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AN EXAMINATION OF ONLINE SOCIAL NETWORK PROPERTIES WITH TIE-STRENGTH

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Abstract

In the past, most researchers focused on the efficacy of tie-strength in various applications for both online and offline social networks. However, how tie-strength can help in the analysis of online social networks was a commonly neglected issue. The massive size and recording properties of online social networks offer the possibility to measure tie-strength objectively. In this study, we examine a social network extracted from a blog network. We then propose a tie-strength measurement and investigate several properties of the network using the tie-strength we defined. We also study how tie-strength plays a role in these properties.

Keywords: online social network, tie-strength, weak ties, strong ties, clustering coefficient

1 INTRODUCTION

The Internet has expanded the scope of social networks in many ways, and the emergence of the online social network is a result of such an expansion. In recent years, online social networks have attracted a significant amount of popularity, and several types of online social networks have been formed, e.g., blog networks. Common characteristics of those networks are anonymity, synchronicity, recordability, and interactivity (Chidambaram 1996). They provide a basis for maintaining social relationships, finding people with common interests, and interacting with other users. A social network, real or virtual, is a network consisting of actors and their relationships (Bornholdt & Schuster 2003). Actors connect to others with one or more relationships; different types of relationships define different types of networks. Social relations can include friendship, kinship, confrontation, conflicts, common interests, etc. As the relational dependency between two nodes grows stronger, the strength of the connection between the two is growing stronger. The study of tie-strength can be dated back to Granovetter (1974), who characterized each relation, or a tie, in a network with a certain level of strength, and then classified ties in a social network into “weak” and “strong”.

Tie-strength has been studied extensively in many fields. We classify research into two groups. One group focuses on using tie-strength as an analytic framework for studying individuals and organizations. Another group focuses on determining measurement tools or scales of tie-strength. However, no attempt has been made to investigate the role of tie-strength in social networks. In this paper we propose a more objective measuring method to quantify tie-strength. We use this method to analyze the correlation between tie-strength and key properties of online social networks. The rest of paper is organized as follows: We review the related work in Section 2. In Section 3 we discuss our experimental method. Results are presented and discussed in Section 4. In Section 5, the conclusion of our work is presented.

2 RELATED WORKS

2.1 Properties of Online Social Networks

A social network is defined by Barnes (1954) as a social structure made of nodes, which are generally individuals or organizations. Sociologists have studied many properties of social networks, such as the shortest path (Milgram 1967), the small-world effect (Pool & Kochen 1978), transitivity or clustering, degree distribution, assortative mixing, and community structure (Newman 2003).

As online social networks attract more attention, researchers start to investigate their properties in more detail. Haythornthwaite (2002) observed that characteristics of a physical social network also appear in online social networks. Furthermore, the impact of communication between nodes is similar in both networks. Ahn et al. (2007) studied three online social networks and found those networks also exhibit properties of traditional social networks, such as shortest path, degree distribution, and clustering. Mislove et al. (2007) studied four online social networks and found that those networks, like real-world social networks, follow the power-law link distribution. They also exhibit small-world and clustering phenomena. Zhou and Davis (2007) conducted an analysis on blog and discovered that it exhibits all the characteristics of a social network.

2.2 Tie-Strength in Social Networks

Tie-strength is a combination of the amount of time, emotional intensity, intimacy, and reciprocal services, which characterize the tie (Granovetter 1974). The term “weak tie” refers to an actor who can be marginally connected or who has little contact with other actors. The term “strong tie” refers to an actor who has contacted with others on a more frequent basis. The tie-strength concept initiated several important claims by many people on a range of topics. Topics include the efficacy of weak ties in a job search (Granovetter 1974; Lin & Dumin 1986; Brown & Konrad 2001; Rankin 2003), diffusion of information through weak ties (Brown & Reigen 1987; Burt 1995; Weening 1993),

models for women to advance in organizations through weak ties (Crowell 2004), and more. Several other studies (Karathanos and Pettypool 1992; Wilson 1998; Lin et al. 1981; Wellman and Wortley 1990; Hansan 1999; Brown and Konrad 2001; Jenseen and Koen 2002; Köhler 2004; Crowell 2004; Levin and Cross 2004) proved that a seemingly unimportant weak tie actually plays an important role in a social network. Claims and theories can only be examined if the tie-strength can be measured and strong ties can be distinguished from weak ties.

