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Dynamic business process modeling and verification for inter-organizational collaboration

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Abstract: To achieve an on-demand and dynamic composition model of inter-organizational business processes, a new approach for business process modeling and verification is introduced by using the pi-calculus theory. A new business process model which is multi-role, multi-dimensional, integrated and dynamic is proposed relying on inter-organizational collaboration. Compatible with the traditional linear sequence model, the new model is an $M \times N$ multi-dimensional mesh, and provides horizontal and vertical formal descriptions for the collaboration business process model. Finally, the pi-calculus theory is utilized to verify the deadlocks, livelocks and synchronization of the example models. The result shows that the proposed approach is efficient and applicable in inter-organizational business process modeling.

Key words: inter-organizational collaboration; pi-calculus; business process modeling; model verification

With the further development of economic globalization and information technology, the structures of government and enterprises have been undergoing profound changes to meet various demands of clients. To satisfy all the needs involves inter-sectional, inter-regional and inter-system cooperation, by means of which, all kinds of business processes can be connected to form an integrated business process platform, with the information and data shared or reused among the individual business processes; thus, the business efficiency and quality can be greatly improved. Although recently the development of e-government and e-commerce has enabled a number of sections to realize the cooperation and sharing of business processes, the established business processes are usually tailor-made, which on the one hand leads to individual processes having a very strong coupling, but on the other hand lacking flexibility and self-adaptation. However, the demands of the clients today are not monolithic, but are always changing to cater to the individual needs; therefore, the cooperative business processes should change accordingly. They should be recomposed dynamically, establish and cancel cooperative relationships in the business processes promptly. They should be open; that is, the individual processes should be able to participate in the construction of the business processes equally and freely. To sum up, the cooperative business processes should be multi-role, multi-dimensional, integrated and dynamic. The highly efficient and reliable business process should be based on the business process modeling. So, how to design such a modeling has become a focus issue and a difficult problem in this field of research.

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Because of the characteristics of the cooperative business process, this paper introduces into the design of the process model, the pi-calculus theory[1-3] of the process algebra, which has the capacity of describing dynamically the changing mobility of concurrent processes. With the help of some case studies, this paper proposes an inter-organizational collaboration dynamic business process modeling that can establish cooperation dynamically on demand. It has a formal description and analysis of the modeling and verifies it in accordance with the pi-calculus theory. This provides a new reference modeling for the design and implementation of inter-organizational business processes of government and enterprises.

1 Related Work

The business process modeling has, nowadays, been developing from the first data flow diagram (DFD), to the flow chart (FC), to the IDEF and to the most widely used Petri Net and UML. DFD, FC, IDEF and UML all describe in diagrams the processes and make it easy to understand, but is not verifiable due to the lack of formal semantics. The workflow technology was earlier used in office atomization (OA), which was too restrictive to the work process and lacked flexibility, so it was more suitably applied to the business processes that were relatively more standardized and stable. Although WFMC has redefined the workflow[4-5], there are mistakes hidden[6] in the inter-organizational collaboration business processes. The Petri Net, with its ample semantic definitions, solid mathematical foundation and visualized interfaces, is the normal modeling tool[7-8]. However, it is more useful in describing static processes than more complex and dynamic ones.

2 Pi-Calculus

Pi-calculus is based on Miller's CCS [9] and can be used to describe the distributive communication system of the dynamic changes of the typological structure. Its peculiarity lies in the fact that it can allow the sending and receiving of the channel in the process. There are two core concepts in pi-calculus: processes and names. A pi-calculus process is an entity which communicates with other processes by the use of names. A name is a collective term for existing concepts such as channels, pointers, and identifiers. Each name has a scope and can be unbound or bound to a specific process. The scope of a bound name can be dynamically expanded or reduced during the lifetime of the system by communicating names between processes.

2.1 Syntax of pi-calculus

The pi-calculus consists of an infinite set N of names $x, y, z, \ldots$ range over names, and also presupposes $A, B, C, \ldots$ range over process identifiers. Let $P, Q, R, \ldots$ range over the process expressions. The syntax of pi-calculus is defined as[10-11]

$$P::=0\ |x(y).P|\bar{x}\langle y\rangle.P|P_1+P_2|P|Q|(\nu x).P|[x=y]P|A(x_1,x_2,\ldots,x_n)$$

① 0 is inaction, a process that can do nothing.

