Mathematical Sciences Letters
An International Journal

http://dx.doi.org/10.12785/msl/040313

Bounds on A Parameter for Ontology Application

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Received: 22 Aug. 2014, Revised: 13 May 2015, Accepted: 12 Jun. 2015
Published online: 1 Sep. 2015

Abstract: Ontology, as a model of knowledge store and represent, has widely used biology science, chemical science and social science. In this paper, by virtue of the ontology graph structure analysis, we present several bounds for the ontology parameter which used to measure the characteristics of ontology. The results achieved in this article illustrate the promising application prospects for ontology algorithms.

Keywords: Ontology, similarity measure, ontology mapping

1 Introduction

The terminology "Ontology" comes from philosophy, and used to describe the essence of things. Ontology had introduced in computer science as a shared conceptual model. Now, it has been applied in image retrieval, knowledge management, information retrieval search extension, information systems, collaboration, and intelligent information integration. Ontology, as an effective concept semantic model, has been widely employed in many other fields such as social science (for instance, see Bouzeghoub et al., [1]), biology medicine (for instance, see Hu et al., [2]), and geography science (for instance, see Fonseca et al., [3]).

Each vertex on an ontology graph represents a concept, each edge on an ontology graph represents a relationship between two concepts. Let G be an ontology graph corresponding to ontology O, the goal of ontology similarity measure is to approach a similarity function which maps each vertex to a real number. The similarity between two vertices is measured by the difference of their corresponding scores. The aim of ontology mapping is to search the similarity vertices form different ontologies. Hence, the problem of ontology mapping can be transformed to ontology similarity measure.

There are some effective technologies for ontology similarity measuring. Wang et al., [4] first proposed that ranking method can be employed in ontology similarity calculation. Huang et al., [5] raised fast ontology algorithm in order to reduce the time complexity of the algorithm. Gao and Liang [6] argued that ontology function can be given by optimizing NDCG measure, and applied such idea in physics education. Gao and Gao [7] obtained the ontology function using the regression approach. In Huang et al., [8] the proposal was getting ontology function based on half transductive ranking. Lan et al., [9] explored the learning theory approach for ontology similarity computation in a setting when the ontology graph is a tree. Using the multi-dividing algorithm in which the vertices divided into k parts correspond to the k classes of rates. The rate values of all classes are decided by experts. Then, a vertex in a rate a has larger value than any vertex in rate b (where $1 \le a < blek$) under ontology function f. Finally, the similarity between two ontology vertices is measured by the difference of two real numbers which they correspond to. Thus, the multi-dividing algorithm is reasonable to learn a score function for an ontology graph with a tree structure. Gao and Shi [10] raise a new ontology algorithm which consider operational cost in the real implement. Gao et al., [11] got an ontology algorithm in terms of diffusion and harmonic analysis on hypergraph.

For theoretical analysis of the ontology algorithms. Gao et al., [12] studied the ontology algorithm form regression point of view. Gao and Xu [13] have studied the uniform stability of multi-dividing ontology algorithm and gave the generalization bounds for stable multi-dividing ontology algorithms. Gao et al., [14] researched the strong and weak stability of multi-dividing

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ontology algorithm. Gao and Xu [15] learned some characteristics for such ontology algorithm. Gao et al., [16] studied the multi-dividing ontology algorithm from a theoretical view. It is highlighted that empirical multi-dividing ontology model can be expressed as conditional linear statistical, and an approximation result is achieved based on projection method. Gao et al., [17] investigated the upper bound and lower bound minimax learning rate are obtained based on low noise assumptions. Gao et al., [18] studied the adaptation procedure for ontology algorithm in multi-dividing setting. Other analysis can refer to [19].

All ontology graphs considered in this paper are finite, loopless, and without multiple edges. Let G be an ontology graph with vertex set $V(G)$ and edge set $E(G)$. For each vertex v, $d(v)$ denote its degree. For each two vertices u and v, $d(u,v)$ denoted as the distance between u and v. The ontology parameter to measure the characteristics of ontology is defined as

$$WW_{\lambda}(G)=\sum_{\{u,v\}\subseteq V(G)}\frac{1}{2}\{d(u,v)^{\lambda}+d(u,v)^{2\lambda}\}.$$

The ontology polynomial is defined by

$$W(G,x)=\sum_{\{u,v\}\subseteq V(G)}x^{d(u,v)}.$$

Several related results on ontology parameter and ontology polynomial can refer to [20], [21], [22], [23], [24] and [25].