The definition of tie-strength is vague; there is no clear rule to classify a connection into a strong tie or a weak tie. However, attempts have been made in the past to determine a valid indicator and predicator of tie-strength. Marsden and Campbell (1984) showed that many indicators are contaminated by situation factors (predicator) with the exception of emotional attachment/support. Petróczi et al. (2007) summarized tie-strength components in off-line social networks as contact frequency, intimacy, voluntary investment in the tie, advice given/received, desire for companionship, multiple social context, period of time, reciprocity, emotional support/intensity, trust, and sociability, among others. Research regarding the measurement of tie-strength in online social networks is rather scarce. Muncer et al. (2000) used posting frequency between users to indicate tie-strength. Paolillo et al. (2001) used informal speech as an indicator of closeness and friendship. Petróczi et al. (2007) proposed a VTS-scale and scoring method for measuring tie-strength. In this study, we use the definition of tie and the tie-strength measuring method from Muncer et al. (2000) with slight modification. The definition of tie and the measurement of tie-strength will be described in Section 3.1 and 3.3.

3 METHODOLOGY

3.1 Dataset

We focus on blog networks for the following reasons. Blogs (Weblogs) are continuous online social groups, and the minimum communication period between users is at least 1 year (Zhou and Davis 2007). The network is fairly stable, and unlike other online social networks, most information is open to the public, which can enhance the validity of our analysis. Blogs also contain all the features of social networks like shared interests, personal preference, different tie-strengths, etc. In addition, blogs tend to form groups with certain shared values, behavioral norms, and inter-blog relationships.

Blogs are usually maintained by individuals with regular commentary entries, descriptions of events, or other material such as graphics or videos. The blogger who writes the weblog is the actor, and blogger generally has read and respond relations with each other (Zhou and Davis 2007). Each hyperlink between two blogs is a communication instance between two bloggers, which can be treated as a tie between nodes in a social network. The number of instances between blogs can then indicate the strength of tie between bloggers.

Wretch.cc¹ is one of the most popular Web-based social network sites in Taiwan, with more than three million users. Members can use services such as bulletin boards, blogs, videos, photo albums, etc. to interact with their friends. The average time a user spent visiting the site was roughly 11 minutes, with 19 seconds spent on each page view. On average, each user will visit 23.1 unique pages per day (Alexa²). Wretch.cc ranks as the number one online social network site in Taiwan (excluding the international site Facebook). With such credentials and regional relevance, we are confident in using the Wretch.cc blog as our data source for this study.

The main page of the blog shows a summarized list of articles, which is displayed in reverse-chronological order. If user desires, each article can be drilled down for further detailed reading, and interaction with the blogger can take place on the article. An article is a unique page with a permalink where other users can interact with the blogger via three different interactions: “reply,” “trackback,”

¹ <http://www.wretch.cc>

² <http://www.alexa.com/>, a web information company which provides information about websites, as of 2011.04.

and “collect.” A “reply” interaction is initiated when a user posts a comment on blogger’s article. A “trackback” interaction is initiated when a user makes a hyperlink to a blogger’s article. Finally, a “collect” interaction is initiated when a user adds a blogger’s article into his/her collection. In addition, each blogger has a “friends list,” which is constructed subjectively by the blogger.

3.2 Data Collection Method

To collect data, we created a wretch.cc account and used the “friends list” in each blog to discover other blogs. The following procedures were performed to record all the data required: 1) collect “friends” from each blog’s “friends list” and store these lists in a “friends collection”; 2) each article in the blog is examined in chronological order, and all interactions that occurred are collected; 3) the above two steps are repeated until there are no more “friends” in the “friends collection.” Ideally, these procedures should be able to extract a closed network from wretch.cc. However, due to high volume of traffic in crawling the dataset, wretch.cc has eventually blocked most of our crawlers a few months after we launched the collection process in 2009. Still, we were able to collect the following amount of data shown in Table 1 for our study.

