Analysis on Reciprocal Community Currency Using Fuzzy Measure Theory

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Abstract

This paper proposes a way to evaluate the ability of exchanging goods or services via community currencies by introducing a method to analyze "reciprocity" within a community based on a fuzzy network analysis. Such currencies are expected to reinforce various social connections in communities that face difficulties due to the attenuation on human relationships. We focus on the notion of "reciprocity" that characterizes many human relationships in communities. Such reciprocity is augmented by the circulation of obligations to return gifts in a community. We use fuzzy measures to analyze reciprocity, where the non-additivity of fuzzy measures may reflect various interactions inside communities. Then we analyze reciprocity based on a fuzzy network analysis that provides us with guidelines for designing communities incorporating community currencies.

Keywords: Community currency, Reciprocity, Fuzzy network analysis, Fuzzy measure, Choquet integral

1 Introduction

Even communities that are not necessarily local still play a part in our daily mutual aid and social activities. Nevertheless, recently communities seem to be in decline because of the attenuation of human relations. So, we hope to invigorate and harmonize them by using community currencies. We can anticipate that community currencies, different from national global currencies, will reflect reciprocity to augment relationships through mutual aid in social communities.

Using fuzzy network analysis, we propose a novel evaluation method of reciprocity on using community currency. In this analysis we will also propose a way of reflecting on the accumulation of social capital through exchanging goods or services via community currencies among their members.

2 Community currency

2.1 General perspectives on community currencies

Community currency is defined as a currency that circulates in a limited area or inside a social group. As usual currencies, people use a community currency to exchange goods or services and to communicate with each other in a community whose members trust their community. Now, community currencies are spreading over the world for various purposes [1]. Generally speaking, there are three types of community currencies: one to promote local economies, another to support mutual aid, and finally a hybrid of the two. In this paper, we will focus on the second type: the role of supporting mutual aid.

2.2 Essence of community currencies

According to Niklas Luhmann [2], currencies have bilateral characters, called "symbolic" and "diabolic", but it is impossible to separate the character into two types. Symbolic generalization is to reach out to differences on three dimensions: time, event, and social dimensions. In fact, this means that currencies can be used whenever, for whatever, and with whomever. Therefore a currency is considered a communication media providing opportunities to communicate with each other.

On the other hand, the diabolic character is pertinent to the negative aspect of currencies. For instance, the diabolic character leads to financial crises, supremacy of money, economic disparities, etc. Luhmann argues that the most diabolic character attenuates reciprocity within a community. It is essensial that the design of community currencies try to erase the diabolic character by limiting symbolic characters and to relink people together.

2.3 Reciprocity

First, we introduce a definition of "reciprocity" as [3]:

1. One-sided presentation of goods or services at one time.
2. Presentation is done expecting that goods or services will be returned in the future.
3. Returns are done for presents from other people based on the past.
4. It is uncertain when to return the present, what present to select, and for whom the return will be done.

Based on this definition, reciprocity is considered a general tendency on mutual exchange in a community. A person feels a demand for his/her contribution that will also restore the balance in the long run, even though all the members of the community may feel an imbalance at each instant of time. Marshall Sahlins [4] classified reciprocities into the following three types, as shown in Fig. 1:

Generalized reciprocity: free awards of gifts or benefits without expectations of any returns. Since the "giver" side and the "taker" side trust each other, the former expects a return ambiguously. Therefore, returning is not always done in the short-term.

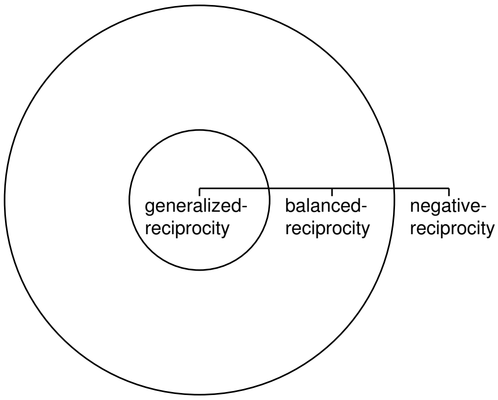

Fig. 1: Three types of reciprocity.

