Mechanisms of Internet-based Collaborations: A Network Analysis Approach

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This research aims at clarifying whether network emergence mechanisms common in social networks are also involved in structuring Internet-based collaboration networks. We compare the observed values of reciprocity and transitivity in 95 Internet-based collaborations networks and 40 social networks with predictions of Random Graph models. All the tested networks exhibit reciprocities that significantly deviate from the predictions. All the Internet-based collaboration networks and some of the social networks – not all - exhibit transitivity compatible with the predictions. We conclude that exchange mechanisms, responsible for reciprocity, are at work in all networks. Cognition balance mechanisms, responsible for transitivity, are at work in many but not all social networks, but there is no evidence for it in any of the tested Internet-based collaboration networks. the explanations for these behaviours are based on the broadcast nature of the Internet-based collaboration networks. We briefly discuss the practical implications for Internet-based collaborative learning.

Introduction

Internet-based learning envisions the participants as a distributed network of Internet-based collaborating actors who are purposefully seeking and constructing knowledge within a meaningful context (Hiltz, 1994). Numerous reports emphasize the social nature of Internet-based collaboration networks (Haythornthwaite, 2002; Richardson and Swan, 2003). Hence we turn to emergence theories of social networks (Monge and Contractor, 2003) for suggestions for mechanisms underlying their behavior.

Network Exchange theory (Bienenstock and Bonacich, 1997; Willer, 1999) postulates a reciprocal selection process. Reciprocity is a common attribute of social networks of people and animals (Skvoretz and Faust, 2002), and of organizations (Monge and Contractor, 2001). (Hakkinen et al., 2001) did identify reciprocity of interaction in Internet-based networks, and (Wang and Fesenmaier, 2003) found that reciprocation is one of the major motivations driving individual's contributions in Internet-based networks.

To develop reciprocity, participants have to go through a “learning process” of assessment of risks, rewards and likelihood of reciprocation, and trust development (Axelrod, 1990). Here each of the actors develops its *ego*, *other*, and the *reflective-self* psychological components of dyads (Kadushin, 2004). Such a learning period can be developed in social networks by using rich "wide-bandwidth" social links. But relations between actors in Internet-based networks are not rich. Actors rarely meet, and network discussions are limited in scope and in time. This, it seems, reduces the likelihood of reciprocation and makes it very difficult to implement a learning period in Internet-based collaboration networks.

Theories of Cognitive Balance and Dissonance (Cartwright and Harary, 1956; Heider, 1958) postulate a transitive cognition balance mechanism to provide consistency in cognition among actors; people attempt to reduce dissonances through persuading others, who will persuade more people. Transitivity is common in social, organizational, technological and biological networks (Newman, 2003), but was not incorporated into models of Internet-based networks. In a typical Internet-based network a participant might be interested at some point in time in a certain issue, whose scope is limited. The lifetime of that issue is short. There is usually no group-wise drive to settle conceptual inconsistencies regarding issues. Hence, no transitive cognition balance mechanism is needed and none will, presumably, be established.

Hypotheses and tests

We hypothesize that in contradistinction to social networks, neither exchange mechanism nor cognition balance develops in Internet-based collaboration networks, beyond what could be developed by chance. We assessed the later by four Random Graph models: Erdös-Rényi (Erdos and Renyi, 1959). Holland-Leinhardt (Holland and Leinhardt, 1976), Molloy-Reed (Molloy and Reed, 1995) and Snijders (Snijders, 1991). In all four models actors in a network are linked at random, subject to some model dependent constraints. The Erdös-Rényi model imposes no constraints. In the Holland-Leinhardt model the total numbers of reciprocal and non-reciprocal links are separately bounded. In the Molloy-Reed model each actor is constrained by a maximal number of possible links. The Snijders model imposes the constraints of both the Holland-Leinhardt and the Molloy-Reed models.

The Erdös-Rényi and Holland-Leinhardt models assume no correlation between the probabilities for creating links, or dyads, respectively. Such correlations are inherent in the two other models. We include both types of models in analyzing each of the sub-structures, as they could provide hints on the origin of excessive sub-structures, if exists. The Erdös-Rényi and the Molloy-Reed models do not carry built-in reciprocity, so we use them as base-line models for identifying reciprocity beyond random links. (The other models constraint the reciprocity levels of their graphs, so they cannot be used in analyzing reciprocity). The Holland-Leinhardt and the Molloy-Reed models do not carry built-in transitivity, so we use these models to identify transitivity. We also use the Snijders model; comparing observed transitivity with values of both the Molloy-Reed and the Snijders models will tell us whether excessive transitivity (if exists) is an artefact of reciprocity or not.

