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The Structural Evolution of the Web2.0 Service Network

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Abstract

Purpose – The purpose of this research is to analyze empirically the structure of the Web2.0 service network and the mechanism behind its evolution over time.

Design/Methodology/Approach – Based on the list of Web2.0 services and their Mashups that is announced on www.programmableweb.com, a network of Web2.0 services was constructed. Within this network, a node represents a Web2.0 service with an open API, and a link between two nodes represents the existence of a Mashup service that uses the two nodes.

Findings – Our findings suggest that the evolution of the Web2.0 service network follows the preferential attachment rule, although the exponent of the preferential attachment is lower than for other networks following a preferential attachment rule. Additionally, our results indicate that the Web2.0 service network evolves to a scale-free network, but the exponent of the power law distribution is lower than for other networks as well.

Originality/ value – The research applied social network analysis to the Web2.0 service network. It showed that its network structure and the evolution mechanism are different from those found in similar areas, e.g. the WWW. The findings imply that there are factors which lower the exponent of the preferential attachment equation and the power law distribution of the degree centralities.

Research limitation/implications – However, we did not investigate the factors responsible for the low values of the exponent of the preferential attachment equation and the exponent of the power law distribution. However, we discussed that it could be correlated with the fact that the interconnection between nodes depends on the property of the nodes.

Keywords – Software Services Economics, Web2.0 Mashup, Scale-Free Network, Preferential Attachment Rule, Self-Organization, Social Network Analysis

Paper type – Research paper

1. Introduction

The progress of Really Simple Syndication (RSS) technology and the introduction of asynchronous JavaScript and XML (AJAX) have propelled the success of new types of services on the Internet (e.g. blogs) (Lai and Turban, 2008; O'Reilly, 2007). It facilitated user-created Web content. This trend differs from the one that characterize the first generation Web, which simply distributed static content from providers to users. The term Web2.0, which defines this new generation of Web sites, was used for the first time in October 2004 (O'Reilly, 2007). In more detail, Web2.0 is defined as a new trend of Internet services, which promote "users to collaboratively create, share and recreate knowledge from multiple sources, leverage collective intelligence and organise action" (Eijkman, 2008, p. 94). For example, YouTube, which offers a platform for sharing video clips of users, provides an Application Programming Interface (API) so that users can access the video clips from other (end-user) Web sites. In general, these APIs allow users to mash up (e.g. combine) one or more Web2.0 services in order to create their own composite, value-added services (Floyd *et al.*, 2007; Weiss, 2005; Zammetti, 2007).

Floyd et al. (2007) argue that the success of Web2.0 comes from the opportunity of sharing resources. This explains the fast growth of the Web2.0 service network. However, the network structure of Web2.0 services has not been elucidated in previous research. It is also not clear how this network evolves over time, despite the fact that researchers suggested that the characteristics of the Web2.0 service network is the reason for the well-working, control-free interactions between Web2.0 services (Lai and Turban, 2008). Because of this reason, it is necessary to understand the structure and the mechanism behind the evolution of the Web2.0 service network. This research aims at analyzing the network characteristic and the evolution mechanism of the Web2.0 service network by social network analysis (SNA).

Some existing literatures on social networks deal with self-organisation of networks. They suggest that simple rules describing the behaviour of individuals may lead to the emergence of a unique pattern for the whole system. In particular, literature investigated self-organised systems in various areas (e.g. academic collaboration, the society and the WWW). They found that these networks are scale-free, which means that the degree distribution follows a power law (Albert and Barabási, 2002; Huberman and Adamic, 1999). The power law is defined as a mathematical equation between two variables P and k such that $P(k)=k^{-\gamma}$ where γ is the exponent which represents the characteristic of the degree centralities distribution of the network.

One of the most famous simple rules leading to a scale-free network is the preferential attachment rule. The preferential attachment rule describes the linkage formation. It states that the more popular a node is, the greater the likelihood that a link will be attached to it is (Barabási, 2003). Some theoretical research proved that the preferential attachment rule with an exponent close to one impacts a network to become a scale-free network with an exponent in the range between 2 and 3 (Krapivsky *et al*., 2000; Barabási *et al.*, 2001; Hołyst *et al.*, 2004; Dorogovtsev *et al.*, 2000). Some empirical research verified the existence of a preferential attachment rule and the scale-free structure for journal citation networks and for the WWW hyperlink network (Albert and Barabási, 2002; Barabási *et al*., 2001; Jeong *et al.* N.D.; Kujawski *et al*., 2007; Newman, 2001). Fu et al. (2008) analyzed the structure of blogs and social network sites. They found a scale-free network structure with an exponent in the range between 2 and 3. However, the analysis of the network structure has not been performed for the Web2.0 service network yet.

For our analysis, we used empirical data on Web2.0 services surveyed from the Web site www.programmableweb.com, which lists Web2.0 services with open APIs and their Mashups. The data was used to construct the Web2.0 service network that we used for our study. The nodes of this network are Web2.0 services with open APIs and a link (also called tie or connection) between two nodes represents the existence of a Mashup that is constructed of these Web2.0 services at least. In order to check whether the Web2.0 service network is a scale-free network and whether it follows the preferential attachment rule, we calculated the ratio of the degree of a node to the sum of the degree of all nodes in the network.

The analysis showed that the Web2.0 service network is a scale-free network, following the preferential attachment rule. However, the exponent of the power law distribution and the exponent of the preferential attachment rule are lower than those for other self-organizing networks. This implies that certain characteristics of the Web2.0 service network impacts the evolution of the network, which could not been explained with the parameters of the preferential attachment rule. As we will discuss in more detail, the cause could be that the interconnection between nodes depends on the property of the node or the type of node.

This paper is organised as follows: Section 2 describes the state-of-the-art in Web2.0 services and scale-free networks. Section 3 defines the indicators used for the analysis and specifies the hypotheses about the characteristics of the network, namely the structure of the Web2.0 service network and the mechanism behind its evolution. Section 4 presents the data set and the analysis results. The implications of the results (e.g. the existence of the preferential attachment rule and the scale-free structure of the Web2.0 service network) are discussed in Section 5. Finally, we conclude the paper with policy recommendations and suggestions for future research.

