering the composite service is an effective way to organize third-party business functions seamlessly, the Petri Nets based service workflow employed to formalizing composition behaviors is discussed. Third, components encapsulated in the composite service may be encountered functional and non-functional problems since services are offered by different organizations. The functional verification includes the correctness, reachability and safety. The non-functional verification is to evaluate the performance of Petri Nets based workflow model ranging over timed constraints and probabilistic behaviors. Therefore, it summarizes Petri Nets based workflow verification techniques to guarantee the quality of services composition. In conclusion, this survey provides academic references to researchers and developers in service computing and process management.

Keywords: *Service Process, Services Composition, Petri Nets, Workflow Descriptions, Formal Modeling and Verification*

1. Introduction

With development of Internet, software architecture has become more flexible to support complex collaborations. Under the economic globalization background of production and logistics, the traditional information management system, such as ERP, CRM, and MIS, has limitations to the enterprise sustainable development. As an important technique to data encapsulation and computing resources integration, Web service becomes one of the most promising infrastructures to develop the cross-platform applications. Today, more and more companies and organizations have taken part into this emerging service software industry, expanding their cooperation or exploring enterprise solution via Web service and services composition to implement core business activities and build dynamic e-commerce mechanisms, among enterprises, customers, suppliers and partners. Thus, Web services have been widely regarded as the next-generation distributed computing model [1].

The single function is hard to satisfy the complex application requirements. In order to perform complex tasks or deal with business across enterprises, a series of Web services are required to properly work together. How to effectively organize kind of services needs service process management to promote enterprise business goals achieved that applying workflow technique to services composition is one of feasible methods. There are many workflow application examples, such as business flows and passenger flows. In facts, the flexible and adjustable workflow helps to obtain maximal benefits, making the balance between service infrastructures and requirements. It is conducive to response market demands, reduce cost of service, improve the quality of service improvement, and keep the permanent competitiveness.

However, the workflow modeling method should be formalized for describing complex interactions of service process, mainly the representation of composite services and multi-dimensional modeling, for example, how to model the composite service in a readable way. Furthermore, the incompatibility and unsafe factors will impact the service process of business systems. The service process may have complex dependencies of business logic. Thus, the functional requirement verification needs to check the behavior consistency. The second problem is non-functional verification of services composition in the form of workflow descriptions. For consumers, satisfaction relies on their user experiences and on judging the quality of service when invoking a service, such as timing-response, cost and reliability. Thus, the response should provide correct values, and the value should be outputted at the right time-points with much lower cost and higher reliability. The services composition verification contains not only functional checking but also non-functional checking. To this end, this paper will review the workflow verification methods of Petri Nets based service process management.

The remainder of this paper is organized as follows. Section 2 introduces the workflow patterns and workflow description supporting tools. Section 3 discusses the service Petri Nets and service workflow modeling techniques. Section 4 presents related works of the functional and non-functional verifications of Petri Nets based service model. Section 5 draws a conclusion and future works.

2. Service Workflow and Its Applications

The Web service proposed by W3C has defined SOA elements by using Internet protocols SOAP¹ for services invocation, and utilizing XML-based specifications WSDL² to describe service's interface and message format [2]. In the area of services computing, IT-based software platforms are mainly implemented by integrating certain business services. The service workflow used as basic plans of function composition defines service invocation and execution strategy, creating value-added services or applications, which is the core technology to enterprise business reengineering, process management and process automation. The main purpose of workflow is convenient to perform different tasks and monitor the specific activity. Hence, workflow is considered as a computerized model of business operation process, consisting of well-defined tasks and roles [3]. Although different workflow definitions have been proposed, they have a similar viewpoint that the workflow as a fully or partially automatic business processes includes series rules of process, documents, information or tasks [4, 5].

