Research on structure designing of agent organization

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Summary
In Multi-Agent System, organization is an effective solution mode to complicated problems. In this mode, the basic elements of agent organizational structure are defined, which provides a basic for the mathematical formulation of organizational structure designing. In this paper, a novel hybrid genetic algorithm is proposed, multi-PRI list dynamic scheduling method are nested in genetic algorithm to gain a new strategy. And the results and computation complexities of hybrid genetic algorithm and traditional multi-phase algorithms to address the problem of organization designing are analyzed and compared.
Key words:
organizational structure; structure designing ; genetic algorithm;,

Introduction

In Multi-Agent System (MAS), agent organization is a mode providing effective solution because of the complexity and distribution of the practical problems [1]. A proper organizational structure is essential to meet the demands of various mission environments. An agent organization performs well only when an organizational structure matches with its mission environments.
The allocation of tasks to resources and aggregation of resources to agents are key problems to an organizational structure. The tradeoff between these two problems is significant to achieve an optimal agent organizational structure by global optimization. Levchuk, et al.[2] presented multi-phase organizational designing methodology making using of an iterative solution of a sequence of smaller and well-defined optimization problems. But a high degree of sub-optimality potentially is introduced in that method [3]. Recently, Yu, et al.[3] proposed a novel congruent organizational designing methodology based on two-double genetic algorithm, which solved the clustering problem and assignment problem simultaneously. But precedence among tasks was not taken into account in this method, which brought restrictions in application.
Genetic algorithms (GAs) are general-purpose global optimization technologies based on the principles of evolution observed in nature [4]. GAs performs well in global optimization with good fitness and solidity. However, because of the weakness in local search, in special fields, GAs can be combined with other optimizing algorithms to reduce the weakness with their strong, such as the list optimization, heuristic searching, simulated annealing and gradient method etc. A hybrid GA for combinatorial optimization, in which GA is combined with dynamic list scheduling method, is proposed to solve the problem of agent organizational structure designing.

2. Problem Statement

2.1 Definitions of agent organizational structure

Essential problem of agent organizational designing is how to design an optimal agent organization in order to fulfill the organizational mission. This problem can be decomposed as two sub-problems, the first problem is the decomposition of agent organizational mission, an optimal organizational process consisting of sequence tasks is created in this phase. The second problem is the scheduling of resources, the organizational designers are requested to specify how tasks are processed by resources and manage resources effectively. An efficient organizational structure that is matched with organizational process is formed in this phase. To design an agent organizational structure is our work in this paper.
PCANS model proposed by Carley [5] describes an organization with three regions and five relationships among elements of three regions. Tasks, resources and agents compose three regions. Sequence relationship among tasks (*P*), requirement relationship of tasks to resources (*C*), allocation relationship of tasks to agents (*A*), cooperation relationship among agents (*N*) and possession relationship of agents to resources (*S*) compose five relationships in an organization. PCANS model provides theoretical basis for analyzing and designing agent organization. We use this concept model for reference in designing organizational structure matched with organizational process.
Agent (*A*): An agent is an intelligent individual which processes tasks by controlling resources. Denote agent set as $\mathbf{A} = \{ a_1, a_2, \ldots, a_q \}$ $(q=|\mathbf{A}|)$, where q is number of agents in an agent organization.
Task (*T*): A task is an activity that entails the use of relevant resources to process task by an individual agent or a group of agents. Denote task set decomposed from

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organizational mission as $T=\{t_1, t_2, \cdots, t_k\}$, where k is number of tasks.

Resource *(P)*: Resources are ability carriers with which agents process tasks. Resources provide different resource functions, agents complete tasks by executing resources function. Denote resource set as $P=\{p_1, p_2, \cdots, p_m\}$, where m is the number of resource entities in an agent organization. Abilities vector of p_i $(1 \leqq i \leqq m)$ can be denoted as $PC=(pc_{i1}, pc_{i2}, \cdots, pc_{in})$,where pc_{ij} $(1 \leqq j \leqq n)$ are abilities of p_i on function f_j.

