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We are so close, less than 4 degrees separating you and me!

Eman Yasser Daraghmi, Shyan-Ming Yuan *

DCS Lab, Department of Computer Science, National Chiao Tung University, Hsinchu 300, Taiwan, ROC

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ABSTRACT

Nowadays, the glory of social networking sites is unprecedented. Thus, we are so close; the world is even smaller than you thought; a friend of your friend probably knows a friend of others friend; Facebook shrunk the gap between us. The six degrees of separation theory proposed in 1967 stated that we are all just six degrees of separation apart. This paper addresses the research problem of identifying the degree of separation from a different viewpoint by considering not only the degree of separation between two normal-persons or famous-persons, but also between two persons with very rare-special features. We re-evaluate and extend the six degrees of separation theory by using a real social searching Facebook tool "We R So Close". Experiments were performed on Facebook platform; and the graph database was used to store the collected data. Results add a new phase to the research that cemented the phrase "six degrees of separation", it reported that the average number of acquaintances separating any two people no matter who they are even with rare-special features, i.e. those who work in rare jobs, is not six but 3.9.

1. Introduction

Nowadays, the glory of social networking sites is unprecedented; Facebook is currently the top one frequently visited website on the web (Alexa, 2013). Excitement for Facebook is apparent in the entire world, as close to more than half of the population is reported to be active users on Facebook. It is not surprising that Facebook has been found to impact on the social structure in the world as it changes the way individuals communicate and associate with one another. It has never been easier to make friends than it is right now, mainly thanks to social networking sites; the gap between us all has shrunk.

According to the small world experiment or the six degrees of separation theory (Milgram, 1967), we are all just six degrees of separation apart (i.e. anyone on the world is connected to any other person on the world through a chain of acquaintances that has no more than five intermediaries). Because of Facebook, people are more closely connected than ever before with less than six degrees of separation having become the norm. If you feel that the world is small, that is because it is. The world is even smaller than you thought, a friend of your friend probably knows a friend of others friend. We are so close, no matter how far, it is only six degrees of separation. There have been several studies of evaluating the theory from different viewpoints on distinctive platforms. The University of Milan reported that the average number of acquaintances separating any two people in the world was not six but 4.74 (Facebook, 2013). They released their results without publishing the used method for analysis. In the recent years, the problem has become one of the favorite among researchers of many disciplines, exploring the probabilistic algorithms to evaluate the six degrees of separation theory; moreover, social network services have the capability to look at the small world problem from both the traditional algorithmic and the new topological approach. It is amazing how close we have come. There is plenty of empirical evidence to support the six degrees of separation theory, so we take a different, more realistic approach.

Since all of the previous findings were great; our study bolsters their conclusion by using a different view and approach. Most of the previous studies examined users' accounts without considering any filtering functions to remove all fake accounts (i.e. run by spammers and the like). For instance, sometimes people add others as friends for the purpose of reaching the highest level in games. In addition, previous research computed the degree of separation between two normal people or between two famous people without considering the complement case or the opposite situation. No one tried to extend and generalize the six degree of separation experiment based on rare-special features; i.e. how many degrees or hops separate you and a person who works in a rare job in a certain country such as linguistics in Thai language who works in Taiwan. We consider the following two points: (1) considering the fake accounts; (2) finding someone with special rare features, i.e. work in special profession or has special uncommon name.

The experiments to be described in this paper were an attempt to re-evaluate and extend the six degrees of separation theory

* Corresponding author. Tel.: +886 3 5715900; fax: +886 3 5721490.
E-mail addresses: eman.yasser85@gmail.com (E.Y. Daraghmi), smyuan@cs.nctu.edu.tw (S.-M. Yuan).

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using data collected by a real social searching tool. In this research, we took a different and more realistic approach to answer the question: is it possible in reality to re-evaluate the six degrees of separation theory? Also, we extended the theory from different viewpoints. We considered the opposite case that most of the previous studies ignore; the target object was changed from purely person-to-person to person who has very rare-special features. We illustrated the results from different opinion and considered all connections even the weak ones. We investigated three high-level research questions (RQs):

(1) Is there any relation between the degrees of separation and the size of the target group (or the population size)? Is it possible in reality to re-evaluate the six degree of separation theory? In other word, is it true that the worlds become smaller and smaller even the population increase? So is the six degrees of separation theory fact or fiction? Do you think it can be definitively proven?
(2) Can we test and extend the theory based on rare-special features? In other words, what is the degree of separation between me and a person who works in a rare job?
(3) What is the impact of removing famous or popular people (such as celebrities) form the chain? Will the degree of the separation be changed?

We targeted this study on the most popular social networking sites SNS, Facebook. To achieve our goals, we implemented a Facebook tool called "We R So Close". The tool provided two main searching functions: the basic search function and the advanced search function to find out the path between two persons or even the path between you and any unknown person who has special-rare features. For the benefit of the analysis, our tool supported the graph database "Neo4j" which is an open source, high-performance, NOSQL graph database that based on flexible graph structures with nodes, edges, and properties to store and record all the collected data (Angles & Gutierrez, 2008; Chang et al., 2008; DeCandia et al., 2007; Leavitt, 2010; Leskovec & Horvitz, 2008; Stonebraker & Hong, 2009). As we are interested in observing the transformation in the structure of the society and studying the impact of social networks services to re-evaluate the six degree of separation theory from different aspects, we conducted a study in the wild. To recruit broadly, we distributed the "We R So Close" tool on Facebook for free over the duration of the study (six months). During the in-the-wild evaluation, of the 949,925,041 (represents 80% of active Facebook users) users who use the tool, 332,643,132 used it actively over the course of six months. The contribution of this study is threefold. In this paper we demonstrate that:

(1) It is possible in reality to re-evaluate the six degrees of separation theory. Because of social networks, the world becomes closer and closer. Social networks affect the structure of our society in many ways, including our communication, self- expression, bullying, isolations, friendships, and even our very own sense of humanity.
(2) Even by changing the target objects to obscure or unknown people who works in rare job, Facebook cuts six degrees of separation to less than four.
(3) The average degree of separation ranges from 3 to 4 even when ignoring popular people, i.e. celebrities who are the most engaged in social network services such as Facebook.

Results illustrate that even by changing the target objects from normal person or famous person to obscure or unknown person who works in a rare job, Facebook cut the six degrees of separation to less than four which mean even the one who works in the rarest job can be found with less than four degrees. We hope our experimental results give people a new viewpoint about online social networks, and boost some new social services based on our results such as new marketing strategies. In summary, this paper contributes in: (1) observing the transformation of the social structure when the number of the social networks users' increases; (2) extending and generalizing the "Six Degrees of Separation Theory" based on rare-special features.

2. Related work

2.1. The small-world network

The small-world network is a type of mathematical graph in which most of the nodes are not neighbors of one another, but these nodes can be reached from every other by a small number of hops or steps. In the context of a social network, the small-world phenomenon of strangers is being linked by a mutual acquaintance. Many empirical graphs are well-modeled by small-world networks. A certain category of small-world networks were identified as a class of random graphs by Duncan Watts and Steven Strogatz in 1998. They noted that graphs could be classified according to two independent structural features, namely the clustering coefficient, and average node-to-node distance (also known as average shortest path length). Watts and Strogatz measured that in fact many real-world networks have a small average shortest path length, but also a clustering coefficient significantly higher than expected by random chance. Watts and Strogatz then proposed a novel graph model (Watts & Strogatz, 1998), currently named the Watts and Strogatz model, with (1) a small average shortest path length, and (2) a large clustering coefficient. In summary, regular networks (Chartrand, 1984; Mathworld, 2011) have a high degree of clustering and high degree of separation (i.e. The degree of separation between two nodes is the length of the shortest path between them. The degree of clustering of some node is defined as the real number of edges between these its neighbors divides the maximal number of edges), on the contrary random network (Newman, Watts, & Strogatz, 2002), which adapt the random graph model (Erdös & Rényi, 1959), have a lower degree of clustering and lower degree of separation.

