

# The Improved Hierarchical Clustering Algorithm by a P System with Active Membranes

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*Abstract:* - In this paper an improved hierarchical clustering algorithm by a P system with active membranes is proposed which provides new ideas and methods for cluster analysis. The membrane system has great parallelism. It could reduce the computational time complexity and is suitable for the clustering problem. Firstly an improved hierarchical algorithm was presented which introduced the K-medoids algorithm. The distance of clusters is defined as the distance between the medoids of these clusters instead of the mean distance between them. Secondly a P system with all the rules to solve the above hierarchical algorithm was constructed. The specific P system is designed for the dissimilarity matrix associated with n objects. The computation of the system can obtain one possible classifications in a non-deterministic way. Through example test, the proposed algorithm is appropriate for cluster analysis. This is a new attempt in applications of membrane system.

*Key-Words:* - Clustering algorithm; the hierarchical clustering; K-medoids algorithm; Membrane computing; P System; Membrane system

## 1 Introduction

Clustering is a core problem in many fields such as data mining, machine learning, biology and statistics. It describes the process of partitioning data set into clusters so that intra-cluster data are similar and inter-cluster data are dissimilar.

Membrane computing has been applied in broad fields such as graph theory, finite state problems, and combinatorial problem. Membrane computing approaches are more suitable used to solve many combinatorial problems because of the vast parallelism. The parallelism lessens the time complexity of clustering process so it meets requirement of processing speed of the huge data [1, 2].

This paper combines these two above to solve the problem of clustering n objects to k clusters by the hierarchical clustering algorithm. It uses the subscript i of point  $a_i$  to represent the i-th object of the original objects and it uses the dissimilarity of any two original objects to define the distance of corresponding points a. Different clusters are represented by different membranes and the traditional hierarchical algorithm are improved. First, each object composes one cluster. The distance between clusters is the same as the distance between the objects. Second, find the closest two

clusters and merge them into one. Then put the information out into the output membrane and compute distances between medoids as the distance between clusters. And then find the closest two clusters..... and so on, until only one cluster left. This strategy is a new application of membrane computing.

## 2 The Improved Hierarchical Clustering Algorithm

The hierarchical clustering algorithm is a classical partitioning algorithm. A data set  $X = \{x_1, x_2, \dots, x_n\}$  of n objects can be clustered into k clusters by it.

Firstly, an n\*n distance matrix  $D_m$  is defined to show the distance between any two objects:

$$D_m = \begin{pmatrix} w_{11} & w_{12} & \dots & w_{1n} \\ w_{21} & w_{22} & \dots & w_{2n} \\ \dots & \dots & \dots & \dots \\ w_{n1} & w_{n2} & \dots & w_{nn} \end{pmatrix} \quad (1)$$

Where,  $w_{ij}$  is the dissimilarity between  $x_i$  and  $x_j$ [3].

Secondly, the matrix elements  $w_{ij}'$  are changed into integer  $w_{ij}$  by rounding for membrane computing. The new matrix  $D_{mn}$  is as follows [4]:

$$D_{mn} = \begin{pmatrix} w_{11} & w_{12} & \dots & w_{1n} \\ w_{21} & w_{22} & \dots & w_{2n} \\ \dots & \dots & \dots & \dots \\ w_{n1} & w_{n2} & \dots & w_{nn} \end{pmatrix} \quad (2)$$

Then, the steps of hierarchical clustering algorithm are as follows:

1. Each object composes one cluster at first. The distance between clusters is the same as the distance between the objects.
2. Find the closest two clusters and merge them into one cluster.
3. Compute distances between clusters again.
4. Repeat steps 2 and 3 until only one cluster left [5].

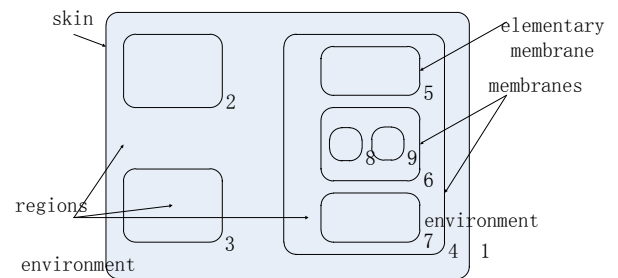
There are four widely used measures for distance between clusters. They are minimum distance, maximum distance, mean distance and average distance. The minimum distance and the maximum distance represent the two extremes of the inter-cluster distance. They tend to be overly sensitive to outliers or noise data. The mean distance a middle ground, but it also a little sensitive. The average distance can overcome the sensitive issues of the outliers. But it is hard to compute.

