Classification of Hyperlink Networks by Multivariate Analysis of Network Indicators: The Case of Japanese Public Libraries

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Abstract
In this study, we classified 47 in-prefecture hyperlink networks formed by the Web pages of Japanese public libraries by applying multivariate analysis to network indicators, and clarified the characteristics of the networks. Our method provides a new way of classifying networks and examining the services of public libraries. We selected nine network indicators representing five aspects of networks: subgroups, position of each node, distance, clustering and degree distribution. We carried out two multivariate analyses of these indicators: principal component analysis and cluster analysis. The results indicate that the position of each node and degree distribution are the aspects that affect the classification most strongly. The in-prefecture networks can be classified into three types: (1) those that have only weak connections; (2) those that have many libraries and only one central library; and (3) those that have many links which are centralized in not one but some libraries. This indicates that in some in-prefecture networks municipal libraries as well as prefectural libraries play a central role.

Introduction
In this study, we classified the in-prefecture hyperlink networks formed by the Web pages of Japanese public libraries by applying multivariate analysis to network indicators representing five different aspects of networks, and clarified the characteristics of the networks.

Recently, webometrics has become more and more important as the Internet has become an increasingly essential part of our lives. In the world of the Web, links are regarded as particularly important and have been the subject of many studies (Thelwall, 2004), because they are the sole means of connecting individual Web pages, making them visible within the overall Web universe, and reflecting their importance.

For public libraries, the importance of the Web and hyperlinks is increasing as well, for two main reasons: (i) the growth of electronic information on the Web has made libraries recognize that they cannot confine themselves to dealing only with traditional print media; and (ii) now that the Web is commonly used as a means of ordinary communication, it not only reflects, but also has the potential to change, pre-existing relations among libraries. The major mission of public libraries is transmitting information to users, and networks formed by cooperation among libraries are essential because users need much more information than any one library can provide on its own. By observing library networks, it is possible to clarify characteristics of the services provided by libraries that would not be revealed by researching each library as a separate unit. Because public libraries are official information agencies, are responsible as such for the hyperlinks they provide via their Web pages (Goto, 2002), and have no commercial motivation for linking to each other's Web pages, analyzing the Web

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page links of public libraries can reveal new information about the relations between these libraries, the services that they provide through their networks in the Web era, and the hyperlink structure of their Web pages, which has been rarely researched.

When we attempt to clarify the basic characteristics of a social system made up of different but interconnected parts, it is essential to look at the system not only in terms of its individual components, but also in terms of the relations between them (Kanamitsu, 2003; Wasserman & Faust, 1994). Studies have identified various characteristics of the hyperlink structure of Web pages (Albert et al. 1999; Thelwall & Zuccala, 2008). Research has also been carried out into the characteristics of the hyperlink structure of public library Web pages. Kawamura et al. (2007) observed the hyperlink network formed by the Web pages of Japanese public libraries, and found that prefectural-level libraries play an important role in the formation of the network, but analyzed only the in-prefecture networks formed by particular links and from a limited perspective. This study fills this gap by examining the hyperlink network in each prefecture in detail, and clarifying the characteristics of these networks.

To analyze a number of networks, it is necessary to classify them, but a methodology for classifying networks has not been adequately developed. Indicators that reveal the characteristics of a network from a single perspective have been developed, but the classification of networks on the basis of a combination of many characteristics has rarely been attempted. Statistical analysis methods such as Quadratic Assignment Procedure (QAP) and Multiple Regression Quadratic Assignment Procedure (MRQAP) (Baker & Hubert, 1981; Krackhardt, 1988; Borgatti et al., 1999) can be used to compare and classify networks. Holmberg & Thelawall (2007) showed by means of QAP that interlinking between local government bodies in Finland is strongly related to geographical proximity. Tang & Thelwall (2003) used QAP to analyze the impact of geographic distance on the Web-link counts of academic Web sites from three different disciplines. However, these methods were only used to hypothesis test and did not attempt to explain the differences and similarities between the networks on the basis of network characteristics. To classify networks in a more fine-grained way, it is necessary to observe them from a variety of perspectives. We therefore carried out multivariate analysis of network indicators that represent several different aspects of networks.

Against this background, this study addresses the following questions:

1. How can the in-prefecture hyperlink networks of Japanese public libraries be classified using multivariate analysis of a variety of network indicators representing different aspects of networks?
2. What does this analysis show us about the characteristics of library networks?