2.2. The small world experiment

The six degrees of separation is the theory stated that anyone in the world can be connected to any other person on the world through a chain of acquaintances with no more than five intermediaries, so a chain of "a friend of a friend" statements can be made to connect any two people in a maximum of six steps (Travers & Milgram, 1969). What if you need to find someone you do not know directly and the communication mediums such as email, mail or telephone were unavailable? Then the only method of communication will be via personal contacts. You can search for a friend of us who directly know the intended recipient. But what if, none of your friends know the recipient directly? Then probably we have to depend on some other intermediate person who can connect one of our friends to the intended recipient. What if there is no such person. Then another intermediate person is required. This gives the rise to an interesting question, "What is the maximum number of such intermediate people needed to make sure that we can send a message to anyone in the world?" or in other words "What is the minimum number of people between any two people in the world ?". The theory was first proposed in the 1920s by a Hungarian author Frigyes Karinthy who published a volume of short stories titled "Everything is Different." One of these pieces was titled "Chains," or "Chain-Links" (Karinthy,

1929). In particular, Karinthy believed that the modern world was shrinking due to this ever-increasing connectedness of human beings. He posited that despite great physical distances between the globe's individuals, the growing density of human networks made the actual social distance far smaller.

In the 1950s, Ithiel de Sola Pool (MIT) and Manfred Kochen (IBM) set out to prove the theory mathematically. Although they were able to phrase the question (given a set N of people, what is the probability that each member of N is connected to another member via 1, 2, 3...and n links?), they were still unable to solve the problem after twenty years of trying (Gurevitch, 1961). In 1967, the American sociologist Stanley Milgram devised a new way to test the theory, which he called "the small-world problem". He randomly selected people in the Midwest to send packages to a stranger located in Massachusetts. The senders knew the recipient's name, occupation, and general location. They were instructed to send the package to a person they knew on a first-name basis who they thought was most likely, out of all their friends, to know the target personally. That person would do the same, and so on, until the package was personally delivered to its target recipient. Although the participants expected the chain to include at least a hundred intermediaries, Milgram found that the number of intermediaries to get each package delivered ranged from two to ten, with five being the most common number. Milgram's findings were published in (Milgram, 1967) and inspired the phrase "six degrees of separation." This study showed that the method not only worked but it could be used to investigate chains as they are affected and shaped by social structure.

Several studies have tried to evaluate the experiment from different viewpoints and on distinctive platforms. Guiot (1976) indicated that Milgram method suffered from some drawbacks: (1) a large number of chains "died" before completion; on the average only twenty-two percent of all chains eventually reached to the target; (2) Milgram method did not incorporate any satisfactory means to determine whether recipients were truly personal acquaintances of the sender; (3) the method was intentionally limited to the tracing of linear chains. Guiot method can be summarized as follows. Each potential starter was called on the telephone. A brief description of the small world problem was given. Then the starter was given selected information about the target. If the starter did not know the target, he was asked to name someone as the next link in the chain and so on. In 2001, Duncan Watts, a professor at Columbia University, attempted to recreate the Milgram's experiment on the Internet, using an e-mail message as the "package" that needed to be delivered, with 48,000 senders and 19 targets (in 157 countries). Watts found that the average (though not maximum) number of intermediaries was around six (Watts, Dodds, & Newman, 2002). In April 2010, Sysomos Inc., posted a study "Six Degrees of Separation, Twitter Style" (Sysomos, 2010). They sliced and diced more than 5.2 billion Twitter friendships (the number of friend and follower relationships) to investigate the connectivity of the Twitter network. They discovered that Twitter is, in many, ways a network with only five degrees of separation. This means that nearly everyone on Twitter is just five steps away from each other. Here are their major findings:

(1) The most common friendship distance is five steps. (The average distance is 4.67 steps).
(2) The second most common friendship distance is four steps.
(3) On average, about 50% of people on Twitter are only four steps away from each other, while nearly everyone is five steps away.
(4) After visiting an average of 3.32 people within the friend network, Twitter users can expect to find one of their followers!

Jure Leskovec and Eric Horvitz presented a study of anonymized data capturing a month of high-level communication activities within the whole of the Microsoft Messenger instant-messaging system (Leskovec & Horvitz, 2008). They examined characteristics and patterns that emerge from the collective dynamics of large numbers of people, rather than the actions and the characteristics of individuals. The dataset contained summary properties of 30 billion conversations among 240 million people. From the data, they constructed a communication graph with 180 million nodes and 1.3 billion undirected edges. They found that the graph is well-connected and robust to node removal. They investigated on a planetary-scale the oft-cited report that people were separated by "six degrees of separation" and found that the average path length among Messenger users is 6.6. The University of Milan reported that the average number of acquaintances separating any two people in the world was not six but 4.74. The findings were posted on Facebook's site Monday night (Facebook, 2013). The experiment took one month. The researchers used a set of algorithms developed at the University of Milan to calculate the average distance between any two people by computing a vast number of sample paths among Facebook users. They found that the average number of links from one arbitrarily selected person to another was 4.74. In the United States, where more than half of people over 13 are on Facebook, it was just 4.37. This mean, there are at most only five intermediate persons between any two people in the world.

3. Method

3.1. We R So Close: An online social searching tool

The "We R So Close" tool was developed to answer our research questions. It consisted of (see Fig. 1): the Facebook-based tool, Neo4j, MySQL database and the WRSC interface.

The Facebook-based tool was written in PHP. Since the Facebook Graph API also supports PHP, our tool was integrated easily with Facebook platform by the iFrame. The Graph API was used for authentication and accessed the participants' profile. The tool consisted of a database agent to process the data, and decided which database these data should be assigned to; it stored users 'states and their log files into MySQL database while stored their relationships as nodes and edges into the Neo4j graph database. The tool was run on our own server for six months. Fig. 2 illustrates the behavior of the iFrame on Facebook platform.

Neo4j component provided the essential API to create and access the stored social-relationships-data that were retrieved from the participants' profiles. In contrast, MySQL database recorded all log information about participants. Fig. 3 illustrates the MySQL database schema.

The WRSC interface served as the intermediary between the tool and the graph database. It consisted of: the application part and the experiment part (see Fig. 4). The application part provided the needed functions (addNewNode, getPath, getSpecificPath) for the front-end "We R So Close" tool. Table 1 lists the functions of the application part components.

The experiment part consisted of the statistical functions needed to compute and analyze the collected data: avgDegree (int[1] targetDBsize[2], int sample), avgDegreeJob (int targetDBsize, String[3] joblist), avgClusterDegree (int targetDBsize), createGraphFromLog (int DBsize) and countNode (int targetDBsize). The avgDegree component computed the degree of separation using a random sample. The target database and the number of samples were

[1] int: is an integer number which is a number of the set $\mathbb{Z} = \{..., -2, -1, 0, 1, 2, ...\}$.
[2] targetDBsize: is the target database size.
[3] String: is series of characters, where a character is the same as a byte.

