数据驱动的区块链框架下政府部门间信息共享

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摘要: 政府部门间的信息共享对提升政府部门的服务和效率具有重要作用. 目前尚未有有效且安全的方法实现数据驱动的信息共享以满足政府部门动态的信息共享需求. 针对政府部门间信息共享, 本文提出了一种利用区块链和数据挖掘技术实现的数据驱动的框架. 首先, 以区块链为核心设计了整个框架, 以实现对政府信息泄露和滥用的监控和预防, 保障信息安全; 然后, 设计了相应的4层次结构, 用以实现提出的框架; 其次, 采用了经典的数据挖掘算法PageRank和Apriori动态设计信息共享的智能合约, 以实现基于政府部门对公共管理和公共服务的实际需求灵活调整信息共享策略的目的; 最后, 给出了解释此框架如何运作的一个案例研究.

关键词: 政府数据处理; 区块链; PageRank; apriori

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Inter-agency government information sharing under data-driven blockchain framework

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Abstract: The inter-agency government information sharing (IAGIS) plays an important role in improving service and efficiency of government agencies. Currently, there is still no effective and secure way for data-driven IAGIS to fulfill dynamic demands of information sharing between government agencies. Motivated by blockchain and data mining, a data-driven framework is proposed for IAGIS in this paper. Firstly, the blockchain is used as the core to design the whole framework for monitoring and preventing leakage and abuse of government information, in order to guarantee information security. Secondly, a four-layer architecture is designed for implementing the proposed framework. Thirdly, the classical data mining algorithms PageRank and Apriori are applied to dynamically design smart contracts for information sharing, for the purposed of flexibly adjusting the information sharing strategies according to the practical demands of government agencies for public management and public service. Finally, a case study is presented to illustrate the operation of the proposed framework.

Key words: government data processing; blockchain; PageRank; apriori

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1 Introduction

Inter-agency government information sharing (IAGIS) is helpful for promoting the administration of government agencies and improving service of government agencies[1]. The Chinese government has published a serry of policies since the year 2015. Under the guidance of rational policies, local governments in China have actively promoted the construction of government information sharing, including building sharing platforms and optimizing the processes of public services.

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At present, government information sharing in China has achieved preliminary success.

Current researches have paid attention on government information sharing. Some researchers focus on the influential factors for information sharing. The tense relationships between agencies and inadequate preparedness of agencies [2] have negative effect on information sharing. Strong relationships of business between agencies [3] and the high demand of agencies for information sharing [4] promote the progress of information sharing. In addition, unified standard for techniques and compatibility of technical infrastructures [5], the use of centralized information systems [6] or collaborative platforms [7] bring positive effect on information sharing. According to the above discussion, the following three issues for effective IAGIS should be addressed.

1) There is a lack of researches on how to improve the IAGIS according to data from government agencies. Few researchers focus on discover diverse demands between government agencies in IAGIS. The personalized recommendation [8] can be used to discover demands of agencies, but it ignores the relationships between agencies.

2) It is important to trace the use of information during sharing to protect protecting agencies' benefits. The blockchain is one of the ideal techniques for its helpfulness on the transparency of processes [9], the privacy problem in government information sharing [10], the more effective marking sharing process [11] and the innovation and transformation of government processes [12].

3) There is a lack of researches on the basic managerial rules for standardizing the process of information sharing. Previous studies [1, 13–15] mainly focus on technical solutions for information sharing, ignoring the basic managerial rules for agencies in IAGIS. The basic managerial rules are important for preventing information abuse during information sharing.

The following four research objectives are presented to address the above three issues.

1) Data-driven IAGIS: This objective is proposed to address Issue 1), for finding appropriate data from government agencies to improve the IAGIS. Government agencies will process lots of enterprises' requests which are possibly related to several government agencies. The analysis of request data is helpful for discovering related agencies. Information sharing between related agencies helps to improve the efficiency and effectiveness of government agencies. The improvements include saving time to confirm inessential repeated information, and achieving more information from related applications.

