The Japan Society of Mechanical Engineers

International Symposium on Scheduling 2009
July 4-6, 2009, Nagoya, Japan
3B2

MEMBRANOUS MULTI AGENT SYSTEM IN FLEXIBLE MANUFACTURING SYSTEMS

Hossein Tehrani Nik Nejad, Nobuhiro Sugimura, Koji Iwamura
Graduate School of Engineering, Osaka Prefecture University
1-1 Gakuen-cho, Nakaku, Sakai, Osaka, 599-8531, Japan
m08thrni@me.osakafu-u.ac.jp

Abstract

Global competition and rapidly changing customer requirements are forcing major changes in the production style and configuration of the manufacturing organizations. Recently, multi agent systems have been widely applied in the manufacturing applications because of their flexibility, re-configurability, and scalability. In this paper, we are trying to add a new property to multi agent system by inspiring from the biological membrane to make it more suitable for applying in the manufacturing area. We define membrane for agents and introduce the membranous multi agent system. It is useful for modeling the complex manufacturing hierarchies and assembly processes for manufacturing system.

Keywords: Multi Agent System, Biological Membrane, Flexible Manufacturing System, Scheduling

1. INTRODUCTION

Global competition and rapidly changing customer requirements are forcing major changes in the production style and configuration of the manufacturing organizations. Increasingly, traditional centralized and sequential manufacturing process planning, scheduling and control mechanism are being found insufficiently flexible to respond to changing production styles and high-mix low volume production environment. The traditional approach limits the expandability and reconfigurability of the manufacturing systems. The centralized hierarchical organization may also result in much of the system being shut down by a single point of failure, as well as plan fragility and increased response overheads. In recent years, Biological Manufacturing Systems (BMS), Multi-Agent Systems (MAS), Holonic Manufacturing Systems (HMS) and Fractal Manufacturing Systems (FMS) have been widely proposed and applied in the manufacturing applications because of their flexibility, re-configurability, and scalability. These approaches are becoming increasingly important for the Flexible manufacturing Systems (FMSs) to increase the productivity and the profitability through the greater shop floor agility and flexibility.

The multi-agent system is an effecting tool for realizing the new manufacturing systems such as BMS and HMS. It provides a systematic way to deal with the dynamic changes of the products and the manufacturing processes in the FMSs.

An agent is an autonomous and flexible computational entity, which is able to act in an manufacturing environment (Wooldridge and Jennings, 1995). Some properties which are usually attributed to agents for solving particular problems are autonomy, social ability, rationality, reactivity, pro-activeness, adaptability, mobility, veracity and benevolence. Research into the application of multi agent system in the manufacturing domain has been steadily growing over 10 last years and has focused on all areas of the manufacturing enterprise ranging from product design to real time control. Although, we cannot address significant practical results of applying multi agent system for practical cases in the manufacturing system.

We believe that the following disadvantages of the current MAS and HMS lead poor results in the practical cases for complex problems in the flexible manufacturing system.

- Lack of mathematical structure and presentation
- Difficulties for defining physical structure and hierarchies of the manufacturing system in multi agent system
- Complex negation protocol for agents' coordination in scheduling and control problems of the manufacturing system.

In this paper, we are trying to add a new property to multi agent system to overcome the above disadvantages and make it more suitable to apply in the manufacturing area. As the initial idea of multi agent system comes from the investigation of the living systems, we have studied the structure and the functioning of living cells, as well as the way the cell are organized in tissues or higher order biological structure to introduce the idea of membranous multi agent system.