By answering these questions, we can contribute to developing effective webometric techniques for network classification, and to deepening our understanding of the Web structure and services of Japanese public libraries.

Network studies

Five different aspects of networks

Network studies can be divided into two basic types: social network studies and complex network studies. Social network studies focus on the patterns of connection between people to understand the functioning of human society. Many studies of this type have been conducted since the 1930s (Freeman, 2004; Wasserman & Faust, 1994). Kanamitsu (2003) identified three approaches to researching networks in social network studies: the top-down approach, the bottom-up approach and the linkage approach. The top-down approach focuses on what subgroups are formed and the bottom-up approach focuses on the position of each node. The linkage approach focuses on the connectivity of the affiliation and the actor, but it is used only for examining bipartite graphs, which are different from the hyperlink network researched in this study.

Social network studies dominated the field for many years, but the situation changed with the emergence of complex network studies, which proposed two new types of network model: small world networks, which have a high tendency to cluster with short path lengths (Watts & Strogatz, 1998), and scale-free networks, in which large nodes are likely to be selected as the target of links (Barabási & Albert, 1999). These models focus on clustering, distance, and degree distribution of networks. They were followed by many studies on the mathematical, statistical, and social aspects of network structures. Albert & Barabási (2002), Newman (2003), and Borner et al. (2007) have conducted reviews in this field.

To summarize, these studies researched the characteristics of networks by focusing on five different aspects of networks: subgroups, position of each node, clustering, distance and degree distribution.

Hyperlink studies

Following the success of complex network studies, many studies on the link structure of the Web have been conducted. They first focused on its overall structure. Albert et al. (1999) found that the network structure formed by Web page links has both small world and scale-free network characteristics, and calculated that the Web was composed of 8 billion nodes, with a diameter of 19. Broder et al. (2000) calculated that the average path length in their data set of 500 million nodes was 16. In response to the growth of the Web, studies on the link structure of particular networks have increased. Thelwall & Wilkinson (2003) examined the link structure of academic Web pages in Australia, New Zealand and England and discovered that their degree distribution is like the Pennock, Flake, Lawrence, Glover, and Giles (PFLGG) models (Pennock et al., 2002), which do not adhere to a perfect power law.

Research in the field of social science has also been conducted. Park et al. (2002) examined the affiliate networks of private companies by analyzing the subgroups that best represent measured relations of nodes and the degree centrality of each node, which indicates how central a node is in a network from the number of edges, and discovered that finance companies occupied the central position in the networks. Thelwall & Zuccala (2008) examined the link structure of academic Web pages in Europe by counting links and discovered that the larger and richer countries such as the UK and Germany dominated the linking and the network clearly reflected geopolitical influence.

However, studies have rarely focused simultaneously on all of the five aspects described above. In this study, we focused on all five aspects when classifying the hyperlink networks, which allowed us to achieve a more fine-grained classification and grasp the characteristics of the networks in greater detail.

Japanese public libraries: services and networks

ILL network

In Japan, public libraries are established by local public agencies. Local public agencies exist at two administrative levels: prefectural and municipal. Each prefecture is made up of a number of municipalities. As of January 21st, 2007, there are 1816 municipalities (Ministry of Internal Affairs and Communications, 2007), divided into 47 prefectures. All prefectures and about 70 percent of municipalities have their own public libraries, and all prefectural libraries and about 70 percent of municipal libraries have their own Web pages (Japan Library Association, 2006).

From the 1970s, Japanese public libraries focused their services on the circulation of books (Maekawa & Ishii, 2006). This led to a rapid increase in library use but also created the impression that the circulation of books is the most important service provided by public libraries. This perception still exists and the number of books circulated is still the most popular standard for evaluating public libraries. It also affected cooperation among them, with the ILL (inter-library loan) system (which facilitates the circulation of books between public libraries) becoming the most popular and established network (referred to henceforth as “ILL network”).