Strictly speaking, we hypothesize that:

H1: the observed reciprocity can be explained by the Erdös-Rényi model
H2: the observed reciprocity can be explained by the Molloy-Reed model

H3: the observed transitivity can be explained by the Holland-Leinhardt model.
H4: the observed transitivity can be explained by the Molloy-Reed model.
H5: the observed transitivity can be explained by the Snijders model.

METHOD

Reciprocity is estimated by the number of reciprocal responses in the network. Transitivity is estimated by the number of transitive triads of responses (i.e. A responded to B, B responded to C, and A responded to C). Each of the Random Graph models creates, by simulation, an ensemble of graphs, each with a certain prescribed probability. We calculated the fraction of ensemble graphs with reciprocity and/or transitivity above the observed value. If this fraction is smaller than the significance level of 0.01, then the abundance of the corresponding sub-structure is significantly above what can be created by a random process, so the hypothesis was rejected for these observed network and model. Otherwise the hypothesis was accepted.

Data

In this study we selected for analysis 95 Internet-based networks formed in courses of the Open University of Israel. The objectives, sizes, response links and participation in the networks vary. The only criterion for selection was that the number of participants (those who post at least one message during the semester) is above an arbitrarily selected threshold of 10.

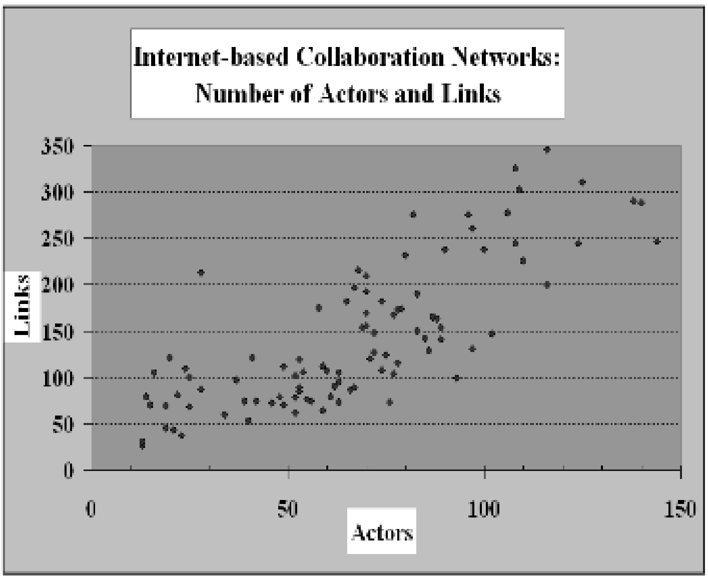

Figure 1: Characteristics of Internet-based collaboration networks used in this study

The characteristics of the observed networks are presented in Fig. 1 and 2. In these figure, as in all other figures in this paper, each point represents one network. The number of actors ranges from 10 to

145, and the number of response links between them, ranges from 40 to 350. From Fig. 2 we see that the density decreases from 0.45 to 0.02; most networks are sparse.

We have also analyzed a set of 40 well known social networks (Kapferer, 1972; Knoke and Kuklinski, 1982; Krackhardt, 1987; Wasserman and Faust, 1994), capturing friendship, advice seeking, assistantship, message exchange and trade relations. The characteristics of these networks are presented in Fig. 3. The range of links and densities are similar to those of the Internet-based networks. On the other hand the number of nodes in these networks (not shown) was limited to 21 - 39.

