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Asynchronous discussion groups as Small World and Scale Free Networks

by Gilad Ravid and Sheizaf Rafaeli

Abstract
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What is the network form of online discussion groups? What are the topological parameters delineating the interaction on such groups? We report an empirical examination of the form of online discussion groups. We are interested in examining whether such groups conform to the *Small World* and the *Scale Free* models of networks. Support for these expectations provides a formal expression of growth, survival potential and preferential attachment in the connection patterns in discussion groups. The research questions were tested with a sample of over 8,000 active participants, and over 30,000 messages. We find that the social network resulting from discussion groups is indeed a *Scale Free Network*, based on In, Out and All Degree distributions. We also find that, for the same sample, discussion groups are a *Small World Network* too. As expected, the clustering coefficients for these groups differ significantly from random networks, while their characteristic path lengths are similar to random networks. Implications of the topology for the design and understanding of discussion groups include the stability and control of such groups, as well as their longevity.

Contents

Background

Online interactions are specified and delineated by technological affordances on one hand, and social preferences on the other hand (Lamb and Kling, 2003; Olson and Olson, 2003). Media for small online group communication can be analyzed on a variety of levels: the individual, group, and the organization level are all appropriate vantage points for different purposes. Analysis in this enigmatic and multidisciplinary field requires reliance on methodological tools drawn from different fields (Olson and Olson, 2003).

The degree of symmetry in group communications in computer–mediated communication has been a source of interest for years. Researchers (Butler, 2001; Rafaeli and Larose, 1993; Te'eni, 2001) have extensively researched this subject. Lately, it is becoming clear that computer–mediated discussion groups are systematically asymmetrical environments (Butler, 2001). In this article we examine applying the Scale Free and Small World network models to analyzing the dynamics in online discussion groups, especially in the context of assessing and understanding the symmetry of participation and contribution to such groups.

Virtual groups are of great interest in a variety of cultural, behavioral and managerial disciplines.

Scale Free, Small World as well as Random are all analytic descriptive models for such networks. These models describe, in mathematical notation, the distribution of the links between nodes in the networks.

Virtual groups are of great interest in a variety of cultural, behavioral and managerial disciplines. For example, the business management field of management information systems has been paying increasing attention to the topic. In the first four years of this millennium (2000–2003) *MIS Quarterly (MISQ)* published 12 articles that refer to "virtual teams." Orlikowski and Barley (2001) specifically discuss the reciprocal relation between virtual teams and intra–organizational discourse. The three consecutive recent "Papers of the Year" in *MISQ* dealt with trust, communication and virtual teams. Majchrzak, *et al.* (2000) argue that social structure impacts the adoption of new technologies. Empirical support for this claim can help further identify the desired structure. The approach proposed in the following is a step in that direction. Te'eni (2001) develops a cognitive–affective model of organizational communication for designing IT. His model, too, ascribes importance to the complexity of the communication arrangement. In the following, we propose a formal representation for this complexity. Jasperson, *et al.* (2002) discuss trust in groups. Measures for the constructs of power, influence, centralization and authority — all central to Jasperson, *et al.'s* thesis — are very well expressed in the terminology of Social Network Analysis (SNA), and in particular Small World and Scale Free models.

The topics of Small World and Scale Free networks as well as tangent fields of study have been gaining momentum in recent years. This research tradition focuses on the mathematical qualities of social and other networks. The presence of such qualities can indicate much about the network. In and Out Degree, cliques, and so on can all appear as measurable properties of communication networks [1]. Mathematical models of networks have been studied in many contexts. A comprehensive survey of the studies done with this method was conducted by Newman (2003), who suggested a classification of four types of networks: Technical, Biological, Information Networks, and Social Networks.

For example, the interconnecting pattern of flight aerial routes has been studied by Amaral, *et al.* (2000). Electrical grids for power lines between population centers were described by Soumaa, *et al.* (2003). Biological nets that have been studied using this method include cell–based metabolic processes (Fell and Wagner, 2000). The evolution of species was the object of study by Campos and Oliveira (2003). Likewise, food chains were studied by Martinez (1991).

