

# A Cooperative and Heuristic Community Detecting Algorithm

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**Abstract**—This paper introduces the concept of community seed, vector and relation matrix. In terms of the relation similarity between free vertices and the existing communities, we put vertices into different groups. A minimum similarity threshold is proposed to filter which gives a method to find the vertices located at the overlapped area between different communities. This paper analyzes a series of network dataset and proves that our algorithm is able to accurately find communities with high cohesion and weak coupling. We use a variety of test to demonstrate that our algorithm is highly effective at detecting community structures in both computer-generated and real-world networks.

**Index Terms**—community seed; relation matrix; minimum similarity threshold; overlapped area; high cohesion and weak coupling

## I. INTRODUCTION

Network has attracted considerable recent attention as one of the most powerful mathematical presentation for complex systems. Network ideas have been applied with success to topics as diverse as scientific citation and collaboration [1], epidemiology [2], ecosystems, to name but a few. Previous study indicates that large complex networks have statistical features such as small-world phenomenon [3], isomerism [4], clustering, scale-free [5]. According to the recent research, complex networks also have obvious community structures [6]. Community structure is the reflection of networks' modularization and heterogeneity; it tells us that the real world is combined by all sorts of vertices. It is of vital significance to deeper study the community structures which hidden behind the complex networks, as well as to intellectually mine them. For example, communities in social networks can be used to find vertices of similar interests and social context; classifying the pages on world wide web is good to improve the search efficiency and accuracy, and help to implement the function of information filtering, hot spots tracking, news analyzing and so on; the discovery of community in biochemistry networks and electronic networks is useful to find the function-related structure units. Finding these communities are not only helps to

reveal how the high cohesion and loose coupling community structures are combined, but also helps people to better understand the distinctive characteristics of structures and functions in different levels of the system.

Community detecting can be defined as: finding the vertices with similar characteristics in the complex network and artificially put them into a virtual group. Vertices in the same group have tightly connections while vertices in different groups have sparse connections [7][8]. After division we get a high cohesion and loose coupling system. The feature of community in complex network is similar to the clustering in data mining, so this feature is also called clustering. The ability to find and analyze communities in complex network can provide invaluable help in understanding and visualizing the structure of complex networks [9-20]. In this paper, we show how this can be achieved.

Classical community discovery algorithms (CDA) include, G-N algorithm [10][15], label propagation algorithm [11-13], the CDA based on dynamical similarity[14], to name but a few. With the development of swarm intelligence, some scholars also came up with the idea of CDA based on genetic algorithm (GA) [16-19] and CDA based on particle swarm optimization (PSO)[20-22]. According to the operational solution strategies, the existing CDAs can be divided into two classes, heuristic CDA and optimal CDA. This paper is enlightened both by the thoughts in PSO and by the cooperative thoughts in CF, we entitled it as cooperative and heuristic CDA (CHCDA). Experimental results in section 4 show that the applications can effectively lower the algorithm's time complexity with good practicality and applicability.

## II. PRELIMINARIES

With the appearance of Green Computing, it has become a tendency to combine multiple algorithms together to reduce the algorithm's time complexity. Particle swarm algorithm simulates the self-organized sports action in nature; multi-function optimization is able to find multiple optimal swarms at the same time. Therefore, we innovatively apply both these ideas to look

for the community seed; then we compare the similarities between free vertices and the existing community. In this paper, we use vertices' degree as the weight of core level, take the core vertex as the best particle, look for and detect the community structures in complex networks.

**A. Relation matrix**

Assume that the network we studied has  $n$  nodes,  $A$  is the adjacent matrix and  $R$  is the relation matrix.

$$R_n = A_n + E_n \tag{1}$$

From the above formula we can see, the difference between  $A$  and  $R$  is, the diagonal elements in adjacent matrix is  $A_{i,i}=0$  while the relation matrix is  $R_{j,j}=1$ .

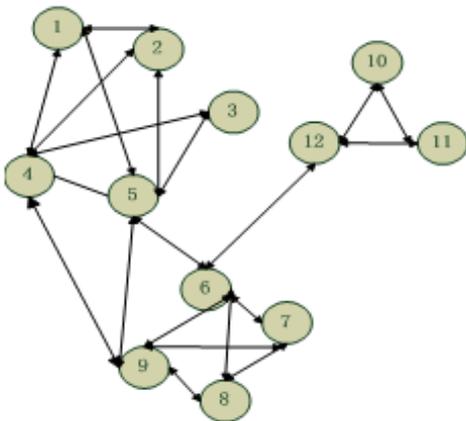


Figure 1. A small artificial network.