So, the mean distance is improved to the medoids distance. It is more robust to noise and outliers and easier to compute. The medoids distance is the distance between the medoid of two clusters. A medoid can be defined as one object of a cluster, whose total distance to all the objects in the cluster is minimal. That is to say, it is a most centrally located point in the given data set.

### 3 P Systems with Active Membranes

P system is an abstracted membrane computing model according to the mechanism of cells processing chemical substances. According to the differences of the biochemical reaction mechanism of biological cells or tissues they simulate, they are divided into three categories: Cell-like P Systems, Tissue-like P Systems and Neural-like P Systems. Cell-like P System simulates the structure and function of cells, and its basic elements include membrane structure, objects and rules. Membranes divide the entire system into different regions. The outermost membrane is called the skin membrane. If

the interior of a membrane has no other membranes, it is called basic membrane, otherwise non-elemental membrane. Objects and rules exist in various regions. Usually objects are indicated by characters or strings. Rules are used for processing objects or membranes within corresponding region. The implementation of rules has uncertainty and maximum parallelism. P System is specifically divided into three types from differences of rules: transition P system, P system with communication rules and P system with active membranes [6]. The basic membrane structure is shown in Fig.1.



**Fig.1.** the basic membrane structure

The membrane structure of P systems with active membranes changes with the implementation of the rules when calculating. It can generate space of exponential growth in linear operation steps and this is helpful to solve computationally hard problems in a feasible time frame.

In general, a P system with active membranes of degree  $m$  is a construct:

$$\Pi = (O, \mu, w_1, w_2, \dots, w_m, R_1, R_2, \dots, R_m, i_o) \quad (3)$$

Where:

1.  $O$  is an alphabet. Its elements are called objects;
2.  $\mu$  is a membrane structure of degree  $m$ , each membrane has a corresponding label,  $H = \{1, 2, \dots, m\}$  is the label set of  $\Pi$ ;
3.  $w_i (i=1, 2, \dots, m)$  is the multiset of objects in membrane  $i$ ;
- $R_i (i=1, 2, \dots, m)$  is the evolution rules of membrane  $i$

The basic evolution rule is a pair  $(u, v)$  in the form of  $(u \rightarrow v)_r$  [8], where  $u$  is a string over  $V$  and  $v = v'$  or  $v = v'\delta$  where  $v'$  is a string over  $\{a_{here}, a_{out}, a_{in_j} \mid a \in V, 1 \leq j \leq m\}$ , and  $\delta$  is a special symbol not in  $V$ . When a rule contains  $\delta$ , the membrane will be dissolved after performing the rule.  $r$  is promoters or inhibitors and  $r = r'$  or  $r = -r'$ . One rule can execute only the promoters  $r'$  appear and one rule can stop only the inhibitors appear. The length of  $u$  is called the radius of the

rule  $u \rightarrow v$ .  $R_i$  is the finite set of the evolution rules. Each  $R_i$  is associated with the region  $i$  over the membrane structure  $\mu$ .  $\rho_i$  is a partial order relation over  $R_i$  called precedence relation. High priority rule is executed prior. [9]. The active membranes have special rules as follows:

(a) object evolution rules:

$$[{}_h a \rightarrow v]_h^e, h \in H, e \in \{+, -, 0\}, a \in O, v \in O^*$$

When the electric charge of membrane  $h^\#$  is  $e$ , (when  $e$  is 0, it means membrane  $h^\#$  has no polarity and can be ignored), the object  $a$  evolves into  $v$ .

(b) communication rules:

$$a[{}_h]_h^{e_1} \rightarrow [{}_h b]_h^{e_2}, [{}_h a]_h^{e_1} \rightarrow [{}_h]_h^{e_2}$$

$$b, h \in H, e_1, e_2 \in \{+, -, 0\}, a, b \in O$$

When the electric charge of membrane  $h^\#$  is  $e_1$ , the object  $a$  out of the membrane evolves into object  $b$  and is introduced in the membrane or the object  $a$  in the membrane evolves into object  $b$  and is sent out of the membrane. Also the polarization of the membrane can be modified, but not its label.