Membrane computing is an area of computer science aiming to abstract computing ideas and models from the structure and the functioning of living cells. In short, it deals with distributed and parallel computing models, processing multi-sets of symbol-objects in a localized manner (evolution rules and evolving objects are encapsulated into compartments delimited by membranes), with an essential role played by the communication among compartments (with the environment as well). In this paper, we mix the biological membrane concepts with multi agent system to overcome the disadvantages of the current multi agent structure for FMS. The proposed membranous multi agent system has the following advantages;

NII-Electronic Library Service

The Japan Society of Mechanical Engineers

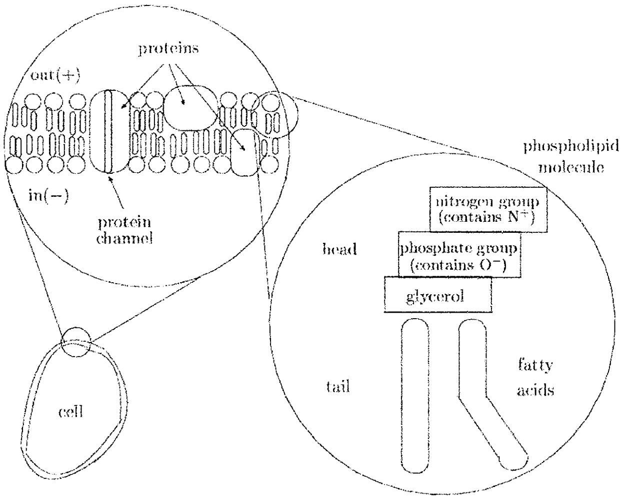

Fig. 1 The structure of the cell plasma membrane

- Considering the physical structure and limitation of manufacturing system in multi agent structure
- Prepare a mathematical scheme for analyzing and improving
- Reliable and compartmentalized negotiation protocol for complex tasks in FMS

2. BIOLOGICAL MEMBRANE- STRUCTURE AND FUNCTION

In this section, we describe in detail some of the basic features of the plasma biological membranes. We have chosen those features that are of interest from a computational and cellular structures point of view. A cell has a complex structure, with several compartments delimited inside the main membrane by several inner membranes: the nucleus, the Golgi apparatus, various vesicles, etc. In principle, all these membranes fulfill the same main roles: they are *separators* and *filters*. (Albert *et al.* 2002, Cavalier et al. 2003) The currently accepted model of the membrane structure is the so-called fluid-mosaic model, proposed in 1972 by Singer and Nicolson. According to this model, a membrane is a phospholipid bi-layer in which protein molecules (as well as other molecules, such as Cholesterol, steroids and others) are totally or partially embedded as shown in Fig. 1.

The phospholipid molecules are composed of two main parts: a polar *head* and a nonpolar *tail.* The head is composed of a phosphate group and a nitrogen group, the tail consists of two fatty acid chains; the head is bonded to the tail by a glycerol. Consequently, the heads of the molecules in the two layers are hydrophylic, while the tails are hydrophobic.

The transmembrane transfer of molecules can take place in a *passive* manner, e.g., by diffusion towards the region of lower concentration, and in an *active* (mediated) manner. The most important active membrane transfer is done by *protein channels* present in various numbers in membranes. Actually, there are two main types of protein channels, some which just select the moving objects by their size, and others, the so-called *carrier proteins*, which interact with specific molecules when helping them to cross the membrane.

Another important aspect is the way the neighboring cells establish protein channels for *inter-cellular communication*: which is our interest in the agent communications and structure in the multi agent system. Due to the fact that the phospholipid molecules can move on the membrane surface when two membranes touch each other, their proteins can "look for each other"; when two proteins come close enough, they bind to each other and establish a unique channel through the two membranes. In this way, a complex communication network can be established among cells.

3. MEMBRANOUS MULTI AGENT SYSTEM

In this section, we discuss key issues related to membranous multi agent systems in and their properties. In the membranous multi agent system, the individual agents have been embraced with a membrane which controls the input and output of the agents. Agents can be organized as a hierarchical structure of membranes, like in a cell (hence described by a tree), or a net of membranes (placed in the nodes of a graph), like in a tissue, or in a neural net. In the following, the membranous multi agent architectures proposed here are discussed from the viewpoints of the agent definitions and coordination.

3.1 Agent with membrane

A multi agent system is made up of two or more related agents. An agent is an autonomous and flexible computational entity, which is able to act in an environment. Some properties which are usually attributed to agents for solving particular problems are autonomy, social ability, rationality, reactivity, pro-activeness, adaptability, mobility, veracity and benevolence. In membranous multi agent system, we define a new property for the agents which have not been discussed before. We define a membrane for each agent who fulfills the same main roles of biological membrane. The membrane controls the input and output of the agents and leads the agents to make hierarchical structure. In addition of computational ability and processing data, the agent is embraced with a membrane for organizing the agents and managing the communications like a living cell.