The administrative unit within which a library is located has a strong influence on the role it plays in the formation of the ILL network for providing resources such as books and information efficiently. Standards set by the Japanese government for the establishment and operation of public libraries (Ministry of Education, Culture, Sports, Science and Technology, 2001) emphasize in-prefecture cooperation. According to these standards, municipal libraries should actively cooperate in the mutual exploitation of resources between libraries, and the networks between prefectural libraries and the municipal libraries in each prefecture are considered to be the basic unit of this cooperation. Prefectural libraries in particular should function not only as large-scale libraries but also as back-up libraries for municipal libraries, and should lead the liaison and coordination of the in-prefecture network. Prefectural libraries are also expected to cooperate with other libraries, including other prefectural libraries. Through this structure, a library is reachable from others by small steps. This demonstrates that, in the ILL network, libraries which are in the same prefecture are strongly connected and prefectural libraries occupy the central position and make the network efficient.

The above points can be summarized as followed: Japanese public libraries can be divided into two types based on administrative unit (prefectural and municipal); the ILL network is affected by prefecture; and prefectural libraries act as mediators in the network.

Hyperlink network

With regard to the hyperlink structure of the Web pages of Japanese public libraries, some fundamental research has been conducted to date. Goto (2002) found that all prefectural libraries linked to libraries in the same prefecture and 40 percent of them linked to libraries in other prefectures. Kitaumi & Matsui (2000) examined the Web pages of Japanese public libraries from various viewpoints, including links. They clarified that 63 percent of libraries linked to higher-level bodies in the administrative structure to which the libraries belonged, e.g. local agencies, 13 percent linked to other libraries, many municipal libraries linked to prefectural libraries, and 40 percent of libraries did not link to other Web pages. Kawamura et al. (2007) analyzed the hyperlink network formed by the Web pages of Japanese public libraries for the first time and demonstrated that it has the same tendencies as the ILL network. They also classified the in-prefecture network into three types: those with hubs and cliques, those with hubs but no clique, and those with neither a hub nor a clique. All the major hubs were prefectural libraries. However, they only researched the networks from the perspective of hubs and cliques, and the networks observed are formed by only the reciprocal edges. In this study, we examined the networks formed by all the edges from all five perspectives in order to provide a more detailed analysis.

Data

Table 1. Basic data on the Web pages of the libraries

Web pages	1345
Web pages of branch libraries	80
Mirror sites	4
Prefectural or municipal libraries	1261
Libraries which don't use an original domain	12

Table 2. Size of network of prefectures

Size of network	0~20	20~40	40~60	60~80	80~100	100~120
Number of prefectures	22	18	5	1	0	1

The basic data we used in this study is summarized in Table 1. Firstly, 1,345 Web pages were chosen from the public library links listed in "Japanese Library Links" (Japan Library Association, 2007), which provides links to the Web pages of all libraries in Japan. Secondly, we divided the pages into two groups: prefectural library Web pages and municipal library Web pages. Eighty of the pages were the pages of branch libraries of prefectural or municipal libraries. Because we focus on the distinction between prefectural and municipal libraries in this study, we regarded the links from and to these branch libraries as equivalent to those from and to their main library. In addition to this, we investigated whether prefectural libraries, which serve a large community of users and whose Web sites are accessed frequently, had mirror sites. We discovered that four prefectural libraries[i] had several mirror sites. We regarded the links from and to these mirror sites as equivalent to those from and to these libraries. As a result, the number of libraries represented in our data totaled 1261.

Thirdly, we downloaded the data from the Web pages. HTML format Web pages were downloaded automatically using wget. However, because wget can collect only those links written with the use of < a > tags, which some ASP or Java script formats do not use, those in or including such formats were downloaded manually. Fourthly, we obtained the link data by distilling the <a> tags of the HTML pages automatically and by checking the non-HTML pages manually. As the Web pages of Japanese public libraries are often part of the Web site of the local agency to which the library belongs, and some links to such libraries are simply links to the top page of the local agency, we considered that Library A provided a link to Library B when the domain of the URL in the <a> tag of the Web page of A was identical to that of B. We could not use this method, however, to correctly collect links to Web pages whose domain is one that is widely used or which overlaps with those of other libraries. We therefore manually confirmed whether links to those domains were actually links to the same public library and found 12 domains were used by other Web pages[ii]. We conducted this work from January 21st to 23rd, 2007.

Finally, we extracted 47 in-prefecture networks from the overall hyper network. The size of each in-prefecture network is summarized in Table 2. While the size of almost all networks is under 40, there is also a network whose size is over 100. The average of edges is 91.76 per network and 3.13 per node.