Network modeling has recently been applied to information flows as well. For example, the following cases have been studied and the networks they represent have been found to be both Small World and Scale Free (as defined below). The links between HTML documents located by Web crawlers were shown to be laid out as Scale Free and Small World networks (Jeong, 2003). Internet routing tables fit Scale Free and Small World models as well, *i.e.*, there exist a few routers which have access to many other routers, while most of the routers can be used to directly reach only a few routers (Faloutsos, *et al.*, 1999). In infometrics research, co–citations in literatures of the disciplines of mathematics and physics have been found to represent a Small World and a Scale Free network. Erdos numbers, popular among mathematicians, are an expression of this kind of network (Redner, 1998). The structure of peer–to–peer networks is both Scale Free and Small World [2]. In information networks there is a high importance accorded to search algorithms. The type of graph and an appropriate fit between the graph and the search method ensures a high search efficiency, which accounts for the attention paid to the Small World and Scale Free models of information networks.

All networks mentioned to this point were either non–social, or only approximations of social networks. Network models of complex and social systems should help shed light on the relation between power and social structure (Ahuja, *et al.*, 2003). Describing a social system as Small World allows better prediction and understanding of message flows, efficiency in information search and retrieval, and the degree of social stability among members of the network. A Small World network suggests rapid diffusion rates. Thus, for instance, it seems that in Small World systems public opinion leaders have a stronger theoretical impact (Fowler, 2003).

Scale Free social systems should exhibit greater tolerance when facing general (random) opposition and attack. At the same time, when such systems will be more vulnerable to systematic, well directed assaults. Scale Free formats of networks indicate specific power and informal influence distributions. Scale Free systems are characterized by growth and preferential attachment. The human–induced preferences exhibited in social contexts are of specific interest with such networks. How do network members construct and carry out their choices? Human communication–based, social networks were empirically studied in the following cases.

Computer–mediated communications involving humans on both ends were studied in a network analysis of boards of directors (Davis and Greve, 1997), and in modeling an e–mail network (Ebel, *et al.*, 2002). Recently, another large–scale study has been conducted, and received world–wide resonance. In e–mail networks, this study found again that e–mail networks act as a Small World network with a varying length of five–seven friends in each network (Dodds, *et al.*, 2003). This study attempted a replication of Milgram's (1967) study. In this study individuals volunteered to initiate a chain of contacts. Participants were asked to send a message to one of 18 destinations. This network is indeed on a very large scale, but the study suffered from an extremely low completion rate (384 chains were completed out of 24,163 initial attempts). In contrast to other, reality–based networks, this network is the result of experimental intervention. The external validity of these findings requires further proof. In the Dodds, *et al.* study, participants were asked to send a message to someone with whom they were better acquainted than with the destination, but the nature of the relationship and its intensity were not fully expressed (Granovetter, 2003).

Lastly, learning over networks (Goyal, 2003) has become a favorite topic of economic and social–mathematical scrutiny. Such learning has important economic implications: whether and when a particular innovation should be adopted. Where would one best search for survival information? Some of the answers to such questions reside in a deeper understanding of network topology. Among the many studies that were examined no study was found that discussed computer–mediated asynchronous forums.

Asynchronous Forums

E–mail is a method of communication in which each participant manages their own messages, letters are composed and sent with a specific recipient in mind, responses are usually sent to individuals, and there is no option to read a response to someone else’s messages. On the other hand, asynchronous forums comprise a unique setting in which textual messages are the connecting line between the forum participants and the knowledge (Harasim, *et al.*, 1995). Participants read or write at their convenience — taking part in this type of communication does not get in the way of the participants’ regular activities (Negroponte, 1996). All correspondence is saved in one shared space. The messages are arranged by threads according to the different discussion groups. The existence of common message storage, the option every forum participant has to read and to write to any other participant, and a communication topology based on messages and knowledge as the main connecting axes, are the characteristics that separate discussion groups from e–mail communication. Differences in the attributes of interaction and the topology of the technology create a social structure of special interest.

Social Networks

Analyzing discussion groups’ messages can be done in a variety of ways. We chose a network analysis approach here. Let us construct a graph (matrix) which includes all the participants of the discussion group. Every participant will be represented once on each axis of the matrix. In the graph, every participant will be represented by a dot. An arc between one participant and another represents a response from the first participant to a message the other had sent. This kind of connection will be represented in the matrix as a numerical value in one of the cells, and on the graph it will be marked as a directed arc connecting between the two dots. The arc is directed in order to show the direction of the connection; a two–way connection (interaction) would be represented by two arcs. The resultant graph represents a network. The resulting network can be analyzed using the standard tools for analyzing networks and graphs [3].