Type	Blog	Article	Friend	Reply	Trackback	Collect
Amount	70,000	10,407,152	225,499	1,792,215	214,562	350,778

Table 1. Data amount collected from wretch.cc

The amount of data collected from the “reply” interactions is much larger than the “trackback” and “collect” interactions. This is due to the following reasons. First, the “trackback” and “collect” interactions can only be activated after a user has signed in as a registered member. Second, when a user wishes to cite another user’s article, it is not necessary for users to initiate a “trackback” action. Instead, users can simply copy/paste the article’s URL to their blogs. Therefore, the actual number of “trackback” activities cannot be accurately recorded. Third, the “collect” relation is a newly introduced function, so users may not be familiar with the functionality. In contrast, the “reply” relation can be posted by any unregistered user. Therefore, a user can post a reply under any nickname. To avoid ambiguity, any reply by an unregistered user is removed from the dataset.

3.3 Measurement of Tie-Strength

In the dataset, a relationship between two users, A and B, is established when A performed a “reply,” “trackback,” or “collect” on B’s article, or added B as a friend in A’s “friends list.” Four types of relations were collected: “reply,” “trackback,” “collect,” and “friends list.” Note that all four relations are directional. For example, if A replies to B’s article, then there is a reply-relation $A \rightarrow B$. Similarly, if A adds B to his friends list, then there is a friends-list relation $A \rightarrow B$.

For the first three types of relations, the action that initiates a relation may be repeated. Hence, we use the interaction frequency between users as an indicator for measuring tie-strength. For example, if B replied to A’s posts five times, while C replied to A’s posts three times, the strength of B’s reply relation to A is stronger than the strength of C’s reply relation to A. We therefore use the number of actions repeated in a relation between two bloggers as the “weight” of the tie.

In contrast to the other three relations, the friends list relations are specified explicitly by bloggers. In general, A adds B to the “friends list” only if A considers B as a friend. Therefore, we use this “friendship” relation to verify if the tie-strength measurement we used for the “reply,” “trackback,” and “collect” relations can indeed reflect/predict the friendship of two users.

Figure 1 shows the relationship between weight of tie-strength and the probability users recognized one another as “friends” for the reply relation. The x-axis represents the weight of a reply relation, while the y-axis indicates the probability that A considers B as a friend given that A has a reply relation to B with a given weight. The result indicates that the weight measured can indeed serve as a tie-strength measurement between two users: the heavier the reply-relation weight one has with

another, the higher the chance the former views the latter as a friend. Our results on “trackback” and “collect” relations show a similar pattern.

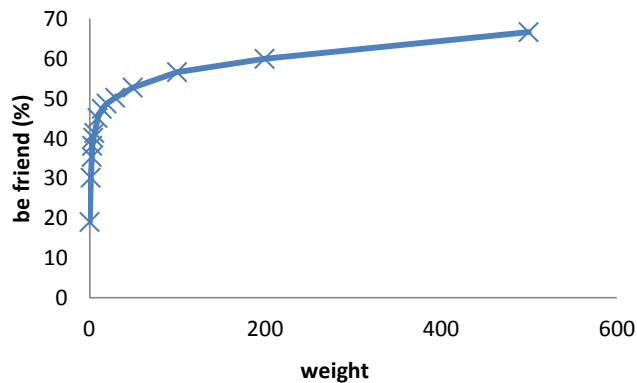


Figure 1. Relationship between weight of tie-strength and the probability users recognized one another as “friends” on “reply” relations

4 EXPERIMENTAL RESULT

Newman (2003) stated that a social network normally consists of the following properties: the shortest path, clustering phenomenon, power-law distribution of degree, homophily, and obvious community structure. In this section we investigate some of the properties from the perspective of tie-strength.

4.1 Distribution of Tie-Strength

First we inspect the distribution of tie-strength, as shown in Figure 2. The x-axis represents the weight of the tie-strength and the y-axis represents the number of links with the weight. All three relations exhibit a power-law distribution; the number of links decreases with an increase in strength. That is, most links in the network are weak ties.