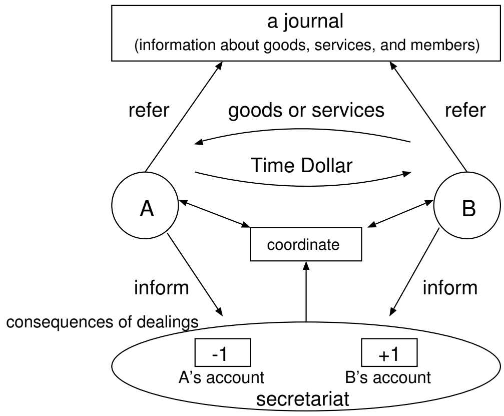

Fig. 2: General description of Time Dollar.

Balanced reciprocity: strict expectations that the recipient of a gift will make a return gift of equivalent value. Not returning a gift brakes social connections. In other words, social connection depends on the flow of gifts.

Negative reciprocity: impersonal exchanges in which each party attempts to take advantage of the other. The relationship between "giver" side and "taker" side is temporary.

Thus, reciprocity is a connection with a social distance between the receiving side and the giving side. Moreover, generalized reciprocity is the most reciprocative, and negative reciprocity is the most economical. To sum up, Sahlins claims that the nature of reciprocity varies depending on social distance [4]. The reciprocal exchange with community currency will sustain the exchange in a community for balance. Thus, reciprocal exchange may be considered a gift. Marcel Mauss [5] said that the exchange of a gift has three kinds of obligations: obligations to give, to receive, and to reciprocate. Gifts are exchanged for their own sake without being a means. On the contrary, the purpose of economical exchange is to get goods or services; economical exchange is simply a means. To exchange a gift is a one-sided relation in the short-term, so the receiving side will feel the obligation to reciprocate. At each exchange, the receiving side will retain this feeling until he/she reciprocates to the giver side or to another person in the community. Moreover, because reciprocation causes a subsequent obligation to reciprocate, a chain of reciprocations will circulate in the community. Therefore, in the long term the balance between the receiving side and the giving side will be maintained.

2.4 Time Dollar

In this section, we introduce Time Dollar[1] as an example that reflects reciprocity. Now more than 200 regions in the United States have adopted this system. The original Time Dollar concept was proposed by Edgar S. Cahn in 1980 [6] as follows (cf. Fig. 2): People who are eager to join Time Dollar must register with a the secretariat (coordinator). The secretariat regularly publishes a journal through which people can get information on the variety of goods and services offered or requested by members. Then, a member may contact another member through an introduction by the secretariat. The essential character of Time Dollar is "pricing" the currency unit at "an hour." This means that whoever a person is and whatever the good or the service is, all are the same price per hour. In fact people may feel an imbalance when dealing, but Time Dollar focuses on the balance of dealing in the long time. Moreover, remarkably, Time Dollars cannot be exchanged with national currency and are except from interest (being without interest, that is, zero interest rate). Hence, there is no legal obligation to repay because the purpose of Time Dollars is to support gifts, there is no meaning to save Time Dollars. This system indicates that Time Dollars are based on trust among members, which is quite different from national currencies to which we are accustomed. Now we believe that people who join Time Dollar will be interested not only in receiving benefits or conveniences but also in contributing to their communities and helping each other.

In the next subsection, we introduce the notion of social capital which is the ultimate objective of Time Dollar [6]. It will provide us with several points of view to consider when we discussing the roles of reciprocity in a community.

2.5 Social capital

The notion of social capital provides us with a useful way of debating civil societies. According to Robert Putnam [7], social capital expresses three basic features of social life: social networks, the norms of reciprocity, and trustworthiness, which together enable us to collaborate efficiently in a community to pursue common purposes. A significant property of social capital is that these three features affect each other, as shown in Fig.3. If they are strengthened, then a community can be revitalized in a virtuous circle, similarly, if weakened, then a community will decline in a vicious circle. Thus when trust is weakened in a community, it is difficult to strengthen it from the beginning, but it is possible to strengthen social networks and norms of reciprocity. Therefore, it is possible to find the validity of community currency from this point of view. On the analysis of social capital in actual societies, Wayne Baker [8] and Jun Kanamitsu [9] evaluated social capital based on network analysis. But, the social capital discussed by Baker is quite different from what Putnam has discussed because Baker regarded social capital as a property belonging to

[1] http://www.timedollar.org/index.htm

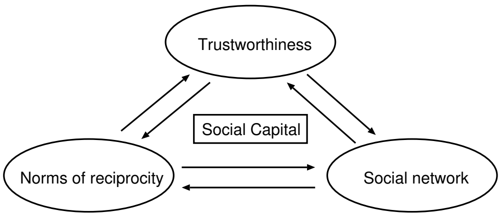

Fig. 3: Concept of Social Capital.

individuals, not to the entire community. Similarly, Kanemitsu's conception of social capital is also different from Putnam's because the former is mainly interested in companies. We have adopted Putnam's social capital because we can discuss reciprocity within a community. Therefore, we propose an evaluation method of reciprocity based on Fuzzy network analysis.