The agents are free to communicate, cooperate, coordinate and negotiate among themselves in the autonomous multi agent system. It makes difficult to secure, organize and control the agent communications and define structure for them. In the membranous multi agent system, the agents are the communications are limited through some predefined channels and we can define and organize the complex structure for large scale architecture when many agents coordinate with each other such as manufacturing systems.

NII-Electronic Library Service

The Japan Society of Mechanical Engineers

3.2 Agents organization in the membranous multi agent system

The agents in autonomous multi agent architecture are autonomous without any structure with the following characteristics and they can communicate freely with any other existing agents.

(1) Structure is not controlled or managed by any other agents or human beings;

(2) Agents can communicate/interact directly with any other agents in the system and also with other external systems;

(3) Agents have knowledge about other agents and their environment;

(4) Each agent has its own goals and an associated set of motivations.

The autonomous structure is well suited for developing distributed intelligent design systems where existing engineering tools are encapsulated as agents and connected to the system for providing special services, and the system consists of a small number of agents. In the manufacturing system, we have complex and dynamic hierarchy. Any proposed multi agent architecture should be matched with the manufacturing hierarchy for successful implementation. We should define static or dynamic hierarchy architecture for multi agent system which provides computational simplicity and manageability for manufacturing systems. This type of architecture is quite suitable for developing distributed manufacturing systems which are complex, dynamic, and composed of a large number of resource and job agents.

In membranous multi agent system, we consider both the physical and the information hierarchical structure of the manufacturing system. The autonomous approach of the multi agent system do not consider the physical limitations and hierarchy of the manufacturing system in the design stage which causes many overhead on the coordination between agents and make it difficult and complex for implementation in manufacturing system.

A membranous multi agent structure has a inherently hierarchical structure as shown in Fig. 2. Several agents with their membranes can be placed inside another agent membrane. Each membrane determines an agent and the space delimited by the agent and the other agents placed inside, if any exists.

A membranous multi agent structure is pictorially represented by an Euler-Venn diagram (like the one in Fig. 2); it can be mathematically represented by a tree, or by a corresponding string of matching parentheses. For instance, the membrane structure from Fig. 2 is represented by the following parentheses expression:

$$[_{Area1}[_{Cell1}[_{Station1}[_{JobA}]_{JobA}[_{Robot}[_{MachineTool01}]_{MachineTool01}[_{JobC}]_{JobC}]_{Robot}]_{Station1}[_{Station2}[_{JobB}]_{JobB}[_{AssemblyCell}]_{AssemblyCell}]_{Station2}]_{Cell1}]_{Area1} \quad (1)$$

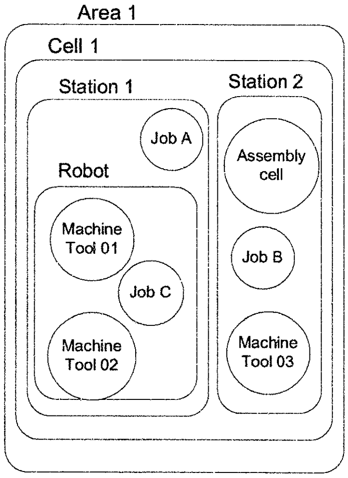

Fig. 2 The hierarchical structure of the membranous multi agent system for manufacturing system

3.3 Agents coordination and negotiation

Coordination is important part for the successful operation of agent-based manufacturing systems which are dynamic and complex. Without coordination, a group of agents can quickly degenerate into a chaotic collection of individuals which is absolutely unacceptable in real manufacturing enterprises.

The manufacturing systems are dynamic and complex with a lot of entity and relationships. The existing coordination mechanisms in autonomous multi agent system have difficulties for handling the complex coordination mechanism of the manufacturing systems where we have many products and resources. The current methods are inefficient for large complex manufacturing system especially when we are looking to develop integrated solutions which leads to very complicated coordination mechanism. In membranous multi agent system, the agents are organized in the hierarchies by their membrane and we have a compartmentalized and localized model for communication between agents. Each agent can only communicates with higher or lower level agents in its hierarchy. The communication and coordination between agents is much easier than autonomous approach for developing coordination mechanism.