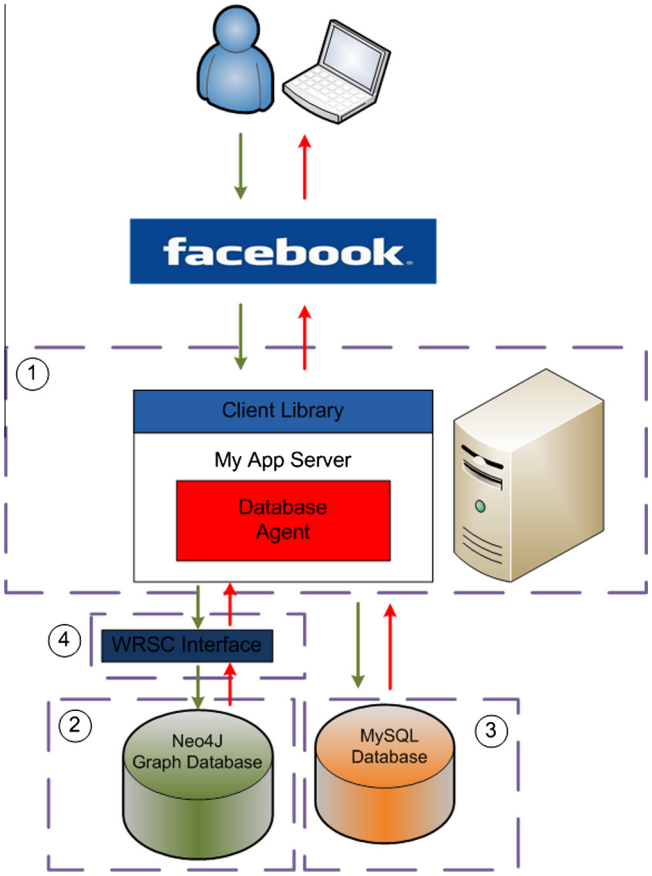

Fig. 1. System overview.

decided by the two parameters (1) targetDBsize; (2) sample. The avgDegree function returned the average degree of separation of the samples, the standard error of samples, and the spending time. We used 95% confidence level for the standard normal distribution to estimate the population mean from the given sample data. We set the sample size as 10,000 which were large enough. Thus, we used z-test for unknown mean and unknown standard deviation. The formula for computing confidence interval is listed in Formula (1), where $\bar{X}$ is the mean of samples, s is the standard error of sample, n number of samples, and z decided by confidence level; $z = 1.96$.

$$\bar{X} \mp z\frac{s}{\sqrt{n}} \tag{1}$$

The avgDegreeJob computed the degree of separation between two nodes such as at least one of these nodes had a job property that was listed on the joblist. The joblist is a text file which contains all the target jobs. The avgDegreeJob returned the average degree of separation, standard deviation, and the spending time. The avgClusterDegree computed the degree of clustering of the target database and returned the average degree of clustering and the spending time. To compute the degree of clustering, we followed the Formula (2), where N is the number of nodes, k_i is number of neighbors for node i. E_i is the number of connected edges between node i and its neighbors.

$$C = \frac{\sum_{i=1}^{N} \frac{2E_i}{k_i(k_i-1)}}{N} \tag{2}$$

The createGraphFromLog created a graph database with a required number of nodes from the log that was recorded in MySQL by inputting the DBsize ("Database size"). The countNode counted the number of nodes and edges in the assigned database. It also searches the number of nodes who has some properties. Note that, when the stored data retrieved for the analysis, the database agent invoked the WRSC interface and executed the needed functions. At the end, the WRSC interface notified the database agent that the work has been completed; and returned the results.

We designed the interface of the tool using the top ten most spoken languages in the world (French, Malay-Indonesian, Portuguese, Bengali, Arabic, Russian, Spanish, Hindustani, English, and Mandarin) to attract Facebook users from different regions (see Fig. 5 the tool designed using Chinese interface). The tool provided two main searching functions: (1) the basic search function works by entering two specific names "the source node and the target node". It shows the path and all intermediaries between them using the shortest path algorithm; (2) the advanced search function works by only selecting a rare profession from a list without specifying a target name to find the path between you and someone who had worked in the selected rare profession. Moreover, in order to get a sample that is representative of active-real Facebook users (i.e. not run by spammers and the like), the tool supported a filtering function is to detect, check all participants' accounts automatically, and remove invalid data and fake accounts, duplicate accounts and non-real accounts. The function examined the account by some weighted criteria; each criterion had a pre-defined point, the function computed the probability of removing that account and made a decision (i.e. to remove or to record the data) based on the account result. For instance, accounts that had a 50% probability to be removed also had a 50% probability to be considered, as real accounts, for analysis. Therefore, the function automatically created questions and sent it to the participant, upon receiving a correct response the account was added to our database otherwise it was considered as non-real accounts.

Following are the criteria that already used in developing our filtering function:

(1) The function checked the profile pictures folder for the participant. If there is only one photo in the whole profile it makes it quite clear that the account may be "fake account".

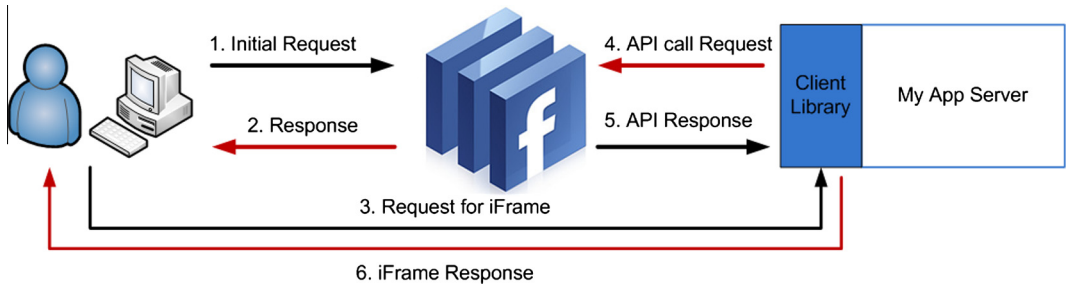

Fig. 2. The behavior of iFrame on Facebook.

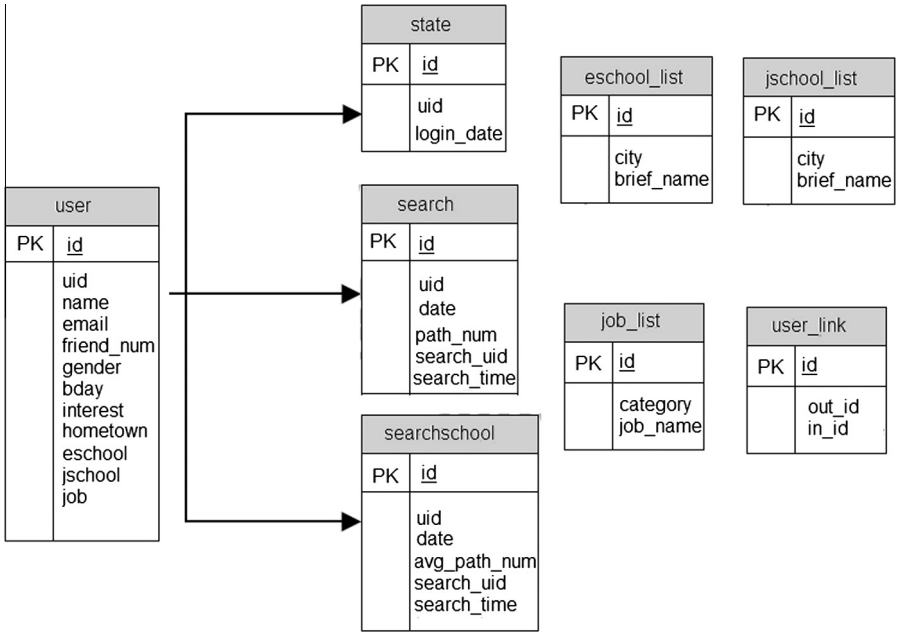

Fig. 3. MySQL schema.

