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An Integrated Approach to Uncover the Mystery Veil of the Criminal Network

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Abstract

In this paper we introduce three models, including Reliability model, Layered model and Centrality model. First, according to the reliability model, we determine a priority list of crime association. Then, we divide the level of the crime organization roughly with layered screen model. Find out the persons who within 4 layers from the center of the organizational layers, and determine their position in the priority list of association. Consider everyone above them in ranking is conspirators. So we get a target list. Final, we use Centrality model to determine the leader and core staffs from the list.

Keywords: Reliability model, Layered screen model, Centrality model, Semantics analysis and Text analysis.

Introduction

With the development of modern telecom technology, a huge flow of quantitative social, demographic and behavioral data is becoming available that traces the activities and interactions of individuals [1], there are lots of telecommunication activities associated with crime, and in many crime investigation practices, these information are often very helpful. This information is called "criminal telecom trace"[2]. Now a credit card fraud will be stopped by analyzing the data of information flow, and the head of offenders will be confirmed. A clear-cut distinction will be drawn to categorize people. In this paper we establish 3 models, including reliability model, layered screen model and centrality model.

Reliability model is designed to take the single node's reliability on criminal organizations as object function and the sequence of object function is arranged. The model is a pretty good description of the characteristics of the members of criminal organization. That is, criminal organization is to pursue security and high-efficiency [3]. We assume that crime organization stresses confidentiality dealing with internal information exchange.

The insiders can be high reliability while the outsiders are of low reliability, so the more information relating to crime a criminal can get, a more trusted person he is within the organization[4]. The results of reliability model are satisfactory and all the known criminals are included. Also, the following persons, including Elsie, Jean, Alex, Paul, Harvey, Ulf, Yao, Dolores, Neal, Seeni, Dwight, Stephanie Kim, Priscilla, Elsie, Beth, William, Lars, and Paigeare confirmed as suspects. The reason why we put Paige (known as innocent) into the category of suspects will be discussed in the main body.

Layered screen model is to screen node by using two layers standard. It can effectively determine the search scope of the suspects and help to find the core of the crime and tell whether the manager involve the criminal activities.

Centrality model is designed to take Betweeness, Connection and Closeness as parameter to determine the Centrality of the object function by weighting scheme. Centrality reflects the importance of a node in an organization and the part each member plays in a small group[5].

A comprehensive plan is concluded as follows: Alex, Ulf, Yao, Sherri, Gretchen, Dolores, Harvey, Reni and Elsie are the key members of the group. Reni has a backstage role. Elsie, Sherri, Dolores, Alex and Gretchen are contact persons. Ulf, Yao and Harvey assume the role of backbone. It is likely that the managers, Gretchen and Dolores, are involved in the crime. Our model has passed the analysis on sensitivity and the minor change on the organization will not exert influence on the analyze results [6].

In the Task II we take topic 1 as suspected topic and Chris becomes suspect. We find that Hazel, Jerome and Eric are highly suspected, which is different from the previous result. It indicates that by adding new information, our model will provide useful massage to track down the criminal [7][8].

In the Task III we have analyzed the important role of semantic analysis and text analysis in the model and obtained more satisfactory results by applying more precise semantic and text analysis. Ranking for Bob and Lnez, who are involved in small case, have been ascertained in a more credible way. The criminal charge for Carol will not be brought up.

In the Task IV the established model is practical and by simple matching, we find the scope of infected cells by applying the above model, that is,

(1) Cell→network node

(2) Infected cells→conspirator in the network;

(3) Uninfected cells→conspirator but with less intelligence in the network

(4) Infectiosity among cells determined by image and chemical message of a pair of cells→suspicion of the topic.

General Assumptions

In order to determine the list of criminals in the message traffic network, we need to establish a program to measure the relevance of each individual and the criminal case, and gradually introduce it. So our goal is pretty clear: Establish a model, algorithms and the priority list. Determine whether the manager involves in the crime and who are the senior staff and leaders. If the information given changes how will the results change. How do the semantic analysis and text analysis improve the accuracy of the model? Apply the model to solve other problems.