The points on the graph are given various names. In the professional literature, they are variously referred to as nodes, actors, vertex, point, and agent. Throughout this article we will use the term *nodes* to indicate points on the graph, *i.e.*, the participants in the discussion group. The connections between different nodes are called, in the literature, line, arc, link, and edge. Here we will use the term *link* to describe the directed arcs.

Different mathematical indices have been developed to describe social networks; some describe the matrix structure while some describe dynamics and developments over time. These indices point out social phenomena taking place in the group. The Scale Free index and the Small World index are two independent characteristics of the network, which describe its structure (Moura, *et al.*, 2003; Wang and Chen, 2003).

Scale Free Networks

A random network (Erdös and Rényi's model) assumes that (1) there is no growth in the network over time, and (2) that the probability of connection between any two points in the networks is equal for all the networks members. The distribution of the number of connections of all nodes between the network members is distributed following a Poisson curve (Newman, 2003). A variety of information, economic and biological systems have been analyzed using Erdös and Rényi's random model (Jeong, 2003).

One should question these two key assumptions of the random model. Are the two assumptions that are at the base of the model perhaps too stringent to fit all networks? Many networks do, in fact, grow over time. For example, a biological network of reproduction, a technological network in telephony, or an information network of co–citation between articles, or a human network of acquaintances, may all be growing networks. In addition, there could be a preference to connect to some nodes over others (preferential attachment). For example, reproduction is not the product of random choice; for example, telephone conversations are only random in rare and extreme cases. It would be interesting to create new assumptions, which assume growth and preference, and to examine their meanings. When modeling these two new assumptions we get Scale Free networks, as suggested by Barabasi and Albert (1999).

In Scale Free networks the distribution of different network parameters act in an exponential fashion. The most interesting and most measured exponentially distributed parameter is the distribution of connections from each node outwards (Out Degree). This uneven distribution means that in these networks some of the members are connected to a lesser degree and some of the members are connected to greater degree, which is how they hold a senior position in the network (Goh, *et al.*, 2002). Networks of this type are relatively resilient, but are not at all immune to attack. In other words, a random removal of network members (a crash) will not hurt its stability, but a directed removal of key points □ hubs □ will cause the network to quickly collapse. On Scale Free networks, the distribution of density or congestion is constant and is not dependent on the exponential coefficient of the distribution of the number of connections (Jeong, 2003).

Small World Networks

Small World networks became first famous in a series of experiments conducted by Stanley Milgram in the 1960s (Frommer and Pundoor, 2003). These experiments examined the number of people a message needs to traverse for it to reach a specified complete stranger. To Milgram’s surprise, and to the surprise of many others, the required chain of contacts comprised an average of only six links to reach its destination. Despite some methodological ambiguities, we can confidently say that the number of nodes required in such a chain of human contacts is much smaller than expected.

One of the reasons the study of Scale Free and Small World networks is gaining momentum in the past few years is the simplicity it provides in explaining seemingly complex phenomena occurring in networks. By attributing the network to a model, we can uncover many facets attributable to its very typology alone. In the following we will illustrate how Small World networks impact behavior. Both experimental and analytical studies found that density classifications are much easier to perform in Small World topology networks. However, the problem of timing becomes more difficult, cooperation in a multi–player "Prisoner’s Dilemma" game occurs less frequently, and oscillating networks are synchronized at a much fast speed (Newman, 2000).

These four examples are just a part of the characteristics of the dynamics of Small World networks. In Small World networks, information searches can be more efficient. When discussing a social human network, we must ask whether the members of the network are aware of the existence of a social network following a Small World type (Granovetter, 2003). In other words, does the individual have global □ not just local □ information, which should help develop a strategy suitable to the structure of the network.

The Scale Free and Small World characteristics of asynchronous networks are important in understanding the developing social order in virtual communities.

In Small World networks the distance between people grows in proportion to the logarithm of the number of members in the network (Comellas and Sampels, 2002). An increase in the number of members of the network influences in a much more restrained fashion the distance between members. This factor is important for designers of information systems serving teams and groups.

The Small World characteristic of a graph is measured by the Clustering Coefficient (CC) and the Characteristic Path Length (CPL) [4]. The Clustering Coefficient is the extent to which the nodes in the graph tend to create a unified group with many internal connections but few connections leading out of the group. The Clustering Coefficient can be seen as a measurement of the nodes’ isolation. The Characteristic Path Length is a measurement of the average distance needed to pass from node to node. A network can be considered a Small World network when its CPL is similar to the CPL of a random network of the same length, but its CC is much larger (at least by a single order of magnitude) when compared to a similar random network. In other words, in Small World networks we will expect to find a large unified group; in networks such as these "hiding" is impossible (Herman, 2003).