2) Traceability of the use of information: This objective is proposed to address Issue 2), for utilizing suitable techniques to trace the use of shared information. The government information databases contain sensitive and private information. An effective IAGIS must have a mechanism for monitoring and preventing the leakage and abuse of information.

3) Permission levels of government agencies for information sharing: This objective is proposed to address Issues 1) and 3), for discovering the basic sharing demands of government agencies and designing the first-level managerial basic rules for information sharing. In processing enterprises' requests, the demands for information sharing among different government agencies are different. A mechanism should be developed to determine the unique permission levels for each government agency to access government information and meanwhile prevent the abuse of government information.

4) Special permissions among related government agencies: This objective is proposed to address Issue 1) and issue 3), for discovering the special sharing demands of government agencies and designing the second-level managerial basic rules for sharing. Some government agencies may have strong relationships because their responsible enterprise requests are highly related. Strongly related government agencies should have special permissions for information sharing, ignoring their permission levels.

According to the above discussions, this paper proposes a IAGIS framework to address the above for objectives. For Objective 1), the framework is operated based on the analysis on data of enterprises' requests for government agencies. For Objective 2), the information sharing transactions are recorded by blockchain [16] which is suitable for tracking the use of shared information and has been applied in various scenarios [17–19]. For Objective 3), the PageRank algorithm [20] is used to determine the permission levels of government agencies by constructing link relationships between agencies to identify their importance in information sharing. For Objective 4), the Apriori algorithm [21] is used to determined special permissions for strongly related government agencies according to association rules.

The contribution of this paper is the illustration of a new data-driven framework for effective and secure IAGIS. On the one hand, our framework can dynamically adjust IAGIS strategies according to enterprises'

request data, to fulfill diverse demands of information sharing of government agencies. On the other hand, our framework is developed based on blockchain to monitor and prevent leakage and abuse of information.

2 The proposed framework

2.1 Overview

Our proposed IAGIS framework is shown in Figure 1. The framework contains two main components: A shared ledger and two smart contracts.

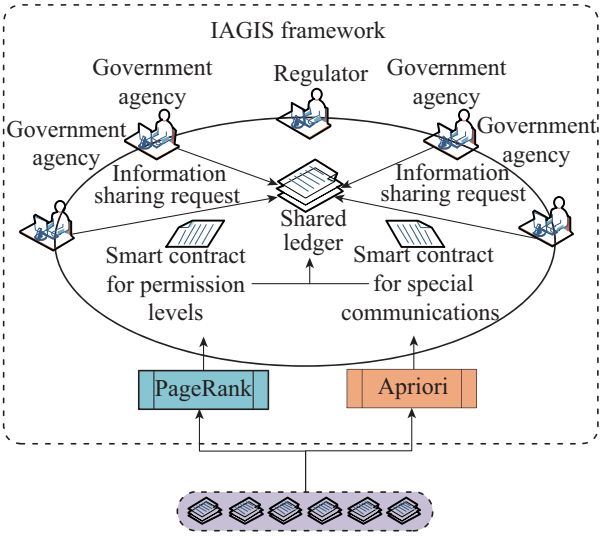

Fig. 1 The proposed IAGIS framework

The regulator can monitor leakage and abuse of information in the shared ledger of blockchain. The traceability of the use of data in blockchain is realized by using the mechanism shown in Figure 2. The transaction stored in the shared ledger will be updated in every new sharing request by adding the digital signature of agency who sends the new request, ID of the agency and timestamp. The digital signature of an agency is created by using the private key of the agency and can be validated by using the public key of the agency. The digital signatures, timestamps and agency IDs can be conveniently used to trace the use of data in blockchain.