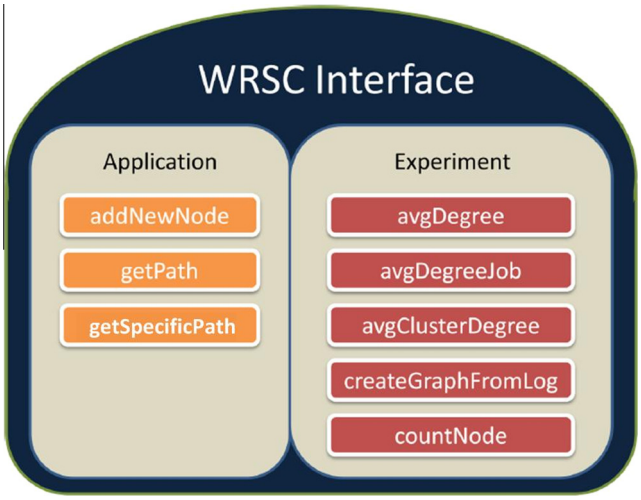

Fig. 4. The WRSC interface.

(2) It checked the info. If the function found that there is no ideal links given regarding school or educational institutions or workplace and that the user is looking for dating and interested in both men and women, it shows signs of "fake account".
(3) It checked the number of friends, if it is less than ten friends; it shows signs of "a fake account". Note that, in this case we also identify this person also as non-social person. If this account then passes all the criteria, it is considered as a real person.
(4) It checked out the friend list. If found that maximum of the friends are of the opposite gender, it can be assumed that the profile is used either for fun or for random dating "fake account".
(5) It looked out for recent wall posts, if it sees loads of people asking "thanks for adding me, do I know you" and yet the posts remains unanswered, it is bound to be a "fake one".
(6) It checked the user profile status updates, wall posts and comments. If the user has not updated a status for quite a long time and has not been involved in any wall posting or commenting of other statuses, it means that the profile is likely to be "non-real account".
(7) It checked the log file, if the account only used for games, it is clear to be "non-real account".
(8) It looked at the recent activities. If it is that the user has just been adding random users and making new friends, and that there are no pages liked or groups joined, it suggests that the user is determined by just adding people and hence the profile is likely to be "non-real account".
(9) It checked the account information, if we find that identical-information stored in our database then this profile is considered as "duplicate account".

3.2. Participants

The method of recruitment was through random sampling. We released the "We R So Close" tool with its two main searching functions on the most popular SNS, Facebook for six months. In order to obtain a sample that is representative of active Facebook

Table 1
The application part components.

The components	Parameters	Function
addNewNode	String self, String[] friendList	Add new nodes, edges, and properties into the graph database according to the user friendList
getPath	String node1, String node2	Find the path between node1 and node2
getSpecificPath	String node1, String feature	Find all paths between node1 and node2 who has specific feature that might be a school name, profession or family name. It returns all the shortest paths between the participant and users with the selected specific feature

Fig. 5. We R So Close, a social searching tool for Facebook.

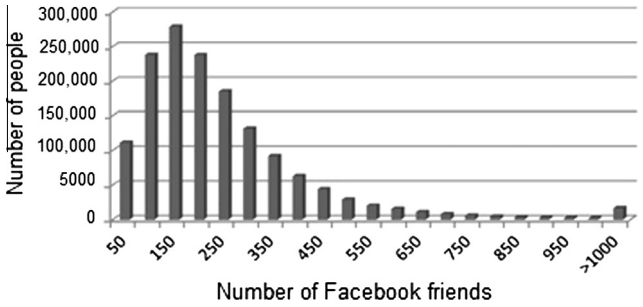

Fig. 6. The distribution of the number of friends.

users, the top ten most spoken languages in the world were used to design the interface of our tool. Data from participants which include: Facebook ID, birthday, gender, profession, and his/her relationships (i.e. one level: participant and his/her friends' data was captured to maintain privacy for other users who do not participate in our experiment) were retrieved after taking the participant permission. The collected data was recorded in the graph database that contained 142,626,096,754 nodes (the number of participants and their friends) and 864,832,688,806 edges (represents the relation between participants and their friends) which cover one-third world-wide population. The majority of the participants (47%) had been registered on Facebook for about three years (33% for more than three years and 20% for less than three years). Male participants comprised 59% of the sample. The mean age of the sample was 20.1 years (SD = .186); participants ranged from 18 to 48 years old. Of the participants, the mean number of friends was 224 as shown in Fig. 6.

3.3. Procedure

The "We R So Close" tool was released on Facebook in May, 2012 and made available to participants for six months. To achieve the goals of this study, the following basic information was required to be filled out one time by participants who visited our tool for the first time; (1) the participant elementary school; (2) junior high school; (3) the participant current and previous profession. Simultaneously, the system retrieved the participants' friends list and stored it in the Neo4j graph database; i.e., 101 nodes with 100 edges between the participant and his friends will be added to the graph database for a participant who has 100 friends.

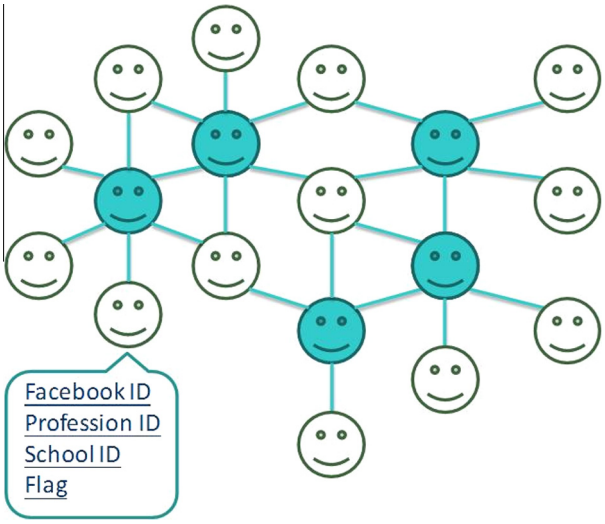

Fig. 7. The design of the graph database.

Fig. 7 shows the graph database design. The blue nodes represented participants of this study, and the white nodes illustrated their Facebook-friends. All nodes had the following four properties: Facebook ID, elementary/junior high school ID, profession ID, and a flag that used to mark if the participant has visited our tool before or not.

The sequence diagram of the experimental procedure is shown in Fig. 8. Once a participant provided consent, s/he was directed to the tool main page that had two main searching functions; the basic searching function found out the path between any two active Facebook users by using the shortest path algorithm and returned all intermediaries between them.

The advanced search function required to select a profession from a list in order to show the path between the participants connected to someone who worked in the selected profession. Hence, we got a classification of professions from the bureau of employment and vocational training in order to identify clearly the list of professions provided by this function; each profession has a title and an id number. This function found out the path between two persons who have a rare-special feature that might be a rare profession; it returned all the shortest paths between them. Fig. 9 shows the index page of our tool.