Our approach is deeply analyzing data in the problem, gradually establishing a model to describe the character of the criminal networks rationally. Also With available data in the scenario (called Investigation EZ) given by supervisor, test the correctness of the model.

Build a model using the degree of association(to measure the relationship between the node and the crime) to rank every node in the network. At the same time, analyze the meaning of the ranking. Through computer simulation, get the influence of information changes on model results. Then we make full use of semantic and text analysis to do further discussion based on our work.

According to the characteristics of a criminal organization, we make the following assumptions:

(1) The criminal organization pays much attention to the confidentiality of the information exchange. People in the organization have a higher degree of association. Similarly, people out of the organization have a lower degree of association.

(2) Sensitive information leads a significant role in determining the identity, but irrelevant information play a secondary role.

(3) If a member of the crime who is deeply trusted by the organization, then he is more likely to be exposed to more information about the conspiracy.

(4) If a member of a criminal organization who plays an intermediary role, he may have more information about the conspiracy and there are a considerable number of underlying criminals obtaining information through him.

Solutions

Table 1: Model parameters.

Parameter	**Meaning**
Rel	Reliability
Rel(i;j)	The element (i;j) of matrix Rel
Bet	Betweeness
Con	Connection
Clos	Closeness
N	The numbers of nodes
Sw	Sum of all the link weigh that connected to one node
Weigh	A number that was given to a link which describes how important is the message it carries
Rcon(k)	Relative connection of node k
Rbet(k)	Relative bewteeness of node k
Rclo(k)	Relative closeness of node k
Con(k)	Centrality of node k

Task I:

Model I

Reliability Model

In order to describe the internal staff of a criminal organization by the level of trust[9], we have introduced the concept of reliability. For any pair of nodes in the information network, the more their topic relevant to the crime can reflect the more they trust each other [10]. First of all, according to the degree of association of the topic, we assign the network connection a weight. Let this weight be R(i, j) ($0<R(i, j)<1$) .Here we consider one of the most simple classification methods, the weight of known sensitive topic is set to 0.9, and weight of non-sensitive topic is set to 0.1. In order to arrive at the reliability between a node and the criminal organization, we add another node to the original network called criminal node. At the same time, connect the known criminals and the criminal node getting several new lines. Because we are sure of that known criminals must involve in the crime, so we set the weight of these new lines to 1.Meanwhile, we get a new figure with different weight (Figure1). In order to determine the reliability of each node for a criminal organization, we make the following processing:

(1) Adjacency matrix R, where $R_{ii}=1$. If there is no line between two nodes which means there is no reliability, so the corresponding position on the value 0.

(2) State transition equation.