(c) dissolving rules:

$$[{}_h a]_h^e \rightarrow b, h \in H, e \in \{+, -, 0\}, a, b \in O$$

When the electric charge in membrane  $h^\#$  is  $e$  and the object  $a$  appears in membrane  $h^\#$ , this membrane can be dissolved. The object  $a$  evolves into the object  $b$  and the other objects do not change.

(d) Division rules:

$$[{}_h a]_h^{e_1} \rightarrow [{}_h b]_h^{e_2} [{}_h c]_h^{e_3}$$

$$h \in H, e_1, e_2, e_3 \in \{+, -, 0\}, a, b, c \in O$$

When the electric charge in membrane  $h^\#$  is  $e_1$  and the object  $a$  appears in membrane  $h^\#$ , the membrane is divided into two membranes with the same label, maybe of different polarizations; the object  $a$  specified in the rule is replaced in the two new membranes by objects  $b$  and  $c$ . All objects different from  $a$  are duplicated in the two new membranes.

(e) Fusion rules:

$$[{}_h b]_h^{e_2} [{}_h c]_h^{e_3} \rightarrow [{}_h a]_h^{e_1}$$

$$h \in H, e_1, e_2, e_3 \in \{+, -, 0\}, a, b, c \in O$$

This rule is opposite to the division rules.

5.  $i_o$  is the output membrane to save the calculation result [7].

The P system for clustering is defined as follows:

$\Pi = (O, \mu, M_0, M_1, \dots, M_n, M_{n+1}, R_0, R_1, \dots, R_n, R_{n+1}, \rho)$   
Where:

$$1) \quad 0 = \{A_{11}, A_{22}, \dots, A_{nn}, \alpha_1, d_{1,2,w_{12}}, d_{1,3,w_{13}}, d_{1,4,w_{14}}, \dots, d_{1,n,w_{1n}}, d_{2,3,w_{23}}, d_{2,4,w_{24}}, \dots, d_{2,n,w_{2n}}, \dots, d_{n-1,n,w_{n-1,n}}, s_0, \delta_1\}$$

Rules of P system with active membranes perform in the manner of uncertainty and maximally parallelism, so it can solve difficult problem in calculating in a feasible time frame. When calculating, rules are used uncertainly and maximum parallel in each membrane. After a number of steps, the P system halt if no rules can be performed and the objects in the output membrane is the result. If rules are always performed, the P system can't halt, then the calculation is invalid, and there will be no result [8].

## 4 A P System for the Hierarchical Clustering Method

### 4.1 The P System for the Hierarchical Clustering Method

When including a subsection you must use, for its heading, small letters, 12pt, left justified, bold, Times New Roman as here. a P system for the improved hierarchical algorithm is proposed. Its structure is depicted in Fig.2.

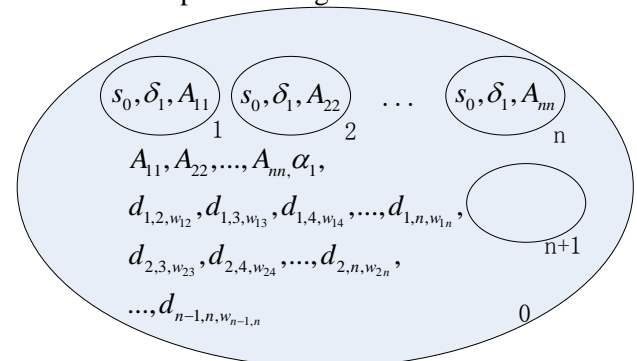


Fig.2 the P system for the k-medoids clustering method

It use the subscript  $i$  of the points  $a_i$  to represent the  $i$ -th object of the original objects and use the matrix  $D_{nn}$  to compare the similarity between the  $n$  objects. The specific algorithm is followed:

First, it set the maximum data in the matrix  $D_{nn}$  Max, the minimum data in the matrix  $D_{nn}$  Min and set the absolute value of these two Abs for convenience.