The Scale Free and Small World characteristics of asynchronous networks are important in understanding the developing social order in virtual communities, and other social structures that may make use of such systems. Proving the existence of these characteristics explicates the manner in which networks arrange into socially stable structures, how the departure of individuals does not disrupt the network, and the efficiency of end–to–end transmission across the network.

In summary, a Scale Free network is created when the network grows over time and preferences exist within the network. As asynchronous discussion groups fulfill these two conditions, we postulate:

> Postulate 1 □ Discussion Groups are a Scale Free network.

As stated, social networks (both human and not–human) create Small World networks. We therefore propose another hypothesis:

> Postulate 2 □ Discussion Groups are Small World networks.

Methodology

In this project we investigate discussion groups formed by users of an LMS (Learning Management System) in a university. Discussion groups are part of the distance learning apparatus of this university. The university awards undergraduate and graduate degrees in seven different faculties. Currently, about 400 different courses are offered in this system. The courses’ online segment includes an Internet site with course material and interactive tools which include e–mail to the instructor, and mostly discussion groups. The discussion groups are used for interaction among the students themselves, as well as between the students and instructors. For the students, participation in the discussion groups is voluntary. It is not part of course requirements and does not play any role in grading.

We collected data regarding discussion groups that operated during the course of four years, from the winter semester of 1999 to the end of summer semester of 2002, that is eight regular semesters and four summer semesters. We decide to combine all the different discussion groups in one data set because of two reasons: first, fragmentation in the discussion groups is arbitrary, and, second, we were interested in analyzing the whole social network (*i.e.* social capital) of the discussion space. During 1999–2002, there were 75,409 students, course coordinators, tutors and advisors enrolled in the system. Of these, 12,506 different students and lecturers sent 158,276 messages to the discussion groups. Of the 12,506 people active in the discussion groups, 3,609 never answered a message and none of their messages were answered; 67 additional people only received an answer to their own messages by posting a response to their own message. Elimination of these two groups yields a study population of 8,830 active members. The 8,830 writers created 30,635 connections, or 3.47 connections on average per person; see Table 1.

Students are free to choose whether to make use of the online course materials, or not. Only those who log onto the system have the choice of accessing discussion groups. Previous studies of LMS in those years reported that about 55 percent of the students choose to enter the courses' Web site (Ravid, *et al.*, 2002); 16.5 percent of all students, in other words 30 percent of students working online, chose to participate in discussion groups and send messages. This phenomenon of participation by reading only (lurking) and participation by sending messages in discussion groups has been analyzed by others (Erickson, *et al.*, 1999; Preece, 1998; Rafaeli, 1988; Rafaeli, *et al.*, 1998; Whittaker, *et al.*, 1998).

Table 1: Study population

Group	Population	Number	Relationship
A	All registered participants	75,409	
B	Participants who send at least one message	12,506	16.5% of A
C	Non–active participants (received no answers and did not answer other messages)	3,609	28.8% of B
D	Participants who only answered themselves	67	0.5% of B
E	Regular participants	8,830	70.6% of B

We built a social network based on the communications of members of this population. In the constructed network, every node is an active participant in the discussion. The connection *i* to *j* is a directed connection with an intensity of *z*. This means that participant *i* sent *z* messages in response to messages sent by *j*. The Scale Free and Small World models ignore connection intensity, and this feature is one of the drawbacks of these models (Granovetter, 2003).The network was built and tested using computer programs Opus2SNA (Aviv, *et al.*, 2003a), Ucinet (Borgatti, *et al.*, 2002), Pajek (Batagelj and Mrvar, 2003), SPSS, and MS Excel.

The Scale Free and The Small World models are predicated on the mere existence of a connection, rather than on intensity. The intensity of the connection does not affect the computation of Small World or Scale Free.

Results

Postulate 1: The social network resulting from discussion groups is a Scale

Free network.