Method of classification

Network indicators

In this study, we selected the following nine network indicators:

(1) size of the network;
(2) density (the actual number of edges divided by the possible number of edges);
(3) size of the largest clique (a group of more than two nodes in which all nodes are connected to all other nodes, calculated without reference to the direction of edges);
(4) indegree centralization (the actual sum of the difference of indegree between any node and the node with the largest indegree, divided by the maximum possible sum [Freeman, 1979]) ;
(5) outdegree centralization;
(6) average path length (the average length of the shortest paths between all pairs of nodes that are reachable);
(7) clustering coefficient. This is calculated in the following way (Watts & Strogatz, 1998). First, a selected node *i* that has more than two nodes in the network is focused on. If the nearest neighbors of the node are part of a complete subgraph, there would be *Gi* edges between them. The ratio between them and the number of edges *Ei* that actually exist between these nodes gives the value of cluster coefficient of the node *i* (*Ci*). The cluster coefficient of the whole network is the average of the cluster coefficients of all *Ci;*
(8) standard deviation of the normalized indegree (the actual number of edges divided by the possible number of edges); and
(9) standard deviation of the normalized outdegree.

(1) and (2) are fundamental indicators, showing the number of nodes and the number of edges. As the number of edges is greatly dependent on the size of the network, we used it in the form of density. The size of the network indicates the number of libraries which have Web pages, and density indicates the number of links in the network. (3) was selected in order to analyze the networks from the perspective of subgroups. The clique is the subgroup that is the most strongly interconnected and the most important in the network. The largest clique indicates the size of the largest group of libraries that are strongly connected with one another in the network. In order to analyze the networks from the perspective of the position of each node, we selected (4) and (5), and focused on the central node in each network, which is one of the most frequently researched areas in social network studies (Kanamitsu, 2003). (4) and (5) show the centrality of the network and the tendency of the node that has the most edges to be more central than any other nodes in the network. They indicate how important the library that occupies the most central position is as a mediator between libraries. In order to analyze the networks from the perspective of distance, we selected (6). This indicates the efficiency of the overall network and how efficiently libraries cooperate with each other in the network. In order to analyze the networks from the perspective of clustering, we selected (7). This represents the tendency to form a group of libraries which are strongly connected to each other. In order to analyze the networks from the perspective of degree distribution of nodes, (8) and (9) were selected. Because, as noted above, the number of edges is dependent on the size of the network, they were normalized. They indicate the inequality of links among

libraries in the network. We calculated all the above indicators using UCI-NET (Borgatti et al., 1999).

Multivariate analyses

In order to analyze these indicators, we carried out two multivariate analyses: principal component analysis with covariance matrix of the features, and cluster analysis with Manhattan distance and Ward's method. Principal component analysis, which has less ambiguity of explanation, was first carried out to view the classification of the networks and how indicators and perspectives affect the classification. In order to confirm the results of the principal component analysis, we carried out hierarchical cluster analysis. As we chose to adopt an exploratory approach to classifying the network, it is useful to confirm the results by several multivariate analysis methods. As the results of cluster analysis depend to a significant extent on the distance and clustering method, we selected the distance and the method reproducing the classification produced by the scatter plot of principal component analysis.

Result

Table 3. The principal component scores of the first and the second principal components

	PC1	PC2
Density	0.51	-0.13
Size of network	-0.18	0.42
Maximum clique size	0.35	0.28
Outdegree centralization	-0.01	0.47
Indegree centralization	0.21	0.37
Average path length	-0.14	0.50
Clustering coefficient	0.31	0.33
Standard deviation of normalized outdegree	0.46	-0.09
Standard deviation of normalized indegree	0.46	-0.05

