When Six Degrees of Separation Meets Online Social Networks: How Low Can the Degree Be?

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Abstract

The proposition of Six Degrees of Separation prompts the realization that the world is not as vast as previously envisioned. Despite the current global population exceeding 8 billion, two strangers can still establish contact through limited intermediaries. When online social networks have garnered widespread influence, can people connect through shorter distances? This issue merits contemplation. This paper described Six Degrees of Separation and the limitations of this theory in practical applications. Combined with online social networks, the paper analyzed the development and change of interpersonal connection degrees. Finally, the paper considered the actual coverage of online social networks and other issues, while also providing a reasoned projection of potential future degrees within the Six Degrees of Separation paradigm.

Keywords

Six Degrees of Separation · Small World Phenomenon · Theory of Six Degrees Contacts · Online Social Networks · Online Society

1 Introduction

How vast is the world? How many intermediaries are required to reach a stranger? In 1929, Hungarian writer Frigyes Karinthy first introduced the concept of Six Degrees of Separation in his book “Chains” [15]. He believed that all individuals on the planet could be connected to any other person through an acquaintance chain within six. In 1967, American sociologist Stanley Milgram conducted a series of experiments to verify the authenticity of this theory [12]. The

investigation aimed at ensuring the accurate delivery of packages as its ultimate goal. Among the successful results, an average degree of 6.2 was observed, thus confirming the validity of Six Degrees of Separation.

Six Degrees of Separation can explore the social distance between individuals and be employed to analyze cooperation among researchers under the same funding [13,14], the relationship between tutors and students within specific fields [2], and even the degree of collaboration between two universities in different disciplines [18]. The derivation of Six Degrees of Separation involves mathematical formulations. Assuming that the number of relatives and friends is denoted as k, the average degree of separation as d, and the maximum number of people that can be contacted as N, these three indicators adhere to the following relationship:

$$N = k^d \quad (1)$$

Using the current global population of 8 billion as an example, ideally, each individual would need to have more than 44.72 (rounded to 45) relatives and friends to attain Six Degrees of Separation. Drawing on the of Rule Of 150 (Dunbar's Number), which posits that human capacity supports stable social relationships with approximately 150 individuals, so it becomes feasible to analyze the theory of Six Degrees of Separation from a theoretical perspective.

During Milgram's experiment design phase, large-scale integrated circuits were in infancy, and computers were entering a period of rapid advancement. At this time, computers had a massive appearance and were primarily utilized for scientific calculations [28]. Milgram did not anticipate that this technology would usher in profound transformations in interpersonal communication and social connections, giving rise to concepts such as the "global village". The world seems to have become smaller under the influence of online social networks. Individuals can leverage abundant social network resources and powerful search engines to contact unfamiliar target candidates more easily [20].

Does Six Degrees of Separation retain its relevance in the realm of online social networks? What magnitude of impact does Six Degrees of Separation exert? Does it genuinely diminish the social distance between individuals as commonly envisioned? To address these issues, researchers need to integrate social platforms and data to reevaluate the social distance between people [7].

This paper provides a comprehensive review of research on social distance assessment in online social networks. It describes the development and changes of Six Degrees of Separation across diverse social network platforms and scales. The paper highlights the deficiencies in the experimental design of Six Degrees of Separation and assesses the extent to which these factors influence the degree in online social networks. Furthermore, the paper integrates the developmental trend of online social networks and essential factors to speculate on the potential limit value of social distance in the future. The primary contributions of this paper encompass:

1. Summarizing the constraints of Six Degrees of Separation in practical applications and whether these factors impact the distance of interpersonal relationships in online social networks.
2. Reviewing the Six Degrees of Separation changes with social platforms and user scales during the development of online social networks.
3. Speculating the potential decrease in the average degree of interpersonal communication in the future based on the developmental trend of online social networks.

The subsequent sections of this paper are organized as follows. Section 2 describes the constraints of Six Degrees of Separation and their influence on online social network analysis. Section 3 outlines the performance of Six Degrees of Separation in online social networks. Section 4 speculates the potential changes in the degree of interpersonal communication with the further expansion of online social network influence. Lastly, Section 5 provides the conclusion of this paper.