4. Experimental results

Hence, before executing the main steps of our experiments, we had a pre-process procedure to check and filter out invalid data. The filtering function was responsible for analyzing the participant's information in order to delete all fake accounts. This preprocess step was very important for minimizing the influence from invalid data and increasing the accuracy of our experiment. Therefore, the current graph database analyzed in this paper is simply graph of real Facebook users who used our "We R So Close tool" at the time when the experiments were performed (May 2012);

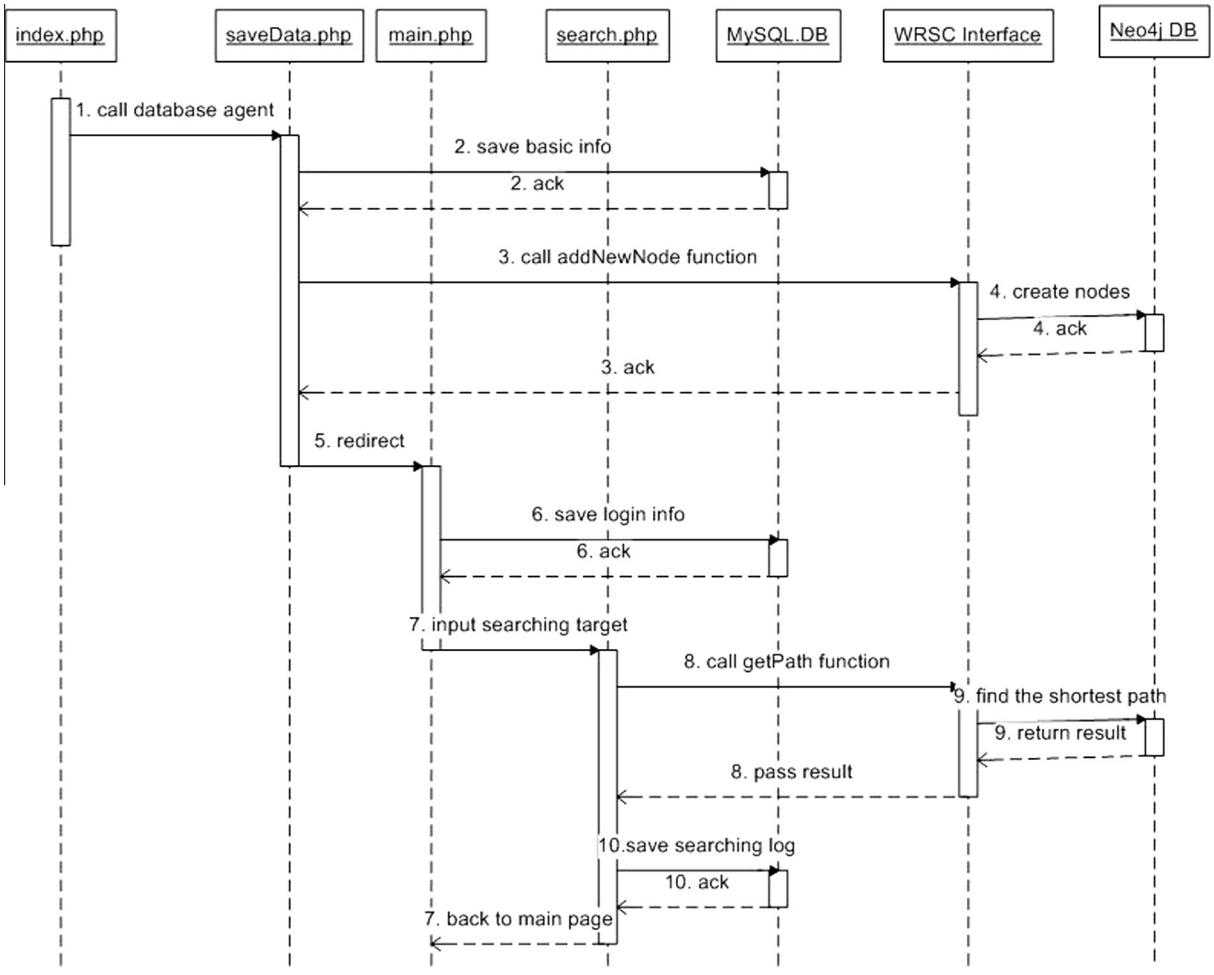

Fig. 8. The procedures sequence diagram.

a real account is the account that represents actual individuals. The decision to restrict our study to real users allows us to eliminate (1) accounts that have been abandoned in early stages of creation; (2) fake accounts; (3) duplicate accounts, and focus on accounts that plausibly represent actual individuals. The graph does not include "pages" that people may "like" or "groups" that people may join. We focus on standard user accounts on Facebook that have a limit of 5000 possible friends. As mentioned in the introduction section, this paper investigates three high-level research questions (RQs). Thus, we decided to address our experiments in three directions: re-evaluating the six degrees of separation theory, extending the six degrees of separation theory and other observed results. The following subsections illustrate the three directions.

4.1. In-the-wild evaluation part I: Re-evaluating the six degree of separation theory (RQ1)

Our first research question (RQ1) aimed to answer whether is there any relation between the degree of separation (the number of hops separating two persons) and the population size (the size of the target group)? Is it true that everyone on the earth is separated by less than six degrees? Is it possible in reality to re-evaluate the six degrees of separation theory by using a Facebook tool? The six degrees of separation theory indicates that I can personally send a mail to Barrack Obama via five intermediate persons. I can contact Chuck Norris via five people. I can connect with Mr. ABC from Mr. ABC from country XYZ through just five persons. So the question is "is it true?", "Can I see how its work?" We (RQ1) aimed to (1) observe the relation between the degree of separation and the size of the target groups (or the population size); (2) compute the degree of separation and the degree of clustering to verify if we can in reality re-evaluate the six degrees of separation theory.

First, we performed the pre-process procedure to check the validity of the collected data using our developed filtering function described in section 3. Then, we confirmed the reliability of the collected data by verifying whether our target database is a small world network. Therefore, we executed the "avgClusterDegree" function, which is a function in the experiment part of the WRSC interface (for more details about avgClusterDegree function, see Section 3.1), to compute the degree of clustering of our graph database. According to the small world model proposed by Watts and Strogatz (1998), a small world network had a higher degree of clustering than a random network. Higher degree of clustering indicates that there are more edges between the nodes (closer relation between friends) which form a close group. Results showed that our target graph was a small world network.

The main objective of this experiment was to re-verify the six degrees of separation theory; we called the "avgDegree" function (for more details about avgDegree see Section 3.1) to compute the degree of separation. The "avgDegree" function takes two input parameters; the target database size (i.e. the graph size) and the sample size. Thus, we backed up the core graph database when the accumulated participants achieved 500, 3000, 5000, 10,000, 30,000, 50,000, 70,000, 100,000, and 150,000 (see column 1 in Table 2). We recorded all the participants' log into the MySQL database component in order to export any size of the graph database from the log when needed and set the sample size at 10,000. We consider all edges (i.e. relations) including strong and weak connections between the nodes (Facebook users). Weak connections are those edges that occur among nodes belonging to different communities. Strong Ties, those edges occurring among nodes in the same community (see Fig. 10). Then, we executed the "avgDegree" function at a confidence level of 95% for estimating the mean of the population from the given sample data (i.e. the average degree of separation). The "avgDegree" function calculated the average degree of separation of the samples, the standard error of samples (see columns 3 and 4 in table 2), and the calculation spending time.

In our experiment, the average degree of clustering was 0.427 and with 0.233 standard deviation. The clustering coefficient revealed that about 40% of the participants know each other and the experimental network had the clustering property. We also

Fig. 9. The index page of the "We R So Close" tool.

Table 2
The degree of separation.