② A prefix form $\alpha.P$. Internal action $\alpha.P$ is after act α completed then implement the process P. There are three kinds of action. The input prefix $x(y)$, a name x may be thought of as an input port of a process; $x(y).P$ inputs an arbitrary name z at port x and then behaves like $P\{z/y\}$. The output prefix $\bar{x}\langle y\rangle$ sends the name y over the channel x and then continues as P. The unobservable prefix $\tau.P$ expresses an internal action of process P.

③ A summation $\sum_{i\in I}P_i$, where the index set I is finite. This process behaves like one or other of p_i. We write 0 for the empty summation, and call it inaction, this process which can do nothing. Henceforward, in defining the calculus, we confine ourselves just to 0 and binary summation, written as P_1+P_2.

④ A composition $P_1 \mid P_2$: this process consists of P_1 and P_2 acting in parallel. The components may act independently.

⑤ A $(\nu x)P$ is Restriction. The process behaves like P but the name x is local, meaning that the name cannot be used for communication with other processes.

⑥ A match operator $[x=y]P$, which allows P to proceed if x and y are in the same channel.

⑦ A defined process $A(x_1, x_2, \ldots, x_n)$. For any process identifier A used thus, there must be a unique defining equation $A(x_1, x_2, \ldots, x_n)::=P$, where the names $x_1, x_2, \ldots, x_n$ are distinct and are the only names which may occur freely in P.

⑧ A replication operator $!P$ informally means an arbitrary number of copies of P running in parallel.

2.2 Interaction structure of pi-calculus

A process is an autonomous entity possessing named ports through which it may communicate with other processes. The name of the process and its ports are introduced as

ProcessName(port-list) = behavior of the process

In the description of the processes, port names with overbars are interpreted as "output" ports while names without overbars are often interpreted as "input" ports, using request as output, and reply as input in the process entity, respectively. This is the same as the IDEF[12] business process expression. The process models a simple client that has an output and an input port named "request" and "reply", respectively, as shown in Fig. 1.

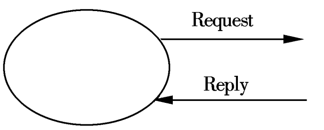

Fig. 1 A simple client interactive mode

- A simple client expression: Client(request, reply) = …$\overline{\text{request}}$…reply….
- A sequential process expression: Client (open, close, request, reply) = $\overline{\text{open}}.\ \overline{\text{request}_1}.\ \text{reply}_1 \ldots \overline{\text{request}_n}.\ \text{reply}_n.\ \text{close}.0$.

Fig. 2 illustrates a simple interaction of a pi-calculus process. Process P sends a message along the channel, which is received by process Q from the channel. In the pi-calculus, the channel name and action one are interchangeable. The whole process can be understood as process P sending a message along channel y, as process Q is receiving the message along the same channel.

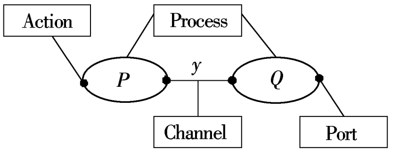

Fig. 2 Pi-calculus process composition

3 Dynamic Inter-Organizational Collaboration Business Process Modeling

3.1 Composition of business process modeling

In the composition of the business process modeling by means of pi-calculus, the processes are divided into activities of different types, which can be composed according to different business relations. An activity is the basic unit of the business process. In the dynamic cooperative business process modeling, the activities are divided into atomic and composite ones. The atomic is the smallest unit of the modeling and the latter is the composite of activities, with the process being composed of a group of orderly activities. The structure of the process in the modeling is shown in Fig. 3.

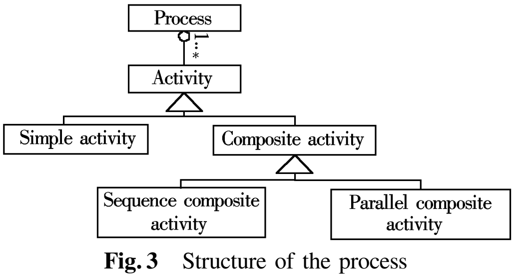

Fig. 3 Structure of the process

3.2 Dynamic cooperative business process modeling

The traditional cooperative business process is a linear sequence structure, with the EAI as the major mode of information exchanges, which is weak in commonality, flexibility, openness and strong coupling. Take the common business process of customer, agent and supplier as an example, as shown in Fig. 4.