2 Limitations of the Six Degrees of Separation and their influence on online social networks

The conceptualization and verification of the Six Degrees of Separation theory intuitively illustrate that the world is considerably smaller than initially perceived. Nonetheless, the experimental results are obtained under idealized conditions, and in real-world social networks, several factors directly affect the average distance of interpersonal communication. This section summarizes these influencing factors and analyzes the impact of these factors on social length in online social networks.

2.1 Success rate and industry coverage issue

In Milgram's seminal experiment, over 300 volunteers participated. Among them, approximately 60 successfully completed the delivery task, resulting in a success rate of less than 25%. The computation of the average social distance in the Six Degrees of Separation theory is restricted to successful results, with unsuccessful experimental results being directly ignored. Moreover, the target for delivery is a stockbroker, and the choice of industry coverage is minimal. Since individuals engaged in this industry often exhibit a relatively expansive communication range, it may contribute to a reduction in the average social distance between interpersonal interactions. However, the potential impact of altering the delivery target to another industry on the average degree of separation remains inadequately verified.

This limitation can be weakened in social distance analysis based on online social networks. On the one hand, the scale of users on social network platforms is substantial. A large amount of user data are readily available, which facilitates the extraction of complete users' social relationships, so the scale of the experiment can be effectively improved. On the other hand, owing to the low threshold for user registration in online social networks, the user base spans a wide range of industries.

This diversity extends beyond specific professional environments, thereby contributing to a more convincing average degree of separation.

2.2 Social cost issue

Six Degrees of Separation is a hypothesis put forward on the assumption of undifferentiated interpersonal relationships. Nevertheless, in actual social relationships, social cost is an essential factor restricting individuals' communication [21]. Even among relatives and friends, the strength and weaknesses of their relationship cannot be uniform [10,11]. Hence, such social cost needs to be comprehensively considered when calculating the degree of separation.

Social cost also exists in online social networks, even more evident than interpersonal communication in real-world. For example, online conversations initiated with general friends may be ignored or even blacklisted due to various concerns. Therefore, it is important for researchers to pay attention to this issue when evaluating the average degree of separation in online social networks. Ke [16] considered this concern in their self-created instant messaging system, introducing a damping factor to express the social cost. An increase in the damping factor signifies an escalation in the social cost between two individuals, leading to a decrease in the likelihood of effective social interaction. Additionally, Daraghmi et al. [8] employed strong and weak connections to represent social costs when verifying the performance of Six Degrees of Separation in online social networks.

2.3 Interpersonal network structure issue

The Six Degrees of Separation theory assumes that the interpersonal network is a tree structure, somewhat deviating from the actual interpersonal network structure [19]. In reality, certain interpersonal relationships exhibit a loop structure, with some individuals even existing in a closed-loop state. In social networks, individuals tend to form communities or clusters based on shared interests [1]. Hence, when calculating the average degree, it is crucial to consider the actual structure of the interpersonal network.

Toyota [22] believed that the degree of clustering between nodes in the interpersonal network (i.e., clustering coefficient) and whether the clustering coefficient would affect the ability of information dissemination should be effectively considered. Following experimental verification, he concluded that the clustering coefficient is not a critical factor affecting information dissemination.

To fulfill clustering requirements and minimize the average path length, Watts et al. [24] proposed a graph structure with small-world network attributes, known as Watts-Strogatz. This graph structure resides between regular and random graphs, accounting for the distance between relatives and friends in virtual social networks. To construct Watts-Strogatz, three parameters need to be determined: the number of nodes N, the number of nearest neighbors K of a node, and the probability p of randomized reconnection. The introduction of p aligns with the requirements of virtual social networks, where individuals have a gathering relationship with

their relatives and friends while having longer-distance connections from some relatives and friends due to geography and other factors, and p is responsible for constructing these long distances. When $p = 0$, Watts-Strogatz degenerates into a regular graph, and the average path length between nodes at this time is $d = N/2K$. As p continues to increase, the randomness of the graph also continues to increase. When $p = 1$, the graph is completely random, and the average path length between nodes at this time is $d = ln(N)/ln(K)$.