Number of Nodes	Population size (Number of possible paths)	Sample means	Stand errors of sample means	95% Confidence Interval for the population means
500	124,750	4.053	1.451	4.053 ± 0.028
3000	4,498,500	3.922	0.821	3.922 ± 0.016
5000	12,497,500	3.906	0.750	3.906 ± 0.015
10,000	49,995,130	3.829	0.684	3.829 ± 0.013
30,000	80,985,487	3.831	0.619	3.831 ± 0.012
50,000	249,975,522	3.860	0.585	3.860 ± 0.011
70,000	449,965,603	3.839	0.581	3.839 ± 0.011
100,000	699,950,385	3.835	0.580	3.835 ± 0.011
150,000	949,925,041	3.868	0.572	3.868 ± 0.011

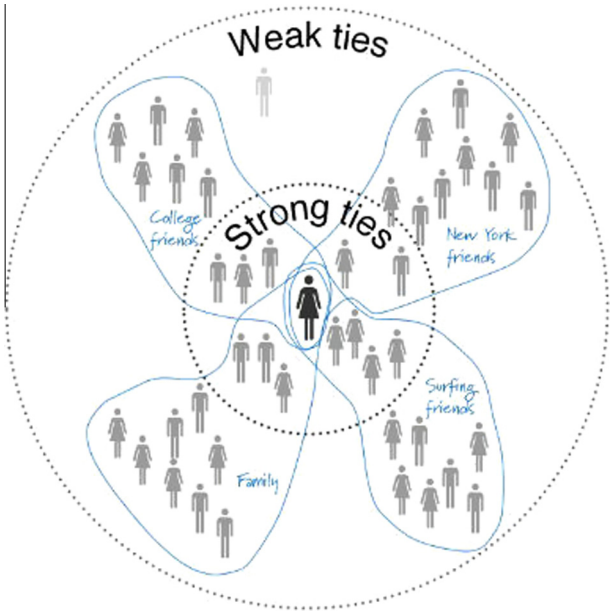

Fig. 10. Strong and weak ties.

found that people tend to have a similar, albeit typically smaller, number of friends as their neighbors, and tend to be about the same age. There was a negative correlation between the population size (i.e. the number of people that are in the group the our sample represents) and the standard error of the sample mean, i.e. smaller population sizes lead to the higher standard error of the sample means (Population size = 124,750, Stand errors of sample means = 1.451) (Population size = 11,249,925,000, Stand errors of sample means = 0.572). Hence, the population size was calculated by the maximum number of edges that can be computed using a given number of nodes. In addition, there was a negative correlation between the population size and the degree of separation. Results showed that the samples mean ranged from 3.82 to 3.84 when the number of nodes increased from 10000 to 100000. Table 2 depicts our results. Our analysis revealed that the average degree of separation for 949,925,041 active Facebook (150,000 node) users around the world was 3.868 (less than four), see Fig. 11. Results showed that it is possible in reality to re-evaluate the six degrees of separation theory by using an online tool.

4.2. In-the-wild evaluation part II: Advanced Analysis Based on rare-special features, extending the six degree of separation theory based on rare-special features (RQ2)

Our second research question (RQ2) attempted to: (1) observe how many intermediates separate you and a Facebook user who has a rare-special features such as distinctive last names or peculiar jobs; (2) extend and generalize the results of the six degrees of separation theory based on these rare-special features. In this paper and because of the size limitation, we focused on our analysis on the rare profession or job as a rare-special feature.

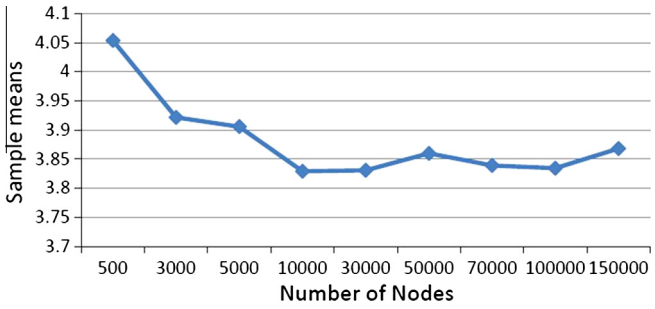

Fig. 11. The average degree of separation.

We got a classification of professions from the bureau of employment and vocational training in order to identify clearly the list of professions provided by our advanced function; each profession has a title and an id number. First, the function provided a list of professions that contains 332 genres to participants. The participant selected a profession from a list and the function showed the degree of separation between him and someone who worked in the selected professions. The distribution of the professions is shown in Fig. 12 a. Since this study targeted the rare-special features such as rare profession, we removed those professions that represent the highest proportion such as students as it is very easy to find a person whose profession is a student. After removing those professions, the distribution of profession turns from Fig. 12a into Fig. 12b, that is obviously a power law graph. To accomplish our goal we focused on the long tail of the power law graph to find out how many degrees between us and a person who has rare profession such as a midwife or oculrist? In the first step of our analysis, we classified the professions into three lists: (1) the first list represents the last 0.1% of the profession distribution (i.e. it consisted of 23 jobs); (2) The second list represents last 1% (i.e. it consisted of 84 jobs); (3) The third list represents the last 5% of the profession distribution (i.e. it consisted of 168 jobs). Then we executed the "avgDegreeJob" function that takes two input parameters (the database size and the job list). It computed the average degree of separation on each job list. As mentioned before, the random sample techniques were used. The sample size was set at 100. This step means that we randomly selected 100 people from our dataset and computed the distance between the person whose profession was contained in the job list and them. Table 3 lists the results.

Results showed that the estimated average degree of separation for finding a person whose profession was belonging to the last 0.1% of the distribution of profession is 3.401 ± 0.119, and the average degree of separation for finding a person whose profession was belonging to the last 5% of the distribution of profession was 2.931 ± 0.133. Results indicated that the average degrees of separation between two persons in the world even with special-rare features were 3.2, and there was a high probability that people can find most profession within 3 degrees of separation on Facebook.

In addition, for more detailed analysis, we focused on the rarest profession list (i.e. the last 0.1% of the profession list that includes 23 professions). We computed the average degree of separation and the standard deviation for each profession. Table 4 presents the results. We randomly selected 30 samples and computed the distance between the samples and each profession list. The average degree of separation was ranged from 3 to 3.9 which indicated that even the rarest profession could be found within only 3.9 degrees of separation. We concluded that Facebook and social networks bring rare professions to light.

4.3. In-the-wild evaluation part III: Other observed results

Research question 3 (RQ3) aimed to observe the influence of celebrities on the structure of the society. Will the degree of separation increased or decreased if we ignore those celebrities and replicate the analysis? This experiment aimed to observe the influence of the higher-degree nodes (higher-degree nodes represent celebrities and famous people who are the most engaging social networks such as Facebook) by comparing the degree of separations before and after removing those nodes.

We conducted an experiment to compute the degree of separation when ignoring high-degrees nodes to study the influence of

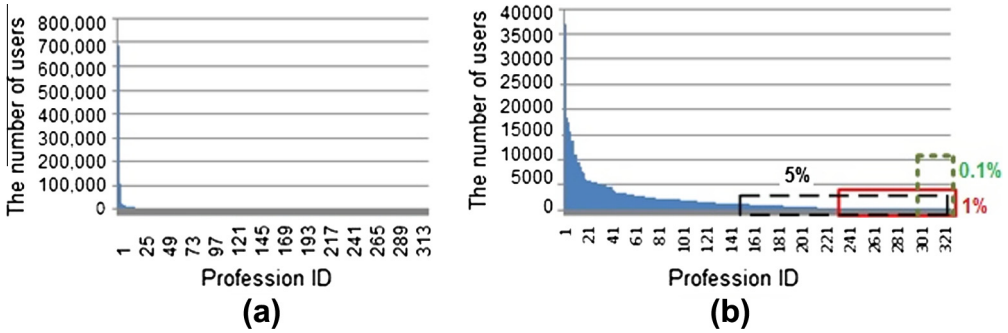

Fig. 12. The distribution of the professions. (a) Before deleting highest proportion of professions. (b) After deleting highest proportion of professions.

Table 3
The average degree of separation for the rare professions.