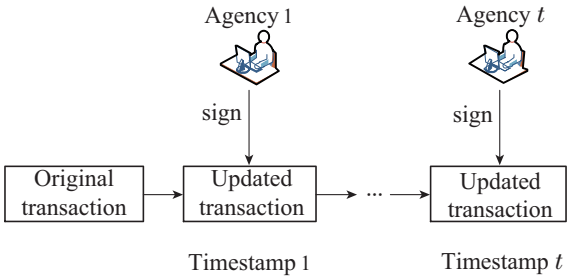

Fig. 2 Mechanism for tracing data in blockchain

The two smart contracts (smart contracts for permission level and smart contracts for special communications) in blockchain are used to determine the conditions in which the IAGIS requests are allowed. The two smart contracts are developed, respectively, by PageRank and Apriori according to enterprises' request data.

2.2 Architecture for implementing the proposed framework

The proposed framework can be implemented by the architecture which is shown in Figure 3. The architecture contains four layers. The user interface layer provides interfaces for users to participate in information sharing. Agencies who participate information sharing (shown in Figure 1) are allowed to interact with each other, share their data and send sharing requests to achieve the demanded data through the user interface layer. All the completed transactions on information sharing are recorded in the shared ledger. Moreover, agencies can also check the shared ledger through the user interface layer. The function layer covers the functions for managing government data. The blockchain layer covers settings and structures of blockchain. The infrastructure layer offers necessary supports and infrastructures for operation of the architecture.

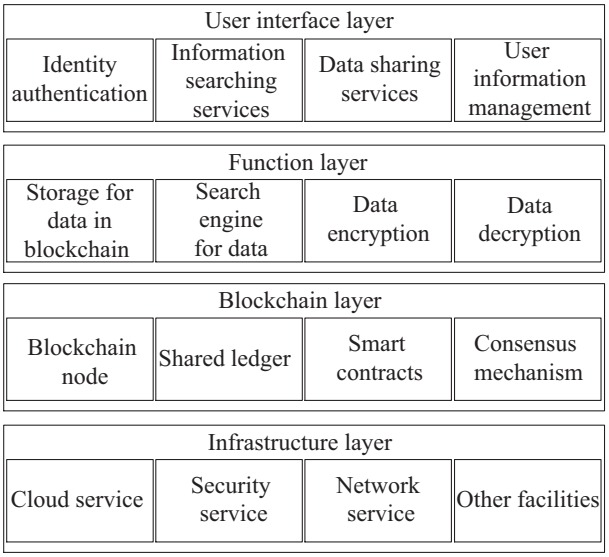

Fig. 3 Architecture for implementing the framework

2.3 Smart contracts for the proposed framework

This section illustrates how to design smart contracts based on the PageRank and Apriori. An example dataset I is given in Table 1. The data is sorted from the earliest accepted date (the dates when government agencies accept the requests) to the latest one. This dataset will be used as an example to illustrate how the two smart contracts are determined by PageRank and Apriori. A case study will be given in Section 3 to further illustrate the operation of our IAGIS framework.

2.3.1 Smart contract based on PageRank

The PageRank is used to design the smart contracts for permission levels. The relationships among government agencies can be determined by PageRank. According to Table 1, we can summarize Table 2 to reflect the relationships among government agencies in the view of enterprises. In the first row of Table 2, the relationship "$G_1 \to G_3 \to G_2$" reflects the fact that E_1 proposes requests from G_1 to G_3 and then to G_3, according to the accepted dates in Table 1. The relationship between all the government agencies can be summarized by an agency directed graph (shown in Figure 4), according to Table 2. Then, we have

$$R = [R(G_1)\ \ R(G_2)\ \ R(G_3)]^{\mathrm{T}},$$
$$A = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix},$$
$$E = [\frac{1}{3}\ \ \frac{1}{3}\ \ \frac{1}{3}]^{\mathrm{T}}.$$

Table 1 The example dataset I

Enterprise	Government agency	Application	Accepted date
E_1	G_1	A_1	T_1
E_2	G_2	A_2	T_2
E_1	G_3	A_3	T_3
E_1	G_2	A_4	T_4
E_2	G_1	A_1	T_5
E_2	G_3	A_3	T_6