Using a small social network of 800 people as an example, based on Six Degrees of Separation, a person needs to know at least 3.04 (i.e., 4) individuals to realize the theory. In Watts-Strogatz, when $p = 1$, the average path length among the 800 people is 6.012, aligning with the theoretical value. The simulated Watts-Strogatz network in this state is depicted in Fig. 1. Moreover, according to the Six Degrees of Separation, under the assumption that there are 8 billion people globally, a person needs to know at least 43 relatives and friends to realize this theory. Setting N to 8 billion and K to 43, the average path length based on $p = 1$ is 6.063, consistent with the experimental results of Six Degrees of Separation. Nevertheless, this result is derived under the completely random situation of Watts-Strogatz and does not reflect the actual online social network situation. Therefore, with a consideration of the interpersonal network structure, the average degree of separation in online social networks may undergo changes.

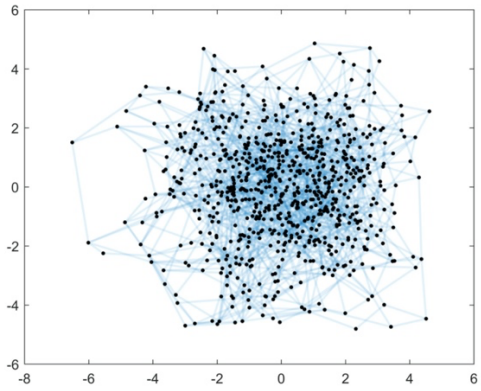

Fig. 1: Watts-Strogatz based on 800 people ($K = 4$, $p = 1$)

2.4 Social differentiation issue

The verification of Six Degrees of Separation occurred within an entirely idealized state, neglecting the influence of external factors such as race, economy, and politics on the average degree of separation. Some countries and regions have more serious social differentiation, which could directly contribute to an increase in the degree. Consequently, the applicability of Six Degrees of Separation may be limited to specific social classes and environments.

These external factors do not seem to be improved in the online social network environment. For instance, certain social platforms implement a membership

mechanism to categorize users according to their activity level, recharge level, and other factors, assigning different privileges to users at various levels. This practice becomes one of the reasons that hinder users from socializing. Furthermore, due to differences in living environment, cognitive abilities, etc., different users may hold diverse views on the same event or even wholly opposing views. Different public opinions will also influence users' social behaviors, thereby affecting the average degree of separation.

3 Six Degrees of Separation influenced by online social networks

The emergence of online social networks has set off an upsurge of instant messaging, seemingly bridging the gap between humans and facilitating interpersonal interaction. Within the influence of this new social mode, how the degree of separation between interpersonal communication has evolved has also inspired discussions and research.

Concurrently, technologies such as data mining, community mining, and precise recommendation have emerged in online social networks, providing convenient conditions for rapidly matching similar users. The emergence of swarm intelligence methods, such as ant colony optimization algorithm and particle swarm optimization algorithm, has accelerated the search speed for user relevance and reduced the cost of communication between individuals. There are two recommendation methods in online social networks that can be employed to expand user communication scope and diminish the degree of separation between users, namely, mutual friend recommendation and potential friend recommendation.

3.1 Mutual friend recommendation

According to the ternary closure theory, if two strangers in a social circle have common friends, the possibility of the two people establishing a connection will increase. The magnitude of this possibility is obviously related to the number of mutual friends. Mutual friend recommendation allows certain users to bypass an intermediate contact and directly establish a connection with the target user. In this case, the degree of separation can be reduced from 1 to 0. Mutual friend recommendation has been implemented in numerous mainstream social networks, such as Tencent QQ, TikTok, etc.

3.2 Potential friend recommendation

Certain social networks exhibit prominent community characteristics, such as Facebook, Twitter, Instagram, etc. In these platforms, potential friend recommendation has emerged as a novel measure to diminish the degree of separation. By calculating the similarity between users through various indicators like user behavior, user attention content, user interest, user topics, and user interaction status, mining potential relationships, and making recommendations, can effectively enhance user interaction and broaden the scope of user communication.

Taking Facebook as an example, we investigated the performance of this social platform based on the average degree of separation in recent related work and summarized them in Table 1.

Table 1: Changes in the degree of separation of the same social platform (take Facebook as an example)

Year	Platform user scale	Average degrees of separation	Reference
2008	100 million	5.28	[6]
2010	600 million	5.06	[6]
2011	721 million	4.74	[3]
2012-2013	950 million	3.868	[8]
2014	1 billion 300 million	5.0	[17]
2016	1 billion 590 million	3.57	[9]

Table 1 illustrates the continual growth in the user base of Facebook over the years. The observed average degree of separation on this platform aligns fully with the concept of six degrees of separation and manifests a diminishing trend in degrees over time. In other words, the cost of communicating with unfamiliar users is steadily decreasing.

