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Hajaj

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(54) **PRODUCING A RANKING FOR PAGES USING DISTANCES IN A WEB-LINK GRAPH**

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G06F 17/30 (2006.01)

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CPC .. ***G06F 17/30345*** (2013.01); ***G06F 17/30882*** (2013.01)

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CPC G06F 17/30528; G06F 17/30675; G06F 17/30734; G06F 17/30864
USPC 707/709, 726, 748
See application file for complete search history.

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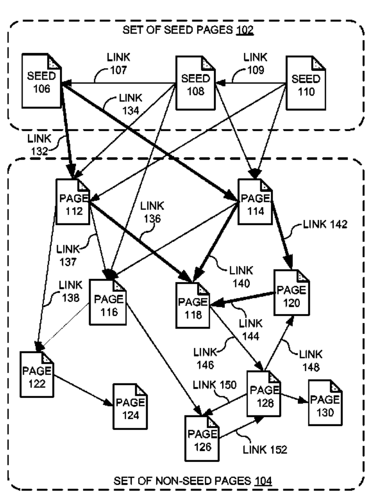
(57) **ABSTRACT**

One embodiment of the present invention provides a system that produces a ranking for web pages. During operation, the system receives a set of pages to be ranked, wherein the set of pages are interconnected with links. The system also receives a set of seed pages which include outgoing links to the set of pages. The system then assigns lengths to the links based on properties of the links and properties of the pages attached to the links. The system next computes shortest distances from the set of seed pages to each page in the set of pages based on the lengths of the links between the pages. Next, the system determines a ranking score for each page in the set of pages based on the computed shortest distances. The system then produces a ranking for the set of pages based on the ranking scores for the set of pages.

22 Claims, 3 Drawing Sheets

A LINK-GRAPH STRUCTURE OF WEB PAGES 100



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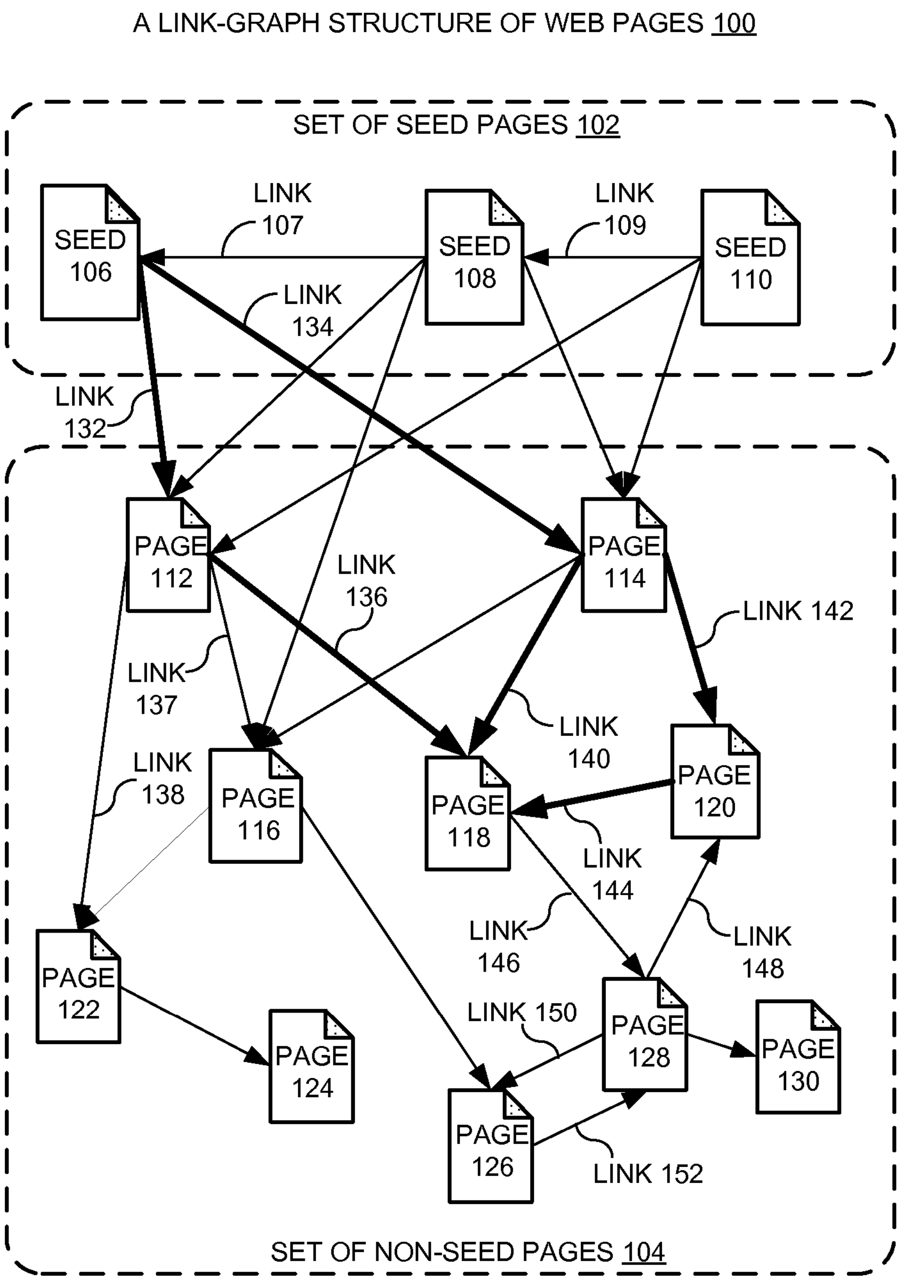
A LINK-GRAPH STRUCTURE OF WEB PAGES 100
SET OF SEED PAGES 102
SEED 106
SEED 108
SEED 110
LINK 107
LINK 109
LINK 134
LINK 132
PAGE 112
PAGE 114
LINK 136
LINK 142
LINK 137
LINK 140
LINK 138
PAGE 116
PAGE 118
PAGE 120
LINK 144
LINK 146
LINK 148
PAGE 122
PAGE 124
LINK 150
PAGE 128
PAGE 130
PAGE 126
LINK 152
SET OF NON-SEED PAGES 104