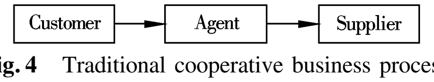

Fig. 4 Traditional cooperative business process

At present, the business services of government and enterprises, which are independent, loosely-distributed, changing and open, demand an integrated software system that is heterogeneous, autonomous and quickly adaptable to changes. From the perspective of the degree of the technological realization, the service oriented computing (SOC)[13] will become the main computing paradigm in an open and heterogeneous environment that is distributed in a complex way. The web services based on the XML specifications and the standards of WSDL, SOAP and UDDI will become the dynamic service composites[14]. It functions as one of the important means of technological realization that can integrate service flexibly and promptly. This paper uses the web service as the basic activity unit of the process. Giving consideration to the linear business process, the changes of the business modes, the appearance of new technology and the guaranteeing of the dynamic interaction of the individual activities, we should design a dynamic cooperative business process modeling and mechanism that are multi-role, multi-dimensional and integrated. Take the same process of customer, agent and supplier as an example (see Fig. 5).

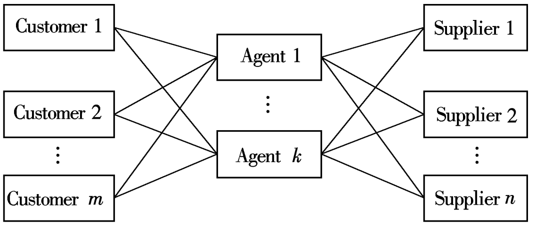

Fig. 5 Dynamic cooperative business process modeling

3.2.1 Multi-dimensional integration

With the establishment of the information system of different organizations, the business process of the same function will change from the linear sequence to an $M \times N$ mesh, with M (horizontal) designating the function of an activity in the cooperative business process and N (vertical) indicating that an individual activity can be replaced by one of the same functions.

3.2.2 Dynamic multi-role interaction

The individual activities participating in the dynamic cooperative business process can be completely autonomous, driving the business process actively or passively in accordance with different interests, goals and starting points. That is to say, every activity can provide or be provided service. For example, from the perspective of the customers, personalized service should be provided to a maximum degree, with excellent quality, fast speed and the greatest convenience. The structure of business modeling is shown in Fig. 6. However, suppliers are in need of more agents and customers to sell more products and gain the highest profits. The business modeling from the perspective of the suppliers is shown in Fig. 7. In order to gain more profits from the suppliers and the customers, agents must choose different suppliers and customers actively. The business modeling from the perspective of the agents is shown in Fig. 8.

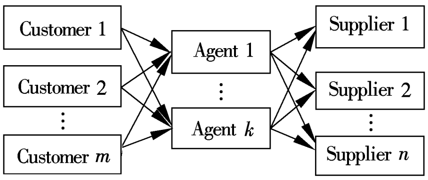

Fig. 6 Customer-oriented business modeling

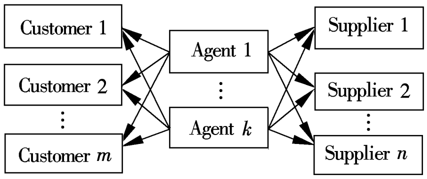

Fig. 7 Agent-oriented business modeling

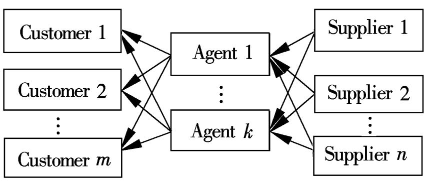

Fig. 8 Supplier-oriented business modeling

3.3 Formal modeling of pi-calculus to dynamic business process

How to accurately describe the crisscrossed interactive cooperative business process poses a great challenge. By employing the unique features of the pi-calculus of the process algebra and the dynamic interaction in mobility, this paper then describes the cooperative business process of the dynamic changes of the typological structure. It chooses the representative interactions of the business processes from the horizontal and the vertical levels to illustrate them with examples.

3.3.1 Horizontal modeling of dynamic cooperative business process

Similar to the traditional mode of EAI, the basic information data of the dynamic cooperative business process can be shared. Fig. 9 shows the horizontal cooperative business process of customer, agent and supplier.