3 Fuzzy network analysis

3.1 Fuzzy graph

For network analyses, we often use graph theory, even though two-valued logics are insufficient to address various social problems. Thus the notion of a fuzzy graph is suitable to deal with the many-valuedness of real society and to easily carry out mathematical analyses [10].

[Def. of Fuzzy set] A fuzzy set $\tilde{A}$ on set X (not empty; called the universe of discourse) is defined as follows:

$$\tilde{A} = \{(\mu_A(x), x) \mid x \in X\},$$

where $\mu_A(x)$ is called the grade of the membership of x on $\tilde{A}$ and satisfies $\mu_A(x) \in [0,1]$. Furthermore, μ_A is called a membership function on $\tilde{A}$.

[Def. of Fuzzy operation] Basic fuzzy operations are defined in Table 1.

product operation	sum operation
logical product : $a \wedge b = min\{a,b\}$	logical sum : $a \vee b = max\{a,b\}$
algebraic product : $a \cdot b = ab$	algebraic sum : $a \vee b = a + b - ab$
limiting product : $a \odot b = 0 \vee (a+b-1)$	limiting sum : $a \oplus b = 1 \wedge (a+b)$

Table 1: Basic fuzzy operations

[Def. of Fuzzy power set] Let U be an universe set. If there is a set i.e.

$$F(U) = \{\tilde{A} | \mu_A : U \to [0,1]\}, \tag{1}$$

then F is called a fuzzy power set.

[Def. of Fuzzy graph] Let N be a finite set, $\tilde{N}$ a fuzzy set i.e. $\tilde{N} \in F(N)$, and $\tilde{L}$ a fuzzy set i.e. $\tilde{L} \in F(N \times N)$ for $\forall x_i, \forall x_j \in N$. If the following holds:

$$\tilde{L}(x_i, x_j) \leq \tilde{N}(x_i) \wedge \tilde{N}(x_j) \;\; for \; \forall x_i, \forall x_j \in N, \tag{2}$$

then $G = \tilde{N}, \tilde{L}$ is said to be a fuzzy graph $\tilde{G}$.

Furthermore, connections between node i and node j in the fuzzy graph need to be defined as the following holds:

$$r_{ij} : \left[\begin{array}{ll} 0 < r_{i,j} \leq 1, & \text{if node } i \text{ and node } j \text{ are connected} \\ r_{i,j} = 0, & \text{if node } i \text{ and node } j \text{ are disconnected} \end{array} \right] \tag{3}$$

The relation of each connection in the fuzzy graph is considered to be a fuzzy relation over N. Let the cardinal number of N be n. Then the relation of each connection is given as the fuzzy matrix:

$$R = (r_{ij})_{n \times n}, \tag{4}$$

where R is called the "fuzzy adjacency matrix."

3.2 α-cut

[Def. of α-cut] Let $\tilde{A}$ be a fuzzy set and $\alpha \in [0,1]$. Then the crisp set is given as:

$$(\tilde{A})_\alpha = \{\, u \mid \mu_{\tilde{A}}(u) > \alpha, u \in U\}, \tag{5}$$

which is called the (strong) α-cut of fuzzy set $\tilde{A}$. Similarly, let R be a fuzzy adjacency matrix. If there is a matrix given as:

$$(R)_\alpha = \left[\begin{array}{ll} 1 & \text{if } r_{ij} > \alpha \\ 0 & \text{if } r_{ij} \leq \alpha \end{array} \right], for \forall i, \forall j \in N, \alpha \in [0,1], \tag{6}$$

it is called the α-cut of fuzzy adjacency matrix R.