Based on basal elements of agent organization defined above, we can describe structure of an agent organization as follows:

Agent organizational structure is relations of organizational basic elements as agents, resource entities and tasks. Agent organizational structure is composed of three kind of relationships, such as structural relationship among agents G_A, relationship between agents and resource entities $R_{A\text{-}P}$ and relationship between resource entities and tasks $R_{P\text{-}T}$. Then agent organizational structure can be described as $G_{Or} = (G_A, R_{A\text{-}P}, R_{P\text{-}T})$. Obviously, the relationships between agents and resource entities $R_{A\text{-}P}$, and relationship between resource entities and tasks $R_{P\text{-}T}$ decide the relationships between agents and tasks $R_{DM\text{-}T}$, which can be written as $R_{A\text{-}T} = f(R_{A\text{-}P}, R_{P\text{-}T})$. Therefore, problem of agent organizational structure designing can be decomposed as two sub-problems, solution of relationships between agents and resource entities and relationship between resource entities and tasks.

2.2 Modeling agent organizational structure designing

Based on description of agent organizational structure and analysis of organizational structure designing, organizational structure designing can be decomposed as two sub-problems, viz. solution of controlling relationship between agents and resources, and allocation relationship between resources and tasks. We construct the mathematical formulation of two sub-problems respectively as follows.

1) Tasks Allocation

The objective of the sub-problem of task allocation is assigning tasks to agents so that time during whole organizational mission is minimized. We make two assumptions before we consider the problem: one is the task can be processed only when all tasks have been processed, another condition is all resources assigned to process a task have got appointed location. A task can be completed with a necessary condition that abilities of resources group assigned to process a task are not less than resources requirement of it, a resource entity can process a task at a time. Solutions of this sub-problem are allocation of resources to tasks. The time and sequence of the tasks processed by the agents are also specified in this phase.

The variables involved in this sub-problem are defined as follows. Assigning variable w_{im}: w_{im}= 1 if P_m is assigned to task t_i, or w_{im}= 0.Transferring variable x_{ijm}: x_{ijm} = 1 if P_m is assigned to task t_i after processing of task t_i, or x_{ijm} = 0.Sequence variable a_{ji}: a_{ji}= 0 if task t_j must be processed after task t_i is processed, or a_{ji}= 1.Time variable s_i: s_i is initial time task t_i being processed, Y' is bound on total processing time during whole mission. Denote total time during completing whole mission as Y, than the optimizing process can be described as follows:

$$\min Y$$

$$\begin{cases} \sum_{j=0}^{N} x_{ijm} - w_{im} = 0, & i, j = 1,2,\cdots,|T|; m = 1,2,\cdots,|P|; \\ \sum_{j=0}^{N} x_{jim} - w_{im} = 0, & i, j = 1,2,\cdots,|T|; m = 1,2,\cdots,|P|; \\ \sum_{i=0}^{N} x_{i0m} = \sum_{i=0}^{N} x_{0jm} = 1, & i, j = 1,2,\cdots,|T|; m = 1,2,\cdots,|P|; \\ s_i - s_j + x_{ijm} \cdot (\frac{d_{ij}}{v_m} + a_{ij} \cdot Y') \le a_{ij} \cdot Y' - t_i, & i, j = 1,2,\cdots,|T|; m = 1,2,\cdots,|P|; \\ \sum_{m=1}^{|P|} pc_{ml} \cdot w_{im} \ge r_{il}, & i, j = 1,2,\cdots,|T|; l = 1,2,\cdots,|F|; \\ s_i - Y \le -t_i, & i = 1,\cdots,N; 0 \le Y \le T; s_i \ge 0; x_{ijk}, w_{ik} \in \{0,1\} \end{cases} \quad (1)$$

Equation (1) is a mixed-binary linear programming problem which is NP-hard. When there is only a resource entity, it is a pedlar problem, when any resource entity can process all tasks, it can be simplified as a Travelling Salesman Problem with priority. it is a problem of project time optimizing in manufacture field. In martial field, it is a problem of tasks scheduling for campaign. for finding solutions to this problem , we proposed multi-PRI list dynamic scheduling (MPLDS) method [6].

2) Tasks and Resources Clustering

The objective of this problem of tasks and resources clustering is to minimize the workload of agents. The workload of an agent is defined as internal cooperation and external cooperation in processing tasks. Internal cooperation is defined as the amount of resource entities that is allocated to an agent, the external cooperation is defined as the amount of identical tasks assigned to processed with the other agents.

We denote bound on internal cooperation of an agent as B^I, and bound on external cooperation of an agent as B^E, bound on task processing workload of an agent as B^T. W^I and $W^E$are weignt of internal cooperation and external cooperation respectively, W_{im} is resources-tasks allocation matrix.