2. Prior research

Web2.0 services

A Web2.0 service API defines the interface for accessing service functions or data. Some Web2.0 service companies release APIs so that any user can integrate applications into his/her Web site and thereby create a new Web2.0 service (Weiss, 2005). The Web2.0 service providers have an incentive to provide API, since it allows them to gain revenue from Mashups that are developed by other commercial Web2.0 service developers. Revenue of Mashups could come from advertising (Roush, 2005). A Web2.0 Mashup is defined as a Web2.0 service composed of one or more Web2.0 services (Floyd *et al.*, 2007). The success factor of Web2.0 Mashups is

the efficient division of labor between providers. Mashup developers create new Web2.0 services by combining existing Web2.0 services and adding specific value to them (Floyd et al., 2007; Zammeti, 2007).

Web2.0 services with an open API can be represented as a network in which a node is a

Web2.0 service with an open API. A link between nodes exists if both services have been used together in a Web2.0 Mashup. We call this network a "Web2.0 service network." Figure 1 shows an example. Actor Tracker is a Mashup. It combines Web2.0 services of eBay and Amazon eCommerce services.

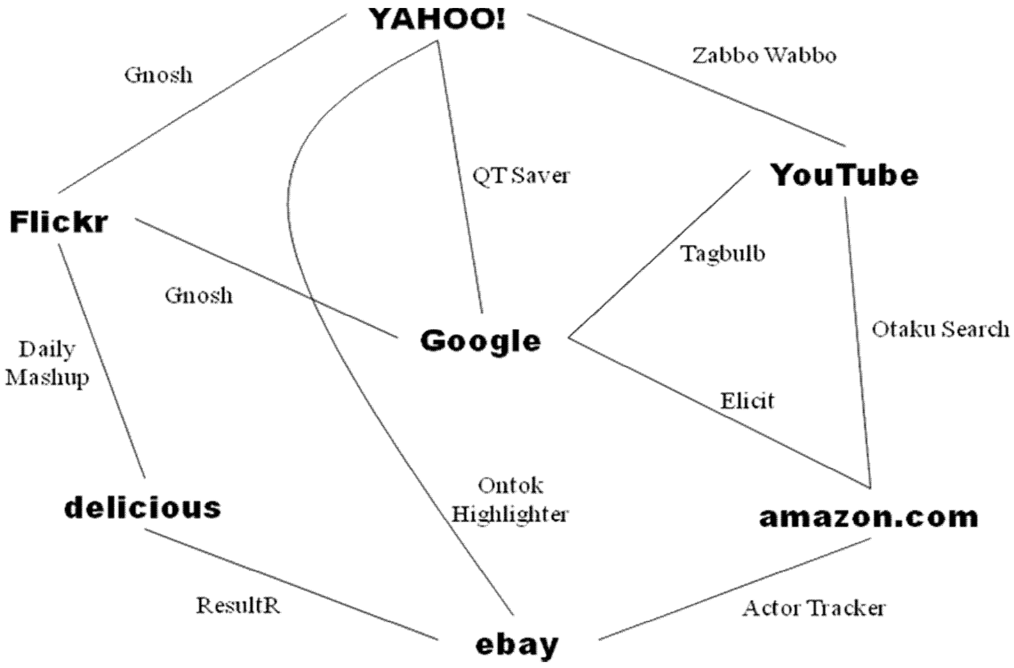

Figure 1. Web 2.0 service network consisting of Web2.0 services connected by Mashups

Web2.0 Service network as a social network

The Web2.0 service network can be considered a representation of collective intelligence of the developers of Web2.0 services (O'Reilly, 2007). Collective intelligence is "empowerment through the development and pooling of intelligence to attain common goals or resolve common problems" (Brown and Lauder, 2000, p. 234). Additionally, Kapetanios (2008, p. 289) defined collective intelligence as "human-computer systems in which machines enable the collection and harvesting of large amount of human-generated knowledge." For ensuring a high level of collective intelligence, the Web2.0 service network acts as the host and organiser of innovation sources. A user has an incentive to voluntarily participate in the innovation if it accurately fulfils his/her needs (von Hippel, 2001). At issue is how the cyber society can stimulate the innovation resources (e.g. the functions and data) that each user and developer possesses and contributes. The Web2.0 service network accomplishes it by offering development and diffusion of Web2.0 services at low cost. This is consistent with von Hippel's theory of development community. The community lowers the cost barriers, so that users can achieve innovation easily.

Network analysis

As interaction between entities became a significant factor of innovation, innovation studies require social network analysis, investigating the relationship between entities (Smart *et al*., 2007). In particular, the structure, the position of nodes and the evolution mechanism of the social network can be analyzed. The two main streams of social network analysis (SNA) are that in sociology and that in physics. By abstracting the relationships of actors as links between nodes, SNA offers a methodology to understand the structural characteristics of social phenomena. This analysis is useful in various areas such as architecting effective communication networks (Monsuur, 2007) and efficient peer-to-peer social networks (Wang and Sun, 2008).

Sociologists are interested in the position of agents in the network and the network structures. For measuring these characteristics, they developed network indices and coefficients such as centralities, cliques, and distance (Brass, 1984; Wasserman and Faust, 1994). For example, Everard and Henry (2002) investigated the degree centrality (the number of neighbours) and the betweenness centrality (the number of paths through the node) of an interlocked directorate of e-commerce companies. They concluded that companies bridging e-commerce companies with established leading companies show high performance. Rodan (2008) developed an agent-based model, which considers the degree and the "cross-cutting ties" of an agent. Findings suggested that the effect of the degree of a node and the cross-cutting ties between groups on their learning performance was positive (Rodan, 2008). By measuring degree centralities of keywords and authors in Wikipedia, Korfiatis *et al.* (2006) statistically investigated heterogeneity of co-editions and the contributions of a variety of authors.

While sociologists have been concerned about the roles of agents and their relationships with the network structure, physicists have analyzed the internal structure of the network and the evolution mechanism of the network. They have shown statistically that many real networks are heterogeneous, which is different from the homogenous model of Erdös and Réiny (Barabási and Albert, 1999; Watts and Strogatz, 1998). Watts and Strogatz (1998) called a network with few nodes and a significantly large number of links in a short path between any two nodes "small world networks." Barabási and Albert (1999) found that the distribution of the degree of nodes follows a power law. They called this kind of network "scale-free." Its exponents are generally between 2 and 3. Scale-free networks possess characteristics such as robustness against failure of a node, fragility against intended attack, and the sand pile effect (Albert *et al*., 2000; Tu, 2000). By analyzing co-developers and co-project relationships in the open source software community, Xu *et al.* (2006) showed that the network of open source software is scale-free. In their analysis, the exponent of the power law of the developers' network is about 3.3, which is quite high. Moreover, Angus *et al*. (2008) showed that the distribution of tagged images in Flickr is scale-free, which implies tags are used in the social and cultural context.