The decline in Facebook's average degrees of separation can be attributed to three main factors:

1. The continuous growth in the number of registered users provides suitable conditions for broadening the scope of user communication and tapping potential user relationships.
2. Facebook consistently introduces new social functions, thereby facilitating the development of potential friend recommendations and other related work. For example, in 2019 alone, Facebook launched over a dozen significant features, including the "memorial" area, "birthday story", Facebook news, Facebook dating, etc., all of which contributed to the enhancement of Facebook's community characteristics.
3. The refinement of data mining, community mining, and the continuous update of recommendation algorithms have significantly improved the precise and personalized recommendation.

Table 2 summarizes the average degrees of separation for various social platforms at a specific point of time. Although the degrees of separation on each platform are not the same, they generally adhere to the Six Degrees of Separation. Furthermore, notable differences exist in the degrees of separation between social platforms, primarily for three reasons:

1. The scale of social platform users. As the user scale increases, the theoretical average degree of separation decreases. The user scale will directly determine the complexity of relationships and the challenge of communication between

strangers.

2. The degree of social content aggregation. Taking "Institutions funded by the National Science Foundation" as an example, since the research subjects are only for institutions funded by the same fund, the singular user type and social purpose lead to a reduction in the average degree of separation between users.
3. The strength of relationships. When considering the strength of interpersonal relationships, even on the same social platform, differences in the degrees of separation can be observed. For example, in ArnetMiner (a researcher academic search network), the average degree of separation is only <3 regardless of the strength of the relationship. However, when relationship strength is considered, the average degree of separation increases to ≈6, highlighting a substantial gap. Moreover, as discussed in Section 2, considering the social cost issue in degree of separation calculations aligns more closely with actual social network requirements.

Table 2: Changes in the degree of separation of the different social platforms

Year	Platform	Experiment scale	Average degrees of separation	Reference
2006	Microsoft Messenger	180 million	6.6	[25]
2009	ArnetMiner	0.5 million	<3 (Regardless of the strength of the relationship) ≈6 (Considering the strength of the relationship)	[26]
2009	Tencent QQ	783.4 million	3.12	[26]
2011	Twitter	-	3.43	[5]
2012	Institutions funded by the National Science Foundation	279862	3.07 2.75 (No organization that only cooperates once or twice)	[13]
2016	Facebook	1 billion 590 million	3.57	[9]

In the calculation of the degree of separation between users on a specific social platform, careful consideration must be given to the representation of social data and the separation calculation. For the term of social data, most studies use graphical structure, directly representing whether individuals are in contact within social networks—this is convenient for analyzing the degree of separation. Graph

databases such as Neo4j can be employed to store corresponding data [8]. When a user's social network becomes extensive, tools such as WebGraph can compress the graph [3]. The purpose of social data representation is to facilitate the solution of the degree of separation. Ke et al. [16] analogized the path problem between individuals to the routing problem in a computer network, utilizing a modified routing table to represent user relationship data. Bakhshandeh et al. [5] directly sent information requests to Twitter via the Internet, thereby avoiding representation and storage of user relationship data.

Regardless of the method used to acquire, represent, and store social relationship data, the ultimate objective remains the calculation of the degree of separation. On the one hand, the degree of separation can be calculated based on the user's friends and the target objects of interest. On the other hand, geographical location can be a basis for deriving the degree of separation. Research indicates a close relationship between geographical location and social relations, playing an essential role in forming the entire social network structure [3]. The study by Backstrom et al. [4] revealed that users who are physically close to each other may interact more frequently on Facebook, suggesting the feasibility of using geographic location information to calculate the degree of separation.

The mainstream methods for calculating degree of separation encompass greedy algorithms and search algorithms. Employing these technologies is because the Six Degrees of Separation can be abstracted as the shortest path problem. Analogous to the routing algorithm, Ke et al. [16] used the Bellman-Ford algorithm to find the shortest path between two users. Bakhshandeh et al. [5] compared the performance of the greedy algorithm based on maximum attention counts, the greedy algorithm based on geographic heuristics, and the greedy algorithm based on boundary search in calculating the degree of separation. Nevertheless, their real-time costs cannot meet the requirements of online evaluation applications. Furthermore, they also compared the two-way search method based on breadth-first and the two-way search method based on probability. They found that the average degree search time of the last method is less than 15 seconds, rendering it suitable for online separation evaluation. Based on a heuristic search method, Lawrence et al. [17] used the ant colony optimization technology to determine the distance between two persons in the graph.