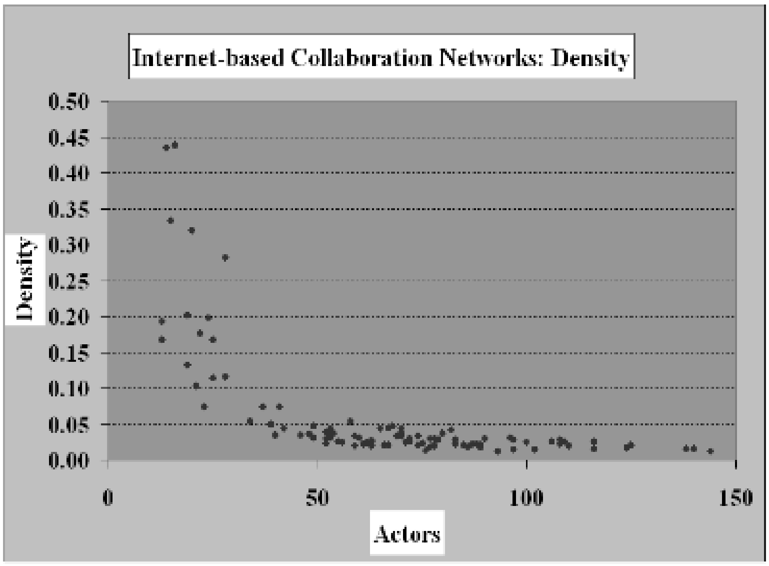

Figure 2: Densities of Internet-based collaboration networks analyzed in this study

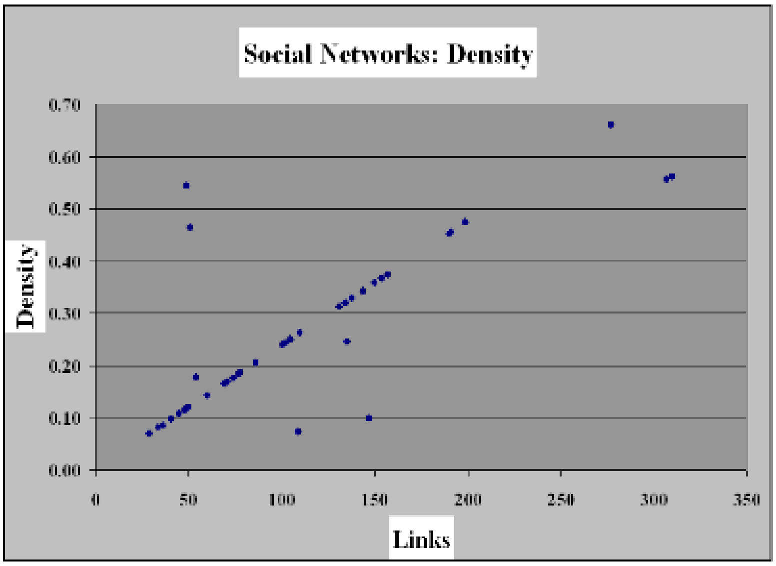

Figure 3: Characteristics of social networks analyzed in this study

Results

Figure 4 presents for each of the 95 Internet-based networks the observed, and the expected values of reciprocity according to the Erdös-Rényi and the Molloy-Reed models. Figure 5 presents the same information for the social networks.

In all cases the observed values are significantly (at the level of p = 1%) larger than the values expected by the two models; Reciprocity in all networks is significantly larger than what might have been created by the corresponding random processes. Hypotheses H1 and H2 are rejected.