In this paper, we determine the minimum ontology parameter of ontology graph with fixed connectivity or edge-connectivity. And, the ontology graph reach the lower bound is presented. At last, we discuss the conclusions for $\lambda<0$.

2 Main results and proofs

In what follows, we denote G be a connected ontology graph with n vertices. It is obvious that the ontology parameter is minimal for any positive real number λ if and only if $G=K_n$, and is maximal for any negative real number λ if and only if $G=K_n$. In both situation, $WW_{\lambda}(G)=\frac{n(n-1)}{2}$. In the following context, we study when a ontology graph with a given vertex or edge-connectivity has minimum ontology parameter, and only consider the situation for $\lambda>0$ in this section.

Theorem 1. *Let G be a k-connected, n-vertex ontology graph, $1\le k\le n-2$, and $\lambda>0$ be a real number. Then*

$$WW_{\lambda}(G)\ge\frac{n(n-1)}{2}+(\frac{2^{\lambda}+4^{\lambda}}{2}-1)(n-k-1).$$

Equality holds if and only if $G\cong K_k\vee(K_1\cup K_{n-k-1})$.

Proof. Let $G_{\min}$ be the ontology graph that among all ontology graphs with n vertices and connectivity k has minimum ontology parameter. According to the fact that the connectivity of $G_{\min}$ is k, there is a vertex-cut $X\subseteq V(G_{\min})$, which satisfies that $|X|=k$.

Let $G_1,G_2,\cdots,G_{\omega}$ be the components of $G_{\min}-X$. Then, we are sure that each of the ontology sub-graphs $G_1,G_2,\cdots,G_{\omega}$ must be complete. Otherwise, if one of them would not be complete, then by adding an edge between two nonadjacent vertices in this ontology sub-graph we would obtain an ontology graph with the same number of vertices and same connectivity, but smaller ontology parameter, a contradiction.

Next, we claim that $\omega=2$. Otherwise, if $\omega>2$, by adding an edge between a vertex from one component and a vertex from another component $G_1,G_2,\cdots,G_{\omega}$, then the resulting ontology graph would still have connectivity k, but its ontology parameter would decrease, a contradiction. Therefore, $G_{\min}-X$ has two components G_1 and G_2. By virtue of a similar discussion, we deduce that any vertex in G_1 and G_2 is adjacent to any vertex in X.

Let n_1 and n_2 be the number of vertices of G_1 and G_2, respectively. Then $n_1+n_2+k=n$ and by direct computation, we obtain

$$\begin{aligned}
&WW_{\lambda}(G_{\min})\\
&=\frac{1}{2}\{\{\frac{n_1(n_1-1)}{2}+\frac{n_2(n_2-1)}{2}+\frac{k(k-1)}{2}+k(n_1+n_2)\\
&\quad+2^{\lambda}n_1n_2\}\\
&\quad+\{\frac{n_1(n_1-1)}{2}+\frac{n_2(n_2-1)}{2}+\frac{k(k-1)}{2}+k(n_1+n_2)\\
&\quad+4^{\lambda}n_1n_2\}\}\\
&=\frac{1}{2}\{\{\frac{n^2}{2}+(k-\frac{1}{2})n+\frac{k(k-1)}{2}+(2^{\lambda}-1)n_1n_2\}\\
&\quad+\{\frac{n^2}{2}+(k-\frac{1}{2})n+\frac{k(k-1)}{2}+(4^{\lambda}-1)n_1n_2\}\}\\
&=\frac{n^2}{2}+(k-\frac{1}{2})n+\frac{k(k-1)}{2}+(\frac{2^{\lambda}+4^{\lambda}}{2}-1)n_1n_2
\end{aligned}$$

which for fixed n and k is minimum for $n_1=1$ or $n_2=1$. This in turn means that $G_{\min}=K_k\vee(K_1\cup K_{n-k-1})$. By directly calculating, we yield

$$\begin{aligned}
WW_{\lambda}(G_{\min})&=\frac{1}{2}\{\{\frac{n(n-1)}{2}+(2^{\lambda}-1)(n-k-1)\}\\
&\quad+\{\frac{n(n-1)}{2}+(4^{\lambda}-1)(n-k-1)\}\}\\
&=\frac{n(n-1)}{2}+(\frac{2^{\lambda}+4^{\lambda}}{2}-1)(n-k-1).
\end{aligned}$$

Hence, we complete the proof. □

Our next result reveals that the edge-connectivity version for Theorem 1 is also established. Here, we don't consider the case of $k=n-1$, since K_n is the only $(n-1)$-edge connected ontology graph.