Furthermore, Edunov et al. [9] employed the Flajolet-Martin algorithm to estimate the number of unique friends for each degree of separation based on probability in big data to evaluate the overall degree of separation of the Facebook friendship graph. Based on graph compression technology and diffusion calculation, Backstrom et al. [3] utilized the HyperANF probability algorithm to analyze the degree of separation. Through calculating the degree of separation in all the aforementioned methods, it is found that the Six Degrees of Separation is fully applicable in online social networks.

Advancements in computer technologies and the implementation of various optimization algorithms have led to degrees of separation on most social platforms being lower than 6. four degrees of separation [3,8], three and a half degrees of separation [17], and other lower degrees of separation theory are put forward. This development indirectly shows that the social distance and social costs of people are further reduced due to the evolution of online social platforms.

4 Possible conjectures on the future "degree" in online social networks

The influence of online social networks continues to expand under the impetus of numerous emerging technologies, and people's dependence on these social platforms is becoming stronger. In the future, how will the degrees of separation change under the influence of online social networks? Whether this value will persist in its current downward trend, reach a limit, or even experience a rebound necessitates a thoughtful analysis of the development trajectory within online social networks.

4.1 Influencing factors of "degree" in the future

Beyond the user scale, industry coverage, and other factors mentioned above, the following factors will also influence the degree of separation in online social networks.

4.1.1 Cross-application factor

The performance of Six Degrees of Separation in online social networks has been studied based on a single platform. However, it is crucial to recognize the emerging trend of social network platforms evolving towards a state of social integration. The goal of social integration is twofold: firstly, to address the functional limitations of individual platforms, and secondly, to streamline the integration of diverse interpersonal relationships among users. The cross-application development of social networks can open up interpersonal relationships restricted by specific platforms, unearthing the potential relationships and connections between users and others across different social platforms. This, in turn, could serve as a viable factor contributing to a further reduction in the degree of separation.

4.1.2 Rich media factor

With the development of computer technologies like streaming media, Flash, and Java, social networking platforms have gradually improved interactive functions such as animation and sound [23]. This will help improve the user experience and increase the user's stickiness to the social platform. Furthermore, a positive user experience helps to establish a favorable reputation among the user groups, serving as an implicit promotion model for social network platforms. This model facilitates the expansion of the user base on the platform.

4.1.3 Registration convenience factor

Registering user accounts on social network platforms has become more

efficient and user-friendly. In the past, the registration process often involved filling in detailed personal information, such as gender and birthday, which could be tedious and lead to user dropout. In the current user registration process, social platforms can rely on their cooperative relationship to directly fill user registration information through authorization. For example, in the WeChat mini-program, users can register and log in seamlessly by granting authorization, enabling a click-to-use functionality. This streamlined operation is conducive to expanding the user scale of social platforms and provides conditions for reducing the degree of separation.

4.1.4 Privacy policy factor

In recent years, users' personal information has been leaked frequently, severely affecting users' personal lives and the reputation of social network platforms [27]. To mitigate such incidents and empower users to choose whether to disclose specific privacy rights, various online social network platforms and operating systems are tightening privacy policies. This approach aims to ensure user privacy security and enhance user choice. For example, on April, 2021, Apple released the new operating system, iOS 14.5, marking the official implementation of Apple's updated privacy policy. According to this policy, applications are required to obtain user consent before tracking the online behavior data of the mobile phone. This strategy serves to protect user privacy, enhance transparency in application tracking methods, and improve users' control over their privacy. Nevertheless, it presents a significant challenge for online social networks like Facebook, which rely on user online behavior data for personalized recommendations and advertising. When users choose not to disclose their online behavior, it impacts the accuracy of recommendations and, consequently, influences the degree of separation.

Table 3 provides a summary of factors that may affect the degree of separation in future online social networks, detailing the extent of their influence and the correlation between these factors and the degree of separation. For example, the user scale of online social networks has an extremely strong impact on the degree of separation, exhibiting a negative correlation. Generally, a larger user scale is associated with a lower degree of separation.

