Process Knowledge Verification Method Based on Petri Net*

Wang Daliang
School of Information Engineering University of Science and Technology Beijing Beijing 100083, China

Zhang De-zheng
School of Information Engineering University of Science and Technology Beijing Beijing 100083, China

Gao Li-xin
School of Information Engineering University of Science and Technology Beijing Beijing 100083, China

Liu Jian-ming
School of Information Engineering University of Science and Technology Beijing Beijing 100083, China

Zhang Huan-sheng
Department of computer Hebei Engineering and Technical College Cangzhou Hebei 061001, China

Abstract

Process knowledge is a key element to construct the domain knowledge database, and the process knowledge is mainly represented by process models. Although there are many methods to represent the process knowledge, they all have complexity and difficulty on the representation of the model construction, furthermore, the key problem lies on the difficulty of the process knowledge verification. Therefore, a method of modeling and verifying process model on the basis of Petri Net is proposed in this paper, and Petri Net representations of basic units in process model are refined. It is proved by examples that the problem of accessibility, deadlock and dead circle can be solved well by this method.

1. Introduction

The construction of domain knowledge system, as one of the major contents of knowledge engineering, is a complicated system engineering. The domain knowledge base contains rich knowledge to meet the widely needs of application, including various kinds of fact, rule, case and process knowledge. Process knowledge, as the key elements of domain knowledge base, is expression and representation of all kinds of process, flow, logic and situational knowledge, etc. Most of these knowledge present as process models, which are important contents in construction and application of enterprise informatization knowledge base. Therefore, knowledge base, as an important kind of knowledge representation form, is being attached more and more attention[1].

Models are abstraction, simplification and simulation of the reality prototype, identity description of the structure and function of the reality model. Process model is an abstract description of enterprise operation mechanism and operating process, it reflects the logic relations among process elements. Previous process models are described by non-formalized language, while to manage and reuse the knowledge requires that models should not only describe relations among activities, but also have much other incidental information to facilitate the explanation and implementation. Modeling the process mainly aims at solving the problem of how to properly describe the system behavior state according to process objectives and system constraint conditions. Now there are many ways to define and describe the process models and further provide a set of complete and effective modeling language.

All kinds of knowledge should be analyzed and evaluated before being stored into knowledge base to proof the effectiveness and completeness. There are different evaluation methods for different domain knowledge. Primary verification methods for process knowledge includes: Modeling Checking of State Machine Model, Temporal Logic, Modeling Checking of Parallel Processing, etc.. The common characteristics are difficulties in modeling and formalization of algorithms and tools that has abroad

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popularization and application prospect. In order to overcome the defects and facilitate the knowledge verification, this paper proposes a process knowledge verification method on basis of Petri Net[2].

2. Method of process knowledge representation

Process knowledge is mainly represented by process model. The development of process model mainly aims at automatic process of process model, which clearly describes structures, attributes, performances and states of the system. In domain knowledge base, there are various methods with various features for modeling process model.

2.1. UML Activity Diagram

Methods of modeling based on UML mainly describe the operation process by various UML graphs, and express mathematic description by graphs. UML activity diagram is a kind of graph modeling dynamic behaviors of system, it is essentially a flowchart describing controlling workflow from activity to activity, so it is suitable for modeling workflow. But activity diagram lacks of interaction capability with external world, which is indispensable in workflow implementation and mainly include 2 parts: manual participation in implementation process and response to external events.

2.2. IDEF Series

IDEF series methods are applied to enterprise modeling and process modeling. It contain a series of modeling method, for instance, function modeling method（IDEF0）、information modeling method（IDEF1）、dynamic behavior modeling（IDEF2）、process modeling method（IDEF3）and object-oriented modeling（IDEF4）,etc.

2.3. EPC (Event-driven Process Chain)

It is mainly applied to business process reengineering (BPR), the configuration and development of software and activity-based cost analysis. EPC is originally introduced by Keller, the key elements of EPC are functions and events: events trigger functions and functions also generate relevant events. Functions and events alternate and affiliate with each other in this way, and finally construct the control flow of operation process.