Evolution of networks

Many researchers have suggested that a preferential attachment rule guides the construction of scale-free networks (Barabási and Albert, 1999; Dorogovtsev *et al*., 2000; Holyst *et al*., 2004; Krapivsky *et al*., 2000; Kujawski *et al*., 2007; Newman, 2001; Park *et al*., 2005; Štefančić and Zlatić, 2005). Barabási and Albert (1999) established a model, in which the probability that a new node links to existing nodes relates to the degrees of the existing nodes (Barabási and Albert, 1999). Newman (2001) suggested a model, in which the probability that two nodes depends on the number of common acquaintances of each node. Through the growing random graph model, Krapivsky *et al.* (2000) determined that the linear probability of new attachments to existing nodes leads to a power-law distribution with an exponent between 2 and infinity. Barabási *et al.* (2001) applied a continuum equation that included the effect of newcomers and internal links. They concluded that scale-free networks should have an exponent between 2 and 3. Using supremacy, which means the number of nodes included in the subgraph from a certain node, Hołyst *et al.* (2004) derived a scale-free network from the preferential attachment rule. Dorogovtsev *et al.* (2000) mathematically derived a power law distribution of degree with exponent between 2 and 3 from the preferential attachment rule whose attractiveness is linear with degree.

Two approaches support these analytical analyses. First, from a variety of fields, the empirical data about networks provide evidence that the preferential attachment rule self-organises scale-free networks. A citation network, an actor network, and the Internet has been investigated (Albert and Barabási, 2002; Barabási *et al*., 2001; Jeong *et al.* N.D.; Kujawski *et al*., 2007; Newman, 2001). The three networks show a linear probability for new attachments to existing nodes and a power law distribution with exponents between 2 and 3 (Albert and Barabási, 2002; Barabási *et al*., 2001; Jeong *et al*., N.D.). Focusing on threads of postings, Kujawski *et al*. (2007) measured topological and temporal statistics of Internet discussions, which grows like a tree network. Newman (2001) investigated the citation network of some databases of physics, biology and medicine. He found that the existence of common acquaintance affects the probability of new links. Valverde and Solé (2007) surveyed data from a platform of an open source project (SourceForge) to analyze the structure of the open source social network consisting of community members. They found that open source social networks were self-organized into a scale free network with an exponent 2, and that it has a hierarchical design. Using blog service (Sina blog) data and social network site (Xiaonei SNS) data, Fu et al. (2008) analyzed the structure of the social networks. Their results showed that both the Sina blog network and the Xiaonei network are scale-free. The exponent of the former is 2.34 and that of the latter is 2.12 (Fu et al., 2008).

Second, to connect the established analytical models and the empirical findings, the simulation approach evaluates the effect of the preferential attachment rule on the evolution of scale-free networks. Davidsen *et al*. (2002) tried to couple small world and scale-free networks by modelling an acquaintances network, in which nodes were linked to each other through a common acquaintance. Park *et al*. (2005) modelled a re-wiring link model to determine if non-growing networks can also be self-organising and scale-free. Štefančić and Zlatić (2005) established a two-step model (setting a group randomly and choosing a group preferentially) and explained that incomplete information can affect the evolution of networks. Schnegg and Stauffer (2007) unified the Erdös-Rényi model and the Barabási-Albert model to explain empirical analyses on social networks consisting of kinship and business relations of local societies. Some of the networks were similar to the scale-free network, but others' distribution of degree looked like a reversed U-curve. The simulation of the Schnegg and Stauffer (2007) model indicated that the larger the effect of the preferential attachment is, the larger the exponent of the power law distribution is.

3. Research model

Definitions

To describe the preferential attachment rule and the scale-free property of the Web2.0 service network, we define the Web2.0 service network. A Web2.0 service with an open API is represented by a node. A Web2.0 Mashup created through a combination of Web2.0 services is expressed as a link between nodes. For example, the Mashup FeedFlinger is created by four Web2.0 services (Yahoo! Terms, Yahoo! Search, Feed Burner, and delicious.com), generating six links in the Web2.0 service network. We assume that all nodes already exist and a multitude of links appear continuously between the nodes. Though nodes are created, updated, and die in the real network, our assumption is based on the lack of data about the update and death of the Web2.0 services.

Degree centrality, which defines the number of links of a node, is a basic indicator in this research. It indicates the position of a node in a network. A high degree centrality means high accessibility to other nodes (Wasserman and Faust, 1994). Links are treated as undirected links because a link between Web2.0 services to create a Mashup does not distinguish a starting point and an end point of the link. The precise definition is as follows:

Definition 1. Degree centrality of node i at period t is the number of undirected links of node i.

For our analysis, the degree centrality was normalised with respect to all links (called *shareness*) in the network for two reasons. First, the probability of linking to a node depends on the proportion of the degree centrality of a node to all degree centralities in the network. Second, the ratio is appropriate for comparing the degree centralities of nodes of different networks. This is essential since the number of links generated in each period is not uniform.

Definition 2. Shareness is the ratio of the number of links of a node to the total number of links in the network.

To be able to observe change over time, the definition of shareness was modified into two types: *instant shareness* and *accumulated shareness*. The former was designed to measure the ratio of new links of a node to those of all nodes in a period. The latter was devised to express the preference of new links to a node. Their definitions are as follows:

Definition 3. The instant shareness of node i at period t is the ratio of degree centrality of node i to the sum of degree centrality of all the nodes in the network at period t.

$$r_i(t) = \frac{c_i(t)}{\sum_{j \in I} c_j(t)} \qquad (1)$$

Definition 4. Accumulated Shareness of node i at period T is the ratio of the sum of the degree centrality of node i over all time periods to the sum of degree centrality of all the nodes in the network over all time periods.

$$R_i(T) = \frac{\sum_{t=0}^{T} c_i(t)}{\sum_{j \in I} \sum_{t=0}^{T} c_j(t)} \qquad (2)$$

Here, I is a set of all the nodes in the network.