FIG. 1

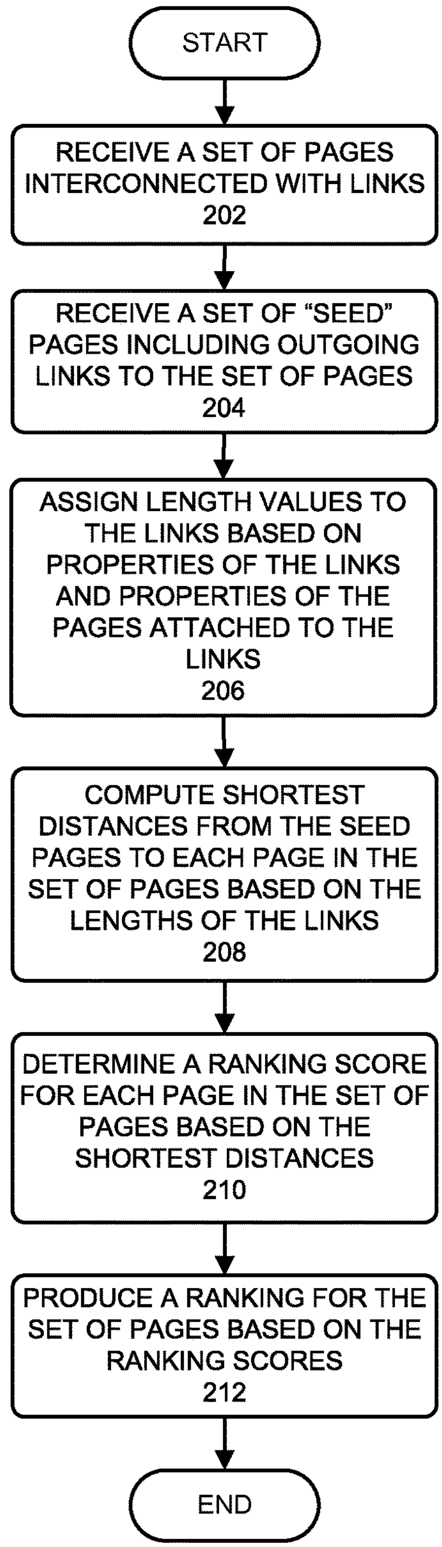
START
RECEIVE A SET OF PAGES INTERCONNECTED WITH LINKS
202
RECEIVE A SET OF "SEED" PAGES INCLUDING OUTGOING LINKS TO THE SET OF PAGES
204
ASSIGN LENGTH VALUES TO THE LINKS BASED ON PROPERTIES OF THE LINKS AND PROPERTIES OF THE PAGES ATTACHED TO THE LINKS
206
COMPUTE SHORTEST DISTANCES FROM THE SEED PAGES TO EACH PAGE IN THE SET OF PAGES BASED ON THE LENGTHS OF THE LINKS
208
DETERMINE A RANKING SCORE FOR EACH PAGE IN THE SET OF PAGES BASED ON THE SHORTEST DISTANCES
210
PRODUCE A RANKING FOR THE SET OF PAGES BASED ON THE RANKING SCORES
212
END