We use Figure 1 to illustrate how CHCDA works.

The theory of "Six Degrees of Separation" tells us that people who have same friends are much easier to become friends themselves than people who are randomly picked up from the society. Before theorem one, we define the concept of common neighbor and the concept of people with similar social relationships.

**Definition 1:** Common neighbor. If node  $a$  has edges to both node  $i$  and  $j$ ,  $a$  is  $i$  and  $j$ 's common neighbor.

**Definition 2:** Similar social relationship. If  $i$  and  $j$  have many common neighbors and exceed a minimum threshold, we call  $i$  and  $j$  have similar social relationships.

In this paper, we use relation similarity to weigh how close the nodes' are. According to the description above we get Theorem 1.

**Theorem 1:** In network  $N$ , We know that  $A$  and  $B$  are friends,  $B$  and  $C$  are friends,  $D$  and  $E$  are randomly chosen from  $N$ . We say that  $A$  and  $C$  are much easier to become friends than  $D$  and  $E$ . In other words,  $similarity(A,C) \gg similarity(D,E)$ .

Graph theory is always used to solve the problems in network; the problem described above is equal to calculate the probability of triangle formation in an undigraph. In other words, we need to prove that the probability of  $Triangle(A,B,C) \gg Triangle(D,B,E)$ .

*Proof:*

- (1) Construct a simple undigraph as Figure 2 shows;
- (2) Set node B as a triangle vertex;
- (3) If nodes A and C are both B's nearest neighbor, the probability of A, B and C to form a triangle is 50%;
- (4) If we randomly choose another two nodes D and E from the graph, the probability of B, D and E to form a triangle is  $0.5 * 0.5 * 0.5 = 0.125$ ;
- (5) Therefore, the similarity between A and C is much higher than D and E.

**Inference 1:** Nodes who have similar social relationship are more probable belong to the same community.

We construct the relation matrix in accordance with Figure 1 as below.

$$Matrix = \begin{bmatrix} 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1 \end{bmatrix}$$

By analyzing the matrix we know, the  $i$ th row of matrix represents the relation vector of  $i$ . As a result, we get the degree of  $i$  as formula 2 shows.

$$Degree_i = \sum_{j=1}^n Matrix_{i,j} - 1 \tag{2}$$

By calculating the cosine similarity between relation vectors, we can find the most similar neighbor for each target vertex or community.

**B. Community vector**

We use vectors to represent the vertices' social relationship. To conveniently calculate the similarity between free vertices and the existing communities, we also use vectors to demonstrate community themes. The

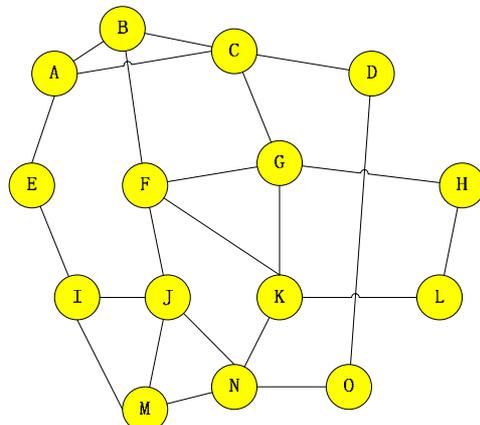


Figure 2. A simple undigraph.

eigenvector of community is combined by the relation vectors of the inner vertices. In this paper, we come up with two methods to demonstrate community eigenvectors.

- Binary vector representation

This method use binary numbers 0 and 1 to represent the community eigenvectors.

For example, the relation matrix of Figure 1 is  $Matrix$ , the relation vector of vertex  $i$  is  $Matrix_i$ . We use  $V_{SN}$  to represent the eigenvector of community  $SN$ , and the vector length is 12, the initial value of  $V_{SN}$  is 0. The binary vector representation method can be described as below.

foreach node  $i$  in  $SN$

$$V_{SN} = V_{SN} \cup Matrix_i \quad (3)$$

$V_{SN}(i)=1$  means that there is more than one edge to vertex  $i$ , while  $V_{SN}(i)=0$  means none. This method is only able to show whether there is an edge to  $i$  or not, but not able to count how many. Therefore, we put forward another method to represent the community's relation eigenvector.