A Scale Free network is a network in which the connections between the different members are distributed exponentially. The following formula shows the general representation of exponentially distribution, the formula state the frequency of number of nodes with degree equal to constant (b_0) plus the degree in power of minus b_1.The examination of the network of the discussion group participants shows the distributions of various degrees, when applied to:

$$Frequency = b_0 + Degree^{-b_1}$$

Table 2: Power regression coefficients

Model	b_0	b_1	R^2	Sig. R
Output degree	647.469	-1.3125	0.812	0.000
Input degree	5389.80	-1.9372	0.929	0.000
All degree	1915.51	-1.4773	0.826	0.000

The correlation level may be examined in the following graphs. The graphs are drawn on logarithmic axes.

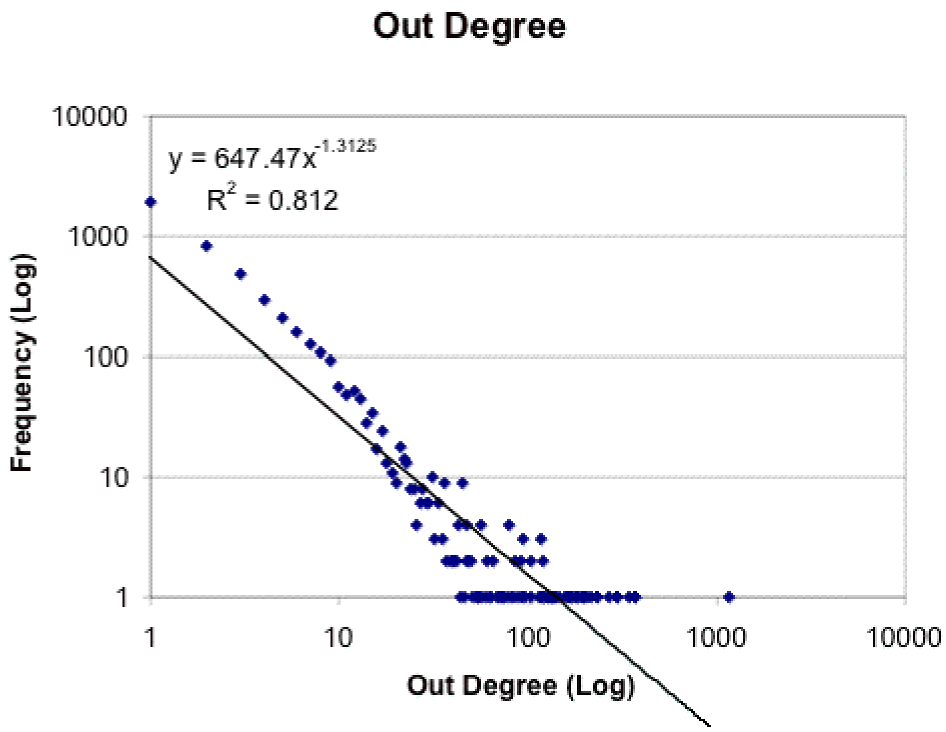

Figure 1: Out Degree Distribution.