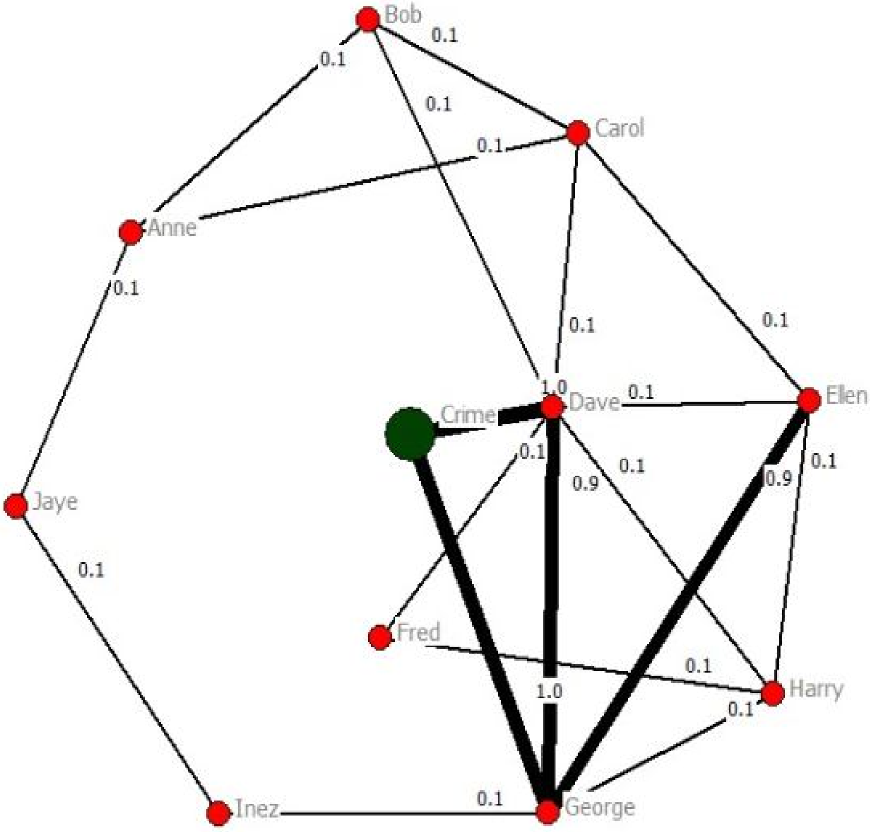

Figure 1: A new network.

We assume that if i can only connect j with k, then i relative to j's reliability equals to the product of i to k's reliability and k to j's reliability.

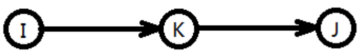

Figure 2

If i can connect with j, then we take the maximum value of i to j's reliability and i to k to j's reliability.

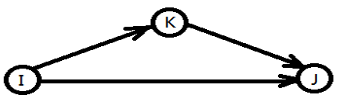

Figure 3

Calculate for each pair of nodes by the state transition equation.

$$\mathrm{Rel}(i,j) = \max\{\mathrm{Rel}(i,j), \mathrm{Rel}(i,k) * \mathrm{Rel}(k,j)\}$$

By the original matrix R (0) construct a new matrix R (1). With the same method, we can get R(2) through R(1).And so back and forth we can construct R(N)in the end. on behalf of the I to j maximum reliability rate. The entry (i, j) of matrix R[N] represent maximum reliability of i to j.

The n+1th line of the matrix represents the maximum reliability of I to criminal node. Rank the matrix Rel [i, n+1](i=0, 1, 2, …, n). We obtain a priority list from the ranking. The higher value on behalf of this node is more relevant to the criminal organization. Unrelated topic will not affect the results.

The established model is applied to the case which supervisor offered. Draw the following list:

Table 2: Result from model 1 about the EA case.

ranking	reliability rate	node	name
1	1	1	Dave
2	1	4	George
3	0.9	2	Ellen
4	0.1	9	Inez
5	0.1	0	Bob
6	0.1	3	Harry
7	0.1	5	Fred
8	0.1	6	Carol
9	0.01	7	Anne
10	0.01	8	Jaye

From the calculation results, we can see known conspirators do really rank the top of the form, Ellen Inez and Bob also rank forward. But we cannot single out Inez and Bob from the ranking from4-8. This model only gives a rough classification. Usethis model to calculate the large-scaledata, results are as Table 3.

From the calculated results, the model can effectively identify the part of criminals, and most of innocence ranked. But still frame Paige, and we do not know the correctness of the ranking. From the calculated results, the model can effectively identify the part of criminals, and most of innocence ranked behind. But we still frame Paige, we do not know the correctness of the ranking, either. Thus we introducea second model.

Table 3: Suspects

ranking	reliability rate	node	name
1	1	7	Elsie
2	1	18	Jean
3	1	21	Alex
4	1	43	Paul
5	1	49	Harvey
6	1	54	Ulf
7	1	67	Yao
8	0.9	10	Dolores
9	0.9	17	Neal
10	0.9	81	Seeni
11	0.9	28	Dwight
12	0.9	30	Stephanie
13	0.9	33	Kim
14	0.9	36	Priscilla
15	0.9	37	Elsie
16	0.9	38	Beth
17	0.9	50	William
18	0.9	60	Lars
19	0.9	2	Paige
20	0.81	3	Sherri
21	0.81	6	Patrick
22	0.81	9	Malcolm
23	0.81	11	Francis
24	0.81	13	Marion
25	0.81	16	Jerome
26	0.81	20	Crystal
27	0.81	22	Eric
28	0.81	29	Wayne
29	0.81	31	Neal