In academic, special issues about service computing and workflow management theme has been discussing Web service related problems, including Journal of Service Research (JSR), International journal of Service Industry Management (IJSIM), Journal of Services Marketing (JSM), Managing Service Quality (MSQ), IEEE Transactions on Services Computing (TSC), and International Conference of ICWS, SERVICE, SCC, CLOUD, APSCC, ECOWS, ICSOC, BPM. Academic researchers continue to publish new

¹ <http://www.w3school.com.cn/soap/>

² <http://www.w3school.com.cn/wsdl/>

computing theory, method and model for service-oriented software development. Most academic groups have set up open forums and launched a series of technical standards and specifications, such as OASIS and W3C. In application industry, IT companies are actively publishing new application platforms, such as HP Eflow, IBM BPW4J, and Apache AXIS 2.0.

2.1. Workflow Patterns

The workflow has key elements, activities, links, logical nodes, data objects and start/stop conditions. The activity is a basic unit, which can be a simple activity or complex activity. The simple activity is the atomic business. The complex activity is made up of other activities with dependences between activities [6]. The business process comprises activity and activity change. In Figure 1, there are kinds of basic workflow patterns, such as sequence, loop, and branch condition.

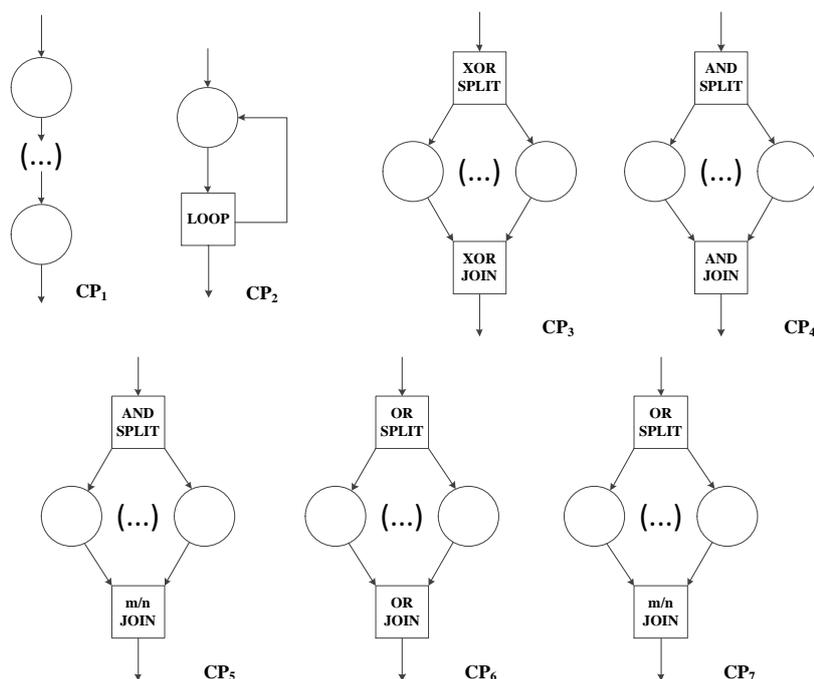


Figure 1. The Workflow Patterns

The sequence pattern means two activities are executed in order. The CP1 of Figure 1 shows the execution scenario. The loop patterns depicts the limited cycle that a new link is used to connect to the previous activity. The branch conditions have 6 logical nodes that XOR-Split, XOR-Joint, AND-Split, AND-Join, OR-Split, and OR-Joint. The Split is used at the bifurcation of branch. The Join is used at the junction of branch. The logical expression AND, OR, and XOR are conjunction, disjunction and mutual exclusion, respectively.

The CP3 of Figure 1 describes the composition patterns of XOR-Split and XOR-Joint. The XOR-Split includes two or more subsequent process, by which only one subsequent process can be selected to run after successfully executing XOR-Split logical node. The XOR-Joint merges two or more subsequent branch into one junction node. If any process is complete, the follow-up activity of logical node will be invoked without synchronizing other process in branch. It is the first in and first out (FIFO) strategy.

The CP4 of Figure 1 describes the composition patterns of AND-Split and AND-Joint. The AND-Split has two or more subsequent processes where all processes should be concurrently executed. The AND-Join merges two or more processes into one junction

node after all branch processes are complete. In CP5 of Figure 1, the m/n-Join is a subset of AND-Join which requests at least m processes should be complete when total n process are executed simultaneously.