Figure 1 is an EPC modeling chart in production process of a cosmetics company :

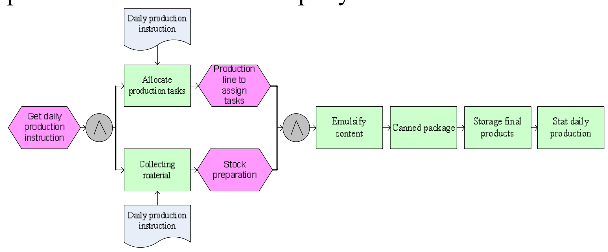

Figure1. An EPC modeling chart on production process in a cosmetics company

2.4. Petri Net

Petri Net stems from a doctoral dissertation by Germany • Carl Adom Petri in 1962, after years of enrichment and development, it already has not only strict math definition, but also direct graphic express, so Petri Net is effective means for system description and behavior analysis. It also serves as a modeling methods particularly suits to describe asynchronous and intercurrent phenomenon, providing a powerful analysis tool for computer science.

Petri Net analysis technology also bring new theoretical concepts into domain knowledge base, by verifying process model, model of inerrability structure and best performance can be selected to run, which attains the expected purpose: verification of process model in domain knowledge base[3].

There are many different modeling methods in construction of domain knowledge base, in practical application, it is hard to confirm which methods or technology is best, so it is necessary to select proper method according to objectives and specific details. In domain knowledge base verification system, process model verification mainly consider methods of great technology support.

3. Process knowledge representation based on Petri Net

3.1. Petri Net Quadruple

Petri Net is can be defined as an quad（P,T,I,O）, therein:

P={p1,p2,......,pn} is finite set of place;

T={t1,t2......,tm} is definite set of transition, and, T and P are disjoint.

I is the input function, mapping of transition T to place. For each $tk \in T$, relevant results can be get:

I(tk)={pi, pj,......}

O is the output function, also mapping of transition to place. For each $tk \in T$, relevant results can be get:

O(tk)={pr, ps,......}

3.2. Examples

Referring to production process in Figs 1, EPC model in Figs 1 are mapped to Petri Net, as Figs 2 shows. In Figs 2, a circle represents a place, a rectangular represents a transition, and a arrow represents a stream. Arc in Petri Net only can be from store-place to transition, or from transition to store-place. Store-place can accept token, token is represented by black spot. P, T, I, O of the net are respectively:

P={p1,p2,p3,p4,p5,p6,p7,p8,p9}

T={t1,t2,t3,t4,t5,t6,t7}

I(t1)={p1}, I(t2)={p2}, I(t3)={p4}, I(t4)={p3,p5}, I(t5)={p6}, I(t6)={p7}, I(t7)={p8}

O(t1)={p2,P4}, O(t2)={p3}, O(t3)={p5}, O(t4)={p6}, O(t5)={p7}, O(t6)={p8}, O(t7)={p9}

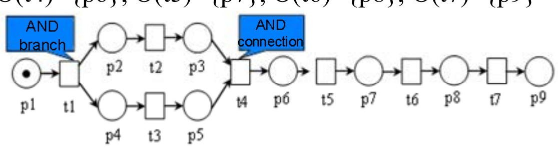

Figure 2. **Petri Net that production process EPC mapping to**

p1: Get daily production instruction
p2: Allocate production tasks
p3: Production line to assign the task
p4: Collecting material
p5: stock preparation
p6: Emulsify content production
p7: Canned package
p8: Storage final products
p9: Stat daily production

Petri Net state is determined by the distribution of token. Number of token in place pi is represents by μi, in figs 2 shows, μ1=1 , μ2=μ3=μ4=μ5=μ6=μ7=μ8=μ9=0. Vector μ=（μ1，μ2，......，μn）can also represent the distribution of the whole Petri Net. Now μ=（1，0，0，0，0，0，0，0，0）.

The transition of a Petri Net depends on the following conditions:

There must be 1 or more transitions meet the transition condition. The transition condition is that all the input place of certain transitions must have relevant tokens, and when there are more than 1 arc at input place directing at this transition, the input place should have tokens with the equal number or more.

There must be firing. Firing means certain events occur, and the corresponding transitions of these events meet the transition conditions.

Take Figs 2 for example, the initial distribution of the token is μ=（1,0,0,0,0,0,0,0,0）. Obviously only t1 is satisfied with the transition condition. After t1 firing, token distribution become μ'=（0,1,0,1,0,0,0,0,0）.