Table 4: Innocents

ranking	reliability rate	node	name
55	0.1	0	Chris
56	0.1	1	Kristina
57	0.1	25	Claire
58	0.1	65	Jia
59	0.1	66	Melia
60	0.1	73	Carina
61	0.1	82	Reni
62	0.09	26	Marian
63	0.09	59	Darol
64	0.09	68	Ellin
65	0.09	75	Bariol
66	0.09	80	Fanti
67	0.081	53	Chara
68	0.081	55	Olina
69	0.081	58	Lao
70	0.081	70	Hark
71	0.081	78	Este
72	0.081	79	Phille
73	0.0729	77	Gerry
74	0.06561	62	Mai
75	0.06561	71	Cory
76	0.01	64	Tran
77	0.009	76	Cole
78	0.0081	52	Vind
79	0.0081	74	Gard
80	0.006561	56	Cha
81	0.006561	61	Le
82	0.006561	63	Quan
83	0.005905	57	Sheng

Model II

Layered Screen Model

Up to now, we still do not give a clear line of the criminal organizationto distinguish who should be included in the suspect.To this end we come up with the third model whose idea is quite simple. It uses two layered criterion to screen the criminal suspects step by step.

The first standard: With given lines, if a talk contains three sensitive topics, we are almost certainly that they are talking about the crime. If a talk contains two sensitive topics, it still has major suspicion. Use of this standard can determine two types of suspects, including a class like number 54Ulf, 67Yao, 21Alex. The otherclass includes number81Seeni, 49 Harvey, 10Dolores, 4Gretchen, 3Sherri. These two types of people are major suspects.The second standard: sum up all the weights of topics which connected with a node as a new criterion.
We arrive at a ranking as shown in Figure:

Table 5: Results from model 2.

No.	Node	Name	SW
1	21	Alex	
2	67	Yao	
3	54	Ulf	
4	81	Seeni	
5	49	Harvey	
6	10	Dolores	
7	4	Gretchen	
8	3	Sherri	
9	7	Elsie	100
10	43	Paul	70
11	18	Jean	50
12	17	Neal	50
13	16	Jerome	50
14	13	Marion	50
15	47	Christina	40
16	34	Jerome	40
17	28	Dwight	40
18	15	Julia	40
19	2	Paige	40
20	50	William	30
21	48	Darlene	30
22	41	Donald	30
23	38	Beth	30
24	37	Elsie	30
25	32	Gretchen	30
26	29	Wayne	30
27	20	Crystal	30
28	19	Kristine	30
29	6	Patrick	30