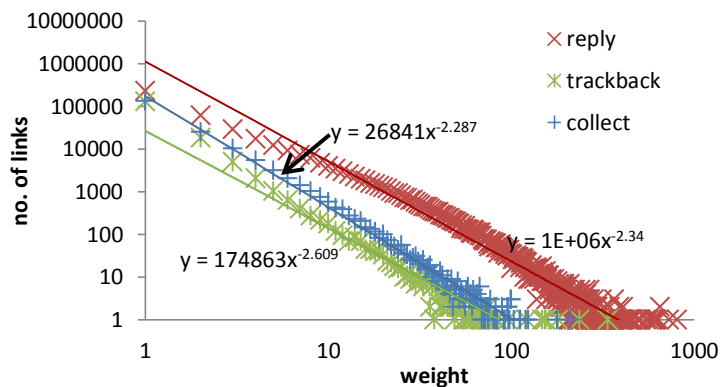


Figure 2. Distribution of weight in links

4.2 Degree of Connection

A social network exhibits a power-law distribution. That is, a network consists of only a small amount of nodes that feature a high degree of connection, and most nodes are loosely connected. A node’s degree indicates how well connected it is in the network. Figure 3 shows the distribution of out-degree (a) and in-degree (b). All distributions follow a power-law distribution, which proves that the data we collected also exhibits similar behavior of a social network. It is interesting to note that the slope of the out-degree is steeper than the slope of the in-degree; that is, the maximum out-degree is smaller than the maximum in-degree. This can be explained as follows. Some blogs are very famous and popular, attracting many users to interact with them (thus yielding a large in-degree). In contrast, the

out-degree is caused by each individual user based on how he/she interacted with others. Due to the limited time a user has, it is relatively rare to find a user with a large number of interactions with many different users.

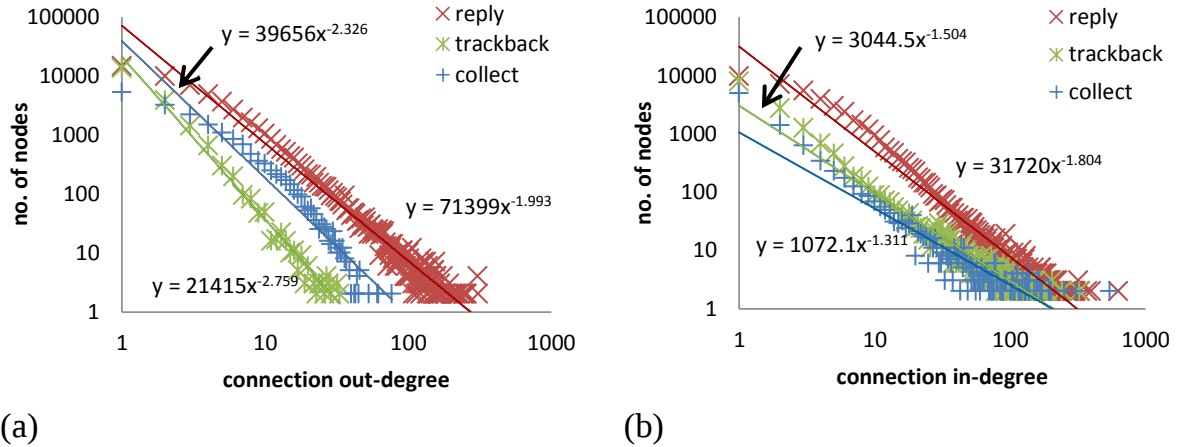


Figure 3 Distribution of number of (a) out-degree / (b) in-degree

Instead of simply counting the number of in-degree and out-degree connections a node has, we include the weight of a degree into our analysis. The total weight is calculated by summing the in/out-degrees of each node. That is, if A has three in-degrees with weights 5, 3, and 18, then A's total weight of in-degree is 26. The total weight can reflect the closeness between a user and a network. The total weight of out-degree indicates how much effort a user placed toward a network; a user with a high out-degree weight means that the user spends more effort and time interacting with other blogs. In contrast, the total weight of in-degree indicates the influence of a user in the network; a user with a high in-degree weight means that other users are more willing to interact with and trusting toward the user. Figure 4 shows the distribution of total weight, and the result shows that it also follows the power-law distribution.

We can see a slight difference between the degree and weight graphs. Hence, the weight of a node may be able to serve as some indicator to analyze the role played by a user in the network. In general, a node with a large degree implies that the node has been well noticed, while a node with a larger total weight implies that the node is very involved in the network.