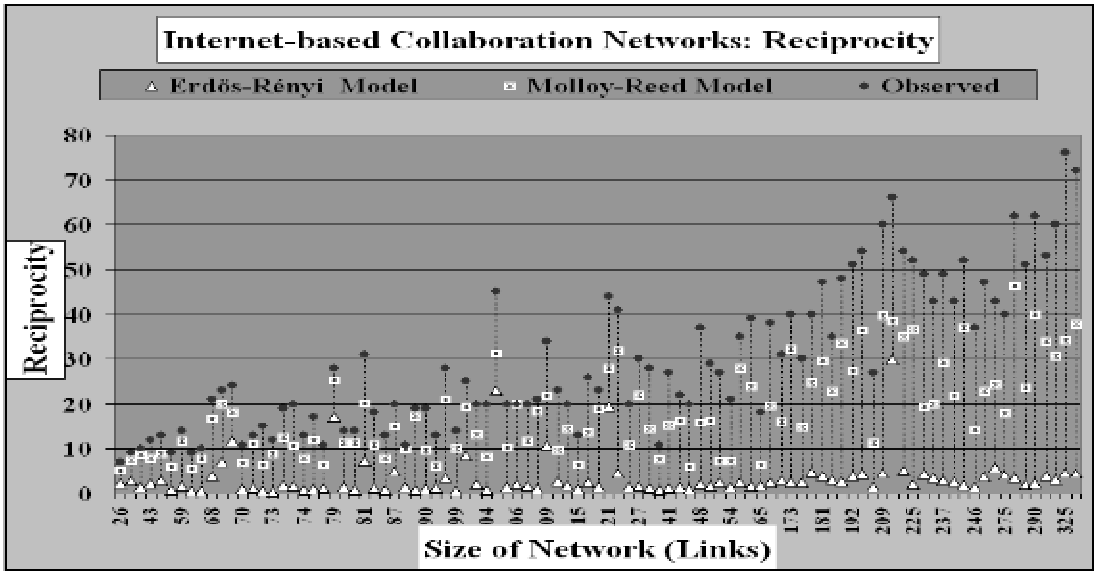

Figure 4: Observed and expected reciprocity in Internet-based collaboration networks

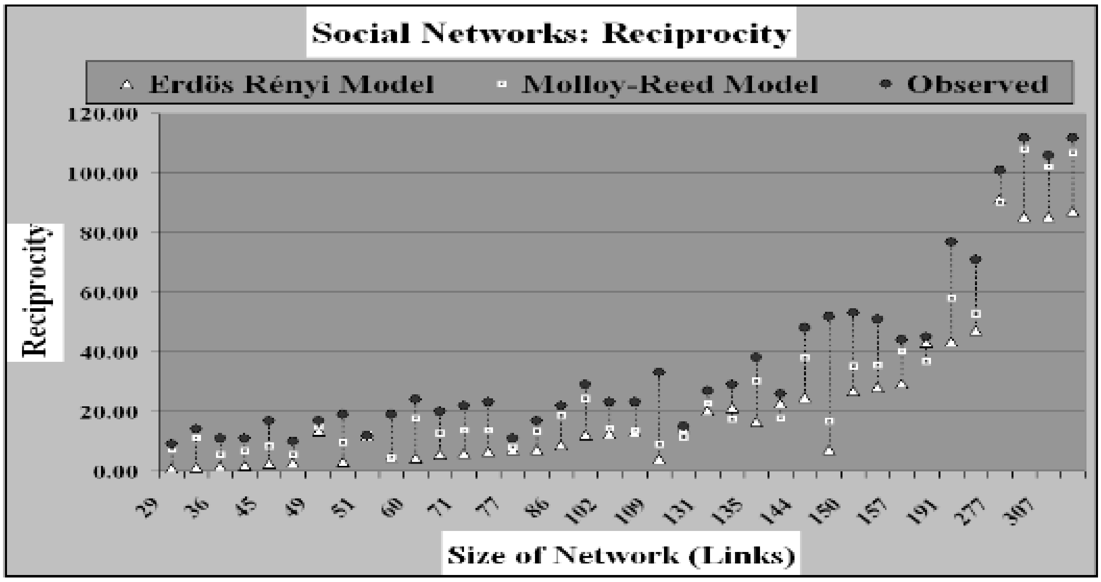

Figure 5: Observed and expected Reciprocities in the social networks

Figure 6 presents, for each of the 95 Internet-based collaboration networks the observed and predicted values of transitivity according to the Holland-Leinhardt, Molloy-Reed and Snijders models. The results for the social networks are presented in Fig. 7. In all of these cases the observed values are substantially higher than the values expected by the Holland-Leinhardt model, at p = 1% level. Hypotheses H3 is rejected for all networks. In the Internet-based collaboration networks the observed transitivity values agree with the values expected by the Molloy-Reed and the Snijders models (which agree with each other); the probability that these models will generate networks with transitivity equal or larger than the observed values is larger then p = 10%. Hypotheses H4 and H5 are not rejected for these networks.

The behaviour of the social networks is less homogeneous: In many social networks the transitivity agrees with the value expected by the Molloy-Reed and the Snijders models (which again agree with each other), but in other social networks the transitivity deviates significantly (in the statistical sense) from the expected predictions (note the logarithmic scale in Fig 7). Hypotheses H4 and H5 are accepted most – but not all, of the social networks; they are rejected for some social networks.