4. Process model verification based on Petri Net

4.1. Petri Net Description of Basic Unit in Process Model

Petri Net has profound mathematical basis and accurate definition, therefore, on contrast to conventional informal diagram technology, it avoids fuzziness, uncertainty and contradiction. After more than 40 years development, the theory becomes increasingly more mature, there are many usable analysis technologies to analyze model properties, for instance boundedness(security), activities(deadlock – free), invariables, etc.. Because Petri Net theory is supported by those mature analysis technologies, it is widely used for process model verification. The theory foundation and development experience of Petri Net make it suitable for domain knowledge base analysis[4].

To verify process model by Petri Net, it is necessary to specify corresponding relations between Petri Net and enterprise process model, therefore, visualizing and modeling the enterprise workflow.

Tabel 1. **The corresponding relations between Petri Net and business process**

Petri Net	Process Model
Store-place	resources (like employees, warehouse),resource state (like busy idle) process
Transition	beginning or ending of operation、events、process、time
Token	resource、resource amount
Label	system state
Accessibility	whether system can reach certain state

Process model is a system when we describe it. The internal activity isn't a disorder set, but a combination according to certain logic relations. Usually there are preference relation, parallel relation, conditional branch relation, circular relation and other basic ones. In the follow discussion, there are basic relations descriptions among process model activities among business processes by Petri Net.

4.1.1 Sequencing router

If the tasks be implemented one by one, it is called sequencing router, as figs 3 shows[5].

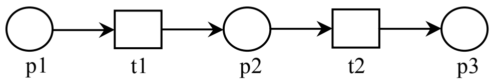

Figure 3. **Sequencing router**

4.1.2 Parallel router

If many tasks be implemented together or in any order, it is called parallel routing. As figs 4 shows.

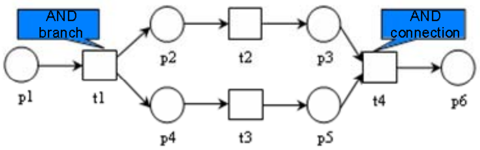

Figure 4. **Parallel router**

4.1.3 Selecting router

Different specific conditions may lead to different routers being selected. Some tasks don't need to be carried, this is selecting router, there is a as figs5 shows.

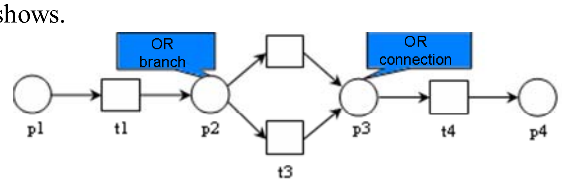

Figure 5. **Selecting router**

4.1.4 Circular router

Circular structure can be used to define activities which may be repetitive, don't carry out next step until certain conditions are satisfied with, as figs 6 shows.

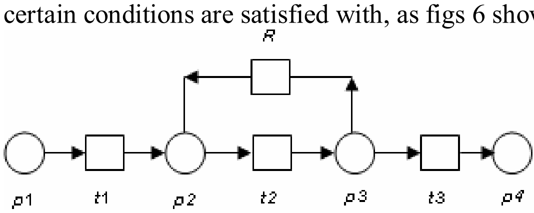

Figure 6. **Circular router**

The above four structures are the basic structures of workflow, they compose the implement structure of workflow.

4.2. Process Knowledge Verification Technologies based on Petri Net

Process model is the result of business process design, its construction is a complex and error-prone process. Correct model is helpful for description of the structure and behavior of the system. However, if mistakes are not found until the input of model definition, it will result in alarge amount of capital outlay. In this system, business models of different enterprises are mapped to Petri Net model according to the interface technology, then relative data output, and finally process model are verified according to relevant theories and methods.

Reference[6] summarized properties need to be verified in process model verification, here further induction are made. The basic properties of Petri Net are classified into 2 major kinds: one is dynamic properties which depends on initial marking, such as accessibility, boundedness, reliability, activity, coverability, continuity, fairness, etc.; the other is structure properties which doesn't depend on initial marking, such as structural liveness, repeatability and consistency. All of these are consistent to basic properties of Petri Net, so Petri Net has remarkable advantages in process model verification. Meanwhile, verification on process model also accord with properties of graphs and strict semantics of Petri Net, which will not be interfered by state space, and be favor of machine implementation.

Some basic properties of Petri Net have been emphatically introduced in this paper.

4.2.1 Reachability

Reachability is the most basic dynamic properties of Petri Net, the rest properties can be defined by it.