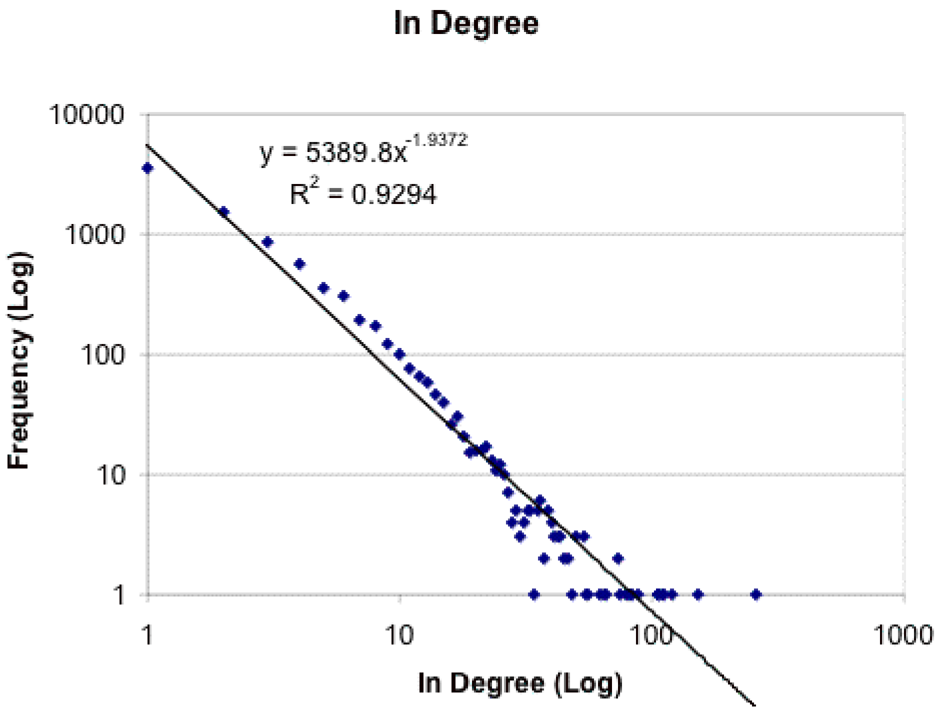

Figure 2: In Degree Distribution.

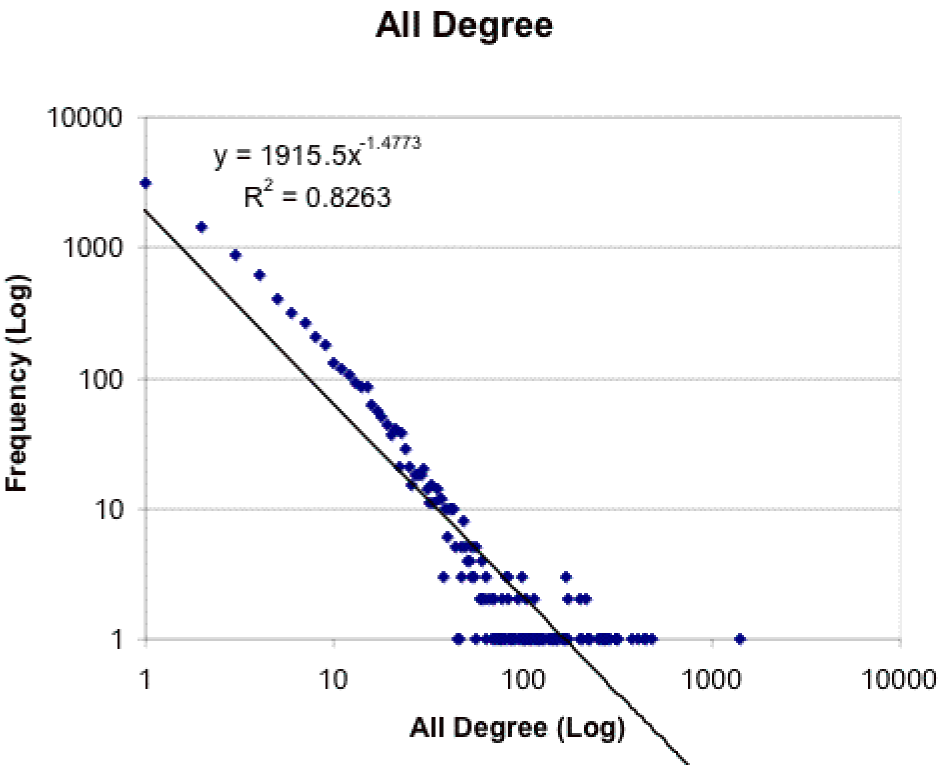

Figure 3: All Degree Distribution.

The exponents displayed in Table 2 and in Figures 1–3 indicate that indeed the network is a Scale Free network, because its degree is exponentially distributed. Indeed most of the professional literature on the subject and related studies have shown that the exponential coefficient is between 2 and 3 (Jones, *et al.*, 2002). There are also studies that show smaller coefficients, for example a Peer to Peer (P2P) network (Jovanovic, *et al.*, 2001), in which the coefficient was 1.4. Here the exponent we recorded (b_1.) is on the order of 1.3 and this means that the decline is more moderate in comparison to other Scale Free networks. We should find more hubs and semi–hubs in the discussions forums network then at other networks.

Postulate 2: The examined network is a Small World network.

Small World networks, as mentioned earlier, are measured by their CPL and their CC. In order for the network to be a Small World network, the CC must be different between the network and a random network, but the CPL must be of the same order of magnitude.

In a random network $CPL_{random}=ln(n)/ln(k)$ and $CC_{random}=k/n$ while '*n*' is the number of nodes and '*k*' is the network's Degree [5]. As indicated above, in the network examined here *n*=8830 and *k*=3.469. The requirement stated by the hypothesis is therefore that $CPL=CPL_{random}$ and also that $CC>>CC_{random}$. By examining the quotients it is enough to see that $CPL/CPL_{random}=1$ and also that $CC/CC_{random}>>1$ (Grossman, 2002; Watts and Strogatz, 1998).