Distribution of profession	Genre of profession	Avg. degree of separation
Last 0.1%	23	3.401 ± 0.119
Last 1%	84	3.131 ± 0.161
Last 5%	168	2.931 ± 0.133

those nodes. A node with more than 1000 friends was defined as a high-degree node (i.e. celebrity). We performed this experiment to re-evaluate the degrees of separation with considering four cases: including all nodes, removing all the nodes who has more than 1000 friends, removing all the nodes who did not use the "We R So Close" tool (the white nodes in Fig. 7), and removing white nodes whose degrees are more than 10. The number 1000 and 10 are decided by the proportion (about 1% of the population). Table 5 shows the results. Our evaluations based on the three standards separately: 5000, 50,000, and 1,00,000 participants in the graph (i.e. calculating the average degree of separation for the four cases among 5000, 50,000, and 1,00,000 users separately). The results concluded that the average degree of separation ranges from 3 to 4 even when ignoring celebrities who are the most engaged in social network services such as Facebook.

4.4. Research comparison

We compared our experimental results with other representative experiments mentioned in the related work section as shown in table 6.

Results indicated that our experimental results had the lowest degree of separation since we followed the strength of weak ties principle proposed by Granovetter in 1973 to build the edges of the graph (Granovetter, 1973). In the original experiment performed in 1967, Stanley Milgram's (Milgram, 1967) examined the idea that any two people in the world are separated by only a small number of intermediate connections. By sending packages to random people, asking them to forward the parcel to the friend or acquaintance that had the best chance of getting it to a set of target persons, he found that people in the United States were connected via an average of 5.5 others. A Microsoft study in 2008 (Theguardian, 2008), using a more conservative definition of a friend, found an average chain of 6.6 people in a group of 240 million who exchanged chat messages. In the third experiment, an English Facebook application named "Six Degrees" was released in 2007 for proving the six degrees of separation. This application was terminated since it violated the privacy policy of Facebook. Therefore, they did not publish any formal paper or detail information thus we cannot get any other idea about their experiment except the

Table 4
The degree of separation for each profession.

Category	Profession	Number	Avg. degree of separation	Standard division
Accounting and Finance	Stock Affair Specialist	1930	3	0
Construction Class	Crane Operator	1888	3	0
Traffic and Logistics Services	Dispatch Messenger	1867	3.4	0.27
Traffic and Logistics Services	Motor Driving Instructor	1856	3.4	0.27
Sales and Marketing	Chain Store Expansion Developer	1674	3.2	0.18
Sales and Marketing	Product Research Supervisor	1544	3.2	0.18
Advertisement Art Editor	Media PR Promotion	1343	3	0
Technology Service	Footwear Engineer	1346	3.4	0.27
Technology Service	Garments Patternmaking Staff	1389	3.3	0.23
Construction Class	Environment Cleaner	1265	3.4	0.49
Entertainment and Performing Arts	Flower Arranger and Designer	1198	3.5	0.28
Construction Class	Spray Painter	1455	3.4	0.49
Technology Service	Stitching Machine Operator	1158	3.3	0.23
Traffic and Logistics Services	Flight Attendant	1099	3.3	0.23
Communication and Media	Other Language	965	3.2	0.18
Cosmetic Surgery	Anesthesiologist	936	3.9	0.1
Sales and Marketing	Negotiation and Customs Clearance Staff	949	3.5	0.28
Communication and Media	Chinese-to-French Translator	579	3.6	0.49
Sales and Marketing	Protective Tariff Staff	386	3.4	0.27
Communication and Media	Chinese-to-Indonesian Translator	381	4	0
Cosmetic Surgery	Midwife	367	3.7	0.46
Communication and Media	Chinese-to-Korean Translator	369	3.8	0.22
Communication and Media	Chinese-to-Thai Translator	193	3.6	0.26

Table 5
Other observed results.

Number of users	Including all nodes (Original)		Removing Nodes With More Than 1000 Friends		Removing all white nodes		Removing the white nodes with degree >10	
	Avg.	Std.	Avg.	Std.	Avg.	Std.	Avg.	Std.
5000	4.05	1.45	4.01	1.29	5.52	4.05	4.13	1.10
50,000	3.91	0.75	3.96	0.85	6.15	3.91	3.87	0.76
100,000	3.83	0.68	3.89	0.66	5.58	3.83	3.89	0.40

Table 6
A comparison between our experiment and others.

	First small world experiment	Microsoft research	Facebook App	Sysomos Inc. analysis	University of Milan experiment	We R So Close
Year	1967	2006	2007	2010	2011	2012–2013
Platform	America, letter	MSN, 600 friends	Facebook, 5000 friends	Twitter	Facebook	Facebook
Scale	300 start points	180,000,000 Nodes 1,300,000,000 Edges	5,800,000 Nodes	5,200,000,000 Edges	721 million active Facebook users	949,925,041 real Facebook users
Degree of Separation	5.5	6.6	5.7	4.7	4.74	3.868
Description	First experiment	Only Communication Network	Lack of detail info	Less limitation of edges	Developed their own algorithm	Using the We R So Close tool

result 5.7 degrees of separation. Sysomos Inc. conducted an analysis on Twitter and the experimental results were 4.7 which show a lower degree of separation than others since the definition of relationship on Twitter is different from the one on MSN and Facebook. On Twitter, it is allowed to follow any person without his permission. Based on this reason, some famous people may have tens of thousands of followers and the variance of the number of neighbors in the social graph will be higher. Another issue is the number of users on Twitter is only one-third of the number of users on Facebook so it covers less population in the world. We can say the social structure on Twitter and Facebook are really different. The last experiment performed at the University of Milan reported in 2011 (Facebook, 2013) that the average number of acquaintances separating any two people in the world was not six but 4.74.

5. Discussion

5.1. Re-evaluating and extending the six degree of separation theory

The six degrees of separation theory led us to infer that it is possible in reality to replicate the small world experiment in order to re-evaluate and extend the theory using data collected by an online Facebook tool. The results of our experiments can be summarized by pointing out that:

(1) Facebook cuts the degree of separation to less than 4; every single person in the world is connected through less than four degrees of separation; there was a negative correlation between the population size (represented by the size of the target group) and the degree of separation (represented by the number of hops separating two individuals in the world); the larger the population sizes the smaller degrees of separation. These results were consistent with reality since in the 1960s, the population size was 3,039,451,023 when Stanley Milgram's performed his experiment "small world experiment" which measured connections in the United States by tracking a package in the mail sent between two randomly selected people to find that every single person in the world is connected through six degrees of separation while now in 2013 the population size is more than 6,848,932,929. One possible conclusion is that more mutual friends and relations between individuals make this world as a close group; the world has a higher degree of clustering. Since each node and relation can play structurally distinct roles in society structure, all edges (relations) including strong and weak connections between users were considered in our experiment. For instance, among a group of three friends A,B and C, if A and B have a strong relation as friends, and also B and C have strong ties as friends, then it is very likely that A and C are also related in some way. Our results also had implications at the operational level; it verified all the collected data by a filtering function that removes all fake and duplicate accounts, thus bolstering our conclusion. We conclude that Facebook helps foster friendships and more besides; it helps you find people you share interests with. Thus, it is possible to re-evaluate the six degrees of separation in reality using an online tool.

(2) Even a person who works in rarest profession can be found within 4 degrees of separation; not only are there few degrees of separation between any two people even with rare-special features, but that individuals can successfully navigate these short paths, even though they have no way of seeing the entire network. These results bolstered our previous conclusion, less than four degrees separating you and others in the world. We concluded that Facebook and social networks have brought rare professions to light since 74% of all connections "strong ties" were between users in the same domain (i.e. individuals were more likely to forward requests to those in the same profession) while mutual friends connections "weak ties" (i.e. acquaintances versus close friends, co-workers and family) helped connect these different domains. Facebook is both well-connected in the sense that you can reach anyone from anyone else in a relatively short number of hops, but at the same time, it is much clustered, with the vast majority of connections spanning a short distance.