FIG. 2

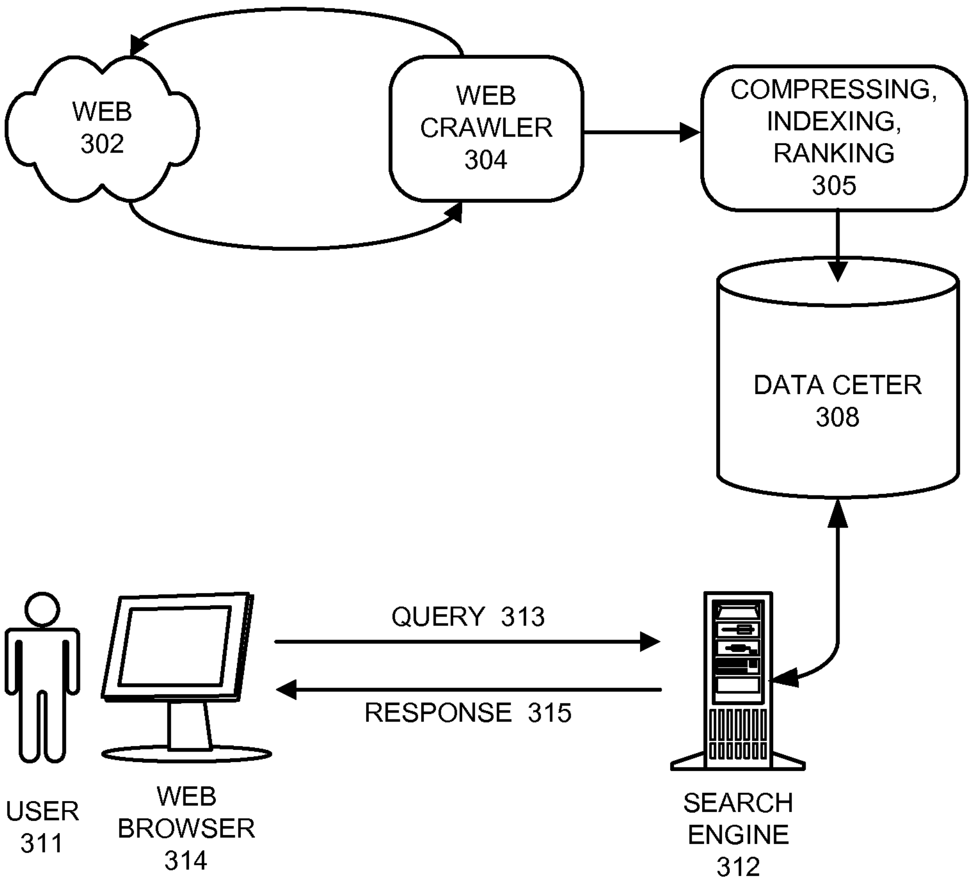
WEB
302
WEB
CRAWLER
304
COMPRESSING,
INDEXING,
RANKING
305
DATA CETER
308
QUERY 313
RESPONSE 315
USER
311
WEB
BROWSER
314
SEARCH
ENGINE
312

FIG. 3

PRODUCING A RANKING FOR PAGES USING DISTANCES IN A WEB-LINK GRAPH

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation of U.S. application Ser. No. 11/546,755, filed Oct. 12, 2006, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND

Field of the Invention

The present invention generally relates to techniques for ranking pages on the web. More specifically, the present invention relates to a method for producing a ranking for pages on the web by computing shortest distances from a set of seed pages to each of the pages to be ranked, wherein the seed pages and the pages to be ranked are interconnected with links.