Preferential attachment

The preferential attachment rule that we use is: A node with a high degree centrality has a higher probability of obtaining new links than a node with low degree centrality. This can be interpreted as the linkage to a node with high accessibility to the network provides more benefits than one with low accessibility. Users who create Web2.0 Mashups may choose Web2.0 services with high degree centrality. Web2.0 services with high degree centrality have a high visibility in the Web2.0 service network. For example, Programmableweb (www.programmableweb.com) provides a variety of rankings and tags of Web2.0 services and Mashups. Indirectly, users searching for appropriate Web2.0 services for their Mashups can reach the Web2.0 services with high degree centrality through their neighbours more easily than they can reach those with low centrality.

The classic preferential-attachment rule considers the attachment probability of a node as a function of the ratio of existing linkages of the node (Barabási *et al.*, 2001; Krapivsky *et al.*, 2000). The model is based on the assumption that the probability of new attachments is a power function of existing degree centrality. Prior research investigated whether the exponent of the power function is larger than one, lower than one or linear. In our research, accumulated and instant shareness are designed to measure the existing proportional linkage and to calculate the new attachment probability. Following the Barabási-Albert (1999) model, we formulate the hypothesis that the instant shareness may depend on accumulated shareness by a power function (Equation 3).

Hypothesis 1. The instant shareness of Web2.0 service i at period t is linearly proportional to the accumulated shareness of Web2.0 service i until period t-1.

$$r_i(t) \sim R_i(t-1)^{\alpha} \qquad (3)$$

The factor affecting the preference of a node can be expanded from the relation between nodes to the attribute of the node. One assumes that users choose Web2.0 services with high performance, which is related by the competency of the companies providing them. For example, if a large company such as Yahoo is interested in the Web2.0 service and invests in them, then the preference of the Web2.0 services may increase due to the high confidence placed in them. In this research, we assumed that networks managed by Web2.0 service providers such as Yahoo Developer Network may have a competitive advantage for attracting users who want to create new Mashups. The Web2.0 service attribute was modelled through a dummy variable, D_i, which is 1 if the Web2.0 service is provided by the company i operating its own network of developers; otherwise it is 0. The dummy variable for a developer's web was assumed to have a linear relationship with instant shareness. This is expressed in the following hypothesis:

Hypothesis 2. The instant shareness of Web2.0 service *i* at period *t* depends on the dummy variable of the developers web.

$$r_i(t) \sim \beta D_i \qquad (4)$$

Scale-free network

The degree centrality indicates the position of Web2.0 services within the network. As found by many previous researchers, the degree centrality distribution of self-organised networks shows the power law distribution (Albert and Barabási, 2002; Barabási *et al*., 2001; Jeong *et al.* N.D.; Kujawski *et al*., 2007; Newman, 2001). Self-organised networks are likely to evolve toward the state where few nodes become hubs and the majority of nodes take few links. The Web2.0 service network may show power law distribution because it is also self-organised via users' selections for creating Web2.0 Mashups. The last hypothesis is established to state that the structure of Web2.0 service network evolves into a scale-free network. This hypothesis is denoted by equation (5) where *k* is the accumulated degree centrality until period *t*, *P(k, t)* is degree distribution at period *t*, and *γ* is the exponent that represents the heterogeneity of degree centrality in the network structure.

Hypothesis 3. Degree centralities of Web2.0 services show a power law distribution along the degree centralities at each time period *t*.

$$P(k,t) \sim k^{-\gamma} \qquad (5)$$

4. Analysis

Data

The lists containing information about Web2.0 services and Mashups from September 1, 2005 through May 31, 2007 were obtained from www.programmableweb.com. An average of 21 Web2.0 services were listed and updated in the site during this period. Data included 445 Web2.0 services and 1,929 Web2.0 Mashups. However, 222 Web2.0 services were removed from the analysis because they are isolated. That is, no user utilized the 222 Web2.0 service for creating Mashup during the study period. Thus, only 223 Web2.0 services were used to evaluate the hypotheses. Additionally, we defined a blank Web2.0 service which represents a Mashup that does not provide any Web2.0 service. Thus, the network that we analyzed consists of 224 nodes.

Network construction mechanism

For being able to apply linear regression on Hypothesis 1, equation (3) was transformed by the natural logarithm to equation (6), where *a* is a constant and *t* means a period:

$$\ln r(t) = \alpha \ln R(t-1) + a \quad (6)$$

Data of 20 months were regressed monthly from October 2005 to May 2007. The observation in September 2005 was not considered because the accumulated shareness was not defined at that period. Table I shows the regression results for Hypothesis 1. The explanation power, R^2, averaged 0.321. The inclusion of a constant is proper in our model because R^2 was larger than the adjusted R^2. But it is ignorable because the probability of a *t*-distribution was not significant at the 10% level at each period. R^2 values are 0.166 in November 2005 and 0.149 in May 2007, which are small compared to those of other periods. The network may have been too immature to reveal the preferential attachment rule. The result of May 2007 is a little bit curious. R^2 values are 0.078 in December 2006 and 0.009 in January 2007, which are extremely small. In these two periods, two or three Mashups bringing many Web2.0 services may distort the network structure. Excluding the odd four periods when R^2 values are smaller than 0.2, the average R^2 increased to 0.376.

The exponent α averaged 0.487. In the periods when R^2 values are small, α values are very small compared to the average: 0.28 in December 2006 and 0.094 in January 2007. Eliminating these two periods, we see that α increases to 0.536, and they are all between 0.300 and 0.525. In 18 periods among 20 data points, α is significant at the 10% level. The probability of *t* distribution averages 0.04, which is significant at the 10% level. The probabilities of *t* distribution are 0.148 in November 2005 and 0.533 in January 2007, which are statistically insignificant. These two periods are included in the four periods of low explanation power. Except for these four periods, the average probability of *t* distribution is 0.01, which is statistically significant at 10% level. Since the result excluding the extraordinary four periods augmented R^2 and the probability of *t* distribution only slightly, we included all the periods in the analysis.