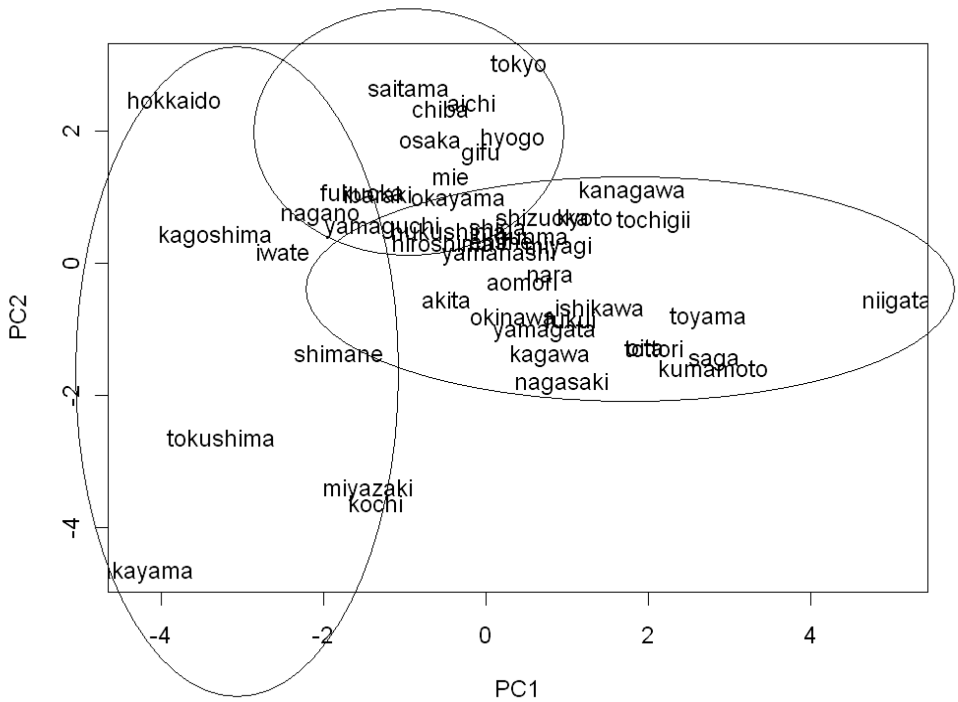

Figure 1. Scatter plot showing the first two principal components

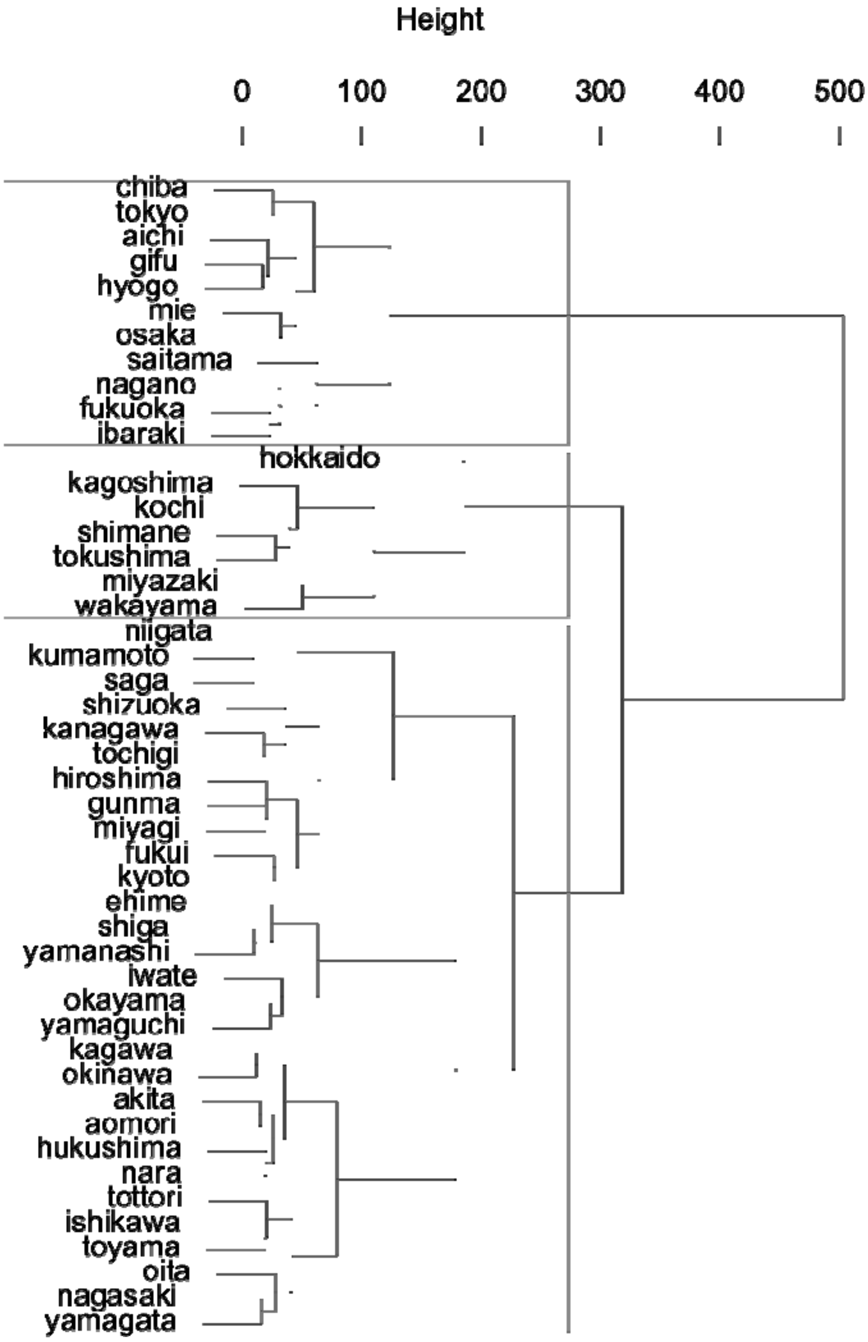

Figure 2. Dendrogram constructed using cluster analysis

As the proportion of variance accounted for by the first principal component was 37.40% and the cumulative proportion of variances accounted for by the first two principal components was 67.70%, we focused on these two principal components. Figure 1 is the scatter plot of principal component analysis. The principal component scores of the first principal component and the second principal component are summarized in Table 3. First, we analyzed the first principal component. The indicators whose score ranked in the top three are density, standard deviation of normalized outdegree and standard deviation of normalized indegree. This indicates that the higher the density is, the larger the difference in the normalized number of edges among nodes is. Because the principal component score of degree centralization, especially outdegree centralization, is not high, the larger difference in the number of edges indicates that not one but some nodes have many edges. We concluded that the first principal component shows the tendency to have many edges most of which are linked to several central nodes in the network.

Next, we analyzed the second principal component. The indicators whose score ranked in the top three are average path length, size of network and outdegree centralization. In most in-prefecture networks, we observed, average path length is less than two and when the geodesic between two nodes includes other nodes, including the central node, average path