Related Art

The relentless growth of the Internet has been largely fueled by the development of sophisticated search engines, which enable users to comb through billions of web pages looking for specific pages of interest. Because a given query can return millions of search results it is important to be able to rank these search results to present high-quality results to the user.

A popular search engine developed by Google Inc. of Mountain View, Calif. uses PageRank® as a page-quality metric for efficiently guiding the processes of web crawling, index selection, and web page ranking. Generally, the PageRank technique computes and assigns a PageRank score to each web page it encounters on the web, wherein the PageRank score serves as a measure of the relative quality of a given web page with respect to other web pages. PageRank generally ensures that important and high-quality web pages receive high PageRank scores, which enables a search engine to efficiently rank the search results based on their associated PageRank scores.

PageRank scores are computed based on the web link-graph structure, wherein the web pages are the nodes of the link-graph which are interconnected with hyperlinks. In this model, PageRank R for a given web page p can be computed as:

$$\forall\, p \in P,\; R(p) = (1-d) + d\sum_{q \to p} \frac{R(q)}{|q|_{out}}, \tag{1}$$

wherein P is the set of all the web pages, $|q|_{out}$ is the out-degree of a specific page q in the set P, and $0<d<1$ is a damping factor.

However, the simple formulation of Equation (1) for computing the PageRank is vulnerable to manipulations. Some web pages (called "spam pages") can be designed to use various techniques to obtain artificially inflated PageRanks, for example, by forming "link farms" or creating "loops."

One possible variation of PageRank that would reduce the effect of these techniques is to select a few "trusted" pages (also referred to as the seed pages) and discovers other pages which are likely to be good by following the links from the trusted pages. For example, the technique can use a set of high quality seed pages ($s_1, s_2, \ldots, s_n$), and for each seed page $i=1, 2, \ldots, n$, the system can iteratively compute the PageRank scores for the set of the web pages P using the formulae:

$$\forall\, s_i \neq p \in P,\; R_i(p) = d\sum_{q \to p} \frac{R_i(q)}{|q|_{out}} w(q \to p), \tag{2}$$

where $R_i(s_i)=1$, and $w(q \rightarrow p)$ is an optional weight given to the link $q \rightarrow p$ based on its properties (with the default weight of 1).

Generally, it is desirable to use large number of seed pages to accommodate the different languages and a wide range of fields which are contained in the fast growing web contents. Unfortunately, this variation of PageRank requires solving the entire system for each seed separately. Hence, as the number of seed pages increases, the complexity of computation increases linearly, thereby limiting the number of seeds that can be practically used.

Hence, what is needed is a method and an apparatus for producing a ranking for pages on the web using a large number of diversified seed pages without the problems of the above-described techniques.

SUMMARY

One embodiment of the present invention provides a system that produces a ranking for pages on the web. During operation, the system receives a set of pages to be ranked, wherein the set of pages are interconnected with links. The system also receives a set of seed pages which include outgoing links to the set of pages. The system then assigns lengths to the links based on properties of the links and properties of the pages attached to the links. The system next computes shortest distances from the set of seed pages to each page in the set of pages based on the lengths of the links between the pages. Next, the system determines a ranking score for each page in the set of pages based on the computed shortest distances. The system then produces a ranking for the set of pages based on the ranking scores for the set of pages.

In a variation on this embodiment, the system assigns a length to a link by computing a function of the number of outgoing links from the source page of the link.

In a further variation on this embodiment, the function is a monotonic non-decreasing function of the number of outgoing links from the source page, so that the length of the link increases as the number of outgoing links from the source page increases.

In a variation on this embodiment, the system computes a shortest distance from a seed page to a given page by summing lengths of individual links along a shortest path from the seed page to the given page.

In a further variation on this embodiment, the system computes the length of a link $q \rightarrow p$ by adding a term $(\alpha+\log(|q|_{out}))$ to the length of the link, wherein a is a non-negative value, and wherein $|q|_{out}$ is the number of outgoing links from the source page q.

In a further variation on this embodiment, $\alpha=-\log(d)$, wherein d is a damping factor.

In a variation on this embodiment, a seed page s_i in the set of seed pages is associated with a predetermined weight w_i, wherein $0<w_i\leq 1$. Furthermore, the seed page s_i is associated with an initial distance d_i, wherein $d_i=-\log(w_i)$.

In a further variation on this embodiment, the computed shortest distance from the seed page s_i to a given page includes the initial distance d_i.