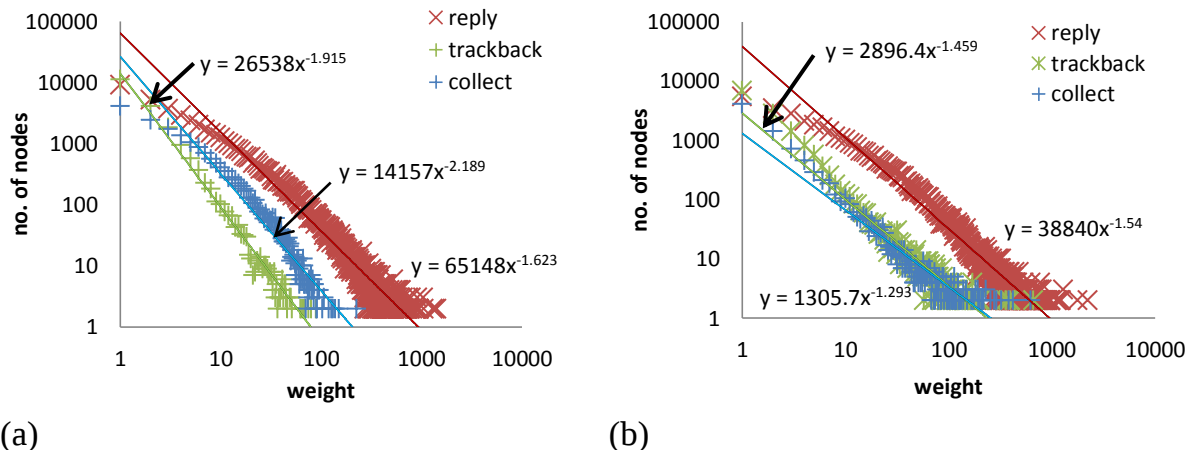


Figure 4. Distribution of weight in (a) out-degree / (b) out-degree

We further studied the relationship between the total weight and the number of degrees by calculating their correlation coefficient. The result is shown in the first two columns in Table 2. In general, the total weight should be positively correlated to the amount of connections, as the more connections a user has, the more interactions the user may have with other users. However, from Table 2 we see that the correlation between out-degree and total weight is not as high as the correlation between in-degree and total weight. This suggests that a user who has replied to many different blogs may have only a

few interactions with each blog. On the other hand, a user may only reply to a few blogs, but the interaction between them is very frequent. Moreover, a user who has attracted many responses may generally have more interaction with each responder.

We also show the correlation coefficient between the inbound connections and outbound connections with respect to degree and with respect to total weight in Table 2. With respect to degree (third column), the correlation between inbound connections and outbound connections is very low (0.212), meaning that a user who has replied many different users may not necessarily attract many responses. However, if we consider the total weight (fourth column), then the correlation between inbound connections and outbound connections increases to 0.51. This means that a user who has replied many times may have a chance to get some reciprocal replies, but perhaps only from a few users. The results for the “trackback” and “collect” relations show no correlation between total weight of inbound connections and total weight of outbound connections. This may be due to the fact that the data collected for these two types of relations are much smaller than the reply-relation, and thus no statically meaningful conclusion can be drawn.

Relation	Degree vs. Total Weight		Inbound vs. Outbound	
	Out-degree	In-degree	Degree	Total Weight
Reply	0.646	0.870	0.212	0.510
Trackback	0.903	0.977	0.004	0.005
Collect	0.805	0.986	-0.018	-0.013

Table 2. Correlation coefficients between connection degree and total weight

4.3 Small-World Phenomenon

Milgram’s (1967) experiment suggested that a social network is a small world in which every two persons are connected via a small number of hops (approximately six). In this section we examine the small-world phenomenon in our dataset, and discuss how weight plays a part in the construction of the shortest path. Due to the relatively smaller amount of data collected for the track and collect relations, we shall focus our study on the reply relation.

In our dataset, there is about a 46 percent chance that we can successfully locate the shortest path between any two given nodes. The distribution of the shortest path lengths is shown in Figure 5. On average, a shortest path has a length of 5.3, which is close to what Milgram observed. Next, we investigate if weight plays an important role in constructing the shortest path. To do so, we draw the distribution of link weight in both network and shortest paths. In Figure 6, we can see that the weight distribution in shortest paths and the weight distribution in the whole network are very closely overlapped. For example, 54 percent of links in the network has a weight of 1, while 55 percent of links in the shortest paths also has a weight of 1.