Table 3: Characteristic Path Lengths and Clustering Coefficients of various networks

	CPL	CC
Discussion Groups Network (Research sample)	4.66618	0.085
Random Network (Average encompassing three computer simulation generated networks)	7.3625	0.000
Theoretical Random Network	7.3045	0.0003928
Ratio between Random Network and the Discussion Groups	0.63	216

Following the results displayed in Table 3, the network is indeed a Small World network. The empirically observed Clustering Coefficient is orders of magnitude larger than in randomly generated networks. The empirically observed Characteristic Path Length, on the other hand, closely resembles the CPL for a theoretical random network.

Discussion

As we have seen, the collection of responses to messages in the discussion groups in a specific academic institute over four years fits the model of both Small World and Scale Free models. Such groups are a hybrid of social and informative networks in Newman's (2003) classification, and therefore their characteristics are slightly different, and of special interest.

When we investigated the 10 most influential people in the network we found that only two (20 percent) of them are instructors. The large majority of hubs were "regular" students. They "earned" their designation as hubs through participation, not through holding a formal

position.

Scale Free networks are a natural result of network growth over time in which there is preference for certain actors over others. Most studies focus upon a preference dynamic in which the strong (hub, the one with high out degree) becomes stronger. Previous studies of reactions to online interactions have found that such reactions depend on the amount of cognitive load placed on the responder (Jones, *et al.*, 2001, 2002, 2004). In other words, there is a preference given to some of the nodes over the others. Scale Free nets are characterized by the fact that most people have few contacts and a small part of the people have extremely many contacts. People who act as multi–connection intersections are termed hubs. Hubs are central agents who connect the different parts of the network in close proximity. Most paths between two people require the mediation of a hub. Often, and as would be expected, the instructors act as hubs in course groups. The instructor must advise and moderate the discussion. From the network's structure perspective it is clear that the instructor is located in a functional center of the group. This central location enables performance of coordination in an efficient manner (Aviv, *et al.*, 2003b). However, instructors are not the only form of a hub. In fact, they are not even the most common hubs. When we investigated the 10 most influential people in the network we found that only two (20 percent) of them are instructors. The large majority of hubs were "regular" students. They "earned" their designation as hubs through participation, not through holding a formal position.

Another confirmation of the Clustering Coefficient of the network can be found in the examination of the impact of the advisor and of the structure of the discussion on the strength of the group (Aviv, *et al.*, 2003b).

We found that the discussion groups organize naturally in a stable social structure which fits their purpose. This structure allows us to keep the social order along with increasing the level of control of the members of the network. The target audiences are larger but the order still remains. This research shows that even forty years after Milgram's findings, and in an environment in which the communication technology is more sophisticated and updated than that of physical mail, this is still a small and efficient world.

The research reported here has some methodological limitations. The data refer to a large number of participants and groups; however they are all associated with the same organization and function, for the same purpose using the same platform. The links used in this study are not a representative sample; therefore generalizing the finding is problematic. Further, the connections that form the model here, as in most research about online communication to date, focus on written activity and do not capture reading activity (Rafaeli, *et al.*, 2004).

Further research on the topology of online discussion groups should take into account comparing groups across organizational boundaries and especially across time. What are the organizational antecedents of Scale Free and Small World patterns? What are their temporal dynamics (Schoberth, *et al.*, 2003, 2004)? Further inquiry into the identity and nature of hubs is strongly suggested by the documentation of hub prominence in discussion groups. How do hubs emerge? Are participants in online discussions aware of the Small World nature of their groups?

In sum, the significance of the support provided here for the hypotheses is rooted in the development of a formal expression of growth, survival potential and preferential attachment in the connection patterns in discussion groups.

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Notes

1. For a discussion of these measures see Adamic, *et al.* (2003) and, Dorogovtsev and Mendes (2003).

2. Jovanovic, *et al.* (2001); for details, see Comellas and Sampels (2002).

3. For a theoretical look of the analyzing tools, see Wasserman and Faust (1994).

4. For a detailed mathematical explanation, see Bornholdt and Schuster (2003).

5. In a random network the Degree equals the number of connections divided by the number of nodes; see Watts and Strogatz (1998).

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