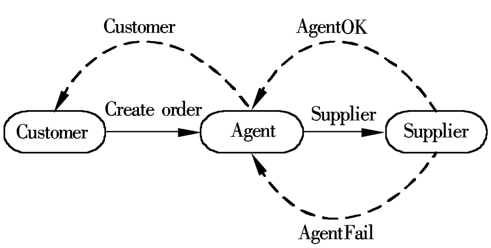

Fig. 9 Horizontal cooperative business process

The whole cooperative business process is as follows: First, customers make demands of the agents; then, the agents will make orders for the suppliers; afterwards, the suppliers can or cannot supply the products; finally, the agents provide feedback to the original customers. The formal description by deploying the pi-calculus will be specified as follows: The descriptive process from the perspectives of the agents or the suppliers is similar.

1 Customer(createorder, customer) =
2 $\overline{\text{createorder}}$⟨customer⟩. customer(result)
3 Agent(createorder, agentok, agentfail, supplier) =
4 createorder(customer). $\overline{\text{supplier}}$⟨agentok, agentfail⟩
5 Agent1(agentok, agentfail, customer)
6 Agent1(agentok, agentfail, customer) =
7 agentok(result1). $\overline{\text{customer}}$⟨result1⟩ +
8 agentfail(result2). $\overline{\text{customer}}$⟨result2⟩
9 Supplier(supplier, agentok, agentfail) =
10 supplier(agentok, agentfail). $\overline{\text{agentok}}$⟨"order ID"⟩ +
11 supplier(agentok, agentfail). $\overline{\text{agentfail}}$⟨"null"⟩
12 Point2Point = (new corder, cust, ok, fail, supply)
13 Customer(corder, cust) | Agent(corder, ok, fail, supply)
14 | Supplier(supply, ok, fail)

Lines 1 and 2 define the customer process. They send the order along the channel of "create order" and receive the results along the "customer" channel. Lines 3 to 5 define the agent process. The agents receive the orders along the channel of "create order" and send the relevant information along the "supplier" channel to the suppliers. Lines 9 to 11 define the supplier process. The suppliers send the yes/no information along the channel of "agentOK" or "agentFail". Lines 6 to 8 define the process during which the agents have received the suppliers' result and send the feedback to the customers along the "customer" channel. Lines 12 to 14 define the whole horizontal process.

3.3.2 Vertical modeling of dynamic cooperative business process

From the perspective of the vertical modeling of the dynamic cooperative business process, the activities with the same function will be at the same level, establishing or canceling promptly the cooperation between the individual business processes based on their individual needs in order to gain the most profits. The dynamic transformation of the individual activities is shown in Fig. 10.

Agents usually order directly from the regular supplier (RS) (see Fig. 10(a)). However, because of market competition, the merchandise from the regular suppliers are of low cost performance, so the agents turn to retailer 1, (see Fig. 10(b)). With changes in the market, retailer 2 can provide a lower price, so the agents cancel the supply-demand relationship with retailer 1 and switch to retailer 2 (see Fig. 10(c)). Be-

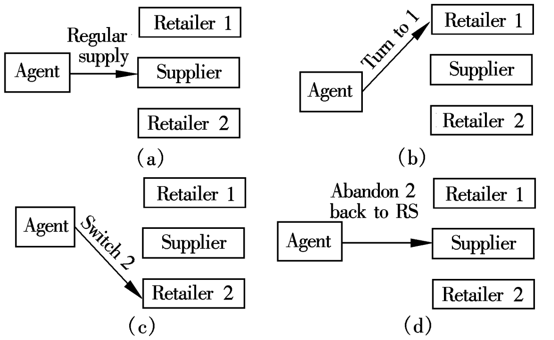

Fig. 10 Dynamic transformation of individual activities. (a) Order to regular supplier; (b) Turn to retailer 1; (c) Switch to retailer 2; (d) Abandon retailer 2 back to RS

cause the regular agents can provide more favorable and convenient service after their business process reengineering, the agents will abandon retailer 2 and turn to the regular suppliers (see Fig. 10(d)). Formal modeling is as follows:

1 AgentRS(turn, switch, abandon, rets) =

2 $\sum$ (r: rets). ($\overline{\text{turn}}\langle r$, nike$\rangle$. Agent$R$($r$, turn, switch, abandon, rets))

3 Agent$R$(r, turn, switch, abandon, rets) = $\sum$ ($r2$: rets). $\overline{\text{switch}}$(

4 $\langle r$, $r2$, mike$\rangle$. Agent$R$($r2$, turn, switch, abandon, rets)) +