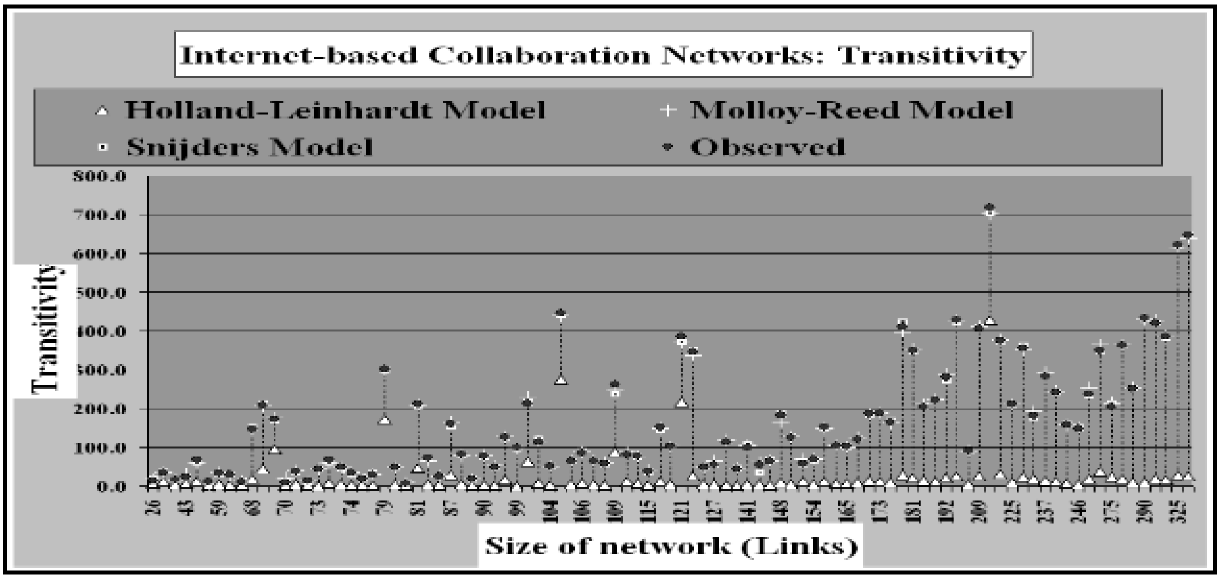

Figure 6: Observed and expected transitivity in Internet-based collaboration networks