Theorem 2. *Let G be a k-edge connected, n-vertex ontology graph, $1\le k\le n-2$, and λ be a positive real* *number. Then*

$$WW_\lambda(G) \geq \frac{n(n-1)}{2} + (\frac{2^\lambda + 4^\lambda}{2} - 1)(n-k-1).$$

Equality holds if and only if $G \cong K_k \vee (K_1 \cup K_{n-k-1})$.

Proof. We now denote $G_{\min}$ as the ontology graph that among all ontology graphs with n vertices and edge-connectivity k has minimum ontology parameter. Let X be an edge-cut of $G_{\min}$ with $|X| = k$. Then $G_{\min} - X$ has two components, G_1 and G_2. Both G_1 and G_2 must be complete ontology graphs. Let $|V(G_1)| = n_1$ and $|V(G_2)| = n_2$. Then we have $n_1 + n_2 = n$.

Let S and T be the set of the end-vertices of the edges of X in G_1 and in G_2, respectively. Denote $|V(G_1) - S| = a_1$ and $|V(G_2) - S| = a_2$. There are

$$\frac{n_1(n_1-1)}{2} + \frac{n_2(n_2-1)}{2} + k = |E(G_{\min})|$$

pairs of vertices at distance 1, and a_1a_2 pairs of vertices at distance of 3. All other vertex pairs, i.e.,

$$\frac{n(n-1)}{2} - |E(G_{\min})| - a_1a_2$$

are at distance 2. Therefore,

$$\begin{aligned}
&WW_\lambda(G_{\min}) \\
=\ & \frac{1}{2}\{\{[\frac{n_1(n_1-1)}{2} + \frac{n_2(n_2-1)}{2} + k] + 3^\lambda a_1a_2 \\
&+2^\lambda[\frac{n(n-1)}{2} - |\frac{n_1(n_1-1)}{2} + \frac{n_2(n_2-1)}{2} + k| \\
&-a_1a_2]\} + \{[\frac{n_1(n_1-1)}{2} + \frac{n_2(n_2-1)}{2} + k] + 9^\lambda a_1a_2 \\
&+4^\lambda[\frac{n(n-1)}{2} - |\frac{n_1(n_1-1)}{2} + \frac{n_2(n_2-1)}{2} + k| \\
&-a_1a_2]\}\} \\
=\ & \frac{1}{2}\{\{(2^\lambda - 1)\frac{n(n-1)}{2} - (2^\lambda - 1)k + (2^\lambda - 1)n_1n_2 \\
&+(3^\lambda - 2^\lambda)a_1a_2\} + \{(4^\lambda - 1)\frac{n(n-1)}{2} - (4^\lambda - 1)k \\
&+(4^\lambda - 1)n_1n_2 + (9^\lambda - 4^\lambda)a_1a_2\}\} \\
=\ & (\frac{2^\lambda + 4^\lambda}{2} - 1)\frac{n(n-1)}{2} - (\frac{2^\lambda + 4^\lambda}{2} - 1)k \\
&+(\frac{2^\lambda + 4^\lambda}{2} - 1)n_1n_2 + (\frac{3^\lambda + 9^\lambda - 4^\lambda - 2^\lambda}{2})a_1a_2.
\end{aligned}$$

which for fixed n and k is minimum for $n_1 = 1$, $a_1 = 0$ or $n_2 = 1$, $a_2 = 0$. This, as in the first theorem, implies $G_{\min} = K_k \vee (K_1 \cup K_{n-k-1})$. Hence,

$$WW_\lambda(G) \geq \frac{n(n-1)}{2} + (\frac{2^\lambda + 4^\lambda}{2} - 1)(n-k-1).$$

The desired bound is established. □

Based on the tricks presented in above section, we get the following conclusions concern $\lambda < 0$.