Suppose $\Sigma=(P,T;F,M)$ is a Petri Net. If there exists $t\in T$ which makes $M[t>M'$, then M' is directly reachable from M . If there exists transition sequence $t_1,t_2,t_3,\cdots t_k$, label sequence $M_1,M_2,M_3,\cdots M_k$ which make $M[t_1>M_1[t_2>M_2\cdots M_{k-1}[t_k>M_k$, then M_k is said to be reachable from M .Set of all labels reachable from M is denoted as $R(M)$. We agrees: $M\in R(M)$.

When Petri Net is used to simulate a practical system, graph $(P,T;F)$ describe system structure, initial marking M_0 represents the initial state of system, $R(M_0)$ represents set of all possible states during system running.

4.2.2 Boundedness and safeness

Suppose $\Sigma=(P,T;F,M_0)$ is a Petri Net, $p\in P$,if there exists a positive integer B which accord with $\forall M\in R(M_0):M(p)\le B$, then store-place is bounded, and the minimum positive integer B satisfying the constraint is boundary of store-place, denoted as $B(p)$,i.e.

$$B(p)=\min\{B\mid\forall M\in R(M_0):M(p)\le B\}$$

When $B(p)=1$, store-place is safe.

Suppose $\Sigma=(P,T;F,M_0)$ is a Petri Net, if each $p\in P$ is bounded, then Σ is bounded Petri Net, and

$B(\Sigma) = \max\{B(p) \mid p \in P\}$ is boundary of Σ.

When $B(\Sigma) = 1$, Σ is safe.

Boundedness reflects demand for resources volume in system running. In practical system designing, number of labels of each store-place in any state in the network is small than volume of the store-place. Thus ensures normal operation of the system.

4.2.3 Liveness

Suppose $\Sigma = (P, T; F, M_0)$ is a Petri Net, M_0 is initial label，$t \in T$。If for any $M \in R(M_0)$，there exists $M' \in R(M)$ which make $M'[t >$，then transition t is live。If every $t \in T$ is live, then Σ is live Petri Net.

The above concepts are proposed to meet the need of determine whether there will be deadlock in practical system.

4.2.4 Deadlock

Suppose $N = (P, T; F)$ is a Petri Net，$P_1 \subseteq P$. If $\bullet S_1 \subseteq S_1 \bullet$，then S_1 is a deadlock of the system. Deadlock is special store-place subset[7].

Verify reachable relations of various states. If transition from state A to state B is impossible (directly or indirectly), then it is unreachable from state A to state B. If it is unreachable from the initial state to certain state, then it demonstrates that there are mistakes in the workflow[8].

The most typical deadlock is that all entities in process are in a waiting state, in this state the process won't go further until certain event happened, while this 'certain event' is impossible in the state. When deadlock happens, the state is called deadlock state. The other form of deadlock is that system is in endless loop that no other events can help to get rid of the loop, this kind of deadlock is called livelock, which means that the overall state is changing, but can't get rid of the dead circle.

There are many analyzing methods about Petri Net, among which reachability tree with coverability trees or incidence matrix with state equation are widely used, in this paper the verification is carried out by reachability tree of Petri Net[9] .

As for bounded Petri Net, because its reachable label set is a finite set, suppose R(M0) as a vertex set, the direct reachable relation among marks as arcs, then a directed graph can be constructed. This kind of directed graph is called reachable marking graph. According to a reachable marking graph, the state changing of the net system and the transition firing sequence can be analyzed, and finally relevant properties of the system can be obtained.

4.3. Examples

Take production process in figs 2 for example. State μ=（1,0,0,0,0,0,0,0,0）fires at t1, token transfer to place p2 and p4, so now token distribution is μ'=（0,1,0,1,0,0,0,0,0）.Take μ as the root of reachable tree, as figs 7 shows. Then search for transition satisfied with the transition condition. And the new state after transition firing can be found. For example, only t2 and t3 satisfies with the condition while any others not. If t3 transit, state will change into (0,1,0,0,1,0,0,0,0), after t2 fires, state will change into (0,0,1,1,0,0,0,0,0). Go on step by step like this, process won't stop until an identical or final state occurs, then an reachable tree of Petri Net is finally constructed.

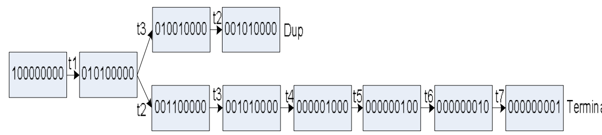

Figure 7. Example of reachable tree of Petri Net

The above example indicates that if leaf node is identical or final state, deadlock and dead circulation is impossible to occur. Meanwhile, we solve the problem of dead circle.