3.3 Fuzzy measure

[Def. of Fuzzy measure] Let (X, $\mathscr{F}$) be a measurable space. If $\mu : \mathscr{F} \to [0,\infty]$ is defined as

$$\mu(\emptyset) = 0, \tag{7}$$

$$A, B \in \mathscr{F}, A \subset B \Rightarrow \mu(A) \leq \mu(B), \tag{8}$$

then μ is called a Fuzzy measure over $\mathscr{F}$. Here, the triple (X,$\mathscr{F}$,μ) is called the "fuzzy measure space."
Conventional measures such as probability measures are kinds of specialized fuzzy measures satisfying the following "additivity of measures":

$$A \cap B = \emptyset \Rightarrow \mu(A \cup B) = \mu(A) + \mu(B), \tag{9}$$

In general, fuzzy measures do not assume the above additivity.

Due to the lack of the above additivity, we have the following three cases with which the corresponding interpretations on underlying social structures are associated:

$$case1. \quad \mu(A \cup B) > \mu(A) + \mu(B) : \tag{10}$$

There exists a positive (enhancing) synergy effect between events (or groups) A and B.

$$case2. \quad \mu(A \cup B) < \mu(A) + \mu(B) : \tag{11}$$

There is a negative (inhibitory) synergy effect between A and B.

$$case3. \quad \mu(A \cup B) = \mu(A) + \mu(B) : \tag{12}$$

Events (or group) A and B are independent of each other.

Thus fuzzy measures can naturally reflect the effects of internal interactions inside groups or systems via their essential characteristics, that is, the non-additivity of measures.

3.4 Choquet integral

We will briefly introduce a novel notion of integral, Choquet integral, defined over non-additive measures [11].

[Def. of Choquet integral] For the following stepwise function

$$f(x) = \sum_{I=1}^{n} r_i 1_{D_i}(x), \tag{13}$$

where $r_0 = 0 < r_1 < r_2 < \cdots < r_n$ and $D_i \cap D_j = \emptyset$ for $i \neq j$, $1_{D_i}(x)$ is defined as follows:

$$1_{D_i}(x) = \left[\begin{array}{ll} 1 & if\ x \in D \\ 0 & if\ x \notin D \end{array} \right]. \tag{14}$$

Choquet integral of f w.r.t. μ is defined as follows:

$$(C)\int f d\mu = \sum_{i=1}^{n} (r_i - r_{i-1})\, \mu(A_i), \tag{15}$$

where $A_i \equiv \bigcup_{j=1}^{n} D_j$,$r_0 \equiv 0$. For example, when $n = 4$, the stepwise function is written as follows:

$$f(x) = \sum_{i=1}^{4} r_i 1_{D_i}(x) = \sum_{i=1}^{4} (r_i - r_{i-1})\, 1_{A_i}(x). \tag{16}$$

Thus, Choquet integral of f w. r. t. μ is represented as follows (cf. Fig. 4):

$$(C)\int f d\mu = I + II + III + IV, \tag{17}$$
$$I = (r_1 - r_0)\cdot \mu(A_1),$$
$$II = (r_2 - r_1)\cdot \mu(A_2),$$
$$III = (r_3 - r_2)\cdot \mu(A_3),$$
$$IV = (r_4 - r_3)\cdot \mu(A_4).$$

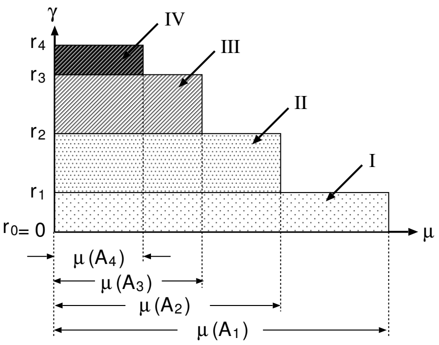

Fig. 4: Choquet integral of stepwise function as summation of horizontal columns I, II, III, and IV.

4 Analysis of reciprocity

In this section, we propose a novel framework for evaluating reciprocity within a community. We must consider not only the total number of transactions in a community but also the network topology that represents the circulation of community currencies and gives information about reciprocity in a community. Reciprocity is inseparable from the phrenic load of others' gifts for three obligations [5]. We consider that reciprocity will increase as long as the balance of the flow can be smoothly maintained. Therefore, reciprocity in a community is not measured by the total of individual transactions because of their non-additivity.