- Relation weighted vector representation

This method is able to count the number of edges direct to the target vertex  $i$ , which to some extent reflects  $i$ 's attraction. We use  $SN_i(a)$  to represent the number of edges in community  $SN_i$  to vertex  $a$ . The larger of  $SN_i(a)$ , the bigger of  $a$ 's attraction. The calculation of relation weighted vector can be described as below.

foreach node  $i$  in  $SN$

$$V_{SN} = V_{SN} + Matrix_i \quad (4)$$

In this paper, the addition rules are as same as in math. Use Figure 1 as example, vertex 4 and 5 belong to  $SN_j$ . If we use binary representation,  $V_{SN_j} = V_4 \cup V_5 = \langle 1, 1, 1, 1, 1, 0, 0, 1, 0, 1, 0 \rangle$ . This result tells us that there are edges direct to vertices 1, 2, 3, 4, 5, 6, 9, 11 in the network, but we do not know how many. If we use relation weighted representation method,  $V_{SN_j} = V_4 + V_5 = \langle 2, 2, 2, 2, 2, 1, 0, 0, 1, 0, 1, 0 \rangle$ , it tells us that for this moment, there are two edges direct to vertices 1, 2, 3, 4, 5, and one edge direct to vertices 6, 9, 11.

Community vector vividly shows the relationship between vertices in the community, which makes it possible to weigh the similarity between free vertices and the existing communities. Besides, it provides an interface for the application of CF to CDA.

### C. Community seed

Based on thoughts in multi-function optimization, the best particle leads the rest ones to locate at the most suitable place[23]. Low degree means the vertex locate at the margin place while high degree means it locates at the core position. Community seed is the best local one in one community. We define the concept of community seed and free members as below.

**Definition 3:** Community seed. If vertex  $a$  is the first member of a community, it leads the following members

to locate around it. The number one vertex becomes the seed of this community.

**Definition 4:** Free members. The remained nodes in  $L_{degree}$  that haven't been divided into communities are called free members.

The steps to choose community seed are as below.

Step 1: All vertices are sorted in decreasing order of degrees which constitute a list  $L_{degree}$ .

Step 2: The set of community seeds  $S$  is initially set to empty.

Step 3: Vertices in  $L_{degree}$  are checked in turn from the beginning to the end of the list. If vertex  $i$  does not have connection with the existing communities  $\{SN\}$ , it becomes a new seed and is added to  $S$ ; if not, calculate the similarity between  $i$  and  $SN$  and if  $similarity(i, SN) < \delta$ ,  $i$  become a new seed and be added to  $S$ ; else if  $similarity(i, SN) > \delta$ ,  $i$  becomes a member of  $SN$ .

Because vertices with higher degrees are checked first, the community seed in each community must be the one with best location. These community seeds respectively guide the rest nodes in the same network to locate at the multiple optima.

The similarity between community  $SN$  and vertex  $i$  is calculated as formula (5) shows.

$$Sim(S, i) = \cos(S, i) = \frac{V_s \cdot V_i}{|V_s| \cdot |V_i|} \quad (5)$$

When the scale of network changes, it become necessary to change the minimum similarity threshold  $\delta$ . The larger of the network scale, the more complex of the relationship between vertices. The largest number of edges in a network who have  $n$  vertices is  $(n^2 - n) / 2$ , which means one vertex has a maximum  $(n - 1)$  neighbors. This paper uses relation matrix to represent the relationship between vertices in a network, every vertex has relation to itself which makes the biggest relation number to  $n$ . The principle of cosine similarity is that the more of the common neighbors that a pair of vertices have, the closer of the relationship between them. In a social network with  $n$  vertices, the maximum of the common neighbors is  $n$ , in other words, if two vertices have  $n$  common neighbors, the similarity between them must be 1, so we set the unit of minimum similarity threshold as  $1/n$ .

## III. CHCDA

In this algorithm, the number of seeds determines the number of communities in the entire network. As a result, we don't need to artificially set the number of communities.

### A. Description of community division

We still use Figure 1 to illustrate how this algorithm works out. For Figure 1,  $L_{degree} = \langle 5, 6, 4, 11, 1, 2, 7, 9, 3, 8, 10, 12 \rangle$ , we set the minimum similarity as  $1/12$ . Vertex 5 has the largest degree, so it becomes the first community seed, we name this community as  $A$ , and  $V_A = V_5$ . We check out the free members in  $L_{degree}$  one by one, and compare the similarities between them and  $A$ .