Denote allocation variable of a resource entity as dp_{nm}, $dp_{nm}=1$ if P_m is assigned to A_n, or $dp_{nm} = 0$.

Denote allocation variable of a task as dt_{ni}, $dt_{ni\,i}=1$ if task t_i is assigned to resource entities controlled by a_n , or $dt_{ni\,i}=0$.

Denote cooperation of identical task between two agents as ddt_{nmi}, $ddt_{nmi}=1$ if A_n and A_m coordinate over task t_i, or $ddt_{nmi}=0$.

So number of tasks allocated to a_n is $\sum_{i=1}^{|T|} dt_{ni}$, internal cooperation of a_n is $\sum_{m=1}^{|P|} dp_{nm}$, external cooperation of a_n is $\sum_{z=1, z\neq n}^{|A|} \sum_{i=1}^{|T|} ddt_{nzi}$.

Maximal workload can be described as:

$$\max_{n=1,\cdots,D} W^I \cdot \sum_{m=1}^{|P|} dp_{nm} + W^E \cdot \sum_{z=1,z\neq n}^{|A|} \sum_{i=1}^{|T|} ddt_{nzi}$$

Denote bound on Maximal workload as C_W, then:

$$C_W \geq W^I \cdot \sum_{m=1}^{|P|} dp_{nm} + W^E \cdot \sum_{z=1,z\neq n}^{|A|} \sum_{i=1}^{|T|} ddt_{nzi}$$

Therefore, process of designing relationship between agents and resources can be described as a binary linear programming problem, objective is to minimize the maximal workload of agent.

$$\min C_W$$
$$\begin{cases} dt_{ni} = w_{mi} \cdot dp_{nm}, \quad m=1,2,\cdots,|P|; n=1,2,\cdots,|A|; i=1,2,\cdots,|T| \\ ddt_{nmi} = \max\{dt_{ni} + dt_{mi} - 1, 0\} \\ \sum_{i=1}^{|T|} dt_{ni} \leq B^T, \sum_{m=1}^{|P|} dp_{nm} \leq B^I, \sum_{z=1,z\neq n}^{|A|} \sum_{i=1}^{|T|} ddt_{nzi} \leq B^E, \quad n=1,2,\cdots,|A| \\ C_W \geq W^I \cdot \sum_{m=1}^{|P|} dp_{nm} + W^E \cdot \sum_{z=1,z\neq n}^{|A|} \sum_{i=1}^{|T|} ddt_{nzi}, \quad n=1,2,\cdots,|A| \end{cases} \quad (2)$$

Equation （2） is a binary linear programming problem, the structural relationship of variables makes the solution process of this problem easer. Dynamic programming and decomposing arithmetic can all be applied in solving this problem, hierarchical clustering approach was applied in solving this problem in reference [7].

In next section, a hybrid genetic algorithm, in which GA is combined with dynamic list scheduling method, will be applied in solving these two problems in agent organizational structure designing.

3. Solving Method Based on Hybrid GA

We employ a hybrid GA to solve the tasks and resources clustering problem associated with the tasks allocating problem. The hybrid GA consists of two parts: outer-loop GA and nested inner-loop MDLS algorithm. Outer-loop GA is the main frame of hybrid algorithm, which address for the sub-problem of tasks and resources clustering. Nested MDLS algorithm works for the allocation relationship between task and resource, results of inner-loop return to outer-loop as the input of fitness function. Termination criteria of outer-loop GA is also termination criteria of whole algorithm. Based on the modeling of agent organizational structure designing, two loops in the hybrid algorithm can be regarded as two iterative phases, one phase is tasks and resources clustering phase, another phase is tasks assigning phase. As we have assigned resource groups to the corresponding task groups in the first phase, we decompose the scheduling problem, with large number of resources and tasks into several independent sub-scheduling problems with smaller number of resources and tasks. Flow chart of hybrid GA is shown in Fig 1.