Table 2 The example dataset I for PageRank

Enterprise	Government agency relationship
E_1	$G_1 \to G_3 \to G_2$
E_2	$G_2 \to G_1 \to G_3$

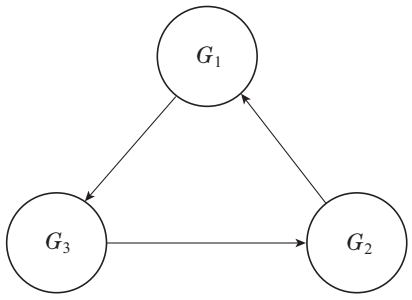

Fig. 4 The example of relationships between government agencies

R givens the ranks of agencies. A reflects the relationship among agencies. E is the adjustment factor for agencies. After iterations, the optimal solution $R^* = [R^*(G_1)\ \ R^*(G_2)\ \ R^*(G_3)]^{\mathrm{T}}$ is achieved to reflect the ranks of G_1, G_2 and G_3. The rank of each government agency indicates the importance of the corresponding agency in information sharing. The basic idea of PageRank is that a web page is more important if more other web pages link to it. Similarly, we can use the basic idea of PageRank to evaluate the importance of a government agency: a government agency is more important in information sharing if more other government agencies link to it in the agency-directed graph which is summarized according to government data of enterprises' requests. For example, G_1 is more important than G_2 in information sharing if $R^*(G_1) > R^*(G_2)$.

The idea of our IAGIS framework for evaluating the importance of government agencies in information sharing can be explained as follows. If a government agency G owns many links from other government agencies, it accepts lots of requests from enterprises after other government agencies, indicating that the function of G is more possibly related to other government agencies. The shared information from other government agencies possibly helps to improve the effectiveness and efficiency of G in dealing with daily transactions.

The permission levels of government agency i can be determined by Equation (1) according to R^* .

$$P_i = \frac{1}{\sum\limits_{j=1}^{n} R^*(G_j)} R^*(G_i) \times 100, \tag{1}$$

For example, if $n = 3$ and $i = 1$, then we have

$$P_1 = \frac{100 \times R^*(G_1)}{R^*(G_1) + R^*(G_2) + R^*(G_3)}.$$

Actually, P is the percentage vector which determines the percentages of government agencies that each government agency is allowed to choose to request information sharing. For example, $P_1 = 30\%$ indicates that G_1 is allowed to request information from 30% of the whole government agencies. $P_1 \times 3$ is the number of government agencies for information sharing. The target government agencies for information sharing are determined by G_1 according to its demands for government information.

According to the above discussions, in this section, the rule of the smart contract for permission levels can be determined in Table 3. The permission levels of government agencies can be adjusted dynamically according to the up-coming data to guarantee effective IAGIS.

Table 3 The rule of the smart contract for permission levels

Given $R^* = \{R^*(G_i)\}_{n\times 1}$, the permission level of G_i is given by

$$P_i = \frac{100 \times R^*(G_i)}{\sum\limits_{j=1}^{n} R^*(G_j)}$$

G_i is allowed to select P_i percent of the whole government agencies (n_i government agencies) for information sharing. Set $n_i = |P_i n|$ ($|P_i n|$ is the rounded value of $P_i n$).

2.3.2 Smart contract based on apriori

The Apriori is used to design a smart contract for special communications among governments. Table 4 is created according to Table 1. The first row of Table 4 indicates that E_1 has requests for G_1, G_2 and G_3.

Table 4 The example dataset I for Apriori

Enterprise	Government agency relationship
E_1	G_1, G_2, G_3
E_2	G_1, G_2, G_3

If we set the minimum support count as 2, the frequent itemsets of government agencies can be achieved in Table 5.