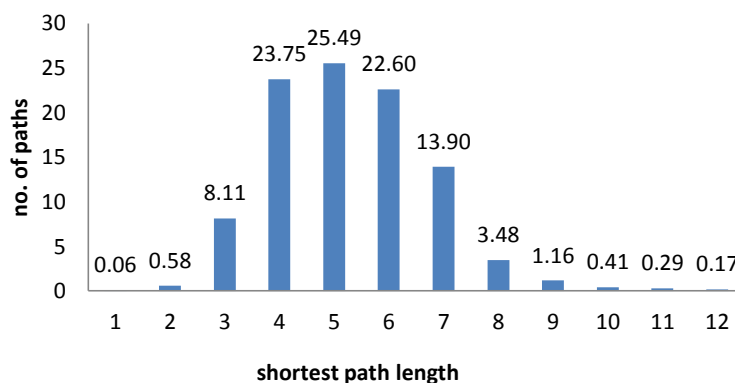


Figure 5. Distribution of shortest path lengths

Weak ties have been suggested by Burt (1995) to be important in bridging subgroups (and in linking persons to resources in a network). Without weak ties, the chance of finding a shortest path between

two nodes may significantly decrease. This observation can also be supported by our dataset: 54 percent of the links have a weight of only 1. These links can be considered weak ties. If they are removed from the network, then the chance of finding the shortest path drops dramatically from 46 percent to be less than 1 percent.

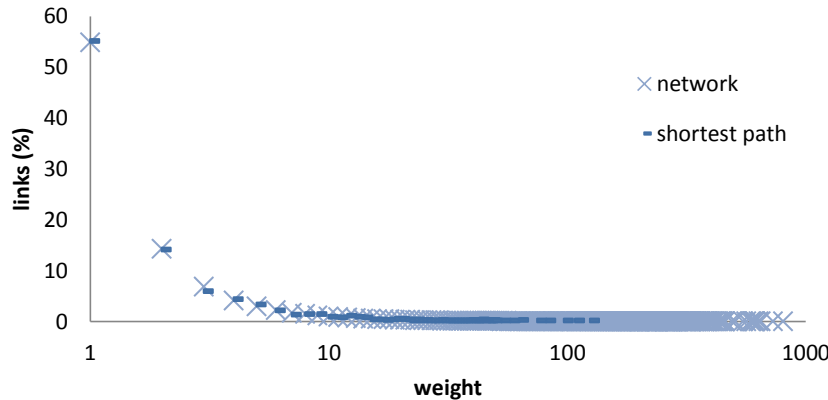


Figure 6. Distribution of weight in shortest path

4.4 Clustering phenomenon

The clustering coefficient measures how well connected among a node's neighboring nodes. A network with a high clustering coefficient implies that if A has a relation with B and C, then the probability that B has a relation with C is high. In general, a social network has a clustering coefficient larger than a random graph, but smaller than a regular graph. In Table 3 we compare the clustering coefficient of our network with a random graph and a regular graph (of the same number of nodes and edges). From the result, we see that our dataset exhibits the above property.

Relation	Random	Our Network	Regular
Reply	0.0002	0.048	0.600
Trackback	0.00003	0.012	0.143
Collect	0.00004	0.034	0.400