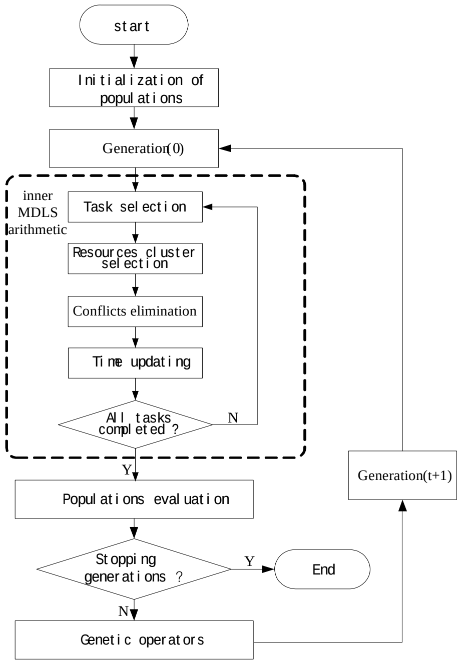

Fig.1 Flow chart of hybrid GA

Denote set of all resources as *FREE*, set of all tasks without predecessors as READY. Steps of hybrid GA can be described as follows:

Step 1: chromosome representation and initialization

Population in our problem corresponds to tasks and resources, the gene is coded to represent the clusters of tasks and resources, randomly generate the initial population.

Step 2: selecting the task

After generating initial population, it comes to the phase of inner-loop MDLS algorithm. A ready task is selected (a task becomes *ready* when all its predecessors have been completed) according to priority coefficients of tasks.

Step 3: selecting resources

Selecting resources to process selected task according to priority coefficients of resources until all resources requirement are met.

Step 4: shearing resources

Shearing resource group which contains selected resources for processing tasks, namely when rest resources in resource group can meet resources requirement of task be processed after one resource entity is sheared, this resource entity should not remain. Shearing is executed according to priority sequence of resources, iterative Shearing terminate when all resources in group are necessary.

Step 5: updating times of task processing

Deleting resources in resource groups after shearing from *FREE*, changing states of them to working, and updating start time and processing time of tasks assigned to each resource entity.

Step 6: population Evaluation

Inputting the internal cooperation and external cooperation workload returned from inner-loop to evaluation function, which is objective function in (2).

Step 7: selection and Genetic Operators

The fitness evaluation provides a partially ordered set of candidate population from the best to the worst. If the termination criteria are not met, successive generations are produced from individuals selected from a partially ordered set according to selecting strategy. The best individual will have a better chance of being selected for reproducing an offspring for the next generation.

We use the normalized geometric ranking method as follows. When population is $\{PO_i \mid 1 \le i \le N\}$, the probability of selecting PO_i is defined as:

$$p = \frac{q(1-q)^{r-1}}{1-(1-q)^N}$$

where q is a specified probability of selecting the best individual, r is the rank of the individual with the best individual ranked, N is the number of population.

Mutation and crossover are basic operators to create new population based on individuals in the current generation. When all genetic operators are completed, new generations are generated, return to step 2.

Step 8: when number of generations equal to predefined generations, algorithm terminate.

We proposed multi-PRI list dynamic scheduling (MPLDS) method [6], details about inner-loop MDLS algorithm are not circumstantiated here.

4. Case Study

4.1 Background of Case

Using scenario and data in the seventh experiment of organizational architecture experiment series carried out by Aptima Co., 18 tasks and 20 resources entities available were given to construct an agent organization in experiment scenario [7]. There are 8 types of different resources abilities, detailed description of resources entities and tasks were given in Table 1 and Table 2.

Table 1: Parameters of tasks

Para / tasks	Resource Requirement								t	(x, y)
	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8		
T_1	5	3	1	0	0	8	0	6	3	70,1
T_2	5	3	1	0	0	8	0	6	3	64,7
T_3	0	3	0	0	0	0	0	0	1	15,4
T_4	0	3	0	0	0	0	0	0	1	30,9
T_5	0	3	0	0	0	0	1	0	1	28,7
T_6	0	0	0	1	1	1	0	0	1	24,6
T_7	0	0	0	1	1	1	0	0	1	28,7
T_8	0	0	0	1	1	1	0	0	1	28,8
T_9	5	0	0	0	0	5	0	0	1	28,7
T_{10}	5	0	0	0	0	5	0	0	1	28,8
T_{11}	0	0	0	0	0	1	5	0	1	25,4
T_{12}	0	0	0	0	0	1	5	0	1	5,95
T_{13}	0	0	0	0	0	8	0	6	2	25,4
T_{14}	0	0	0	0	0	8	0	6	2	5,95
T_{15}	0	0	0	2	1	4	0	0	1	25,4
T_{16}	0	0	0	2	1	4	0	0	1	5,95
T_{17}	0	0	0	0	0	8	0	4	1	5,60
T_{18}	0	0	0	8	6	0	4	1	2	5,60

A task graph contains 18 tasks are shown in Fig.2, which details the relationships of priority and dependence among tasks.