0 represents the collection of objects in the P system.

$$2) \mu = [{}_0 [{}_1 [{}_2 [{}_2 \dots [{}_n [{}_n [{}_{n+1} [{}_{n+1} ]_0]$$

$\mu$  represents the membrane structure of the P system.

$$3) M_0 = \{A_{11}, A_{22}, \dots, A_{nn}, \alpha_1, d_{1,2,w_{12}}, d_{1,3,w_{13}}, d_{1,4,w_{14}}, \dots, d_{1,n,w_{1n}}, d_{2,3,w_{23}}, d_{2,4,w_{24}}, \dots, d_{2,n,w_{2n}}, \dots, d_{n-1,n,w_{n-1,n}}\}$$

$$M_1 = \{s_0, \delta_1, A_{11}\}, M_2 = \{s_0, \delta_1, A_{22}\}, \dots, M_n = \{s_0, \delta_1, A_{nn}\} M_{n+1} = \{\lambda\}$$

M represents the collection of initial objects in each membrane.  $M_{n+1}$  is the output membrane of this P system.

The rules in  $R_0$  [9,10]:

$$r_1 = \{(\eta_{ij} A_{ip} A_{jq} d_{i,j,t} \rightarrow \eta_{i(j+1)} A_{ip} A_{jq} d_{i,j,w_{pq}}) \cup (\eta_{ij} \rightarrow \eta_{i(j+1)})_{-(A_{ip} \cup A_{jq})} \mid 1 \leq i, j, p, q \leq n, -1 \leq t \leq Max\}$$

$$r_2 = \{\eta_{i(n+1)} \rightarrow \eta_{(i+1)(i+2)} \mid 1 \leq i \leq n-1\}$$

$$r_3 = \{\eta_{n(n+1)} \rightarrow \lambda\}$$

$$r_4 = \{((A_{ip} [{}_i [s_0, \delta_1, A_{jq}]_j \rightarrow b_{ij} [A_{ip}, a_q, \alpha_t]_i) \cup (A_{ip} A_{jq} \rightarrow \lambda)$$

$$\cup (\alpha_t \rightarrow d_{ij})_{in_{n+1}})_{(d_{i,j,0}) \cup \alpha_t} \mid 1 \leq i, j, p, q \leq n, 1 \leq t \leq n-1\} \cup \{(\alpha_n \rightarrow \#)_{in_{n+1}})_{(d_{i,j,0}) \cup \alpha_n} \mid 1 \leq i, j, p, q \leq n\}$$

$$r_5 = \{(d_{j,t,p} \rightarrow d_{-1,-1,-1})_{b_{ij}} \cup (d_{i,j,0} \rightarrow d_{-1,-1,-1})_{b_{ij}} \mid 1 \leq i, j, t \leq n, -1 \leq p \leq Max\}$$

$$r_6 = \{b_{ij} \rightarrow \lambda \mid 1 \leq i, j \leq n\}$$

$$r_7 = \{d_{i_1,j_1,t_1} d_{i_2,j_2,t_2} \dots d_{i_{\frac{n(n-1)}{2}},j_{\frac{n(n-1)}{2}},t_{\frac{n(n-1)}{2}}} \rightarrow d_{i_1-1,j_1-1,t_1-1} d_{i_2-1,j_2-1,t_2-1} \dots d_{i_{\frac{n(n-1)}{2}-1},j_{\frac{n(n-1)}{2}-1},t_{\frac{n(n-1)}{2}-1}} \mid 1 \leq i, j \leq n, 1 \leq t \leq Max\}$$

The rules in  $R_i$  ( $1 \leq i \leq n$ ):

$$r_1' = \{\alpha_i \delta_i a_i \rightarrow \alpha_i \zeta_i O_i \mid 1 \leq i \leq n\} \cup \{(\alpha_i \delta_i \rightarrow \alpha_i \delta_{i+1})_{-a_i} \mid 1 \leq i \leq n, 1 \leq t \leq n-1\}$$

$$r_2' = \{s_i O_i a_j A_{hp} \rightarrow b_j O_i s_{t+w_{ij}-w_{pj}} A_{hp} \mid 1 \leq i, j, p, h \leq n, t \leq nAbs\}$$

$$r_3' = \{s_i A_{jp} O_h \rightarrow s_0 A_{jp} a_p \mid -nAbs \leq i < 0, 1 \leq j, p, h \leq n\} \cup \{s_i A_{jp} O_h \rightarrow s_0 A_{jp} a_h \mid 0 \leq i \leq nAbs, 1 \leq j, p, h \leq n\}$$

$$r_4' = \{b_i \rightarrow a_i \mid 1 \leq i \leq n\}$$

$$r_5' = \{\zeta_i \rightarrow \delta_{i+1} \mid 1 \leq i \leq n\}$$

$$r_6' = \{\delta_{n+1} A_{jp} \alpha_i \rightarrow (\alpha_{i+1} A_{jp} \eta_{11}, out) \delta_1 A_{jp} \# \mid 1 \leq j, p \leq n\}$$

$$\rho = \{r_i > r_j \mid 1 \leq i < j \leq 7\} \cup \{r_i' > r_j' \mid 1 \leq i < j \leq 6\}$$