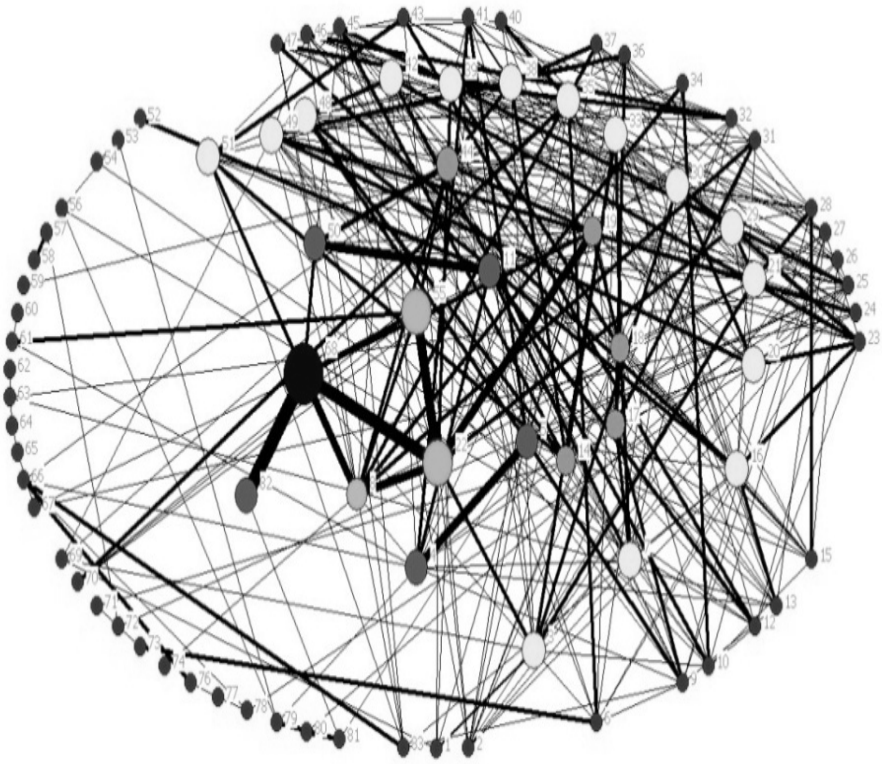

Figure 5: a same picture as Figure 4, but delete unimportant person.

From the figure, it can be seen that the ranking has an apparent distinguish between the levels. Through the screening of a two-tier standard, integrated network diagram is as follows: Figure 4 &5.

From the results of models, we can get a conclusion that number 21Alex, 67Yao, 54Ulf, 81Seeni, 49Harvey, 10Dolores, 4Gretchen, 3 Sherri are at the heart of the criminal organization. 7Elsie, 43Paul, 18Jean, 17Neal, 16Jerome, 13Marionhave high suspect degree. We are ought to consider the yellow part of the table (number 3-51). As for the white part, included in the scope of investigation is of little value.Once key personnel are arrested, the criminals in the white list could be easily exposed. Model two provide an evident distinction boundary. People ranking above number 51 should be seen as the focus of the investigation object. At this point, we narrow the search scope within 29 people.

As shown in the figure, compare the first 29 lines of model 1 and model2 together (Table 6). The degree of coincidence reaches to 75%. This is a very satisfactory result, and it verifies the correctness of model 1. Number 10 Dolores ranks front both in the two models.

Table 6: Compare the first 29 lines of model 1 and model2 together.

Reliability model	layered screening model
2	2
3	3
	4
6	6
7	7
9	
10	10
11	
13	13
	15
16	16
17	17
18	18
	19
20	20
21	21
22	28
28	29
29	
30	
31	
32	32
33	
	34
36	
37	37
38	38
	41
43	43
	47
	48
49	49
50	50
54	54
60	
67	67
81	81

Model III

Centrality Model

So far, the analysis of the internal hierarchy of criminal organizations relies solely on the model 2. We need another model forto verify it.

According to some other features of a criminal organization:

If a member plays an intermediary role in a criminal organization, he may be exposed to more information about the conspiracy. There are a considerable number of the underlying personnel need to go through him to get criminal intelligence so as to commit the crime.

Some members would be very active;it is likely to exchange information, or to cover up the important conversation by a large number of unrelated conversations.

The core members of criminal organizations should have a higher ability to control the small group that surrounding them.

Accordance with the above characteristics, we use the social relations analysis (SNA) to introduce intermediary degree, associate degree and tightness to describe the three characteristics above.

Network properties are defined as follows:

$$\mathrm{Con}(k) = \sum_{i=1}^{n} a(i,j) \qquad (1)$$

Formula (1) indicates the connection of node A_k(node stands for entity).Connection represents the activity of the node in the network. Where n are the total nodes of the network. When$a(i,j) = 1$, there is a direct connection between i and j. when $a(i,j) = 0$, there is no connection.

$$\mathrm{Bet}(k) = \sum_{i=1}^{n} \sum_{j=1}^{n} g_{ij}(k) \qquad (2)$$

The shortest path through A_k is called betweeness, and let it be$Bet(k)$. It shows the capability of the node to connect other nodes as an intermediary. Formula (2) defines the betweeness.
Where $g_{ij}(k) = 1$ indicates that the shortest path between i and j via k.

$$Clo(k) = \sum_{i=1}^{n} l(k,i) \quad (3)$$

The sum of shortest path between A_k and every node in the network is defined as closeness. It describes the capacity that it controls its own small group surrounding it. To some extent, it can be regarded as the core of the sub-network.