Table 5 The frequent itemsets of government agencies

L_1	$\{G_1\}$	$\{G_2\}$	$\{G_3\}$
support count	2	2	2
L_2	$\{G_1, G_2\}$	$\{G_1, G_3\}$	$\{G_2, G_3\}$
support count	2	2	2
L_3		$\{G_1, G_2, G_3\}$	
support count		2	

The final association rules (e.g. $\{G_1\} \Rightarrow \{G_2\}$) of $\{G_1, G_2, G_3\}$ can be achieved by evaluating confidence of each rule. The government agencies in the selected association rules are allowed to share information without considering their permission levels. We can design the smart contracts by selecting the frequent itemsets with values of support count higher than minimum support count and then further evaluate the itemsets by discovering association rules with values of confidence higher than minimum confidence. The process of designing rule of the smart contract is presented in Table 6.

Table 6 The process of designing rule of smart contract for special communications

1) Generating the collection L of final frequent itemsets according to minimum support count.
2) Selecting the association rules of frequent itemsets according to minimum confidence.

The rule of smart contract for special communications is determined in Table 7.

Table 7 The rule of smart contract for special communications

Given the collection of final association rules $H = \{H_i | i = 1, 2, \cdots, |H|\}$, for any government agencies in , they can share information among each other without considering their permission levels. For any one agency G_i, the list of agencies from which G_i is allowed to request information is denoted as O_i. O_i is generated by filtering H.

2.3.3 The process of realizing smart contracts

For any one agency G_i, the process of realizing smart contracts based on PageRank and Apriori is described by presenting the flow chat in Figure 5 and the pseudo code in Figure 6. If G_i finds the demanded information from G_j, it will send a sharing request containing related information n_i, m_i, O_i and L_i. n_i is the total number of agencies from which G_i is allowed to request information. n_i is determined by using PageRank. m_i is the total number of agencies from which G_i has already requested information. O_i is the list of agencies from which G_i is allowed requested information. O_i is generated by using Apriori. L_i is the list of agencies from which G_i has already requested information. The smart contract judges whether G_i can be assigned sharing permission and whether related information should be updated, according to the aforementioned rules of the smart contracts.

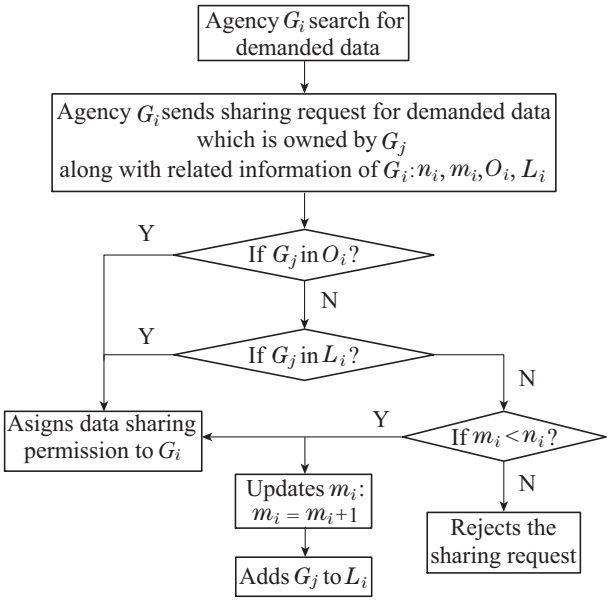

Fig. 5 The process of realizing smart contracts

3 A case study of a district in a chinese city

3.1 Dataset

The dataset $\mathcal{G}$ used in this section is collected from a district in a Chinese city. The detailed information of this dataset is shown in Table 8. The names of the 20 government agencies are coded as indexes, from D1 to D20.