4.2 Possible conjectures on the future "degree"

It is unquestionable that Six Degrees of Separation is entirely applicable in online social networks. Because the distinctive interaction ways of online social networks are quite different from real and traditional interactions (such as phone calls, faxes, etc.), this makes the degrees of online social networks show a continued downward trend and has various performance in different social platforms. In future social networks, what is the limit value of the degrees? This issue requires a reasonable guess based on the developmental trajectory of social networks.

The above 12 factors in Table 3 are comprehensively considered, and they are

categorized based on future development trends into four groups: enhanced positive correlation, weakened positive correlation, enhanced negative correlation, and weakened negative correlation.

Table 3: The influence of factors in the development of online social networks on the degrees of separation

Influence factor	Influence ability	Correlation with degrees of separation
User scale	Extremely strong	-
Privacy policy	Extremely strong	+
Recommendation algorithms	Strong	-
Social cost (strong or weak user relationship)	Strong	+
Social network function	Strong	-
Social platform cross-application	Strong	-
Public opinion (social differences)	Mid	+
Rich media	Mid	-
Convenience of registration	Mid	-
Industry coverage [8] (including rare occupations)	Weak	+
Social network structure [22]	Weak	-
Celebrity effect [8]	Weak	-

4.2.1 Enhanced positive correlation

The future trend toward continuous improvement and refinement of privacy policies is driven by the imperative to better protect users' data. This trend, limiting platforms in analyzing users' online behaviors, emerges as a crucial factor contributing to the increase in the degree of separation. Due to the large number of participants, the great freedom of expression, public opinion presents a complex trend, which will cause more serious social differentiation and will also lead to an upward trend in the degree of separation. Additionally, as the user scale in online social networks continues to grow, the broader industry coverage will encompass more rare occupations. The increase of these rare occupations will result in an increase in degree, but the impact of this factor is weak and will not become the mainstream element of degree's development.

4.2.2 Weakened positive correlation

While there are costs associated with communication between individuals, these costs exhibit a decreasing trend with the development of online social technologies. Reducing the costs is conducive to establishing interactive chains between strangers so that the degree of separation is further diminished.

4.2.3 Enhanced negative correlation

Continuous enhancement of registration convenience will encourage more users to join specific social networks, improving the expansion of the user scale and shaping a more intricate network social structure. Moreover, social platform operators will continue to optimize their recommendation algorithms, expand the functions of social platforms, enhance cross-application capabilities, and improve rich media deployment to increase user stickiness. These factors are pivotal in diminishing the degree of separation.

4.2.4 Weakened negative correlation

Diversified, virtualized, and anonymized communication methods empower ordinary individuals to become well-known, leading to a diminishing trend in the original celebrity effect, which was primarily driven by a small group of influential individuals. As the celebrity effect weakens, the network structure that relies on celebrities will be reduced, consequently increasing the degree of separation. Nevertheless, the influence of this factor is limited and will not affect the overall developmental trend of the degree.

Through the segmentation and analysis of the developmental trends of these factors, coupled with existing research results, it is a possible reasonable conjecture that the degrees in online social networks will experience further reduction in the future. For comprehensive social platforms like Facebook, Twitter, and Tencent QQ, the limit value of degree may be 3. For professional social platforms such as ArnetMiner and LinkedIn, the possible limit value of degree will not be lower than 2.5. The distinction between the two types of platforms in the degrees of separation lies in the fact that while comprehensive social platforms boast a large user base, the relatively dispersed social content may impede further reduction of the degree. In contrast, for professional social platforms, the social purpose is apparent. Although the user scale may be small, it may still exhibit lower degree of separation.

5 Conclusion

This paper conducted a comprehensive review of the performance of Six Degrees of Separation in online social networks. Initially, the paper described the Six Degrees of Separation and highlighted its limitations in practical applications. Subsequently, the paper summarized the observations of Six Degrees of Separation across various online social networks, offering reasonable explanations for the changes in degrees based on these performances. Furthermore, the paper compiled a summary of factors that may affect the future development of the degree and provided reasonable speculations regarding the future limit values of degrees. As online social networks continue to develop in-depth, the overall developmental trend of degree will continue to persist a downward trend. Nevertheless, the rate of decline will expected to decelerate due to technological bottlenecks and other constraints.

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