Figure 3 is the dividing result of binary representation and Figure 4 is the dividing result of relation weighted representation.

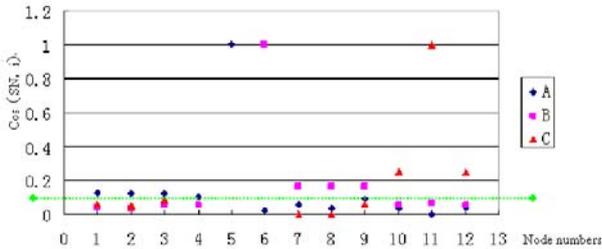


Figure 3. Division of binary community vector representation

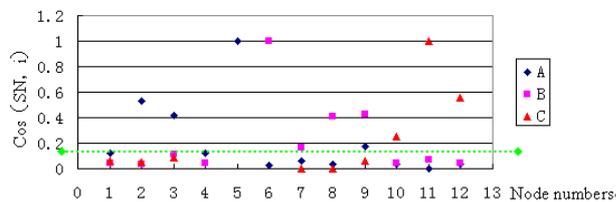


Figure 4. Division of relation weighted community vector representation.

The green dotted line in Figure 3 and Figure 4 is the line of minimum similarity threshold. Compare the results of different community representations, we can see that they get the same community structure, but the relation weighted representation can effectively expand the elasticity of relations between nodes and reduce the fuzzification of node's position.

Besides, there is a distinctive node in figure 4, node 9 belongs to both A and B. However, the similarity between community B and 9 is much higher. We call node 9 the contactor of A and B. Figure 5 shows the dividing results of relation weighted representation.

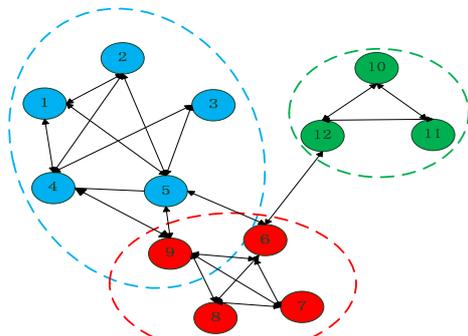


Figure 5. Divided social structure of the network in figure 1.

**B. Procedure of cooperative CDA**

- Step 1: Construct the adjacent map for network N;
- Step 2: Build the relation matrix;
- Step 3: Sequence the vertices in network N and build up  $L_{degree}$ ;

- Step 4: Look for the community seeds, define the community vectors.
- Step 5: Divide vertices into different communities.

**IV. EXPERIMENTAL RESULTS**

, We apply CHCDA to the dividing of Zachary club and dolphins network to test the feasibility of our algorithm.

**A. Zachary Club Network**

Zachary Club is a one of the most classical network for analyzing network structures. In 1970s, Wayne Zachary took three years to observe the social relationships of members in a US college's karate club, after then he constructed the Zachary's karate club network. The dataset includes 34 nodes and 78 edges, each node represents one member in the club, and edges state the relationship between members. In the procedure of investigation, he found that the director and the coach had disputes with each other about charging problems which result in the whole club break into two parts. The manager and the coach separately became the head of one part. In Figure 6, different colors represent members in different groups. As a real social network, Zachary club is often used to test the efficiency of community discovery algorithm.

Using CHCDA, we firstly construct the relation map of Zachary club. The degree ranking list is  $L_{degree} = \langle 34, 1, 33, 3, 2, 4, 32, 9, 24, 6, 7, 8, 14, 15, 28, 30, 31, 5, 11, 20, 25, 26, 29, 10, 13, 16, 17, 18, 19, 21, 22, 23, 27, 12 \rangle$ ,  $\delta = 1/34$ . During the test, we use relation weighted representation to illustrate how this algorithm works well.

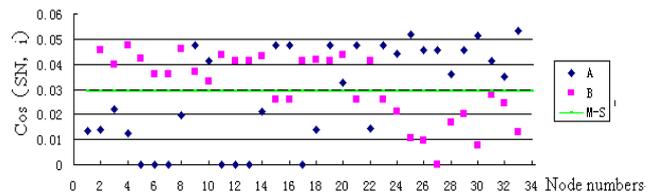


Figure 6. Division results of nodes in Zachary Club

In Figure 6, X axis represents the serial number of nodes in Zachary and Y axis represents the similarity between vertices and the existing communities. As we can see, the similarity values are much smaller than 1, so we take out of the similarity between vertex 1 and community B, vertex 34 and community A because they are too high to mark in the graph. Besides, similarity between 9 and A, 9 and B, 10 and A, 10 and B, 20 and A, 20 and B are all above the minimum similarity threshold, so 9, 10 and 20 are the connectors for community A and B, Which shows that CHCDA is really effective for discovering the overlapped area of communities. Figure 7 is the dividing result of CHCDA.