Since Google is utilised for an extraordinary number of web2.0 services and it averaged 58 Mashups for the period (1,156 Mashups until May 2007), we investigated whether it is an outlier. In order to deal weather Google Maps distorted the structure of the network, the data sets were regressed without it. According to our results, the average R^2 is 0.478, which is higher than in the original analysis. The exponent α and the probability of *t*-distribution are 0.791 and 0.000 in average, respectively. Google Maps does not lead to wrong acceptance of Hypothesis 1. Our results support Hypothesis 1. The exponent of equation (3) is 0.49:

$$r(t) \sim R(t-1)^{0.49} \qquad (7)$$

Table 1. Regression results of equation (6) related to Hypothesis 1

YY-MM	R^2	A	α	sig. of a	sig. of α
05-Oct	0.4	-0.731	0.909	0.548	0.027
05-Nov	0.166	-2.235	0.307	0.018	0.148
05-Dec	0.326	-1.672	0.511	0.04	0.021
06-Jan	0.395	-1.837	0.525	0.005	0
06-Feb	0.428	-1.771	0.525	0.003	0
06-Mar	0.512	-1.481	0.57	0.006	0
06-Apr	0.357	-2.16	0.44	0.001	0
06-May	0.265	-2.145	0.464	0.001	0.001
06-Jun	0.619	-0.62	0.785	0.28	0

06-Jul	0.347	-2.192	0.383	0	0.001
06-Aug	0.376	-1.675	0.509	0.013	0.002
06-Sep	0.342	-1.886	0.514	0.005	0.001
06-Oct	0.45	-1.441	0.637	0.014	0
06-Nov	0.448	-2.178	0.465	0	0
06-Dec	0.078	-3.267	0.277	0	0.05
07-Jan	0.009	-4.473	0.094	0	0.533
07-Feb	0.246	-2.277	0.435	0	0.001
07-Mar	0.247	-2.081	0.522	0.002	0
07-Apr	0.26	-2.274	0.433	0.001	0.001
07-May	0.149	-2.712	0.429	0.001	0.007
average	0.321	-2.055	0.487	0.047	0.040

For testing Hypothesis 2 with a linear regression, equation (4) was transformed to equation (8), where *b* was a constant:

$$r(t) = \beta D + b \qquad (8)$$

In Table II, the explanation power, R^2, was 0.099 on average. Only 5 data sets among 20 had R^2 values larger than 0.10. R^2 values for only two data sets are larger than 0.200. The probability of *t*-distribution averages 0.237. The dummy variable *D* is statistically insignificant at the 10% level except in October 2005 when it is 0.013 and in December 2005 when it is 0.044. The explanation powers at these times were larger than 0.200. Explanations on the magnitude of constant *b* and coefficient *β* were not made because *D* was just a dummy variable. When Google Maps, the probable outlier, was removed, the dummy variable was insignificant. Thus, Hypothesis 2, which stated that the effort of Web2.0 service providers may improve node attributes, can be rejected.

Structure of the Web2.0 service network

Finally, equation (5) representing Hypothesis 3 was transformed by the natural logarithm for linearization, where *c* is a constant:

$$\ln P(k) = -\gamma \ln k + c \qquad (9)$$

The accumulated degree centralities of each Web2.0 service from September 2005 to May 2007 were calculated to understand the position and importance of each Web2.0 service (Table III). The exponent *γ* in May 2007 was calculated to be 0.521. The result is sufficiently explained because R^2 is 0.604 and the probability of *t*-distribution is 0 in May 2007. However, it is different from the usual scale-free networks in which the exponent lies between 2 and 3. Figure 2 shows the distribution of degree centrality. The horizontal axis shows the degree centrality of each Web2.0 service on the natural logarithm scale, and the vertical axis shows the number of nodes that have degree centrality in the natural logarithm scale. The points in the graph mark the empirical values. The estimated results from the empirical values are illustrated on a line in the graph. The pattern of the results indicates that the distribution of nodes with respect to degree centralities follows the power law. The dispersed region in the bottom right of the distribution is the result of noise caused by low probability (Štefančić and Zlatić, 2005).

Table 2. Regression results of equation (7) related to Hypothesis 2

YY-MM	R^2	b	β	sig. of b	sig. of β
05-Oct	0.478	-5.251	2.14	0	0.013
05-Nov	0.064	-3.943	0.664	0	0.384
05-Dec	0.26	-4.828	1.515	0	0.044
06-Jan	0.058	-4.752	0.688	0	0.215
06-Feb	0.078	-4.612	0.72	0	0.159
06-Mar	0.06	-4.565	0.573	0	0.171
06-Apr	0.071	-4.58	0.572	0	0.155
06-May	0.18	-4.991	0.998	0	0.006
06-Jun	0.171	-4.495	0.96	0	0.045
06-Jul	0.019	-4.144	0.275	0	0.488
06-Aug	0.014	-3.952	0.238	0	0.595
06-Sep	0.026	-4.507	0.424	0	0.396
06-Oct	0.033	-4.785	0.449	0	0.259
06-Nov	0.062	-4.879	0.519	0	0.095
06-Dec	0.004	-4.578	-0.175	0	0.644
07-Jan	0.003	-5.055	0.158	0	0.699
07-Feb	0.147	-4.915	0.801	0	0.01
07-Mar	0.169	-5.316	0.992	0	0.002
07-Apr	0.034	-4.682	0.414	0	0.252
07-May	0.053	-5.144	0.568	0	0.114
average	0.099	-4.699	0.675	0	0.237

In Table III, the regression showed good explanation power (average R^2 = 0.647). R^2 was larger than 0.600 for all but three periods: R^2 was 0.441 in October 2005, 0.581 in November 2005, and 0.580 in February 2006. That the regressions in the initial two periods have low explanation power may be the result of the small number of links in the initial state. After that initial fluctuation, the network evolved scale-free. The average γ is 0.530, which is statistically significant at the 10% level, and the probability of t-distribution averaged 0.002 except for in the initial two periods (when it is zero). The γ of 0.700 for September 2005 is high and the γ of 0.459 for October 2005 is small. This initial-state fluctuation may have been come by the same reason as for R^2 values in these time periods. The constant is included because the probability of t-distribution was zero on average. After the initial three periods are removed from the analysis, R^2 increases to 0.657 and γ decreases to 0.525. In this analysis all the periods ware kept because these fluctuation had little influence on the results. To conclude, the results supported Hypothesis 3 and led to the following equation:

$$P(k,t) \sim k^{-0.53} \qquad (10)$$

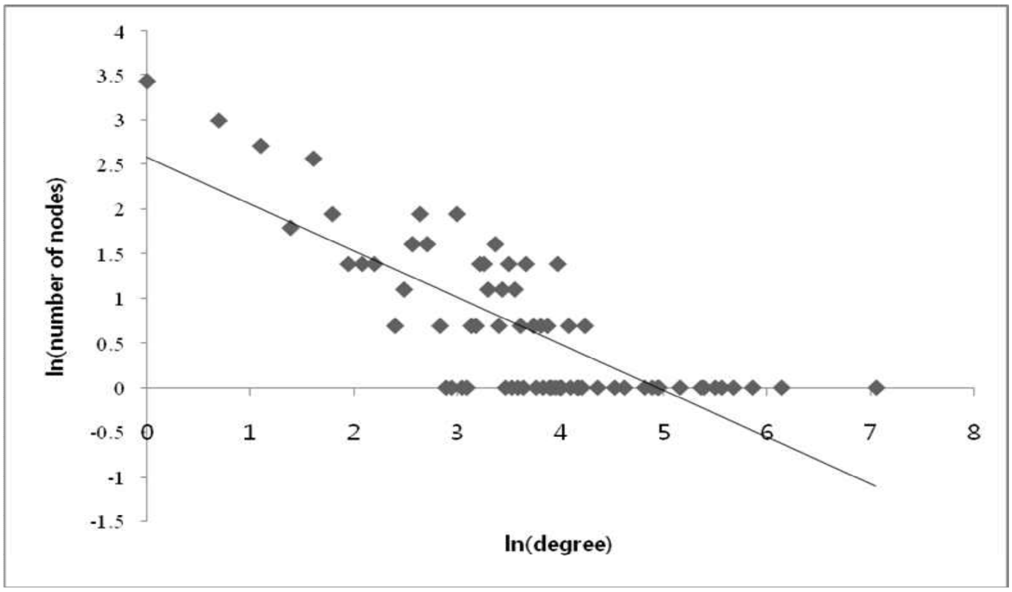

Figure 2. The distribution of degree centralities for the Web 2.0 service network

Table 3. Regression results of equation (9) related to Hypothesis 3

YY-MM	R^2	c	γ	sig. of c	sig. of γ
05-Sep	0.732	1.932	0.7	0.006	0.03
05-Oct	0.441	1.505	0.459	0.001	0.007
05-Nov	0.581	1.777	0.505	0	0
05-Dec	0.635	1.897	0.551	0	0
06-Jan	0.703	2.098	0.55	0	0
06-Feb	0.58	2.049	0.506	0	0
06-Mar	0.609	2.113	0.493	0	0
06-Apr	0.648	2.191	0.52	0	0
06-May	0.695	2.299	0.516	0	0
06-Jun	0.681	2.305	0.52	0	0
06-Jul	0.714	2.382	0.528	0	0
06-Aug	0.697	2.429	0.536	0	0
06-Sep	0.645	2.367	0.532	0	0
06-Oct	0.671	2.427	0.536	0	0
06-Nov	0.755	2.57	0.552	0	0
06-Dec	0.68	2.454	0.528	0	0
07-Jan	0.615	2.454	0.5	0	0
07-Feb	0.634	2.487	0.515	0	0
07-Mar	0.629	2.563	0.528	0	0
07-Apr	0.637	2.577	0.525	0	0
07-May	0.604	2.578	0.521	0	0
average	0.647	2.260	0.530	0.000	0.002

5. Discussion

Scale-free Web2.0 service network

Regarding the structure of the network, Web2.0 services and Mashups are expected to evolve obeying the preferential attachment rule and the power law. An implication of a scale-free network is that a node can reach others efficiently through a few hubs. These efficient connections become clear as the network size increases. Each Web2.0 service is involved in a variety of services provided by different companies. The small world phenomenon of Web2.0 services indirectly shows that Web2.0 evolved due to combination of many services by some hubs such as Google Maps and Flickr. These key nodes indicate that creating Web2.0 Mashups follow a trend. For example, one of the current Mashup trends is searching images (Flickr) and video clips (You Tube) on a map (Google Maps). The trend indirectly proves that Web2.0 services evolve systematically which is a desirable evolution pattern. A variety of Web2.0 services created on the trend reflects User's demand.

In view of technological fragility, a heterogeneous structure may involve irrationality (Tu, 2000). From a technological perspective, one sees that a scale-free Web2.0 service network contains structural fragility because many services depend on a few Web2.0 services. This architecture requires a stable operation of Web2.0 service providers, especially key players. For example, almost one-half of all Mashups will fail if the server of Google Maps, a hub, is out of order. If the cost of operation by a few large Web2.0 service providers is smaller than those of a homogenous network, the scale-free network is a desirable outcome.

When considering fair competition, the Web2.0 service network may not be so desirable because a majority of Web2.0 services depends on few hub Web2.0 services. However, the relationships between Web2.0 services are both competitive and complementary. Any hub Web2.0 service needs other Web2.0 services whether they are hubs or not. Even Web2.0 services in the same service category need each other. For example, the Web2.0 Mashup ACME GeoRSS Map Viewer utilises both Google Maps and Yahoo! Maps which are in the mapping category. We conclude that heterogeneity of degree distribution contributes to the progress of the system in which a few Web2.0 services lead and a majority of Web2.0 services follow complementarily.

The low level exponent in the preferential attachment rule and the scale-free network presents an interesting issue. In prior research, generally, a linear preferential equation led to the scale-free network with nearly $2 < \gamma < 3$ (Barabási *et al*., 2001; Fu et al., 2008; Krapivsky *et al*., 2000). However, our results show $\alpha = 0.49$ for Hypothesis 1 and $\gamma = 0.53$ for Hypothesis 3. This low exponent of the scale-free network appears in other studies as well. The exponent in the page network of Wikipedia is roughly smaller than 2 though the network seems to be scale-free (Hendler et al., 2008). For the tag network of Flickr data, the exponent was smaller than 1 though the network seems to be scale-free (Angus et al., 2008). This unusually low exponent should be investigated since it says that the evolution of the Web2.0 service network may have some additional mechanisms impacting the building of a scale-free network.