4.1 Adjacency matrix

We draw a fuzzy graph of community. Each arc represents trading history, and each node represents a member in a community. A fuzzy adjacency matrix is obtained by an inverted flow of community currency because exchanges imply not dealing of goods and service such as in legitimate currency but a gift. We obtain the dealing frequency of each person in a community and draw a dealing matrix T. Let n be the number of nodes of a graph. t_{ij} is defined as the dealing frequency from node i to j as follows:

$$T = (t_{ij})_{n\times n}. \tag{18}$$

Next, we define *max_income*, such that

$$max\_income = \sup_i \left(\sum_j t_{ij} \right), \tag{19}$$

where *max_income* is the amount of community currency of a member who obtained the maximum amount of currency in the community. By the ratio of matrix T by *max_income*, we get a fuzzy adjacency matrix R that relatively represents the community currency of each member compared with that of a person who got the most community currency in the community. Moreover, by focusing on the individual, this matrix also expresses the relative distribution of community currencies from other people in a community.

$$R = (r_{ij})_{n\times n} = \frac{1}{max\_income} T. \tag{20}$$

R satisfies the following conditions:

$$r_{ij} \geq 0 \quad (1 \leq i \leq n, 1 \leq j \leq n), \tag{21}$$
$$\sum_j r_{ij} \leq 1 \quad (1 \leq i \leq n). \tag{22}$$

4.2 Reachability matrix

We define M_m as a limited reachability matrix that represents the chains of reciprocation obligations. A limited reachability matrix indicates whether node i can reach node j by tracing m pieces of link [12]. Considering a limited reachability matrix, we introduce Propagational Investment Currency System (PICSY) [13], which is a new currency system that aims to construct reciprocative societies. Fig. 5 illustrates the concept of PICSY.

Suppose that members a, b, and c use PICSY. First, person b gives an evaluation value 0.3 to person a who gives goods or services to person b. Next, person c gives an evaluation value 0.4 to person b who gives goods or services to person c. Then, in PICSY, person c is regarded to give an evaluation value 0.4×0.3 to person a.

PICSY can express the chains of obligation to reciproate by spreading the concept of evaluation. We support PICSY, but we measure not individual subjectivity but the amount

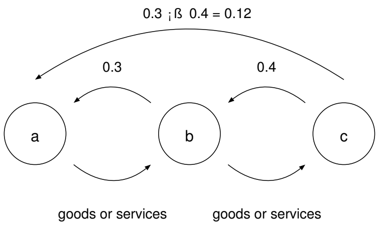

Fig. 5: Concept of PICSY.

of community currency. So objectivity to evaluation is mortgaged in our proposed system.

Next, we define a limiting reachability matrix M_m as follows:

$$M_m = I \oplus R \oplus R^2 \oplus \cdots \oplus R^m. \tag{23}$$

Let $X = (x_{ij})_{n\times n}$ and $Y = \left(y_{jk}\right)_{n\times n}$ be fuzzy matrices. Then we define the composition of the fuzzy matrices as follows:

$$X \cdot Y = Z = (z_{ij})_{n\times n} = \left(\bigoplus_{j=1}^{n} x_{i,j} \cdot y_{j,k}\right)_{n\times n} \quad (1 \le i \le n, 1 \le k \le n). \tag{24}$$

So, the limiting sum of fuzzy matrix $X = (x_{ij})_{n\times n}$ and $Y = (y_{ij})_{n\times n}$ is given as follows:

$$X \cdot Y = Z = (z_{ik})_{n\times n} = (x_{ij} \oplus y_{ij})_{n\times n}, \tag{25}$$

where $1 \le i \le n, 1 \le k \le n$. Moreover, $R^2 = R \cdot R, \cdots, R^n = R^{n-1} \cdot R$

4.3 α-cut

Next, we apply α-cut to a limiting reachability matrix. α-cut classifies communities by levels of reciprocity. The reciprocity measure is introduced in the next paragraph. First, we decide α-cut level according to the community that the secretariat of a community wants to design because reciprocity changes according to social distance in a community [4]. For example, we regard dealings between participants who are receptive to them as "generalized reciprocity." On the contrary, we regard dealings between passive to them as "balanced reciprocity." To detect the level of reciprocity, we use the α-cut operation to extract a fuzzy network by the α-cut level. It explains that some communities at various levels of reciprocity are piled up in the community. Hence, we call the α-cut level f: the level of reciprocity. Next, we will evaluate reciprocity at each α-cut.

4.4 Reciprocity measure

Next we evaluate reciprocity. Since we consider it the balance of the phrenic load of others' gifts, we notice two measures; "integration" and "radiality." they indicate the degree an individual is connected and the degree of reachability within a network, respectively [14]. The integration measure is based on inward ties, and the radiality measure is based on outward ties. We consider the integration measure as the degree of benefits from a community and the radiality measure as the degree of contributions to a community.