5. Results of system analysis

In this paper by software of Petri Net Analyser Version 1.0, process model is constructed by Petri Net and performance evaluation are made, finally conclusion are drawn on the feasibility of process model verification by Petri Net.

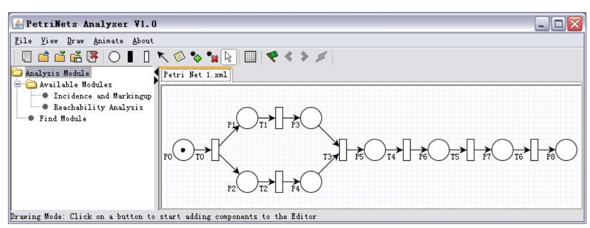

Figure 8. Petri Net model of process model

In Figs 8, there are Petri Net description of process model shown in Figs 1, each basic unit is described in detail in Figs 1.

The result of performance analysis is given in this paper, as Figs 9 shows.

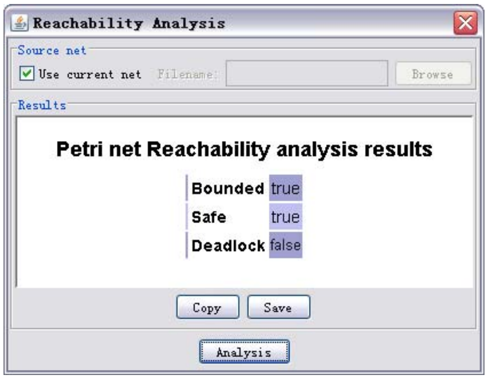

Figure 9. **Analysis result of process model**

Figure 9 show the ergodic analysis result of reachability tree of Petri Net model, which is based on pocess model given in Figs 1. The model is bounded, it indicates that there isn't new token in state changing of Petri Net, that is to say, there is no generation of new resources in transition process. The model is safe, it indicates that token number of all places is no more than 1 in the model. There is no deadlock in the model, which shows that deadlock is impossible for resource competition.

6. Conclusion

Process model, as an important knowledge form, lacks effective verification methods. In this paper process model are mapped to Petri Net-represented model, process model in domain knowledge base are verified by adopting Petri Net analysis technique, which ensures the correctness and effectiveness of process model. This method provides an practicable and effective means for management and maintenance of the domain knowledge system.

7. References

[1] A.Kovalyov and R.McLeod, New Rank Theorems for Petri Nets and their Application to Workflow Management, 1998 IEEE International Conference on Systems, Man, and Cybernetics, San Diego, California, USA. 1998, PP.226-231.

[2] A. Kovalyov, Efficient Methods for Verification of Distributed and Concurrent Systems by Petri Nets, Formal Methods for Open Object-Based Distributed Systems, Stanford University, Stanford, California, USA. Sept. 2000.

[3] E.Best, J.Desel, Partial order behavior and structure of Petri Nets. Formal Aspects of Commuting, Vol.2 No.2, 1990, pp.123-138.

[4] P.Civera, G.Conte, D.Del Corso, F.Maddaleno, "Petri Net models for the Description and verification of parallel bus protocol", Computer Hardware Description Languages and their Applications, M.R.Barbacci and C.J.Koomen(Eds), Elsevier(North-Holland), 1987, pp.309-326.

[5] C.A.R.Hoare. Communicating Sequential Processing, Prentice/Hall, London,1985.

[6] F.Commoner： 'Deadlocks in Petri Nets'. Wakefield. Applied Data Research, Inc., Report #CA-7206-2311, 1972.

[7] W.M.P. van der Alast, A.H.M. ter Hofstede. Verification of Workflow Task Structures: A Petri-net-based Approach[J]. Information Systems, To appear, 2000.

[8] Girault C, Valk R. Petri Nets for System Engineering—A Guide To Modeling, Verification, and Application. Berlin: Spring-Verlag, 2003.

[9] A.Kovalyov, R.McLeod, O.Kovalyov. Performance Evaluation of Communication Networks by Stochastic Regular Petri Nets. The 2000 International Conference on Parallel and Distributed Processing Techniques and Applications(PDPTA' 2000), USA.2000, Vol.4, pp. 1191-1998.