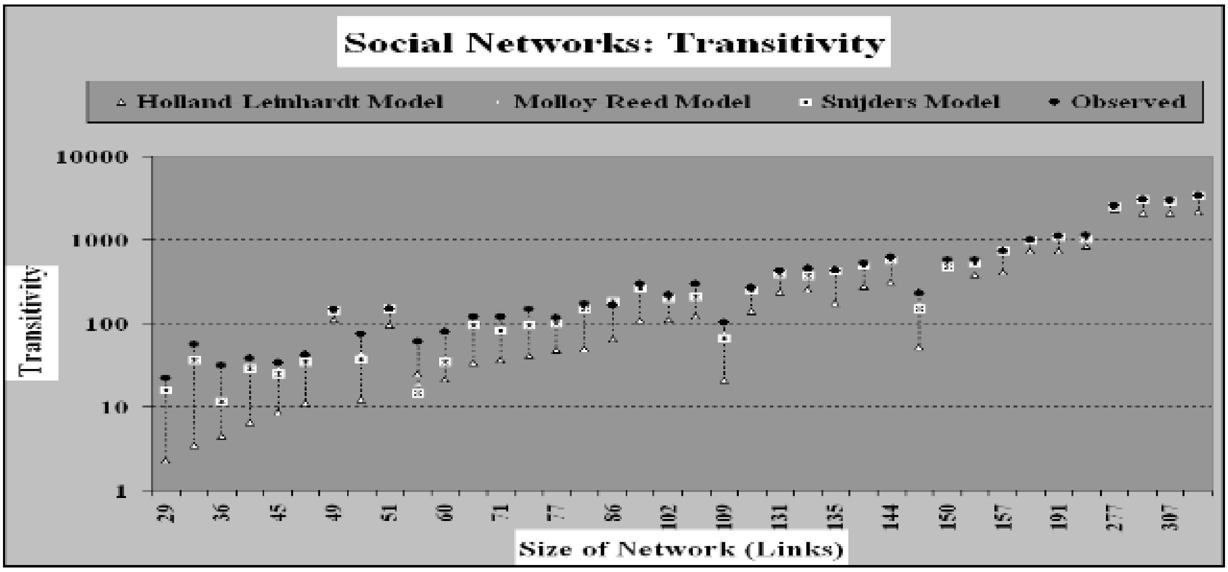

Figure 7: Observed and expected transitivity in social networks

The results are summarized in Table 1

Table 1: Results 1

Structure	Internet based collaboration network	Social networks
Reciprocity	Observed in all networks above unconstrained and constrained randomness: H1 and H2 rejected for all networks	Observed in all networks above unconstrained and constrained randomness: H1 and H2 rejected for all networks
Transitivity	Observed in all networks not to be above constrained randomness: H3 rejected for all networks H4 and H5 accepted for all networks	Observed in some networks above constrained randomness: H3 rejected for all networks H4 and H5 rejected for some networks

Discussion

The predictions of the Erdös-Rényi and Holland-Leinhardt models do not fit – in all the tested networks, with the observed values of reciprocity and transitivity, respectively. These models assume independence of links and dyads, respectively, which in sparse networks predict relatively too low values of the higher sub-structures. This is similar to the inadequacy of Erdös-Rényi model in describing many biological and technical networks (Newman, 2003). Links and dyads in nature are typically correlated so generalized random graphs, e.g the Molloy-Reed model, are more suitable for identifying excess of sub-structures, or motifs (Milo et al., 2002).

We see that social networks and Internet-based networks have similar but not identical motifs. In some of the social networks and all the Internet-based collaboration networks transitive configurations are not motifs, but in some social networks transitivity is a real motif; it is not an artefact of excess in reciprocity. In all the social networks and Internet-based collaboration networks the reciprocal configurations are motifs. This imply that while there is an evidence for cognition balance mechanism in some social networks, as was previously observed in previous studies (Wasserman and Faust, 1994), there is no evidence for this mechanism in all of the Internet-based collaboration networks. On the other hand, there is evidence for the exchange mechanism in all networks, social and Internet-based.

As noted above, the lack of cognition balance mechanism in typical Internet-based networks is due to the lack of group-wise drive to build a consensus. Transitive structures are building blocks of more complex cohesive structures such as response-cliques, which facilitate constructing knowledge by consensus (Aviv et al., 2003). To achieve knowledge construction suitable collaborative features – positive interdependence – (Johnson and Johnson, 1999) should be designed. A comparative case study analysis (Aviv et al., 2005) demonstrated that a goal-directed design of the team network forced its participants to reach consensus, which lead to the cognition balance mechanism.

As noted in section 1, to establish reciprocity the actors need to go through a learning period during which they develop the three psychological components of a reciprocal dyad. The key explanatory for the feasibility of this process is broadcast nature of the communication – posted messages are readable by all; the learning process is shortened since actors learn relatively quickly who is and who is not a potential reciprocator. Moreover, postings are "public appearances" of actors, exhibiting their behavioural aspects, such as providers of support (Constant et al., 1996; Hiltz et al., 1986; Walther, 1994), and they attract respect from others; this leads develops their *ego* and *reflective-self* component and to the awareness of the *other*. These considerations lead to the suggestion (Wellman and Gulia, 1999) that reciprocity is feasible in Internet-based networks, a suggestion supported by this research. Note that in many online collaboration there a role of a major responder assigned to one of the actors, e.g. a Tutor. Reciprocity would imply that actors prefer to respond to the major responder than to their peers. If interaction between peers is required, we have to distribute the roles of responders between actors.

Future Research

Reciprocity and transitivity are just two network characteristics. There are many others – clustering, degree and power distribution, and cliquishness, to name a few. Some of these features affect the behavior of various types of networks. For example, certain degree distributions (the so called “scale free" distributions (Barabasi and Hawoong, 1999)) characterize a large number of extremely large networks (Newman, 2003), "Small World" topology (regular connectivity with few short-cuts) lead to synchronization between nodes (Barahona and Pecora, 2002). These network effects are all interdependent, and can be incorporated into a more general analysis using parametric models, such as p* (Anderson et al., 1999; Wasserman and Pattison, 1996) or discriminative classifiers (Middendorf et al., 2004). Such comparative global analyses are required in order to answer the fascinating question: What type of networks are Internet-based collaboration networks?

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