Six Degrees of Separation Principle

This principledescribe the connectivity of the social network: to establish contact between any two people in the community we just need four intermediaries. The theorem is derived under the ideal assumptions, the researchers made a lot of social experiments to verify the universality of this theorem.Taking criminal networks into accountit also belongs to social network. Our case quantity is relatively small, so we think there is up to two middlemen between any of two.
We need to work out the shortest path. Line with high degree of association should be assigned lower weight. Now we define a new weight.

$$Weight = 1 - SuspicionDegree$$

With Floyd algorithm we can calculate the shortest path between two node, and record the path.
For any point in the figure, calculate the number of dots connected with it(connection), the number of its most short-circuit(betweeness) and the sum of the shortest path connected with other points (closeness).
Centrality should be combined with three parameters rationally to represent the degree of association between node and criminal issues.
Relative connections

$$R_{Con}(k) = \frac{Con(k)}{n-1}$$

Relative betweeness

$$R_{Bet}(k) = \frac{Bet(k)}{(n-1)^2}$$

Relative closeness

$$R_{Clo}(k) = \frac{Clo(k)}{(n-1)^3}$$

Centrality

$$Cen(k) = R_{Con}(k) + R_{Bet}(k) - R_{Clo}(k)$$

The results are very satisfactory, Bob and Inez ranked second only to known suspects, Although it may cast doubt on Bob's ranking front because of his conversation is too frequent, the weight we assign to topic has big difference. It won’t bring great influence to the result. Bob ranked high because he has a high betweeness within the organizations, and he played the role of a messenger.

Table 7: Use model to solve the EZ case.

Ranking	**Centrality**	**Node**	**Name**
1	0.259807956	2	Dave
2	0.197942387	5	George
3	0.069821674	1	Bob
4	0.068449931	10	Inez
5	0.045404664	7	Carol
6	0.040603567	8	Anne
7	0.037037037	3	Ellen
8	0.02962963	4	Harry
9	0.014403292	9	Jaye
10	0.004252401	6	Fred

Applied to large amounts of data, the results are ranked as follows

Table 8: Results in model 3 about suspects.

Ranking	**Centrality**	**Node**	**Name**
1	0.288278427	32	Gretchen
2	0.246499797	7	Elsie
3	0.245751839	15	Julia
4	0.239064291	43	Paul
5	0.230447541	3	Sherri
6	0.224344902	2	Paige
7	0.219727115	17	Neal
8	0.217950625	24	Franklin
9	0.21228635	44	Patricia
10	0.206811966	34	Jerome
11	0.205918008	48	Darlene
12	0.202188194	10	Dolores
13	0.197403368	13	Marion
14	0.195494842	20	Crystal
15	0.192949174	47	Christina
16	0.189689463	18	Jean
17	0.185070407	4	Gretchen
18	0.184632587	21	Alex
19	0.167835457	29	Wayne
20	0.165295229	8	Hazel

Table 9: Results from model 3 about innocents.

Ranking	**Centrality**	**Node**	**Name**
55	0.060790071	0	Chris
56	0.059169375	80	Fanti
57	0.056376685	62	Mai
58	0.053758288	33	Kim
59	0.052661199	78	Este
60	0.048749293	69	Han
61	0.048606013	68	Ellin
62	0.042954977	70	Hark
63	0.042823305	66	Melia
64	0.042021118	60	Lars
65	0.039452961	77	Gerry
66	0.036891513	52	Vind
67	0.03647981	55	Olina
68	0.032053365	81	Seeni
69	0.029724794	75	Bariol
70	0.027339091	72	Andra
71	0.026372767	56	Cha
72	0.026064443	53	Chara
73	0.025747051	79	Phille
74	0.024569253	63	Quan
75	0.02435397	64	Tran

Overall, in the office people who is more active with higher ranking? The results of the ranking are not that ideal, because model 2 is fit to determine the known relationship among small groups. On the basis of ranking from model 1, we screen part of the suspects.