length is higher. We concluded that the average path length is affected by outdegree centralization and the second principal component shows the tendency for there to be many nodes with one node in the central position, especially as a provider of connections.

The dendrogram constructed by the cluster is shown in Figure 2. We divided the dendrogram into three parts, as shown by the boxes in Figure 2. The same grouping of the networks can also be seen in Figure 1. The top cluster of the dendrogram corresponds to the top grouping in Figure 1. This suggests that in these prefectures, there are many libraries with Web pages and libraries are connected to each other through a particular central library. A typical network is Chiba, shown in Figure 3. The locations of the nodes and the distances between the nodes in the figure were calculated using the Kamada-Kawai spring-based algorithm (Kamada & Kawai, 1989), via Pajek (Batagelj & Mrvar, 2003). The middle cluster of the dendrogram corresponds to the left-hand grouping in Figure 1. This suggests that nodes in these networks have only a weak connection. The bottom cluster of the dendrogram corresponds to the bottom-right grouping in Figure 1. This suggests that there are many links in these networks, and libraries have strong relations without a particular central library, and some nodes have many links. A typical network is Niigata, shown in Figure 4.

The above results show that the in-prefecture networks are classified into three types:

- those that have only weak connections;
- those that have many nodes and only one central node; and
- those that have many links which are centralized in not one but some nodes