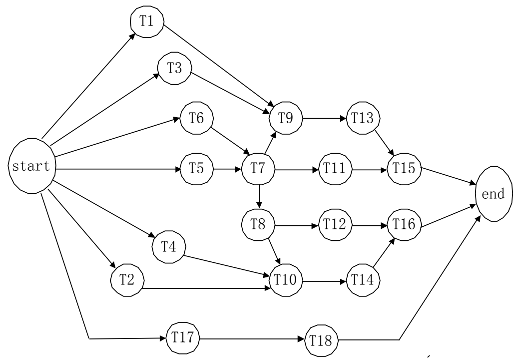

Fig. 2 Task graph

Table 2: Parameters of resources entities

Para \ Resource	Resource Capability								V
	fc_1	fc_2	fc_3	fc_4	fc_5	fc_6	fc_7	fc_8	
1	10	10	1	0	9	5	0	0	2
2	1	4	10	0	4	3	0	0	2
3	10	10	1	0	9	5	0	0	2
4	0	0	0	2	0	0	5	0	4
5	1	0	0	10	2	2	1	0	1
6	5	0	0	0	0	0	0	0	4
7	3	4	0	0	6	10	1	0	4
8	1	3	0	0	10	8	1	0	4
9	1	3	0	0	10	8	1	0	4
10	1	3	0	0	10	8	1	0	4
11	6	1	0	0	1	1	0	0	4
12	6	1	0	0	5	1	0	0	4
13	6	1	0	0	1	1	0	0	4
14	0	0	0	0	0	0	10	0	2
15	0	0	0	0	0	0	0	6	5
16	0	0	0	0	0	0	0	6	7
17	0	0	0	6	6	0	1	10	2
18	1	0	0	10	2	2	1	0	1
19	1	0	0	10	2	2	1	0	1
20	1	0	0	10	2	2	1	0	1

4.2. Comparison of results

Solution with Hybrid GA method is shown in Fig.3. From comparison of two methods we can know, clustering of resources and tasks in prophase leads to decrease ofcooperation workload among agents, unnecessary cooperation are reduced. Optimal task allocation leads to compaction of task processing under conditions that resource requirements are met, total time of mission completing is shortened and utilizing rate of resources is improved. Results show, solving method based on hybrid GA using global searching ability of GA, available solution space are searched. At the same time, using MDLS algorithm to solving task allocating problem whose dimensions is lowered. So near optimal organizational structure can constructed. Though method based on hybrid GA avoids local optimization induced in traditional multi-phases method and operates better performance, but when number of tasks and resource entities are very large, computational complexity is hard to avoid.

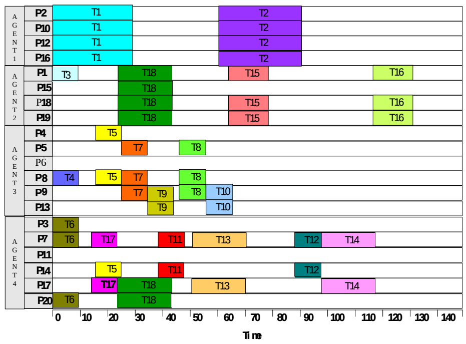

Fig. 3 Organizational structure and tasks process Gantt-Chart Based on Hybrid GA arithmetic

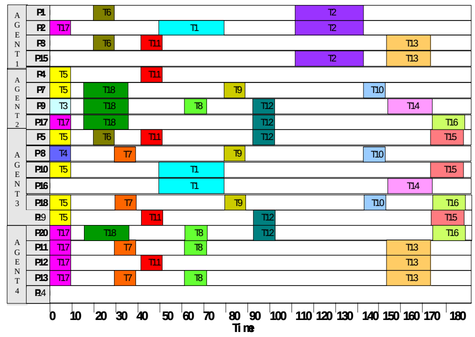

Fig. 4 Organizational structure and tasks process Gantt-Chart Based on Multi-phases arithmetic

5. Conclusion

A novel hybrid genetic algorithm is proposed to design an agent organizational structure , in which GA was combined with local optimizing arithmetic in novel algorithm, mechanism of global optimization was combined with actions of local optimization. Results of example show, agent organizational structure constructed by our proposed designing process has better performance compare with traditional multi-phase optimizing method. How to extend our approach to improve adaptability of organizational structure in uncertain circumstance is another extension that will be addressed in our future work.

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