If some of them rank front in the second ranking, he is most likely to be the core member of the organization.

If some of people rank back, he can be the leader of the criminal organization; in order to secure safety they prefer one-way communication. They just keep in touch with the core members. By comparison with model 2, Reni is the direct behind the scene. Elsie, Sherri, Dolores, Alex, Gretchen are messengers.Ulf, Yao and Harveyare the diathesis backbone.

Manager Gretchen and Dolores are most likely to involve in the crime.

This information is quite useful to investigators; by monitoring the messenger can obtain information about criminal behavior so as to capture all the criminals at one swoop.

Sensitivity analysis

To sum up, we get 3 models. It is very obvious that 3 models are not sensitive depend on the weight of links in network. Because the weight we have assumed are so heavy that even if the weights change a little bit the results won't change a lot.

To add or delete nodes which only connected with unimportant message will not affect the results of model 1 and model 2. In the procedure of algorithm, those nodes cannot be considered. But the result from model 3 will change if the node added in or deleted has many links to other nodes. Take in to consideration that model 3 is a assistant model toward model 1 and model 2. The analysis output could stay still. Even if there is truly some differences our integrated approach will provide some new information to help investigators with the case.

Comparison of the Three Models

To compare 3 models with each other, we have found that model 1 can provide a priority list according to the degree of association. Model 2 can give a discriminate line so the investigators can categorize people conveniently. With results from Model 1 and 2, model 3 can tell us details about the crime gangs.
A better idea is, firstly we give a priority list of people. And then, with the help of model 2 we can decide who should be suspected. Finally, model 3 can tell us who the leader of the criminal gang is.

The ranking of some nodes in the priory list is obviously wrong. For example, Paige is a known non-conspirator. But the ranking is very high. In this case, those people like Paige are unusual. They may realize some clue of the coming crime act. But will not be involved into it. Some of them are even the victim of the crime. The content of their message maybe a reflection of their minds. So if investigator pays more attention on them, some crime-related key factor can be discovered.

Task II

Turn topic 1 into a issue which is considered a part of conspiracy. And turn Chris into a known conspiracy. Recalculate 3 models. We have a result as Table 9.

Table 10: Result after the change.

No.	**Node**	**Name**
1	54	Ulf
2	21	Alex
3	67	Yao
4	3	Sherri
5	4	Gretchen
6	8	Hazel
7	16	Jerome
8	49	Harvey
9	10	Dolores
10	81	Seeni
11	7	Elsie
12	43	Paul
13	17	Neal
14	22	Eric
15	32	Gretchen
16	15	Julia
17	13	Marion
18	48	Darlene
19	34	Jerome
20	18	Jean

We can know that 54Ulf, 21Alex, 67Yao, 3Sherri, 4Gretchen, 8Hazel, 16Jerome, 49Harvey, 10Dolores, 81Seeni, 7Elsie, 43Paul, 17Neal, 22Eric, 32Gretchen, 15Julia, 13Marion are suspects. 81 Seeni may be the leader of them. 54Ulf, 21Alex, 67Yao are middlemen. And 3Sherri, 4Gretchen, 8Hazel, 16Jerome, 49Harvey, 10Dolores, 7Elsie are other important person in the crime gang. It is amazing that the suspect of Hazel, Jerome, and Eric were significantly improved.

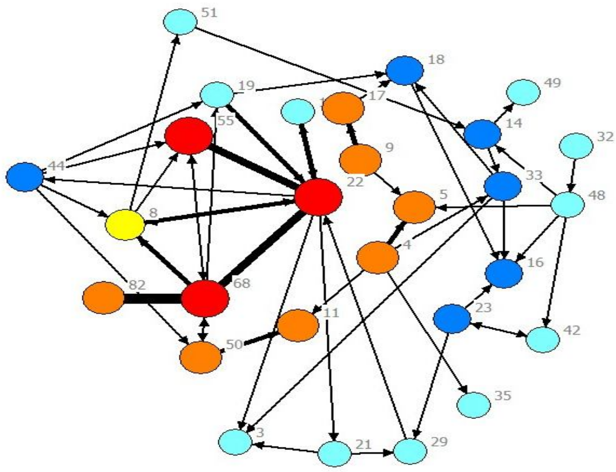

Figure 6: The structure of the crime gang.