In membranous multi agent system, the agents communicate and coordinate with each other with multisets which are represented by strings of symbols. We use V^* to denote the set of all strings over the alphabet V existing in the membranous multi agent system. For $a \in V$ and $x \in V^*$ we denote by $|x|_a$ the number of occurrences of a in x. The multisets over a given finite support (alphabet) are represented by strings of symbols. The order of symbols does not matter, because the number of copies of an object in a multiset is given by the number of occurrences of the corresponding symbol in the string.

Each agent contains a multiset of objects, and a set of evolution rules for processing the objects inside its membrane. The objects are represented by symbols from a given alphabet. Typically, an evolution rule from agent r is of

NII-Electronic Library Service

The Japan Society of Mechanical Engineers

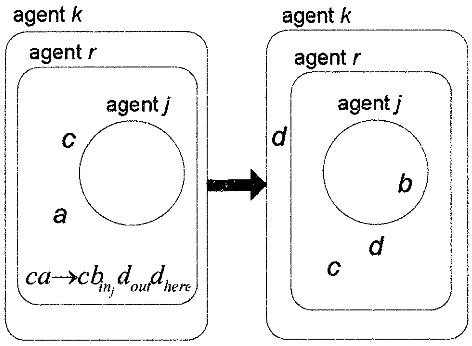

Fig. 3 evolution rule in the membrane of agent r

the form $ca \to cb_{in_j} d_{out} d_{here}$ and it "says" that a copy of the object a, in the presence of a copy of the catalyst c (this is an object which is never modified, it only assists the evolution of other objects), is replaced by a copy of the object b and two copies of the object d. Moreover, the copy of b has to "immediately" enter the membrane of the inner agent j (hence to enter agent j), a copy of object d is sent out through the membrane of agent r, and a copy of d remains in membrane of the agent r as shown in Fig. 3. Note that the considered evolution rule can be applied in the membrane of agent r only if this agent includes the membrane of agent j.

We also define a priority relation among rules. This mean that in the membrane of each agent a partial order relation on the set of rules is given-then, a rule can be chosen (to process a multiset of objects) in a given step only if no rule of a higher priority is applicable.

The objects in the membrane of the agents evolve by means of evolution rules, which are also localized, associated with the hierarchy structure of the membranous multi agent system. There are three main types of rules:

(1) multiset rewriting rules,

(2) communication rules,

(3) rules for handling the dynamic hierarchy of the agents.

The multiset rewriting rules correspond to the chemical reactions possible in the compartments of a cell, hence they are of the form $u \to v$, where u and v are multisets of objects. However, in order to make the compartments cooperate, we have to move objects across membranes of the agents, and to this aim we add target indications to the objects produced by a rule as above. These indications are: *here*, *in*$_j$, *out*, with the meaning that an object having associated the indication *here* remains in the same agent membrane, one having associated the indication *in*$_j$ goes immediately into a directly lower agent membrane indicated by label j, and *out* indicates that the object has to exit the agent membrane, thus becoming an element of membrane of the agent surrounding it. These rules are useful for data processing by agents in their membrane for handling the manufacturing tasks in membranous multi agent system.

The communication rules are of the forms: $a \to (a, tar)$, $ab \to (a, tar_1)(b, tar_2)$ where a, b are multiset of objects, and tar, tar_1, tar_2 are target indications of the forms *here*, *in*$_j$, *out*. Such a rule just moves objects from an agent membrane to another one. These rules make communication and coordination between agents through their membrane and with the multiset of objects and there is no process on the objects to be transferred.

The last rules are defined for changing the agent structure and organization by dissolving, dividing or merging the membrane of the agents. Agent membrane dissolving and dividing are only two of the many possibilities of handling the dynamic of the agent membrane structures. One possibility is creation agent with its membrane, based on rules of the form $a \to [_h v]_h$, where a is an object, v is a multiset of objects, and h is a label from a given set of agent and its membrane. Using such a rule in an agent membrane j, we create a new agent membrane, with label h, having inside the objects specified by v.