## 4.2 An Overview of Computations

When including a subsection you must use, for its heading, small letters, 12pt, left justified, bold, Times New Roman as here. Membranes 1 to n represent the n clusters in initial condition. The object  $A_{ii}$  shows that the medoid of i-th cluster is  $x_i$  at this time. Rules in membrane 0 execute firstly. The object  $d_{i,j,t}$  shows that the distance between membrane i and membrane j is t. Let all the third subscript t decrease at the same until one of them is zero (An object  $d_{i,j,0}$  appears). It means that cluster i and cluster j are the nearest clusters. (If more than one  $d_{i,j,0}$  appear at the same time, one of them is chose uncertainly.) Next the object  $A_{jq}$  in cluster j changes to  $a_q$  (Because there is only one medoid in one membrane, it is set the medoid of membrane i. The medoid of membrane j changes to ordinary point.) and all objects in membrane j is merged into

cluster i. The object  $\alpha_i$  enters into membrane i to active rules in membrane i to re-determine the medoid because there are new points entered. At the same time,  $A_{ip}$  and  $A_{jq}$  disappear, all objects  $d_{i,j,t}$  and  $d_{j,t,m}$  are changed to  $d_{-1,-1,-1}$  because membrane j has disappeared and  $d_{ij}$  is sent to membrane n+1 to show that membrane i and membrane j is merged in circle t. To this, the two nearest clusters are merged.

If any membrane from 1 to n accepts an object  $\alpha_i$ , this membrane should re-determine its medoid. Each point will be set as the new medoid from  $a_i$ . Then calculate the difference between the dissimilarity between the new medoid and the remaining point and the dissimilarity between the original medoid and the remaining point and add the data to the subscript of object S. If the subscript of S is less than 0 after calculating all the dissimilarity with remaining points, the point  $a_i$  can reduce the total consumption. So it is set as the new medoid.

Else the original center point is maintained, rename object  $O_h$  to  $a_h$ . The object  $\delta_{i+1}$  is produced to go to the next cycle to compare the object  $a_2$  and the medoid and so on until all the objects  $a_i$  are compared. Last objects in this membrane are restored to initial state and the information of the medoid and the object  $\alpha_{i+1}$  (This shows the hierarchical clustering algorithm goes into the next circle.) and  $\eta_{11}$  are put out. The object # is used to stop the computation step.

The object  $\eta_{11}$  activates rules in membrane 0. The objects  $d_{i,j,t}$  are re-valued according to the new medoids. Then, it goes to the second circle. When there is only one cluster left, the computation is over.

### 5 Test and Analysis

To illustrate how the membrane system shown in Fig.2 run specifically, the 7 integral points (1,1), (2,1), (2,2), (3,4), (4,2), (4,3), (5,4) shown in Fig.3 is considered:

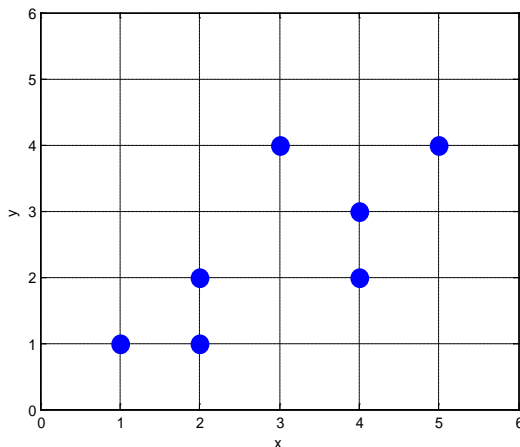


Fig.3 the 7 points waiting for being clustered  
First of all, it defines the dissimilarity matrix  $D_{77}'$ . In this example, it uses the distance between any two points as the dissimilarity. Because the points are integral points, matrix  $D_{77}$  is the same to matrix  $D_{77}'$ :

$$D_{77} = D_{77}' = \begin{pmatrix} 0 & 1 & 2 & 13 & 10 & 13 & 25 \\ 1 & 0 & 1 & 10 & 5 & 8 & 18 \\ 2 & 1 & 0 & 5 & 4 & 5 & 13 \\ 13 & 10 & 5 & 0 & 5 & 2 & 4 \\ 10 & 5 & 4 & 5 & 0 & 1 & 5 \\ 13 & 8 & 5 & 2 & 1 & 0 & 2 \\ 25 & 18 & 13 & 4 & 5 & 2 & 0 \end{pmatrix} \quad (4)$$