It means that our integrate approach is practical. With new information inputted into the model, it cans feedback useful information about new conspiracy and crime gang structure.

Task III

About semantic and content analysis

The weights that a message carries play an important role in our model. The more accurate the weights are given, the more precise the result is. Our assumptions are ideal. The weights about conspiracy messages are much larger than the weights of messages that have less relationship with conspiracy. An accurate semantic and content analysis should avoid such situation：

(1) Put a common message among a sensitive topic.

(2) A message that is closely related to the crime is missing.

If accurate semantic and text analysis is applied, we will not miss people like Inez, and will not wrong people like Carol.

For example, we analyze message on our own, and assign weight on every link. As shown in Figure 7.

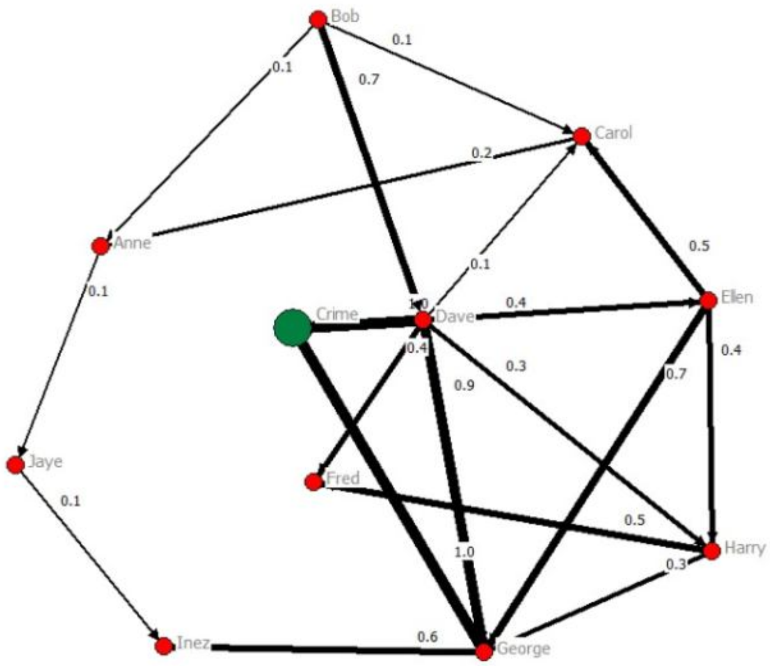

Figure 7

The results show that more accurate semantic analysis can really help improve the accuracy of our model.

We get results in Table 11.

Table 11

No.	**Node**	**Name**
1	1	Dave
2	4	George
3	2	Ellen
4	9	Inez
5	0	Bob
6	3	Harry
7	5	Fred
8	6	Carol
9	7	Anne
10	8	Jaye

Task IV

Our model can not only determine each person's criminal association to the criminal networks and analyze the structure of criminal organization, but also solve the problem of cellular network. For example, given the image and chemical data of each cell in a certain range and we know part of the infected cells and uninfected cells. We can calculate the possibility of infection of each cell according to the model.

We make the following correspondence:

(1) Cells→ Network nodes

(2) Infected cells→ Conspirators in the network

(3) Uninfected cells→ Non-conspirators in the network

(4) Infectiosity among cells determined by image and chemical message of a pair of cells→ suspicion of the topic.

Conclusion

We propose a set of comprehensive plan: First, according to the reliability model, we determine a priority list of crime association. Then, we divide the level of the crime organization roughly with layered screen model. Find out the persons who within 4 layers from the center of the organizational layers, and determine their position in the priority list of association. Consider everyone above them in ranking is conspirators. So we get a target list. Final, we use model 3 to determine the leader and core staffs from the list.

Our approach can be used in many fields. Similarly, cell infection can also use our model to get vital information.

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