The CP6 of Figure 1 describes the composition patterns of OR-Split and OR-Join. The OR-Split has two or more subsequent processes where it will trigger more than one process, rather than all processes. However, it is not necessary to know whether it is synchronous. The OR-Join will merge two or more branches into one junction node once one process is complete. Then the follow-up activity of logical node will be invoked after the junction node.

2.3. Workflow Description Tool Classification

According to the implementation way, the workflow description method is categorized into Graphic Based Description, Mathematics Based Description, and Executable Description.

2.3.1. Graphic Based Description: The Graphic Based Description aims to facilitate users to understand graphical symbol modeling, including UML (Unified Modeling Language) and EPC (Event driven Process Chains). The activity diagrams of UML used for service workflow describe interactions between business participants and business processes [7]. The sequence diagrams of UML used for service workflow show the message communication and temporal relationships among component services. The EPC used for service workflow is a graphical description language, including functions, events and logical connectors [8].

2.3.2. Mathematics Based Description: The Mathematics Based Description includes Logic-based, Event rule-based, Algebraic-based and Petri Nets Description. For Logic-based description, the Concurrent Transaction Logic (CTR) gives the local and overall properties of workflow, in which the proof theory and semantic are used to reasoning. For Event rule-based description, the ECA (Event, Condition and Action) defines rules that if the event in rules is executed the condition will be evaluated whether it is satisfied or not. If it is satisfied, the action in rules will be performed [9]. For Petri Nets description, it is state-based modeling and analysis tool, which is suitable to formalize execution dependences between tasks in service workflow.

2.3.3. Executable Description: The Executable Description includes YAWL (Yet Another Workflow Language), BPMN (Business Process Modeling Notation), BPEL (Business Process Executing Language) and jDPL (jBPM Process Definition Language). The YAWL supports the resource pattern of workflow and dynamic workflow modeling. The BPMN is XML based process modeling description language, which helps developer to understand the internal mechanism of enterprise business process in the form of visual graphs. It supports 3 type modeling methods, mainly the Process Orchestration, Choreography and Collaborations. The WS-BPEL and BPEL4WS extended from BPEL are the Web service based business process orchestration languages. It allows different organization's business processes to cooperate with each other.

2.4. Existing Workflow Tools

The COSA system generated by Ley GmbH Corporation from Germany³, has Activities and Conditions in its modeling language, where the activity corresponds to transition and the conditions corresponds to places of Petri Net. The FLOWER system⁴ generated by Pallsa Athena Corporation from Netherlands, supporting

³ <http://www.pass-bpmsolutions.de/>

⁴ <http://flower.codeplex.com/>

structured/unstructured process, which adopts data-driven, redo, skip and AIF (Activity Independent Forms) mechanisms to ensure the flexibility of software system. The Domino Workflow generated by IBM based on Lotus Domino/Notes supports unstructured process, which consists of person, work group, department and role. The Visual WorkFlo toolkit⁵ generated by FileNet Corporation includes activities and routing elements. The routing element consists of XOR-split, Loop, AND-split, AND-join and Release. The Verve Workflow is an embedded workflow engine, allowing multiple instances and runtime instance dynamic modifications, which include activity and transition that each transition is related to conditions. It also supports synchronization. The I-Flow based on JAVA/CORBA⁶ is a Web-centric workflow. The Action Workflow concerns the cooperation and employs BPM to modeling business process. Furthermore, a business process extraction tool is developed to automatically discover and extract the enterprise business process from e-commerce system.

3. Formal Modeling Service Workflow Using Petri Nets

The service workflow describes entity relationships between activities during process executions, such as beginning condition, stopping condition, executor, navigation behavior rules, user tasks, activity, and data definition. However, the service workflow is semi-formal, which can't be analyzed and verified by workflow execution tools to check whether service process satisfies the given properties. In addition, most existing workflow tools are unable to automatic verification that if service workflow has bugs it is forced to stop running. Thus, the service workflow should be translated into formal model for providing the high quality.