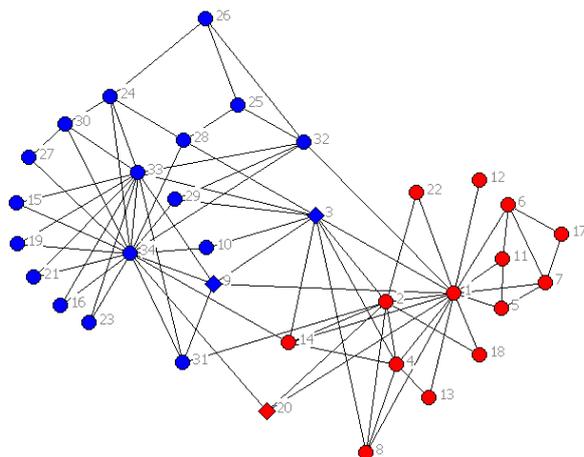


Figure 7. CHCDA division results for Zachary Club

**B. Dolphins Network**

Dolphin network is also a common dataset in the study of social networks. Lusseau and his fellows conduct systematic surveys about dolphins in Doubtful Sound, Fiordland, New Zealand. The survey course constantly remains over 7 years and covers the entire home range of Doubtful Sound population which includes 62 vertices and 159 edges. In Figure 8, each vertex represents a dolphin; a link means two dolphins have regular contact. We set the minimum similarity as 1/62 and get Figure 9.

Figure 8 shows that the entire network is divided into two parts. Besides, there are some special dolphins locate at the overlapped area, such as vertex 20, 31 and 37.

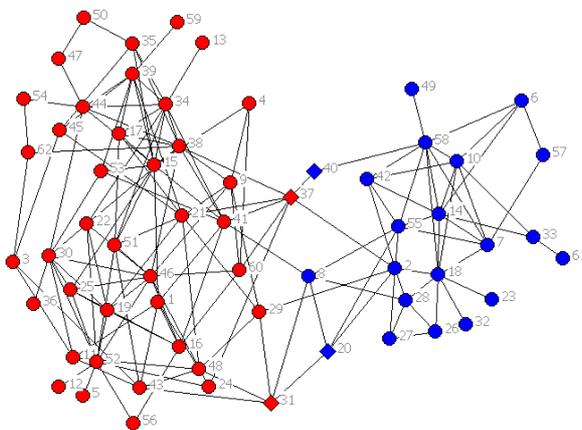


Figure 8. CHCDA division results for Dolphin

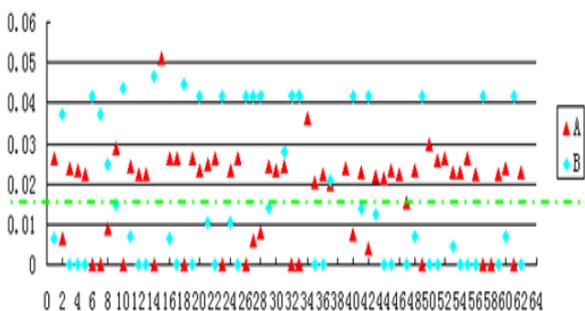


Figure 9. Division results of nodes in Dolphin

Individuals who lie on the boundaries of communities become bridge between unconnected communities. They play important roles in the procedure of information spreading. The discovery of connectors has great value to promote the communication and interaction between communities, especially in the E-commerce and citation network.

**V. CONCLUSION**

In this paper, we have analyzed the problem of detecting community structure in networks. During the research, we come up with a cooperative community detecting algorithm based on the ideas in multi-model optimization. We have three innovation points in this paper: (1) Introduce the concept of community seed, declare that community seeds guide the rest individuals to locate at the multiple optima. (2) Put over the idea of relation matrix, use relation similarity to weigh the social intimacy between nodes. (3) Apply CF's thoughts to community discovery; find the contactors between different communities. Those three characteristics enable the CHCDA algorithm efficiently finds the potential communities in large complex network.

Follow-up works include formulate the minimum similarity threshold and choose suited community vector representation for different social networks.

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