The membrane system clustering these seven numbers into two classes is shown in Fig.4:

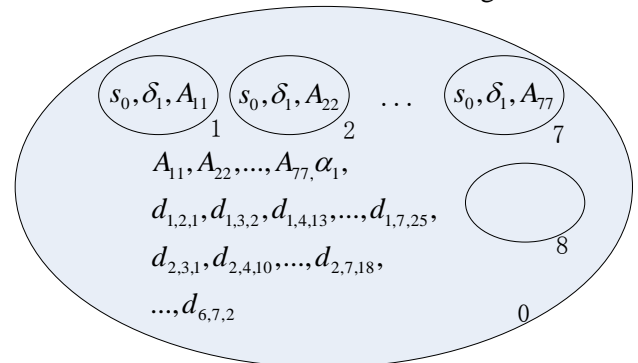


Fig.4 the P system clustering seven numbers into two classes

Steps of two circulations of the clustering are listed in Table 1 and Table 2. Because the steps are almost the same, only parts of them are listed here.

Table 1 steps of the first circulation of the clustering

membrane number	0	1	2	n+1
$t_0$ :				
$A_{11}, A_{22}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_1, d_{1,2,1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{2,3,1}, d_{2,4,10}, d_{2,5,5}, d_{2,6,8}, d_{2,7,18}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,5}, d_{6,7,2}$	$s_0, \delta_1, A_{11}$	$s_0, \delta_1, A_{22}$	$\lambda$	
$t_1$ :				
$A_{11}, A_{22}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_1, d_{1,2,0}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{2,3,0}, d_{2,4,9}, d_{2,5,4}, d_{2,6,7}, d_{2,7,17}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}(r_7)$	$s_0, \delta_1, A_{11}$	$s_0, \delta_1, A_{22}$	$\lambda$	
$t_2$ :				
$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{1,2,0}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{2,3,0}, d_{2,4,9}, d_{2,5,4}, d_{2,6,7}, d_{2,7,17}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{12}(r_4)$	$s_0, \delta_1, A_{11}, \alpha_1, a_2$	$\times$	$d_{112}$	

Table 1(continued) steps of the first circulation of the clustering

<i>membrane number</i>	0	1	2	$n+1$
$t_3$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{2,4,9},$ $d_{2,5,4}, d_{2,6,7}, d_{2,7,17}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{12}(r_5)$	$s_0, \delta_2, A_{11}, \alpha_1, a_2(r_1')$	$\times$	$d_{112}$
$t_4$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{2,5,4}, d_{2,6,7}, d_{2,7,17}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{12}(r_5)$	$s_0, A_{11}, \alpha_1, \zeta_2, O_2(r_1')$	$\times$	$d_{112}$
$t_5$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{2,6,7}, d_{2,7,17}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{12}(r_5)$	$s_0, A_{11}, \alpha_1, \zeta_2, a_2(r_3')$	$\times$	$d_{112}$
$t_6$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{2,7,17}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{12}(r_5)$	$s_0, A_{11}, \alpha_1, \delta_3, a_2(r_5')$	$\times$	$d_{112}$
$t_7$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{12}(r_5)$	$s_0, A_{11}, \alpha_1, \delta_4, a_2(r_1')$	$\times$	$d_{112}$
$t_8$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}(r_6)$	$s_0, A_{11}, \alpha_1, \delta_5, a_2(r_1')$	$\times$	$d_{112}$
$t_9$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}$	$s_0, A_{11}, \alpha_1, \delta_6, a_2(r_1')$	$\times$	$d_{112}$
$t_{10}$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}$	$s_0, A_{11}, \alpha_1, \delta_7, a_2(r_1')$	$\times$	$d_{112}$
$t_{11}$ :	$A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}$	$s_0, A_{11}, \alpha_1, \delta_8, a_2(r_1')$	$\times$	$d_{112}$
$t_{12}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, \eta_{11}$	$s_0, A_{11}, \delta_1, a_2(r_6')$	$\times$	$d_{112}$

Table 2 steps of the second circulation of the clustering

<i>membrane number</i>	0	5	6	$n+1$
$t_0$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, \eta_{11}$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_1$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, \eta_{12}(r_1)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
...				