In general, the formal method includes Petri Nets, Automata and Process Algebra. The automata or process algebra lacks of considering the state spaces which will easily lead to state space explosion problem. While, adopting Petri Nets to service workflow has advantages: 1) Petri Nets is convenience to formal analysis and verification. 2) The graphics expression makes the model easy to understand, such as concurrency issue descriptions. 3) Pet Nets supports lots of analysis methods that reachability graph, identification tree and invariant computing. Thus, Petri Nets is recommended to formalize service workflow [10].

3.1. Petri Nets and Service Petri Nets

Definition 1. (Petri Nets). Petri Nets avoids the ambiguity, uncertainty and contradiction problem [11]. The classical Petri Nets is a triple $PN::=(P, T, F)$, that is,

- 1) P is a finite set of places.
- 2) T is a finite set of transition.
- 3) $F \subseteq (P \times T) \cup (T \times P)$ is a finite set of flow relations.
- 4) It satisfies that $P \cup T \neq \emptyset$, $P \cap T = \emptyset$, $F \subseteq (P \times T) \cup (T \times P)$, $dom(F) \cup cod(F) = P \cup T$, $dom(F) = \{x | \exists y: (x, y) \in F\}$, $cod(F) = \{y | \exists x: (x, y) \in F\}$.

In graphical description, circle is place (P), rectangle is transition (T) and arrow is flow relation (F). The Petri Nets is worked under following rules:

- 1) When all input place have at least a token for transition $t \in T$, only the current transition t in enabled state can be changed.
- 2) After transition t is executed, all input place of current transition t will consume a token. And all output places of current transition t will produce a token.

⁵ <http://toolkit.idsproject.org/>

⁶ <http://en.wikipedia.org/wiki/CORBA>

The analysis of Petri Nets model helps to achieve real-time inventory optimization problem, human resources allocation, cost reduce and operation efficiency improvement. Petri Nets has been widely used in many research fields, such as communication protocol authentication, network performance analysis, parallel program design, knowledge inference, and artificial neural network. The Petri Nets is improved during its developing, including color characteristic, time characteristic, hierarchy characteristic and predicate characteristic, such as Color Petri Nets, Event-driven Petri Nets, Stochastic Petri Nets, Deterministic Time Petri Nets and Hierarchical Petri Nets. The service Petri Nets for service process is as follow.

Definition 2 (Service Petri Nets). Considering the service interface, the service workflow is mapped to extended Petri Nets, called as service Petri Nets, which is a 7-tuple $SN := (P, T, F, i, o, l, M_i, M_o)$ [12], that is,

- 1) P is a finite set of places, where each place is a state.
- 2) T is a finite set of transitions, where each transition corresponds to an operation execution of Web service.
- 3) $F \subseteq (P \times T) \cup (T \times P)$ is a finite set of flow relations, each directed arcs represent a relation from operation execution to state or from state to operation execution.
- 4) i is input place, o is output place, and the pre-set of i and the post-set of o should have a least one interaction without *null*.
- 5) $l: T \rightarrow A \cup \{t\}$, A is set of operations, and t is an empty operation.
- 6) M_i, M_o corresponds to starting and stopping label respectively.

The service workflow patterns in Figure 1 should be transformed into Petri Nets patterns. The control structure in the form of Petri Nets for service process modeling has sequence, concurrent, selection, and loop, that is,

$$S ::= X \mid S1 \square S2 \mid S1 \oplus S2 \mid S1 \diamond S2 \mid \mu S \mid S1 \parallel_C S2$$

Where 1) X is atomic service or empty service without any operation.

2) $S1 \square S2$ is a sequence structure that $S1$ is first executed after which $S2$ is invoked.

3) $S1 \oplus S2$ is a concurrent structure that $S1$ and $S2$ are executed concurrently.

4) $S1 \diamond S2$ is a selection structure that only $S1$ or $S2$ can be executed.

5) μS is a loop structure that S should be executed for μ times.

6) $S1 \parallel_C S2$ is another concurrent structure that $S1$ and $S2$ have communications during their concurrent execution.

Due to the formal method characteristics, the process management problems, for example, multi-goals programming, decision-making theory, queuing theory, forecasting and simulation, can be realized on Petri Nets based workflow model.