In a variation on this embodiment, the system determines the ranking score for a given page based on the computed shortest distances by using k shortest distances from the k nearest seed pages to each page, wherein k is a predetermined positive integer.

In a further variation on this embodiment, the system determines the ranking score for a given page based on the computed shortest distances by using the kth shortest distance among the computed shortest distances.

In a further variation on this embodiment, the ranking score for the given page can be proportional to $e^{-D(p)}$, wherein D(p) is the kth shortest distance.

In a further variation on this embodiment, the function for the length of the link includes a weight of the link.

In a variation on this embodiment, the links associated with the computed shortest distances constitute a reduced link-graph.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** graphically illustrates a link-graph structure of a set of pages on the web in accordance with an embodiment of the present invention.

FIG. **2** presents a flowchart illustrating the process of ranking pages on the web based on shortest distances in accordance with an embodiment of the present invention.

FIG. **3** illustrates the crawling, ranking and searching processes in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not limited to the embodiments shown, but is to be accorded the widest scope consistent with the claims.

The data structures and code described in this detailed description are typically stored on a computer-readable storage medium, which may be any device or medium that can store code and/or data for use by a computer system. This includes, but is not limited to, magnetic and optical storage devices such as disk drives, magnetic tape, CDs (compact discs), DVDs (digital versatile discs or digital video discs), or any device capable of storing data usable by a computer system.

Overview

One embodiment of the present invention provides a system that ranks pages on the web based on distances between the pages, wherein the pages are interconnected with links to form a link-graph. More specifically, a set of high-quality seed pages are chosen as references for ranking the pages in the link-graph, and shortest distances from the set of seed pages to each given page in the link-graph are computed. Each of the shortest distances is obtained by summing lengths of a set of links which follows the shortest path from a seed page to a given page, wherein the length of a given link is assigned to the link based on properties of the link and properties of the page attached to the link. The computed shortest distances are then used to determine the ranking scores of the associated pages.

A Link-Graph and Seed Pages

FIG. **1** graphically illustrates a link-graph structure **100** of a set of pages on the web in accordance with an embodiment of the present invention. Link-graph **100** comprises a collection of pages which correspond to the nodes of the link-graph, and a collection of directed links between the pages, wherein these directed links correspond to the arcs of the link-graph. Note that each link is a directed connection from a "source" page to a "destination" page.

As illustrated in FIG. **1**, the collection of pages is classified into two subsets of pages: a set of seed pages **102**, and a set of non-seed pages **104**. Seed pages (hereinafter referred to as "seeds") **102** form the "root" nodes of link-graph **100**, which comprise: seed **106**, seed **108**, and seed **110**. Although for simplicity FIG. **1** is described in the context of three seeds, generally the present invention can use much more than three seeds. Note that seeds **102** are interconnected with link **107** and link **109**.

Non-seed pages **104** include pages **112-130**, wherein each page is either directly or indirectly connected to one or more seeds through the links in the link-graph. In one embodiment of the present invention, seeds **102** are specially selected high-quality pages which provide good web connectivity to other non-seed pages.

More specifically, to ensure that other high-quality pages are easily reachable from seeds **102**, seeds in seeds **102** need to be reliable, diverse to cover a wide range of fields of public interests, as well as well-connected with other pages (i.e., having a large number of outgoing links). For example, Google Directory and The New York Times are both good seeds which possess such properties. It is typically assumed that these seeds are also "closer" to other high-quality pages on the web. In addition, seeds with large number of useful outgoing links facilitate identifying other useful and high-quality pages, thereby acting as "hubs" on the web.

One approach for choosing seeds involves selecting a diverse set of trusted seeds. Choosing a more diverse set of seeds can shorten the paths from the seeds to a given page. Hence, it would be desirable to have a largest possible set of seeds that include as many different types of seeds as possible. However, because selecting the seeds involves a human manually identifying these high-quality pages, the total number of the seeds is typically limited. Moreover, having too many seeds can make the selected seeds vulnerable to manipulation. Consequently, the actual number of the selected set of seeds is limited.

As illustrated in FIG. **1**, a link from a seed to a page is represented by an arrow pointing from the seed to the page. For example, seed **106** links to page **112** and page **114** through links **132** and **134**, respectively. Such links assert a "support" from the seed to the linked pages.