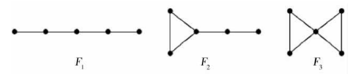

Fig. 1: Fig. 1 The avoiding induced subgraph

Theorem 3. *Let G be a k-connected, n-vertex ontology graph, $1 \leq k \leq n-2$, and $\lambda < 0$ be a real number. Then*

$$WW_\lambda(G) \leq \frac{n(n-1)}{2} + (\frac{2^\lambda + 4^\lambda}{2} - 1)(n-k-1).$$

Equality holds if and only if $G \cong K_k \vee (K_1 \cup K_{n-k-1})$.

Theorem 4. *Let G be a k-edge connected, n-vertex ontology graph, $1 \leq k \leq n-2$, and λ be a negative real number. Then*

$$WW_\lambda(G) \leq \frac{n(n-1)}{2} + (\frac{2^\lambda + 4^\lambda}{2} - 1)(n-k-1).$$

Equality holds if and only if $G \cong K_k \vee (K_1 \cup K_{n-k-1})$.

Theorem 5. *Let G be a connected ontology graph with n vertices and m edges. Let d_i be the degree of v_i. The diameter of G satisfies $diam(G) \leq 2$ and any induced subgraph of G is not isomorphic to F_1, F_2 or F_3 described in Figure 1. Let $L(G)$ be the line graph of G. We have*

$$W(L(G),x) = (\frac{m(m-1)}{2} - m)x^2 + (-m + \frac{1}{2}\sum_{i=1}^{n} d_i^2)x.$$

Proof. The number of vertices of $L(G)$ is m and the number of edges of $L(G)$ is $-m + \frac{1}{2}\sum_{i=1}^{n} d_i^2$.

If $diam(G) \leq 2$, then

$$W(G,x) = (\frac{n(n-1)}{2} - m)x^2 + mx.$$

Since $diam(G) \leq 2$ and G has no F_i, i=1, 2, 3 as its induced subgraph then $diam(L(G)) \leq 2$. Therefore, we deduce

$$W(L(G),x) = (\frac{m(m-1)}{2} - m)x^2 + (-m + \frac{1}{2}\sum_{i=1}^{n} d_i^2)x.$$

Thus, the desired result is obtained. □

Corollary 1. *Let G be a connected r-regular ontology graph with n vertices. Let d_i be the degree of v_i. The diameter of G satisfies $diam(G) \leq 2$ and any induced subgraph of G is not isomorphic to F_1, F_2 or F_3 described in Figure 1. Let $L(G)$ be the line graph of G. We have*

$$W(L(G),x) = \frac{nr}{4}(\frac{nr}{2} - 3)x^2 + (-\frac{nr}{2} + \frac{nr^2}{2})x.$$

Proof. Since G is an r-regular ontology graph with n vertices, the number of edges of G is $m = \frac{nr}{2}$ and $d_i = r$.

By virtue of Theorem 5, we get

$$W(L(G),x) = \frac{nr}{4}(\frac{nr}{2}-3)x^2 + (-\frac{nr}{2}+\frac{nr^2}{2})x.$$

Theorem 6. *If ontology graph is a tree T with vertices v_1, v_2, $\cdots$, v_n and d_i is the degree of vertex v_i, $i = 1,2,\cdots,n$ then*

$$W(L(T),x) = (\sum_{i=1}^{n}\frac{d_i(d_i-1)}{2})x + \sum_{i<j}(d_i-1)(d_j-1)x^{1+d(v_i,v_j)}.$$

Proof. Edges of T will be the vertices of $L(T)$. For each vertex v_i there are d_i edges incident to it. These edges form a complete graph on d_i vertices in $L(T)$. Therfore the sum of the distances between these d_i vertices is $\frac{d_i(d_i-1)}{2}$ $(i = 1,2,\cdots,n)$.