3.2. Petri Nets based Service Process Modeling Method

Petri Nets is suitable to modeling the distributed system. A lot of researches have paid attention to Petri Nets for service process modeling and analysis. The main classifications are the control aspect of service process, the message and interface aspect of service process, and the semantic aspect of service process.

In the control aspect of service process, the key research point is composition behavior structures and behavior associations. In literature [13], Petri Nets algebra is proposed to describe control flows of services composition, and kinds of operations based on Petri Nets are defined. In literature [14], colored Petri Nets for services composition model is

proposed, in which four kinds operations are introduced, for example, sequence, selection, loop, *etc.* In literature [15], service process is modeled according to workflow theory, and the trust-based Web service workflow QoS scheduling method is discussed. In literature [16], services composition problem is studied by Horn clause set, by which the necessary rule sets are extracted. Then, Petri Nets is used to formalize these rules to organize composite service. In literature [17], automatic services composition model is proposed based on colored Petri Nets. The author gives semantics for model synthesis, which improves the reliability and maintainability of service process. In literature [18], an object Petri Nets (OPN) is used to services composition that each Web service is mapped to a PNO system in which different Petri Nets can be interacted via message delivery mechanism.

In the message and interface aspect of service process, the interface and message interaction are main researches. In literature [19], a colored Petri Nets based message oriented service model is proposed, which focuses on meta-message descriptions and service cooperative communications. The model includes the message domain and service process. It not only achieves the communications among services but also the gives service process description for automatic services composition under predefined rules. In literature [20], Web service model contains internal processes and workflow module of external interface, where workflow is employed to formalize internal processes. In literature [21], a Petri Nets based automatic composition method is used for Semantic Web services. This method consider input/output and service behavior constraints. In literature [22], a Petri Nets based method is proposed for the simulation and verification of meta-activity and components. It is extended from the universal component description language (UCDL), which provides expression generation algorithm for Petri Net.

In the semantic aspect of service process, the transform algorithm for how to convert service operation semantics into executable codes is a hot research topic. In literature [23], situation calculus and Petri Nets method are introduced to describe DAML-S (The DARPA Agent Markup Language for Services) for semantic Web service operations. First, DAML-S of semantic Web service is mapped to situation calculus, then service Petri Nets is constructed. In literature [24], Petri Nets is used to model Web service business process execution language, such as BPEL4WS or BPEL. It uses workflow structure to describe the features behavior of the business process. Based on structural activities analysis and fault compensation mechanism, the Petri Nets based incremental refinement technology is employed to model service process. In literature [25], Web service composed by semantic Web services markup language (OWL2S) is considered to ensure the reliability of with high performance. A generalized stochastic Petri Nets model (GSPN) is introduced to for modeling, analysis, verification, and assessment of service process.

4. Formal Verification of Service Process

The component services may be published by different organizations. The service workflow verification is way to find the defects, existing in services composition in advance, which helps to improve the success rate of services composition and enhance the user satisfactions. After service process modeling, the formal verification of service Petri Nets can determine whether the composite service satisfied the specific properties or not. In this part, we will introduce the existing works about functional verification, compatibility verification, and non-functional verification.

4.1. Functional Verification

Functional verification aims to verify interactions of service Petri Nets. The reachability, safety, termination, boundedness, liveness, deadlock and livelock will be verified for functional correctness.

In literature [26], the correctness definition of workflow is proposed, which includes terminable conditions and no dead transition conditions. In literature [27], it points that the correct service process should allow the inner process to have dead transitions. Thus, the new concept of weak soundness is proposed. In literature [28], composition net is used to describe interactions among multiple services and the service compatibility analysis is defined to Petri Nets deadlock detection. A control strategy of deadlock prevention is proposed in which additional message channel is added to get a living Petri Net and partial transition may be terminated in order to avoid deadlock occurrence. In literature [29], to ensure the correctness of services composition under environmental constraints, the concepts of Web service domain and Web environment domain are proposed based on Petri Nets to formalize Web services composition. Then the interaction between Web service domain model and Web environment domain model are analyzed to give the composition condition and its correctness decision algorithm. In literature [30], based on BPEL, services composition is defined as Petri Nets composition where the reachability graph verification is proposed. In literature [31], in order to verify the consistency between the global abstraction of BPEL and Local executable processes of participants, Petri Nets is employed to model BPEL and the automatic verification tool Wombat4ws is used. In literature [32], senior object Petri Nets model (HOPN) is proposed with object-oriented and layered characteristics. This model improves the reusability and reduces the complexity of service process. The liveness analysis algorithm has capacity of deadlock prevention and deadlock detection, by which the correctness and effectiveness of the model formalized by HOPN can be verifiable.