The set of non-seed pages **104** are also interconnected with links. For example, page **112** has three outgoing links **136**, **137**, and **138**, which target at pages **118**, **116** and **122**, respectively. Furthermore, page **114** has two outgoing links **140** and **142**, which connect to pages **118** and **120**, respectively. Additionally, page **120** links to page **118** through link **144** as shown.

Note that pages **118**, **120** and **128** form a loop, wherein these pages point to each other in a circular manner though links **144**, **146**, and **148**. Furthermore, page **126** and page **128** also form a loop in which they point to each other through links **150** and **152**. Note that even though there is no direct link from seed **106** to page **118**, page **118** is reachable from seed **106** via three distinct paths which are highlighted: (1) seed **106** <link **132**> page **112** <link **136**> page **118**; (2) seed **106**<link **134**> page **114**<link **140**> page **118**; and (3) seed **106**<link **134**> page **114**<link **142**> page **120**<link **144**> page **118**. We are interested in determining a "shortest" path from seed **102** to page **118** among all of these possible paths, wherein the shortest path will be subsequently used to determine a ranking score for page **118**. Note however that, the illustrated lengths of the links in FIG. **1** are not related to the metric which is used to determine the "lengths" of the links in computing the shortest path. We will discuss how to compute the lengths of the links below.

Using a Large Number of Seeds

In one embodiment of the present invention, a large number of reliable international seed pages $s_1, s_2, \ldots, s_n$ are used to compute the PageRank scores. For each i=1, 2, . . . , n, we would like to calculate PageRank R_i based on Equation (2), and set the final PageRank for a page p in the set of pages P to be:

$$R(p)=k\_max_{i=1, \ldots, n}R_i(p), \tag{3}$$

where k is a positive integer between 1 and n, and k_max represents the k^{th} largest value.

With a large set of seeds, one may want to promote some seeds and demote others. This can be done by assigning each seed s_i an optional positive weight w_i (which has a default value of 1), and modifying (3) by:

$$R(p)=k\_max_{i=1, \ldots, n}w_iR_i(p). \tag{4}$$

Note that using the k^{th} largest ranking score facilitates suppressing unfairly high scores due to lack of proportionality at the vicinity of the seeds. In practice, it is sufficient to choose k to be a small integer, for example, 3, 4, 5, or 6.

So far, we have ignored the complexity issues from using the large set of seeds. Next, we will discuss how to reduce the complexity of Equation (3), or (4).

Converting Weight to Length and Distance

To compute distances between pages in link-graph **100**, we need to assign a "length" to every link. The length of a link can be a function of any set of properties of the link and the source of the link. These properties can include, but are not limited to, the link's position, the link's font, and the source page's out-degree.

Referring to Equation (2), for each link q→p, the contribution of page q to page p with respect to seed s_i can be expressed as:

$$C_i(q, p) = d\frac{R_i(q)}{|q|_{out}}w(q \to p). \tag{5}$$

In practice, it is found that the incoming contributions for a page have a significantly skewed distribution such that the sum of the all the incoming contributions is dominated by one or very few terms. Hence, one can make an approximation of the PageRank score for page p with respect to seed s_i by replacing Equation (2) with the dominant term in (2), that is:

$$\forall\, s_i \neq p \in P,\ R_i(p)\max_{q\to p} C_i(q, p) = d\max_{q\to p}\frac{R_i(q)}{|q|_{out}}w(q \to p). \tag{6}$$

Note that Equation (6) provides a reasonable approximation of the PageRank for p.

Let $s_1, s_2, \ldots, s_n$ be a set of seed pages, and for every $1 \le i \le n$, let w_i be an optional positive weight (with default value of 1), we can approximate the PageRank of page p in the set of pages P with respect to the set of seeds s as:

$$\forall\, 1 \le i \le n,\ R_i(s_i) = w_i; \tag{7}$$

$$\forall\, 1 \le n,\ s_i \neq p \in P,\ R_i(p) = d\max_{q\to p}\frac{R_i(q)}{|q|_{out}}w(q \to p); \tag{8}$$

$$\forall\, p \in P,\ R(p) = \text{k\_max}_{i=1,\ldots, n}R_i(p). \tag{9}$$

Next, for each link q→p, we define the length of the link to be:

$$L(q \to p) = -\log(d) + \log\left(\frac{|q|_{out}}{w(q \to p)}\right). \tag{10}$$

Note that the length equation (10) includes a term log ($|q|_{out}$), so that the length of the link increases as the number of outgoing links from the source page q increases. More generally, the length is a monotonic non-decreasing function of the number of outgoing links from the source. This definition is related to the PageRank computation in a sense that a higher ranking score is corresponding to a smaller out-degree $|q|_{out}$, wherein the smaller out-degree results in a shorter length of the link. We will provide other length models for computing the length of a given link below.