The merging of two agents can be considered also as the reverse of the separation operation, formalized as follows: let K be a set of objects; a separation with respect to K is done by a rule of the form $[_{h_1} K]_{h_1} \to [_{h_2} K_1]_{h_2} [_{h_3} K_2]_{h_3}$, with the meaning that the contents of agent membrane h_1 is split into two agent membranes, with labels h_2 and h_3, and with multiset of objects K_1 and K_2 respectively. These kinds of rules are useful for handling the assembly processes and dynamic structure of the manufacturing system.

By these three type of rules in membranous multi agent system, we have enough set of rules for data processing, communication and coordination and also for handling the dynamic structure of the manufacturing system.

3.4 Membranous multi agent system as a P-System

By the above explanations, we are ready to present a membranous multi agent system as a p-system with the following parameters;

$$MAS = (O, \mu, \omega_1, \dots, \omega_m, (R_1, \rho_1), \dots, (R_m, \rho_m))$$

- O is set of strings that are necessary for functions of the agents and the communication coordination among the agents.
- μ is a physical manufacturing structure consisting of m agents,
- $\omega_i, 1 \le i \le m$, are strings which represent multi-sets over O associated with the agent i ; $i = 1,2, \dots, m$
- $R_i, 1 \le i \le m$, are finite sets of evolution rules over O ; R_i is associated with the agent i; an evolution rule is the form $u \to v$, where u is a string over O and v is a string over $O_{tar} = O \times TAR$, for $TAR = \{here, out\} \cup \{in_j | 1 \le j \le m\}$; ρ_i is a partial order relation on the set of rules in the membrane R_i

NII-Electronic Library Service

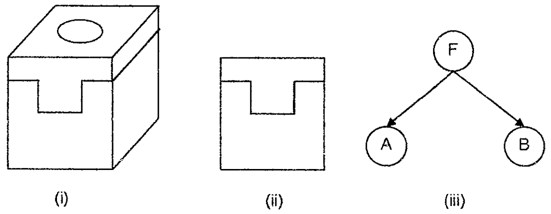

Fig. 5 Assembly part for manufacturing

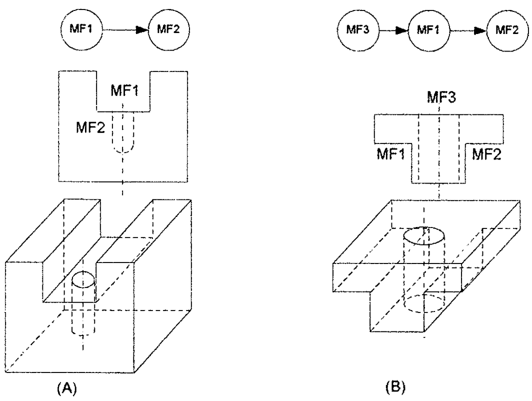

Fig.6 Sub-parts for manufacturing

The essential ingredient of a P system is its agent with membrane structure, which can be a hierarchical arrangement, like in a cell or a net of membranes (placed in the nodes of a graph), like in a tissue, or in a neural net. So it can be used for presenting any kind of manufacturing structure.

There are two types of strings in the membrane of the agent for handling the manufacturing tasks

- Basic strings: This kind of strings always exists in the membrane of agents for presenting the status, existence, capabilities and technical information.
- Temporary string: The strings which have been created for coordination and handling tasks and then removed from the membrane of the agents.

4. MANUFACTURING SYSTEM

The basic configuration of the target manufacturing cell is shown in Fig. 4. The manufacturing system consists of two machine tools with cutting tools, pickup table, gantry robot and assembly table. The input jobs are transformed by a process plan to the finished products through the manufacturing processes including machining, transportation. The raw materials are firstly fixed on pickup table and transmitted machine tools in order to carry out the machining processes required. The sub parts transmitted to the assembly table for final assembly process.