4.2. Compatibility Verification

The compatibility verification aims to verify the collaboration among service components in services composition. This research content includes: 1) the syntax compatibility between service components; 2) the semantic compatibility between service components; 3) the behavior compatibility between service components. In literature [33], the Petri Nets based optimization control strategy is proposed to avoid incompatible problems of interaction behaviors in services composition. The reduction rule is designed to generate the reduced state reachability graph for service process, which can identify the deadlock state and non-deadlock state. The transition of deadlock state is added with corresponding places and flow relations. In literature [34], colored Petri Nets is used describe Web services, and then the communication transition sequence, similar transition sequence and equivalent transition sequence are defined, by which the compatibility and similarity of Web service process are verified. In literature [35], the Siphons theory is used to study the Petri Nets based service process compatibility. In literature [36], there definitions for service process compatibility are defined and the deadlock problem in asynchronous service process is discussed. In literature [37], the Petri Nets is used to model BPEL that the process compatibility is studied.

4.3. Non-Functional Verification

The non-functional verification requires that the service process should meet the specific performances of user requirements. For example, if workflow used for services composition contains flaws in time constraints and stochastic behaviors, it will result in economic losses and safety accidents.

Time constraints in service process includes the service should accomplish specific functions in a certain time. In literature [38], workflow timed graph defines constraints about activity execution delay, including the activity time property, deadline, fixed date and time distances. In literature [39], the workflow model WF-Net is extended with time, that activity time is changed to transition time pairs which is used to liveness, safety and rationality verification. In literature [40], in order to improve the capacity of timeliness

information processing for workflow, the time property is introduced to workflow and the temporal workflow is proposed. The temporal workflow is used to describe and analyze the time related issues in workflow. In literature [41], the Petri Nets is employed to simulate and verify WS-CDL and timed Petri Nets is introduced to analyze time characteristics and priority level. In literature [42], timed process model based process time prediction algorithm and task time allocation strategy are proposed.

Workflow performance analysis includes the probability calculation and the performance monitoring under instable network environment and uncertain factors. In literature [43], the Jackson queuing network theory and Markov chain are used to the static and dynamic performance analysis of Petri Nets for service process. The general stochastic Petri Nets (GSPN), a quantitative method, has advantages in composition and its interactions. In literature [44], BPEL specifications are mapped to GSPN model to evaluate the performance of the composite service. In literature [45], GSPN model is employed to model and verify OWL-S process model where mapping rules for transforming OWL-S model to GSPN model are designed. In literature [46], stochastic Petri Nets is used to analyze the reliability of service process that the BPEL specification for services composition is transformed to WS_RPN. The reliability is verified by the execution path analysis.

5. Conclusions

The service oriented architecture and service oriented computing make business process management (BPM) methodologies further developed. In general, the workflow for service process uses Web services on demand to quickly build a value-added service or new Web application. But, it only specifies the task, relationship, and logic data dependency. These selected services invoked by each task may be dynamically updated according to the operation situation and allocation of resources during workflow executions. Thus, it calls for formal modeling and verification method to manage and monitor components and their interactions. In this paper, a survey on workflow verification of Petri Nets based service process management is introduced. First, the workflow classifications and description methods are discussed. Then, the formal model for service process is presented by Petri Nets. Finally, the formal verification methods for service workflow are introduced.

However, more technical problems of service process management need to be studied in further, such as model expression ability, running monitoring system, security authorization and application integration of service workflow. As further research, we will focus on the optimization strategy for the state explosion problem of workflow model synthesis.

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