Now, assume v_i and v_j be the vertices of T. Let x_1, x_2, $\cdots$, x_{d_i-1} be the edges incident to v_i and y_1, y_2, $\cdots$, y_{d_j-1} be the edges incident to v_j. Where x_l, $(1 \le l \le d_i-1)$ and y_k, $(1 \le k \le d_j-1)$ do not have common vertex and these are not the edges of the path between v_i and v_j. The distance between x_l and y_k in $L(T)$ is $1+d(v_i,v_j)$. Hence, the sum of the polynomial between all edges x_1, x_2, $\cdots$, x_{d_i-1} incident to v_i and all edges y_1, y_2, $\cdots$, y_{d_j-1} incident to v_j is

$$(d_i-1)(d_j-1)x^{1+d(v_i,v_j)}.$$

Therefore, we infer

$$W(L(T),x) = (\sum_{i=1}^{n}\frac{d_i(d_i-1)}{2})x + \sum_{i<j}(d_i-1)(d_j-1)x^{1+d(v_i,v_j)}.$$

We finish the proof. □

Two subgraphs G_1 and G_2 of G with the vertex sets $V(G_1)$ and $V(G_2)$ respectively are said to be independent if $V(G_1)\cap V(G_2) = \emptyset$.

Theorem 7. *Let $(K_p)_i$, $i = 1,2,\cdots,k$ be the k independent complete subgraphs on p vertices of K_n. Let $G(n,p,k)$ be the ontology graph obtained from complete graph K_n via deleting the edges of $(K_p)_i$, $i = 1,2,\cdots,k$, $1 \le k \le \lfloor\frac{n}{p}\rfloor$ and $0 \le p \le n-1$, then*

$$W(G(n,p,k),x) = \frac{kp(p-1)}{2}x^2 + (\binom{n}{2} - \frac{kp(p-1)}{2})x.$$

Proof. Let $(K_p)_1$, $(K_p)_2$, $\cdots$, $(K_p)_k$ be the independent subgraphs of K_n. Let $v_{(i-1)p+1}, v_{(i-1)p+2}, \cdots, v_{(i-1)p+p}$ be the vertices of $(K_p)_i, i = 1,2,\cdots,k$. So in $G(n,p,k)$, there are $\frac{kp(p-1)}{2}$ pairs of vertices are at distance 2 and remaining $\binom{n}{2} - \frac{kp(p-1)}{2}$ pairs of vertices are at distance 1. Therefore

$$W(G(n,p,k),x) = \frac{kp(p-1)}{2}x^2 + (\binom{n}{2} - \frac{kp(p-1)}{2})x.$$

Thus, the desired result is obtained. □

Theorem 8. *Let e_i, $i = 1,2,\cdots,k$, $0 \le k \le n-2$ be the edges of complete graph K_n incident to a vertex v of K_n. Let $K_n(k)$ be the ontology graph obtained from K_n via deleting the edges e_i, $i = 1,2,\cdots,k$. Then*

$$W(K_n(k),x) = kx^2 + (\binom{n}{2} - k)x.$$

Proof. Let v is adjacent to $v_1, v_2, \cdots, v_k$ in the complete graph K_n. Therefore in K_n, there are k pairs of vertices which are at distance 2 and remaining $\binom{n}{2} - k$ pairs of vertices are at distance 1. Thus, we infer

$$W(K_n(k),x) = kx^2 + (\binom{n}{2} - k)x.$$

We finish the proofing. □

3 Conclusion

In computer science, ontology is defined as a shared conceptual model. Currently, ontology has been applied in intelligent information integration, collaborative information systems, information retrieval, knowledge management, e-commerce and other fields. Our paper, from theoretical point, focuses on a class of bounds for ontology parameter which can be considered to measure the properties (such as stability and vulnerability) of ontology graphs. To the best of our knowledge, these results are the first to state in ontology field.

Acknowledgement

We thank the reviewers for their constructive comments in improving the quality of this paper. This work was supported in part by Key Laboratory of Educational Informatization for Nationalities, Ministry of Education, the National Natural Science Foundation of China (60903131), and Key Science and Technology Research Project of Education Ministry (210210). We also would like to thank the anonymous referees for providing us with constructive comments and suggestions.

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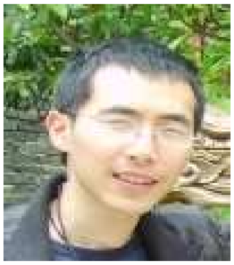

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