5 $\overline{\text{abandon}}\langle r$, mike$\rangle$. AgentRS(turn, switch, abandon, rets)

6 Supplier(turn, switch, abandon) = (turn($r1$, c). $\overline{r1}\langle$"addagent", $c\rangle$ +

7 switch ($r1$, $r2$, c). $\overline{r1}\langle$"dropagent", $c\rangle$. $\overline{r2}$! $\langle$"addagent", $c\rangle$ +

8 abandon($r1$, c). $\overline{r1}\langle$"dropagent", $c\rangle$). Supplier(turn, switch, abandon)

9 Retailer(r) = r(action, c). Retailer(r)

10 Market = (new chTurn, chSwitch, chAbandon, retSet = {ret1, ret2})

11 AgentRS(chTurn, chSwitch, chAbandon, retSet) |

12 Supplier(chTurn, chSwitch, chAbandon) |

13 Retailer(ret1) | Retailer(ret2)

In brief, the cooperative business process can always be described from the horizontal or vertical level and the pi-calculus can accurately and concisely describe the whole process of the structural changes and interactions.

4 Verification of Dynamic Business Process with Pi-Calculus

The aim of the analytical approach of the formal modeling is to assist in the design and verification of the system modeling. Pi-calculus, as a powerful and mature formal process calculus, can describe in detail the dynamic interactive business processes. Using pi-calculus to reason the whole interaction of the system, testifies to the validity, accuracy and feasibility, and find the deadlocks, livelocks and synchronization in the system of the modeling. The tools that can support the pi-calculus verification include the executable PIE-PI, such tools of process algebra as VPAM, JACK and PICT based on the formal language. This paper adopts the mobility workbench (MWB)[15], which is a tool for manipulating and analyzing mobile concurrent systems described in pi-calculus. The software environment employed in this paper includes Windows XP, Standard ML of New Jersey v110. 57 and MWB'99. It is verified in the modeling that there is no deadlock in the dynamic business process by means of the "deadlocks" command. To operate the dynamic business process with the "step" command, the results are the operational process of every step. For example, what is the channel between the customers and the suppliers or what is the message along the channel? This helps to analyze and verify if each interaction of the process conforms to the business process. In the process of verifying and reasoning the dynamic cooperative business process modeling by applying the pi-calculus, it finds the unreasonable parts in the description process, and revises the modeling to make it more reasonable and practical to ensure the feasibility of the design and implementation of the cooperative business process, thus avoiding such defects as the short life of the information system established in individual organizations and the high costs of reconstruction and greatly lowering the investment risks. Due to the limited length of this paper, the specific process is omitted.

5 Conclusion

In accordance with the changes on demand of the inter-organizational business process, which is characteristic of being multi-role, multi-dimensional, integrated and dynamic, we proposes a formal modeling of the process by employing the pi-calculus. The pi-calculus is a formal language for defining concurrent, communicating processes, including, but not restricted to, business processes. It is clear, concise and easy to understand, so it is most suitably used to describe dynamic mobile processes. It has a good abstract mechanism and good reasoning ability, capable of formal reasoning and verification of the modeling established to guarantee the validity and feasibility of the cooperative business process and to greatly lower the risks of the cooperative projects of the organizations. It can guarantee the chance of success and is a very good method of process modeling. The method proposed in this paper can cater to the trend of the dynamic inter-organizational business process, providing new approaches to inter-regional and inter-organizational information interaction.

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跨组织动态协作业务流程组合建模与验证

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摘要:为了实现随需应变、动态组合的跨组织协作业务流程模型,将 pi-演算理论引入业务流程建模与验证中,应用 pi-演算理论建立了多角色、多维度、多集成性的业务流程跨组织协同的模型. 新的业务流程模型为 $M \times N$ 多维度网状关系,同时兼顾了以往单一的线性顺序关系模型,并分别从横向与纵向对该协作业务流程模型进行了形式化描述. 最后依据 pi-演算理论对样例模型的死锁、活锁以及同步性进行了验证,确保了模型的正确性和可行性. 跨组织动态协作业务流程模型具有稳固的理论基础,为跨部门、跨区域分布式信息交互提供了新的思路和方法.

关键词:跨组织协作;pi-演算;业务流程建模;模型验证

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