Table 2(continued) steps of the second circulation of the clustering

membrane number	0	5	6	$n+1$
$t_{24}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, \eta_{56}(r_2)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{25}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,4}, d_{6,7,1}, \eta_{57}(r_1)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{26}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,5}, d_{6,7,1}, \eta_{58}(r_1)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{27}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,5}, d_{6,7,1}, \eta_{67}(r_2)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{28}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,5}, d_{6,7,2}, \eta_{68}(r_1)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{29}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,5}, d_{6,7,2}, \eta_{78}(r_2)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{30}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-1}, d_{1,3,2}, d_{1,4,13}, d_{1,5,10}, d_{1,6,13}, d_{1,7,25}, d_{-1,-1,-1}, d_{-1,-1,-1},$ $d_{-1,-1,-1}, d_{-1,-1,-1}, d_{-1,-1,-1}, d_{3,4,5}, d_{3,5,4}, d_{3,6,5}, d_{3,7,13}, d_{4,5,5}, d_{4,6,2}, d_{4,7,4}, d_{5,6,1}, d_{5,7,5}, d_{6,7,2}(r_3)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{31}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}(r_7)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{32}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{66}, A_{77}, \alpha_2, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}(r_7)$	$s_0, \delta_1, A_{55}$	$s_0, \delta_1, A_{66}$	$d_{112}$
$t_{33}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{5,6,0}, d_{5,7,4}, d_{6,7,1}, b_{56}(r_4)$	$s_0, \delta_1, A_{55}, a_6, \alpha_2$	$\times$	$d_{112}, d_{256}$
$t_{34}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}, b_{56}(r_5)$	$s_0, \delta_2, A_{55}, a_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$
$t_{35}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}(r_6)$	$s_0, \delta_3, A_{55}, a_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$
$t_{36}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \delta_4, A_{55}, a_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$



Table 2(continued) steps of the second circulation of the clustering

membrane number	0	5	6	$n+1$
$t_{37}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \delta_5, A_{55}, a_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$
$t_{38}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \delta_6, A_{55}, a_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$
$t_{39}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \zeta_6, A_{55}, O_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$
$t_{40}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \zeta_6, A_{55}, a_6, \alpha_2(r_3')$	$\times$	$d_{112}, d_{256}$
$t_{41}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \delta_7, A_{55}, a_6, \alpha_2(r_5')$	$\times$	$d_{112}, d_{256}$
$t_{42}$ :	$A_{11}, A_{33}, A_{44}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}$	$s_0, \delta_8, A_{55}, a_6, \alpha_2(r_1')$	$\times$	$d_{112}, d_{256}$
$t_{43}$ :	$A_{11}, A_{33}, A_{44}, A_{55}, A_{77}, d_{-1,-1,-2}, d_{1,3,1}, d_{1,4,12}, d_{1,5,9}, d_{1,6,12}, d_{1,7,24}, d_{-1,-1,-2}, d_{-1,-1,-2}, d_{-1,-1,-2},$ $d_{-1,-1,-2}, d_{-1,-1,-2}, d_{3,4,4}, d_{3,5,3}, d_{3,6,4}, d_{3,7,12}, d_{4,5,4}, d_{4,6,1}, d_{4,7,3}, d_{-1,-1,-1}, d_{5,7,4}, d_{-1,-1,-1}, \eta_{11}, \alpha_3$	$s_0, \delta_1, A_{55}, a_6, \alpha_2(r_6')$	$\times$	$d_{112}, d_{256}$

**4 Conclusion**

This paper improves the hierarchical algorithm and constructs a P system to realize it. This algorithm is suitable for cluster analysis by example test, but it needs to be further studied whether it is suitable for cluster analysis of large amount of data. Speaking from a theoretical point of view, the P system has great parallelism. So it can reduce the time complexity of computing and increases the computational efficiency. The following research work will focus on the theoretically analyze of the algorithm's time complexity. Additionally, membrane computing is a new biological computing method. Now its theoretical research is mature, but its application is not particularly extensive. A lot of applications will emerge in various fields in the future. The application in cluster proposed in this paper is one example. There are many clustering method and this paper only use the hierarchical algorithm. Membrane computing can be applied to a variety of other clustering methods.

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