Table 3. Clustering coefficients of our network: random and regular graphs

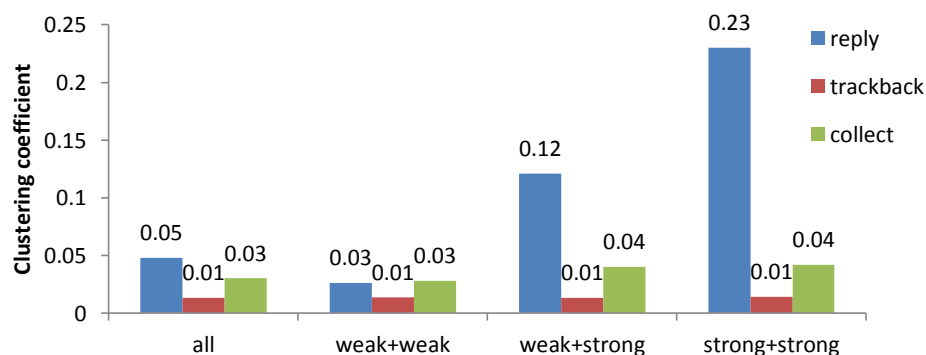


Figure 7. Clustering coefficient with different combination of tie-strength

Next, we study the impact of tie-strength in clustering coefficient. For this experiment, a tie is classified as weak when its weight is below the average; otherwise, it is a strong tie. We consider the following question: If A and B have a weak (strong) tie, and A and C have a weak (strong) tie, then what is the chance that B and C have a relation? Altogether, there are three combinations: (weak, weak), i.e., both B and C have a weak tie with A; (weak, strong), i.e., one of B and C has a weak tie with A, while the other has a strong tie with A; and (strong, strong), i.e., both B and C have a strong

tie with A. Figure 7 shows the result. The “All” category is the result that does not distinguish tie-strength; that is, the result in Table 3 (second column). For the reply relation, we see that, among the three cases studied, two nodes that are weakly tied to a common node have the least chance to be tied together. However, if one of them is strongly tied to the common node, then the chance for the two nodes to be connected increases significantly. If both nodes are strongly tied to the common node, then the chance for them to be connected is the highest. The result for the trackback and collect relations also demonstrates this phenomenon, although the situation is not as salient as the reply relation (once again possibly due to the fact that the number of the relations collected is much smaller than in the reply case).

The above finding suggests that although social networks have a high clustering coefficient (relative to a random graph), the clustering phenomenon is primarily boosted by strong ties. To verify this, we further analyze how weight in ties influences clustering. We focus on the reply relation due to the large volume of data we have collected. Figure 8 shows the chance that two nodes, B and C, have a relation when both B and C have a tie with another node, A, of a strength greater than or equal to a given weight. We see that the stronger the tie-strength B and C have with A, the higher the chance for B and C to have a relation.

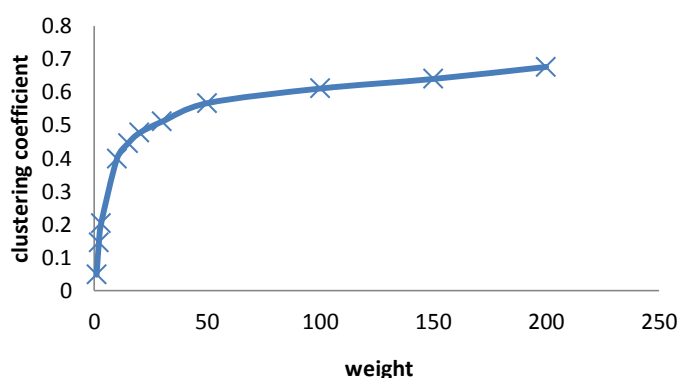


Figure 8. *Clustering coefficient of a link between two nodes with a common neighbor with changes of tie-strength*

In addition, we also measure the tie-strength of B and C in the previous experiment and calculate the chance for the link between B and C to be a strong tie. See Figure 9. The result indicates that the higher the tie-strength B and C have with a common node, the more likely a strong tie-strength will exist between B and C.

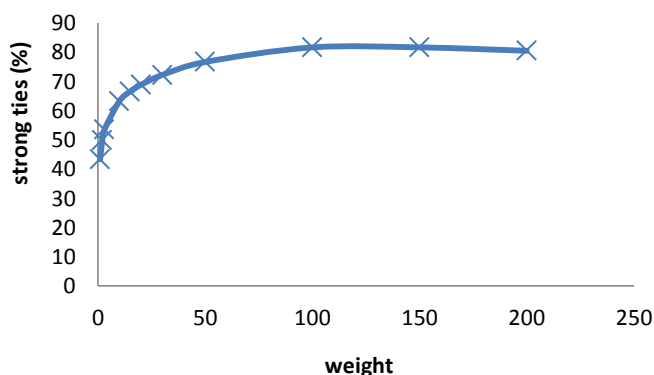


Figure 9. *Probability of discovering a strong tie with changes of tie-strength*

4.5 Relationship Symmetry

Finally, we discuss the association between relationship symmetry and tie-strength. As mentioned earlier, a social network normally exhibits bi-directional relationships; that is, when A has a link

toward B, then B also has a link toward A. We examine this property in our dataset by comparing it with a random network. The result is shown in Table 4. We see that symmetry relationship exists in our dataset. This finding is similar to the observation in social networks.