For example, let us consider an assembly part shown in Fig. 5. This part consists of two manufactured sub-parts as shown in Fig. 6 and one assembly processes. The assembly diagram of the final product is shown in the Fig. 5 (iii).

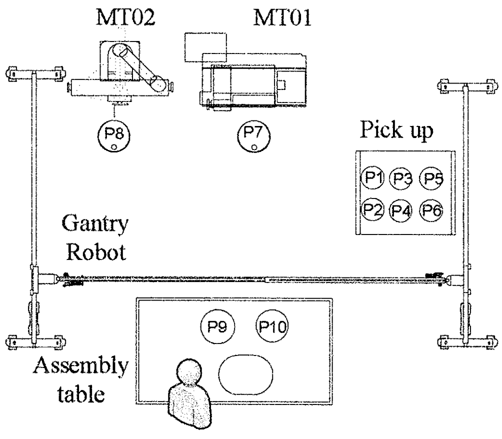

Fig. 4 Manufacturing cell

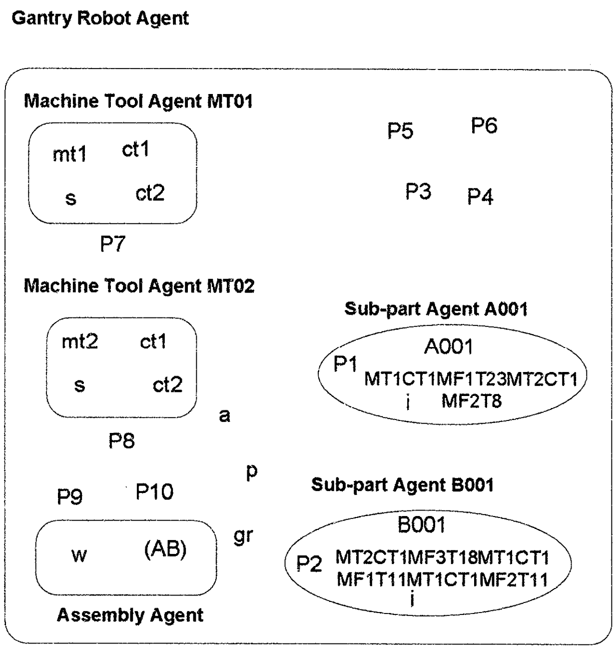

Fig. 7 Agents and their initial structure

The sub part A includes, one slot MF1, and one hole MF2 as shown in Fig. 6. The manufacturing features and process plan for sub-part A, B are shown in Fig. 6.

The agents and the initial structure of the membranous multi agent system are shown in the Fig. 7. As you can see in the Fig. 7, we have different agents with their membrane and initial structure of the agents for handling the tasks of manufacturing cells of Fig. 4. Each agent includes some strings for handling the agents' tasks and makes coordination with other agents in its membrane. It also contains evolution rules for string processing and making coordination with other agents for manufacturing tasks. For example consider sub part agent ***B*** (*Sub-part agent B001* as shown in Fig.7) includes the following strings in its membrane;

- String "s": specify the status of the sub-part agents and change during the manufacturing according to the status

NII-Electronic Library Service

The Japan Society of Mechanical Engineers

of the sub-part. For example at the initial state, the status string is "i" as shown in Fig. 7 that means the sub-part is idle and waiting for next machining operation or transportation.

- String "B001": specify the sub-part type and sub-part code in the manufacturing system. It is fixed string and does not change.
- String "p": specify the current position of the sub-part in the manufacturing cell. For example at the initial state, the position string is "P2" table as shown in Fig. 8 that means the sub-part is located at position P2 of the pick-up station.
- String "MT□CT□MF□T□": it specifies the process plan including machine tool number, cutting tool number and the machining time of all the machining process of related sub-part. It has a key role for initializing the firing the manufacturing process of the sub-part in the system.

The sub-part agents include the rewriting rules for data processing, communication rules for communication with other agents and other rules for dissolving, merging the membranes of the sub-part agents. We have listed some evolution rules of the agents in Fig. 8. These rules have been used for scheduling and control the manufacturing cell, dynamic transition and handling the manufacturing processes. We use dispatching SPT rules for scheduling the sub-parts on the machine tools. The transition of membranous multi agent system for manufacturing cell is shown in Fig. 9. As you can see, by using a sequence of evolution rules, the system transit to final state as shown in Fig. 9.