3.2 Smart contract for permission levels

The igraph package in R is used to perform PageRank. The dataset $\mathcal{G}$ is in the form Table 1 and further transformed to the form of Table 2. The agency directed graph of $\mathcal{G}$ is shown in Figure 7. It can be seen that agencies D1, D4, D5, and D9 own many links with other government agencies.

```
Contract {# smart contract for special communications (Apriori)
    Function Judge (G_j, O_i){
        If G_j in O_i Then
            Assign sharing permission
            Return TRUE
        Else Return FALSE
    }
}
Contract {# smart contract for permission levels (PageRank)
    Function Judge (G_j, L_i, n_i, m_i){
        If G_j in L_i Then
            Assign sharing permission
            Return TRUE
        Else If m_i < n_i Then
            Assign sharing permission
            m_i = m_i + 1
            L_i.add(G_j)
            Return L_i, m_i
        Else Return FALSE
    }
}
```

Fig. 6 The pseudo code of realizing smart contracts

The PageRank values of each government agency are shown in Table 9. Values of the "Number of Agencies" are calculated according to Equation (1). Note that the 0 values indicate no permissions for information sharing.

Table 8 The details of dataset

Item	Content
Number of instances	1643
Number of government agencies	20
Types of requests	123
Number of enterprises	864
Range of accepted dates	Jan.– Jul. 2018

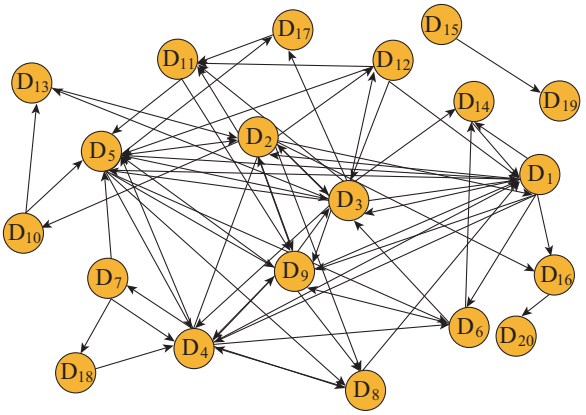

Fig. 7 The agency directed graph of $\mathcal{G}$

Table 9 The PageRank values of government agencies

Government agency	PageRank value	Number of agencies	Government agency	PageRank value	Number of agencies
D1	0.128	3	D20	0.036	1
D4	0.106	2	D16	0.030	1
D5	0.099	2	D17	0.027	1
D9	0.097	2	D7	0.025	0
D2	0.075	1	D13	0.023	0
D3	0.073	1	D12	0.023	0
D8	0.056	1	D19	0.018	0
D11	0.050	1	D18	0.017	0
D6	0.049	1	D10	0.017	0
D14	0.043	1	D15	0.010	0

The rule of smart contract for permission level is designed in Table 10. D1 is permitted to choose 3 government agencies for information sharing, for example, D2, D3, and D9. The number of agencies from which an agency is allowed to request information is recorded as related information for the agency to raise information sharing request (see Section 2.3.3).

The agencies can be grouped into three levels. The first level includes D1, D4, D5 and D9. These four agencies are allowed to have higher permissions for information sharing. As we can see in Figure 7, arrows from many agencies point to D1, D4, D5 and D9, indicating that D1, D4, D5 and D9 more possibly rely on the information from other agencies when dealing with enterprises' requests. Higher sharing permission for D1, D4, D5 and D9 is more likely to improve their work efficiency. The second level includes D2, D3, D6, D8, D11, D14, D16, D17 and D20. A certain number of arrows from agencies point to these agencies. Their work efficiency can also be improved to some extent through information sharing. The third level includes D7, D5, D10, D12, D13, D18 and D19. A small number of arrows from other agencies point to these agencies. The possibilities that work efficiency of these agencies will be improved through information sharing is low. Information sharing permissions are not assigned to those

agencies for the purpose of preventing the information abuse and saving resources.

Table 10 The rule of smart contract for permission levels

Each government agencies can determine a fix number of specific government agencies for information sharing in this contract:
D1: $n_1 = 3$
D4, D5, D9: $n_4 = n_5 = n_9 = 2$
D2, D3, D6, D8, D11, D14, D16, D17, D20: $n_2 = n_3 = n_6 = n_8 = n_{11} = n_{14} = n_{16} = n_{17} = n_{20} = 1$
D7, D10, D12, D13, D15, D18, D19: $n_7 = n_{10} = n_{12} = n_{13} = n_{15} = n_{18} = n_{19} = 0$

3.3 Smart contract for special communications

The SPSS modeler is used to perform Apriori. The dataset $\mathcal{G}$ is transformed to the form of Table 4 and then processed by Apriori. The result is shown in Table 11. In Table 11, the final frequent itemsets with values of support count is higher than 10 (The value of minimum support count is set as 10). Moreover, when selecting the association rules according to the frequent itemsets, the value of minimum confidence is set as 0.2.