Ranking of top Web2.0 services

Despite of the small initial variations, the preferential attachment rule tends to widen the distribution inequality and then keeps the ranking of centrality from changing. In the Web2.0 service network, Web2.0 services ranking in the top five with regard to accumulated degree centrality show this tendency (Table IV). The top five rankings are invariant in the study period; Google Maps maintains the top position and only eight other Web2.0 services occupy the top five spots. Among them, delicious, Flickr, and Amazon eCommerce entered the top five ranking 22, 20, and 19 times respectively during the study period. If the ranking had changed randomly, then 105 Web2.0 services could ideally have occupied the top five spots in the study period. The ranking of Amazon eCommerce dropped from the top two between October 2005 and February 2006 to the top three between March 2006 and May 2007. The ranking of Flickr showed an increasing tendency in the initial period and maintained second place from March 2006 to the end of the study period. This implies that Web2.0 service linkages in the Web2.0 service network may depend on a variety of factors, such as quality improvement of services due to Web2.0 service providers' effort, and trend changes due to market context, as well as the classic preferential-attachment rule caused by visibility and network externality. The interplay of multiple factors induces a smooth change under a stable structure.

The position of Google Maps at the top spot is peculiar. Considering the advantage of the first mover, Google Maps should follow Amazon eCommerce because Amazon released its Web2.0 services in 2003 and Google Maps released its Web2.0 services in June 2005 (Roush, 2005). This peculiarity can be explained by users who started using geographic searches, or "browser for the earth," instead of keyword searchers (Roush, 2005, p. 56). This phenomenon shows that the Web2.0 service network reflects changes in market contexts. Mashups made with Web2.0 services with open APIs encourage the combination of user's innovative resources with excellent Web-service functions and data, such as maps, to yield rich innovation in a variety of contents (Rouse *et al*., 2007). Such creativity is the realisation of a network of inventive minds meeting in cyberspace (DeBresson and Amesse, 1991; Freeman, 1991).

Table IV. Top 5 rankings of accumulated degree centrality

Year	Ranking of degree centrality				
	1	2	3	4	5
Sep-05	Google Maps	Yahoo Maps	delicious.com	Microsoft Virtual Earth	Flickr
Oct-05	Google Maps	Amazon eCommerce	delicious.com	Yahoo Maps	Technorati
Nov-05	Google Maps	Amazon eCommerce	delicious.com	Yahoo Maps	Flickr
Dec-05	Google Maps	Amazon eCommerce	delicious.com	Flickr	Yahoo Maps
Jan-06	Google Maps	Amazon eCommerce	Flickr	delicious.co m	Yahoo Maps
Feb-06	Google	Amazon	Flickr	delicious.co	Yahoo Maps

	Maps	eCommerce		m	
Mar-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Maps
Apr-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
May-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Jun-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Jul-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Aug-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Sep-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Oct-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Nov-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	Yahoo Search
Dec-06	Google Maps	Flickr	Amazon eCommerce	delicious.com	YouTube
Jan-07	Google Maps	Flickr	Amazon eCommerce	delicious.com	YouTube
Feb-07	Google Maps	Flickr	Amazon eCommerce	delicious.com	YouTube
Mar-07	Google Maps	Flickr	Amazon eCommerce	You Tube	delicious.com
Apr-07	Google Maps	Flickr	Amazon eCommerce	You Tube	delicious.com
May-07	Google Maps	Flickr	Amazon eCommerce	You Tube	delicious.com

6. Conclusion

In this paper, the structure of the Web2.0 service network and the rules of its evolution were analyzed. The results suggested that the structure evolves to a scale-free network following the preferential attachment rule. However, the values of the exponents in our results differ from those in typical preferential attachment and scale-free systems. A network with low exponents, such as ours, is likely to fluctuate due to changes in external contexts.

The considerations suggest further studies in this research. First, several evaluations should be conducted for completely establishing the model. Thes evaluations should deal with time correlation between the introduction of Web2.0 services and Mashups, cumulative probability for removing noise in low probability scenarios, and the preferences categorised by acquaintances (Davidsen *et al.*, 2002; Newman, 2001; Štefančić and Zlatić, 2005). Finally, a qualitative analysis is necessary. So far, this research focused on the quantitative analysis (especially, degree centrality) to explain the network's self-organisation. The qualitative analysis is needed to determine which element impacts on the interconnection of nodes and whether the network is open.

References

Albert, R. and Barabási, A.-L. (2002), "Statistical mechanics of complex networks", *Review of Modern Physics*, Vol. 74 No. 1, pp. 47-97.

Albert, R., Jeong, H. and Barabási, A.-L. (2000), "Error and attack tolerance of complex networks", *Nature*, Vol. 406 No. 6794, pp. 378-82.

Angus, E., Thelwall, M. and Stuart, D. (2008), "General patterns of tag usage among university groups in Flickr", *Online Information Review*, Vol. 32 No. 1, pp. 89-101.

Barabási, A.-L. and Albert, R. (1999), "Emergence of scaling in random networks", *Science*, Vol. 286, pp. 509-12.

Barabási, A.-L., Jeong, H., Néda, Z., Ravasz, E., Schubert, A. and Vicsek, T. (2001), "Evolution of the social network of scientific collaborations", [online], available at arXiv:cond-mat/0104162v1 (accessed 1 February 2008).

Barabási, A.-L. (2003), *Linked: How Everything is Connected to Everything Else and What it Means for Business, Science, and Everyday Life*, Plume Books, New York, NY.

Brass, D.J. (1984), "Being in the right place: A structural analysis of individual influence in an organization", *Administrative Science Quarterly*, Vol. 29 No. 4, pp. 518-39.

Brown, P. and Lauder, H. (2000), "Human capital, social capital, and collective intelligence", in Baron, S., Field, J. and Schuller, T. (Eds.), *Social Capital: Critical Perspective*, Oxford University Press, New York, NY, pp. 226-42.

Davidsen, J., Ebel, H. and Bornholdt, S. (2002), "Emergence of a small world from local interactions: Modeling acquaintance networks", *Physical Review Letters*, Vol. 88 No. 12, pp. 12701-4.

DeBresson, C. and Amesse, F. (1991), "Networks of innovators: A review and introduction to the issue", *Research Policy*, Vol. 20 No. 5, pp. 363-79.