For any given pair of pages u and v, let D(u, v) be the distance of the shortest path from u to v (if no such path exists, D(u, v)=∞). We define a distance system including the "shortest distances" $D_i(p)$ from the set of seeds s to page p according to:

$$\forall\, 1 \le i \le n,\ D_i(s_i) = d_i^0; \tag{11}$$

$$\forall\, 1 \le i \le n,\ s_i \neq p \in P,\ D_i(p) = \min_{q\to p}(D_i(q) + L(q \to p)); \tag{12}$$

$$\forall\, p \in P,\ D(p) = \text{k\_min}_{i=1,\ldots, n}D_i(p), \tag{13}$$

wherein $d_i^0 = -\log(w_i)$, with the default value of $d_i^0=0$ when $w_i=1$.

Note that similar to assigning the k^{th} largest value of $R_i(p)$ as the final PageRank R(p), we have set the final "shortest distance" for page p as the k^{th} shortest distance among the set of shortest distances $D_i(p)$, for the same reason as mentioned above.

The relation $R^*(p)=e^{-D^*(p)}$ defines a transformation from Equations (7), (8), and (9) to Equations (11), (12), and (13) such that:

$$\forall 1 \le i \le n, p \in P, D_i(p)=d_i^0+D(s_i,p); \tag{14}$$

$$\forall 1 \le i \le n, p \in P, R_i(p)=e^{-D_i(p)}; \tag{15}$$

$$\forall p \in P, R(p)=e^{-D(p)}. \tag{16}$$

From observing Equation (15), one would appreciate that a larger PageRank score for page p is corresponding to a shorter distance from seed s_i to page p. The meaning of Equation (16) is that instead of calculating the PageRank score R(p), one can alternatively calculate D(p), which is the distance from the k^{th} nearest seed top (where the distance from seed s_i can include an optional initial distance d_i^0). Hence, the goal of the ranking computation is translated into findings the shortest distances to any given page from the nearest k seeds. This computation can be preformed together for all the pages and seeds.

Other Length Models

Referring back to Equation (10), if we ignore the weights that can be assigned to a link, we can rewrite the length of the link to be:

$$L(q \rightarrow p)=\alpha+\log(|q|_{out}), \quad (17)$$

wherein $0 \leq \alpha = -\log(d)$.

We then examine the conditions where a monotonic non-decreasing function $0 \leq f: N \rightarrow R$ can be used for defining the lengths of the links given the out-degrees of the source pages: $L(q \rightarrow p)=f(|q|_{out})$.

We then consider the two following scenarios:

1. The page q directly links to n pages;

2. The page q' is a root of a directed tree with n leaves. We expect that the distance between q and any of the pages it links to will not be greater than the maximum distance between q' and its leaves. In particular, for the case where q' links to n_1 pages which each additionally links to n_2 pages, we get:

$$f(n_1 n_2) \leq f(n_1)+f(n_2). \quad (18)$$

As expected, $f(d)=\alpha+\log(d)$ satisfies this condition, and so does $f=1$. More generally, every function $f(x)=g(\log(x))$, where g is a concave non-negative real function on $[0, \infty)$, will satisfy condition (19), because for every $0 \leq n_1$, n_2,

$$g(\log(n_1 n_2))-g(\log(n_2))=g(\log(n_1)+\log(n_2))-g(\log(n_2)) \leq g(\log(n_1))-g(0) \leq g(\log(n_1)). \quad (20)$$

General Process of Ranking Based on a Shortest Distance

FIG. **2** presents a flowchart illustrating the process of ranking pages on the web based on shortest distances in accordance with an embodiment of the present invention. During this process, the system first receives a set of pages to be ranked, wherein the set of pages are interconnected with links (step **202**). Next, the system receives a set of n seed pages or "seeds", wherein the seeds include outgoing links reaching out to the set of pages to be ranked (step **204**). Hence, the set of pages, the seeds, and the links form a directed link-graph similar to the one illustrated in FIG. **1** (wherein n=3). The system then assigns length values to the links based on properties of the links and properties of the pages attached to the links (step **206**). In one embodiment of the present invention, the length of a given link is computed using Equation (10), wherein the length is a function of the number of outgoing links from the source page of the link.