Relation	Actual	Random
Reply	17%	0.006%
Trackback	1.3%	0.0008%
Collect	0.8%	0.0003%

Table 4. *Percentage of symmetric relationship*

Next we study how tie-strength plays a part in relationship symmetry. We examine links in each node and calculate the correlation coefficient between links and the weight of the tie. We compare the result against a random network. The random network has a similar network structure as our dataset, but the weight of each link in the network is assigned randomly; hence, the weight distribution in a random network is uniformly distributed. The result is shown in Table 5. As expected, there is no correlation between relationship symmetry and tie-strength in a random network. In contrast, the correlation is high in our dataset: if user A has a more frequent “reply” interaction with user B, then user B is likely to initiate a “reply” back to A. This suggests that the interaction between people is reciprocal. When A establishes a relationship with B, B may also establish a relationship with A, although the strength on both relations may not be symmetric.

Relation	Actual	Random
Reply	0.544	-0.002
Trackback	0.240	0.003
Collect	0.347	0.011

Table 5. *Correlation coefficient between bi-directional link and tie-strength*

4.6 Summary

We provide a brief summary of findings from our observation. (1) The distribution of weight follows power-law; it implies that most links in the online social network are weak ties. Only a small number of users spend a significant amount of time and effort interacting with others on the blog. (2) The correlation between the out-degree and weight is lower than the correlation between the in-degree and weight. This implies that users who have replied to many different blogs may only maintain few interactions. However, users who reply to few blogs may have frequent interactions with them. (3) Results in Section 4.3 and Section 4.4 showed that the online social network exhibits the same characteristics as a traditional face-to-face social network. The online social network has a high clustering coefficient and exhibits small-world phenomenon. (4) The strength of dyadic ties will influence the strength of the third tie in triads. This implies that when a user’s relationship is strong, then a user’s friend will have a higher chance to become the friend of the user’s another friend. (5) The correlation between relationship symmetry and tie-strength is high; this implies that interactions between users are reciprocal. However, there is not enough data to support that tie-strength in the reciprocal relationship is symmetric.

The above findings suggest that a social network, extracted from an online social network site, satisfies most properties of a traditional social network. This shows that online social networks can be viewed as traditional face-to-face social networks.

5 DISCUSSIONS AND CONCLUSIONS

In this section, we discuss some implications of our findings, followed by the conclusion and some proposed future improvements to the study.

5.1 Discussions

The structural properties of social networks, like degree, are often used as a measure of how well connected an actor is in the social network. For online social networks, such as blogs, the in-degree can be used as an indicator of a given blog's popularity and prestige. The out-degree can indicate a user's diversity of interest. Google's PageRank (Page et al. 1998) included both in- and out-degree as measuring variables in a link analysis algorithm to "measure" a Web page's relative importance within the set of hyperlinks.

PageRank's algorithm considers each link in a set of a network has equal weight, but in fact it is not true in both WWW and social networks. Some cheaters have found a way to increase the in- and out-degree count by using link farms or by selling links to other Web sites to increase PageRank. Our findings suggest that a blog with a high in-degree weight does not necessarily indicate that it is highly involved in the network. Also, a blog with a low out-degree weight does not indicate that it is a "loner" in the network. We believe that including tie-strength in the analysis of a social network can improve the identification of popular blogs within the network. This can also encourage users to take the effort to interact with other users since their work will be noticed. One of our future work will be focusing on this study.

5.2 Conclusions

We analyzed the network data collected from *wretch.cc*. Based on this dataset we presented a quantification method of tie-strength in online social networks, and the role tie-strength plays in defining characteristics of the blog network. The method to quantify a weight of tie has been proved valid and can be used as a tie-strength measurement between two users in this type of online social networks. Based on our results, we can safely conclude that the social network extracted from the online social network site can be viewed and studied as a traditional social network.

Our attempt to understand the tie-strength in an online social network has opened up some topics for further discussion. For example, we only focused on data collected from the blog network, *wretch.cc*. This dataset may represent other blog networks in Taiwan; however, this dataset may not fully represent other online social networks like Facebook. The usage and functionality of Facebook differ from most blog networks. Therefore, analyzing different types of online social networks may lead to different conclusions.

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