Dorogovtsev, S.N., Mendes, J.F.F. and Samukhin, A.N. (2000), "Structure of growing networks with preferential linking", *Physical Review Letters*, Vol. 85 No. 21, pp. 4633-6.

Eijkman, H. (2008) "Web2.0 as a non-foundational network-centric learning space", *Campus-Wide Information Systems*, Vol. 25 No. 2, pp.93-104.

Everard, A. and Henry, R. (2002), "A Social network analysis of interlocked directorates in electronic commerce firms", *Electronic Commerce Research and Applications*, Vol. 1, pp. 225-34.

Floyd, I.R., Jones, M.C., Rathi, D. and Twidale, M.B. (2007), "Web mash-ups and patchwork prototyping: User-driven technological innovation with Web2.0 and open source software", *The 40th Hawaii International Conference on System science*, pp. 86c.

Freeman, C. (1991), "Network of innovators: A synthesis of research issues", *Research Policy*, Vol. 20 No. 5, pp. 499-514.

Fu, F., Liu, L. and Wang, L. (2008) "Empirical analysis of online social networks in the age of Web2.0", *Physica A*, Vol. 387 No. 2-3, pp. 675-84.

Hendler, J., Shadbolt, N., Hall, W., Berners-Lee, T. and Weitzner, D. (2008), "Web science: An interdisciplinary approach to understanding the Web," Communications of the ACM, Vol. 51 No. 7, pp. 60-9.

Hołyst, J.A., Fronczak, A. and Fronczak, P. (2004), "Supremacy distribution in evolving networks", *Physical Review E*, Vol. 70, pp. 046119-5.

Huberman, B.A. and Adamic, L.A. (1999), “Growth dynamics of the World-Wide Web”, *Nature*, Vol. 401 No. 6749, pp. 131-2.
Jeong, H., Néda, Z. and Barabási, A.-L., “Measuring preferential attachment for evolving networks”, [online], available at arXiv:cond-mat/0104131v1 (accessed 1 February 2008).
Kapetanios, E. (2008), “Quo Vadis computer science: From Turing to personal computer, personal content and collective intelligence”, *Data & Knowledge Engineering*, Vol. 67 No. 2, pp. 286-92.
Korfiatis, N.T., Poulos, M. and Bokos, G. (2006), “Evaluating authoritative sources using social networks: an insight from Wikipedia”, *Online Information Review*, Vol. 30 No. 3, pp. 252-62.
Krapivsky, P.L., Redner, S. and Leyvraz, F. (2000), “Connectivity of growing random networks”, *Physical Review Letters*, Vol. 85 No. 21, pp. 4629-32.
Kujawski, B., Hołyst, J., Rodgers, G. J. (2007), “Growing trees in internet news groups and forums”, *Physical Review E*, Vol. 76 No. 3, pp. 036103-8.
Lai, L.S.L. and Turban, E. (2008) “Groups formation and operations in the Web2.0 environment and social networks”, *Group Decision and negotiation*, Vol. 17 No. 5, pp. 387-402.
Monsuur, H. (2007) “Stable and emergent network topologies: A structural approach”, *European Journal of Operational Research*, Vol. 183 No. 1, pp. 432-41.

Newman, M.E.J. (2001), “Clustering and preferential attachment in growing networks”, *Physical Review E*, Vol. 64, pp. 025102-4.
O’Reilly, T. (2007), “What is Web2.0: Design patterns and business models for the next generation of software”, *Communications & Strategies*, Vol. 65 No. 1, pp. 17-37.
Park, K., Lai, Y.-C. and Ye, N. (2005), “Self-organized scale-free networks”, *Physical Review E*, Vol. 72 No. 2, pp. 026131-5.
Rodan, S. (2008) “Organizational learning: effects of (network) structure and (individual) strategy”, *Computational and Mathematical Organization Theory*, Vol. 14 No. 3, pp. 222-47.
Rouse, L.J., Bergeron, S.J. and Harris, T.M. (2007), “Participating in the geospatial web: Collaborative mapping, social networks and participatory GIS”, in Scharl, A. and Tochtermann, K. (Eds.), *The Geospatial Web: How Geobrowsers, Social Software and the Web2.0 are Shaping the Network Society*, Springer, New York, pp. 153-8.
Roush, W. (2005), “Killer maps”, *Technology Review*, October, pp. 54-60.
Schnegg, M. and Stauffer, D. (2007) “Dynamics of networks and opinions”, *International Journal of Bifurcation and Chaos*, Vol. 17 No. 7, pp.2399-409.
Smart, P., Bessant, J. and Gupta, A. (2007) “Towards technological rules for designing innovation networks: A dynamic capabilities view”, *International Journal of Operations & Production Management*, Vol. 27 No. 10, pp. 1069-92.
Štefančić, H., Zlatić, V. (2005), “’Winner takes it all’: Strongest node rule for evolution of scale-free networks”, *Physical Review E*, Vol. 72 No. 3, pp. 036105-6.
Tu, Y. (2000), “How robust is the Internet?”, *Nature*, Vol. 406 No. 6794, p. 353.
Valverde, S. and Solé, R.V. (2007) “Self-organization versus hierarchy in open-source social networks”, *Physical Review E*, Vol. 76 No. 4, pp. 046118.
von Hippel, E. (2001), “Innovation by user communities: Learning from open-source

software", *MIT Sloan Management Review*, Vol. 42 No. 4, pp. 82-6.
Wang, F. and Sun, Y. (2008) "Self-organizing peer-to-peer social networks", *Computational Intelligence*, Vol.24 No.3, pp. 213-33.
Wasserman, S., Faust, K. (1994), *Social Network Analysis: Methods and Applications*. Cambridge University Press, New York, NY.
Watts, D. J., Strogatz, S. H. (1998), "Collective dynamics of 'Small-World' networks", *Nature*. Vol. 393, pp. 440-2.
Weiss, A. (2005), "The power of collective intelligence", *Networker*, Vol. 9 No. 3, pp. 16-23.
Xu, J., Christley, S. and Madey, G. (2006), ":Collective dynamics of 'small-world' networks", in Bitzer, J. and Schroder, P.J.H. (Eds.), *The Economics of Open Source Software Development*, pp. 247-69.
Zammetti, F. W. (2007), *Practical Javascript, DOM Scripting, and Ajax Projects*. Springer-Verlag, New York, NY.

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