5. CONCLUSION

The manufacturing systems are dynamic and complex with a lot of entities and relationships. The existing autonomous multi agent systems have difficulties for handling the complex coordination mechanism of the manufacturing systems where we have many products and resources. In this paper, we mixed the multi agent system with biological membrane to make it more suitable to apply in the manufacturing area. The following remarks are concluded;

- Membranous multi agent architecture is developed by combining the multi agent architecture and biological membrane concept.
- We consider both the physical and the information hierarchical structure of the manufacturing system in membranous multi agent system.
- The agents contains multi set of objects and evolution rules for data processing and making communication and coordination
- A case study has been done to show the how the agents coordinate in membranous multi agent system for solving the manufacturing problems.

We will focus to expand the membranous multi agent system as an effective tool for organizing and handling new manufacturing system.

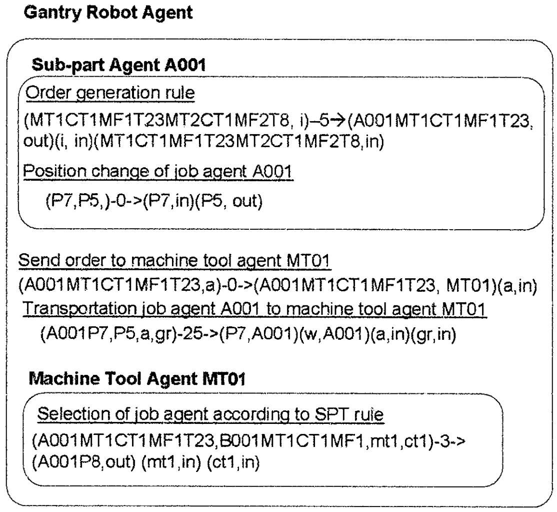

Fig. 8 Evolution rules inside the membrane of agents

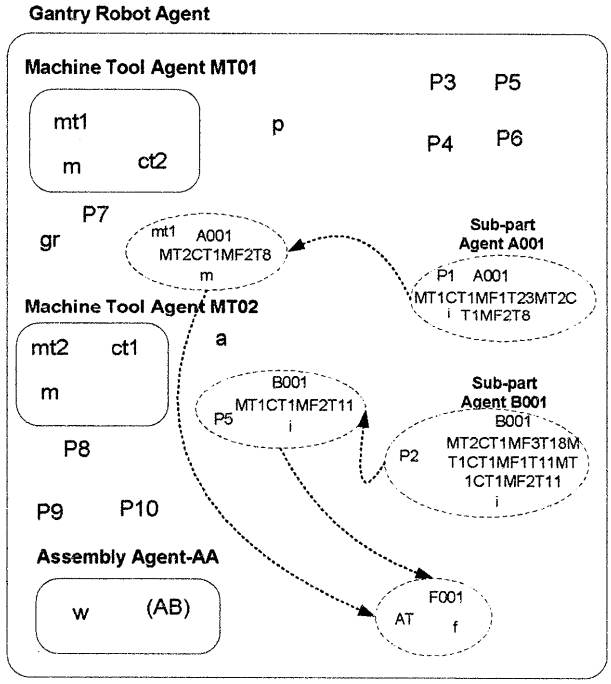

Fig. 9 Transitions of membranous multi agent system

References

Alberts B., A. Johnson, J. Lewis, M. Raff, K. Roberts, P. Walter. (2002). *Molecular Biology of the Cell, 4th ed.* Garland Science, New York.

Cavaliere M., C. Martin-Vide, Gh. Paun. (2003). *Proceedings of the Brainstorming Week on Membrane Computing*, Technical Report 26/03, Rovira i Virgili University, Tarragona.

Wooldridge, M. and N. R. Jenning. (1995). Intelligent agents-theories, architecture, and languages, *Lecture Notes in Artificial Intelligence*, Springer Verlag, Berlin, ISBN 3-540-58855-8 890.

NII-Electronic Library Service