(3) Our findings illustrated that the results of the original analysis (i.e. first experiment; computing the degree of separation using all nodes) and the advanced one (computing the degree of separation with ignoring celebrities) were equally

less than four degrees. We used celebrities as an example to illustrate our work since Facebook is one of our daily obsessions, and celebrities from all over the world use the social network to stay in touch with their fans; from posting cute snaps to shooting down rumors through status updates, stars use Facebook in a variety of different ways. The reason behinds ignoring them was they may be the key for shorten distance in the graph which may be not reflect the real life situation since adding a celebrity as a friend on Facebook does not mean he indeed on of your real friends. One possible explanation is: Because of Facebook, a group of three mutual friends "weak ties" for one celebrity could create visible connections from invisible relation, i.e. they may have the chance to chat and share interests or a friend of mine "strong tie" who is one of that celebrity fans can suggest me to one of other fans, and then this fan can also suggest me to one of his friends and so on. This chain really makes the world smaller and smaller "strong ties". Thus, even by removing nodes with higher degrees, Facebook cuts the degrees to less than four Facebook since it has changed the whole idea of friendship. Strong and weak ties tend to serve different functions in our lives; when we need a big favor or social support, we ask first our friends "strong ties such as close friends and families". However, when we need information about something we do not know, we may ask are our "weak ties". They may have more diverse knowledge and more diverse ties than our close friends do. A well balanced social network has both types of ties. Because of these strong and weak ties, our world becomes closer and closer. Finally, we concluded that even if we change the population of the whole world to an individual country or one individual society no matter our position on the society, no matter what is our profession, the degrees of separation would fall even further in 3.

In summary, Facebook cuts the degree of separation to four. Table 6 indicated that our experimental results had the lowest degree of separation between previous studies. Some possible explanations are summarized in the following points:

(1) We consider all edges (relations) including strong and weak connections between the nodes (Facebook users). Weak connections are those edges that occur among nodes belonging to different communities. They are people we may know casually; the person you buy a magazine from or who you chat with at the bus stop. Strong Ties, those edges occurring among nodes in the same community; they are your friends who you can rely on and share many connections; they provide social support. In 1973, Mark Granovetter proposed the strength of weak ties theory: human relationships (acquaintance, loose friendship) that are less binding than family and close friendship but yield better access to information and opportunities (Granovetter, 1973). The reason behind considering weak connections is that Facebook representable by means of mutual un-weighted friendship relations. Weak ties act as bridges among communities and shortcut bridges shortening distances between nodes belonging to different communities. These connections may reveal the links that otherwise might not be visible. The inter-community links (i.e., weak ties) mainly connect communities of small size among each other. On Facebook, most ties are weak. Only a small part of connections among individuals fall in the same community. Nowadays, we establish friendship connections on Facebook with individuals which instead are loose friends or acquaintances.

(2) To collect a huge amount of data, we expanded the region of the experimental environment. The top ten most spoken languages in the world (French, Malay-Indonesian, Portuguese, Bengali, Arabic, Russian, Spanish, Hindustani, English, and Mandarin) were used to design the interface of our tool. Thus, we relied on collecting users' data from a user itself not only downloading his profile without his permission from Facebook. We collected lots of participants' data and conducted a series of analysis along with our sample size keep on growing. Finally we got a stable estimated mean of the population.

(3) To bolster our results, we verified all the collected data by a filtering function to remove all fake, duplicate and non-real account accounts; thus targeting real Facebook users.

5.2. The six degrees of separation theory application and impact

While we conducted that social networks cut the degree of separation to less than four, whether or not we are all linked by six (or five or three) degrees is not the point. The question is: what has made human connections closer?

This experiment highlights that social networks reveals links that otherwise might not be visible. And more important, social networks are able to provide tools to create new connections from "invisible" relationships. It has never been easier to make friends than it is right now. Facebook has changed the way people communicate; it basically allows you to talk to every person you have ever met. Also, you can see what people are doing when you are not in physical contact with him/her. It is entirely possible to have hundreds of friends on Facebook; it has been shown the median friend count on Facebook is 224. They may not be friends you know on a personal level and spend time with in the real world on a weekly basis. But they are friends nevertheless. This is exactly what makes social networks somewhat unique, they are well-connected in the sense that you can reach anyone from anyone else in a relatively short number of hops. Thus, shrinks the degree of separation. There is another side of the tale, which is that social networking sites can get beyond a breaking up of some relationships. Social networks can put you back in touch with those you have lots in common with, and that common ground is often the starting point for long-lasting relationships. The new relationship, founded on the steps of Facebook, could be the friendship that was needed at the time. It is not just your inner circle of close friends and even closer family members that social networking sites allow you to communicate with easily and effectively, either. They open the world up to you, making it a smaller place than it has ever been before. When it comes to social networks everyone is equal, regardless of location. Family living abroad can be kept up to date on the latest happenings in your world as quickly as those living next door. Friends who you have not seen since school, and who have since moved away, are able to keep in touch. Social networking sites have made the world a smaller place.

The reason for using the six degrees of separation theory as a research topic is that it can completely transform the productivity of social networks and opening new opportunities for business marketing. In summary, its application and impact can be summarized, but not limited to, the following:

The six degrees of separation can be considered as a key for creating smarter career networking. The key idea is developing a search function or a tool (i.e. the advanced function in our tool) that helps individuals (i.e. job hunters and managers) to get in touch with the right person (i.e. the hiring manager; the one who can decide that you are precisely the right person for the job). Individuals first have to identify their dream job title clearly; for example, "Senior Technology Manager for Internal System Networking at Castleton Software" is better than "IT and networking

guy at a small software shop." They might have to research the specific title given for certain tasks at their dream companies. The function then starts hitting the professional and personal connections with all the specific information from the company, location, title, and department, and ask them questions, such as: "Do you know someone who works for a company that has an ongoing relationship with my target company?", "Do you know anyone who used to work for my target company?", "Do you know someone who works in the same general industry as my target company?" Social networks have caused professional and personal profiles to be merged. The merging of personal and professional improves the connectivity. The degree of separation drops when someone can reach across a social network and say "I am X's neighbor, you are his former coworker here, are you hiring?"

Social networks have also lowered the cost and the effort of maintaining strong ties that share similar interests or goals. A hobby shared by one individual is now a hundred of strong ties friends who are familiar with each other's interests and passions. New connections are formed in what would have previously been a private interest. A broad array of ties results in a large number of people belonging to many more communities (i.e. groups). One for religious preferences, several for local social groupings, connections to family, membership as an alumnus and in one's career path result in far more connection points for each person. This keeps friendships larger than they would be otherwise. Thus, testing specific software features or interfaces, and distributing election campaigns become easier; it can assist in making a deciding about how to reach out to groups of users for software requirements development or general surveys, save the time and the effort by identifying the largest groups of users to test the software.

6. Conclusion

We are so close; the world is even smaller than you thought; a friend of your friend probably knows a friend of their friend; In this study, we addressed three research problems of: re-evaluating the degree of separation theory using data collected by an online Facebook tool, identifying the degree of separation from a different viewpoint by considering not only the degree of separation between two normal-persons or famous-persons, but also between two persons with very rare-special features, and observing the influence of the high-degrees node i.e. celebrities on the society structure. Results showed that Facebook shrunk the gap between us. We collected data from more than 949,925,041 users on Facebook to re-verify, extend, and generalize the small world theory. We built a huge database that represents 80% of Facebook users in the entire world. Experiments were performed on Facebook platform. With the help of the Neo4j graph database and the state of arts, we computed huge amount of social data. Our results centered around three main observations, we observe the average degrees of separation or the average numbers of acquaintances separating any two people no matter who they are even with rare-special features were only 3.868. We compared our results with those from smaller social networks and find mostly, but not entirely, agreement on common structural network characteristics. It does not matter who we are, less than four degrees separating you and me.

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