[Def. of Integration measure] Let D be a distance matrix and n be the number of nodes of a network. Then the integration measure is defined as:

$$I(j) = \frac{\sum_{i\neq j} RD_{ij}}{n-1}, \tag{26}$$

where $I(j)$ is the integration score for node j and RD_{ij} is called a reverse distance given as :

$$RD_{ij} = diameter - d_{ij} + 1, \tag{27}$$

$$D = (d_{ij})_{n\times n}, \tag{28}$$

$$diameter = \sup_{ij}(d_{ij}), \tag{29}$$

where $diameter$ is given as the maximum value within the distance matrix. The lower distance value, the higher value a reverse distance has.

[Def. of Radiality measure] Similarly, the radiality measure is defined as:

$$R(j) = \frac{\sum_{i\neq j} RD_{ji}}{n-1}. \tag{30}$$

We propose a measure of the reciprocity measure on a fuzzy network based on the integration and the radiality measures. For this purpose, the reverse distance in a fuzzy network with α-cut by r_i is defined as:

$$RD_{ij} = \left(\hat{R}_{ij} \wedge \hat{R}_{ij}\right)_{r_i}. \tag{31}$$

[Def. of Reciprocity measure] The reciprocity measure of an individual in a fuzzy network with α-cut by r_i is defined as:

$$\mu_{(individual)}(j_{r_i}) = \frac{I(j) + R(j)}{(2 + |I(j) - R(j)|)}. \tag{32}$$

The reciprocity score will be high when both the integration and radiality measures are high and their difference is small. Besides, the integration measure for the network with α-cut by f is operationally defined as:

$$\mu\left((M_m)_{r_i}\right) = \sum_{j}^{n} \frac{I(j) + R(j)}{(2 + |I(j) - R(j)|)}. \tag{33}$$

The reciprocity measure is the amount from 0 to n. This measure has the nature of a fuzzy measure. The reciprocity measure of connections in all communities is not a total ofeach reciprocity connection to be divided. It has different synergies: positive, negative, and without.

4.5 Choquet Integral

Finally, we propose a reciprocity measure of an entire community by totaling reciprocity measures at each α-cut level.

This value represents the degree of reciprocity in the networks of a community. Reciprocity is represented as the sum of the rectangular blocks described in Fig. 6.

$$Reciprocity\ of\ R = (C)\int f d\mu = \sum_{i=1}^{n} (r_i - r_{i-1})\, \mu((M_m)). \tag{34}$$

Assume that α-cut level is $r_1 = 0.25$, $r_2 = 0.5$, and $r_3 = 0.75$, the Choquet Integral for evaluating the reciprocity of the entire community is shown in Fig. 6.

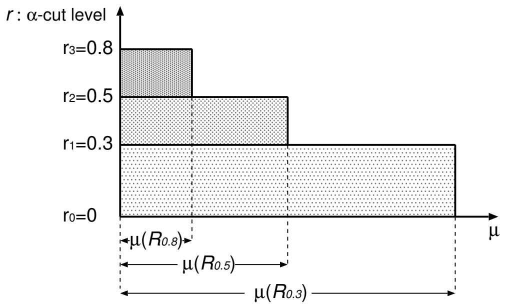

Fig. 6: Choquet Integral for evaluating the reciprocity of an entire community.

5 Discussion and Conclusions

In this paper, we proposed a method based on a fuzzy network analysis to evaluate the reciprocity of a community. Reciprocity contributes to the emergence and the accumulation of social capital. Note that we can calculate the parameters in this analysis even though the evaluation measure has on the non-additive nature. The non-additivity of evaluation measures reflects the non-additivity relationships among members of a community or their activities. Furthermore, the secretariat of community currency can obtain useful suggestions from the results of evaluations. Using this information, the secretariat can effectively promote dealings via community. The secretariat of a community should not just wait for the outcome of community currency, but should promote its circulation because we believe that the emergence of social capital needs to be moderately controlled. There are many community currencies in Japan, but little effect has been made to reinforce various communities. Because it only depends on bottom-up movements, social connection disappear naturally. Furthermore, we plan to extend our method to incorporate time sequence aspects because we want to know how the quality of reciprocity in a community changes, which will help us to get information on guiding and designing communities. We only discussed the reciprocity of entire communities. Considering the aspects of individual members, we must know the community size to which members feel reciprocity. Finally, we plan to apply this analysis method to actual communities.

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