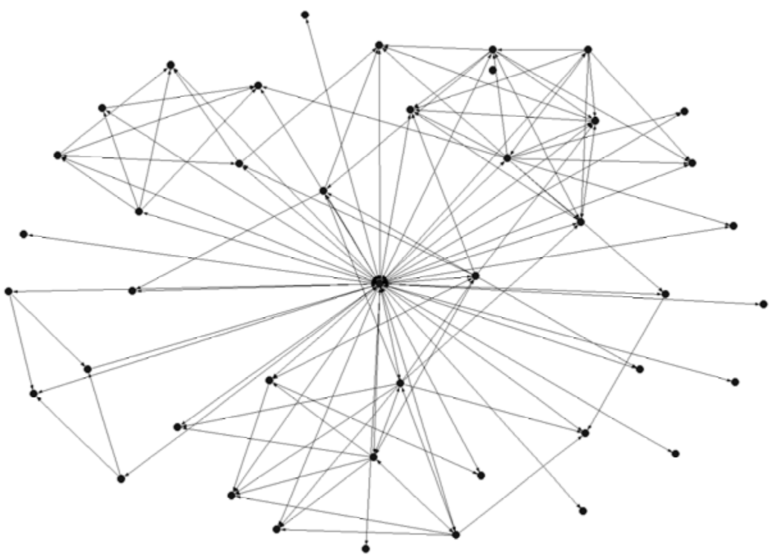

Figure 3. The in-prefecture network of Chiba

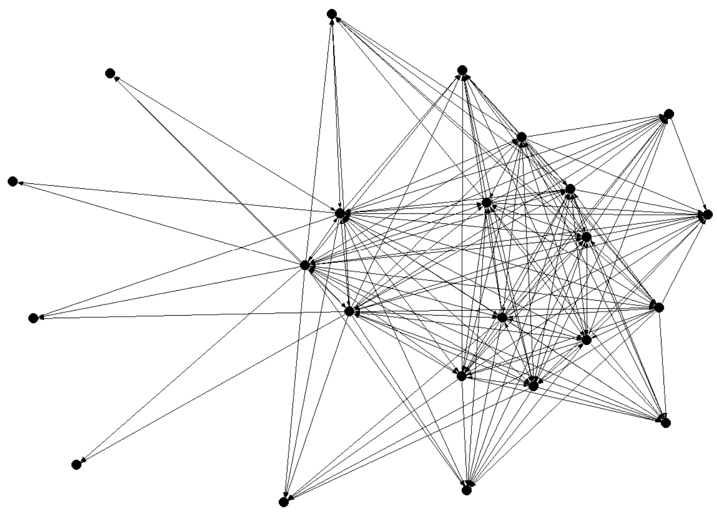

Figure 4. The in-prefecture network of Niigata

Discussion

Firstly, what can be said about the relation between the five aspects of networks and the above classification? The results of the analysis of the first principal component show the strong effect of degree distribution. The results of the analysis of the second principal component show the strong effect of two aspects, the position of each node and distance. However, as discussed above, average path length is affected by centralization in the in-prefecture networks. From these results, we conclude that degree distribution and the position of each node are the aspects that are most important for classifying the in-prefecture hyperlink networks. Distance is strongly affected by the position of each node. Clustering and subgroups, which were focused on by Kawamura et al. (2007), are not so important in the classification. The networks are characterized not by groups of libraries that are connected to each other, but by the inequality of links among libraries and the role of the library which occupies the most central position as a mediator between libraries.

Next, what can be said about the implications of this classification? Kawamura et al. (2007) found that only prefectural libraries play a central role in the in-prefecture networks. We investigated the prefectural libraries in each in-prefecture network and found that in all networks, these certainly have many links. The classification indicates that some of the in-prefecture networks, such as Chiba, are characterized by the concentration of links in the prefectural library. However, it also indicates that in other in-prefecture networks, such as Niigata, not only prefectural libraries but also some municipal libraries occupy a central position in the network. Such libraries are mediators between libraries in the network along with prefectural libraries and important for analyzing the characteristics of the hyperlink network.

Conclusion

In this study we classified the in-prefecture hyperlink network formed by the Web pages of Japanese public libraries by applying multivariate analysis to nine network indicators. Two of these indicators, network size and number of edges, are fundamental indicators, while the other seven represent five aspects of networks that have been focused on in previous studies, namely:

- subgroups;
- position of each node;

- distance;
- clustering; and
- degree distribution

We carried out two multivariate analyses of these nine indicators: principal component analysis and cluster analysis. The results indicate that the position of each node and degree distribution are important for classifying the in-prefecture hyperlink networks. The in-prefecture networks can be classified into three types:

- those that have only weak connections;
- those that have many libraries and only one central library; and
- those that have many links which are centralized in not one but some libraries.

This indicates that the in-prefecture hyperlink networks have different characteristics from those shown in previous studies, which found that only prefectural libraries play a central role. Our results show that in some cases other municipal libraries also play an important role.

This study investigated part of the structure of the Web – the hyperlink network formed by the Web pages of Japanese public libraries – by analyzing five different aspects of that network and revealing its characteristics in greater detail. We showed that some municipal libraries occupy important positions in the service network of Japanese public libraries, which indicates that the liaison and coordination of the in-prefecture network may be led not only by prefectural libraries but also some municipal libraries. We also showed that our method is applicable for the classification of networks.

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