Table 11 The association rules

A	B	Support count	Confidence
D7	D4	27	0.259
D3, D5	D2	18	0.389
D3, D5	D9	18	0.222
D2, D3	D12	15	0.200
D2, D3	D5	15	0.467
D2, D3	D9	15	0.200
D4, D9	D5	14	0.286
D2, D5	D12	12	0.333
D2, D5	D3	12	0.583
D2, D5	D9	12	0.250
D5, D9	D3	11	0.364
D5, D9	D2	11	0.273
D5, D9	D4	11	0.364
D11	D3	10	0.300
D11	D5	10	0.200
D11	D2	10	0.200

According to the association rules in Table 11, the rule of smart contract for special communications can be designed in Table 12. Agencies in the groups are allowed to share information without considering their permission levels. Take $\{$D2, D3, D12$\}$ as an example, D2, D3, and D12 are allowed to share their information flexibly. The information sharing requests are also checked by the program according to the smart contract for special communications. As we can see in Table 9, D12 do not have the permission to request other government agencies for information sharing. The smart contract for special communications guarantees that some government agencies with low permission levels can also utilize information from other government agencies to improve their efficiency and effectiveness in their daily work.

Table 12 The rule of smart contract for special communications

Any government agencies in the following groups are allowed to share information flexible among/between each other without considering their permission levels.
D7, D4, D2, D3, D5, D3, D5, D9, D2, D3, D12, D2, D3, D9, D4, D5, D9, D2, D5, D12, D2, D5, D9, D3, D11, D5, D11
The lists of agencies from which an agency can request data are presented as follows:
D5: $O_5 =$\{D2, D3, D4, D9, D11, D12\}
D3: $O_3 =$ \{D2, D5, D9, D11, D12\}
D2: $O_2 =$ \{D3, D5, D9, D12\}
D9: $O_9 =$ \{D2, D3, D4, D5\}
D12: $O_{12} =$ \{D2, D3, D5\}
D4: $O_4 =$ \{D5, D7\}
D11: $O_{11} =$ \{D3, D5\}
D7: $O_7 =$ \{D4\}
Other agencies: $\varnothing$

The agencies also be grouped into three levels. The first level includes D2, D3, D5 and D9. These agencies are frequently related to a certain number of agencies in dealing with enterprises' requests. The second level includes D4, D9, D12 and D11. These agencies are frequently related to relatively small agencies. The third level includes D1, D6, D8 and D10. These agencies are frequently related to no agencies. Work efficiency of agencies in the first and second levels is possibly improved through information sharing.

4 Conclusion

In this paper, a data-driven IAGIS framework is proposed. This framework is developed based on blockchain to monitor and prevent leakage and abuse of government information. Moreover, the classic data mining algorithms PageRank and Apriori are applied to design smart contracts for information sharing according to the data of enterprises' requests.

In real-world scenarios, enterprises' requests and the public services possibly change over time. The information sharing strategies should also be dynamically and flexibly changeable to fulfill practical demands of enterprises and individuals. Our framework offers a new data-driven solution for IAGIS. The information sharing strategies can be adjusted according to real-world data under our framework, which is helpful for improving public management and public service.

There can be two future directions for IAGIS. In the aspect of management, corresponding managerial rules

should be designed and implemented to regulate the operation of IAGIS frameworks and users' behaviors. In the aspect of technology, the suitable big data techniques can be discussed for data-driven IAGIS framework to adjust information sharing strategies more efficiently with the rapid increases of enterprises' request data and the public service.

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