Next, the system computes shortest distances from the set of seeds to each page in the set of pages based on the lengths of the links between the pages (step **208**). More specifically, for each given page in the set of pages, the system identifies k "nearest" seeds among the set of seeds, wherein k<n. In other words, these k nearest seeds produce the k shortest distances to the given page among the set of n seeds. For example in FIG. **1**, we can choose k to be 1.

Note that it is possible for a selected seed to comprise more than one page. In such cases, the shortest path from the seed to any target page will be defined as the shortest path from any of the seed's pages to the target page.

The system next determines a ranking score for each page in the set of pages based on the computed shortest distances (step **210**). In one embodiment of the present invention, for each given page, the system first identifies the kth nearest seed in the computed shorted distances for the give page, and subsequently computes a ranking score for the given page based on Equation (16). Finally, the system produces a ranking for the set of pages based on the ranking scores for the set of pages (step **212**). Note that however, not all the pages in the set of pages receive ranking scores through this process. For example, a page that cannot be reached by any of the seed pages will not be ranked.

Note that the results from above ranking process can be used for seed tuning. Specifically, the ranking process produces lists of the nearest seeds and the lengths of the shortest paths for all the ranked pages. The system can process these results to extract information for each of the seeds with respect to the ranked pages. Next, the system can use this information to evaluate the quality and the contribution of the seeds, and then modify the list of seeds and/or the weights of the seeds based on this information.

A Reduced Link-Graph

Note that the links participating in the k shortest paths from the seeds to the pages constitute a sub-graph that includes all the links that are "flow" ranked from the seeds. Although this sub-graph includes much less links than the original link-graph, the k shortest paths from the seeds to each page in this sub-graph have the same lengths as the paths in the original graph. For each page p, the maximum number of links to page p in this sub-graph is at most k. Furthermore, the rank flow to each page can be backtracked to the nearest k seeds through the paths in this sub-graph.

Crawling Ranking and Searching Processes

FIG. **3** illustrates the crawling, ranking and searching processes in accordance with an embodiment of the present invention. During the crawling process, web crawler **304** crawls or otherwise searches through websites on web **302** to select web pages to be stored in indexed form in data center **308**. In particular, web crawler **304** can prioritize the crawling process by using the page rank scores. The selected web pages are then compressed, indexed and ranked in **305** (using the ranking process described above) before being stored in data center **308**.

During a subsequent search process, a search engine **312** receives a query **313** from a user **311** through a web browser **314**. This query **313** specifies a number of terms to be searched for in the set of documents. In response to query **313**, search engine **312** uses the ranking information to identify highly-ranked documents that satisfy the query. Search engine **312** then returns a response **315** through web browser **314**, wherein the response **315** contains matching pages along with ranking information and references to the identified documents.

Note that the application of the present invention is not limited to the web and web pages. The general technique of producing ranking scores can be expanded to any hyperlinked database, which can include, but is not limited to, hyperlinked documents of an enterprise.

The foregoing descriptions of embodiments of the present invention have been presented only for purposes of illustration and description. They are not intended to be exhaustive or to limit the present invention to the forms disclosed. Accordingly, many modifications and variations will be apparent to practitioners skilled in the art. Additionally, the above disclosure is not intended to limit the present invention. The scope of the present invention is defined by the appended claims.

What is claimed is:

1. A method, comprising:

obtaining data identifying a set of pages to be ranked, wherein each page in the set of pages is connected to at least one other page in the set of pages by a page link;

obtaining data identifying a set of n seed pages that each include at least one outgoing link to a page in the set of pages, wherein n is greater than one;

accessing respective lengths assigned to one or more of the page links and one or more of the outgoing links; and

for each page in the set of pages:

identifying a kth-closest seed page to the page according to the respective lengths, wherein k is greater than one and less than n,

determining a shortest distance from the kth-closest seed page to the page; and

determining a ranking score for the page based on the determined shortest distance, wherein the ranking score is a measure of a relative quality of the page relative to other pages in the set of pages.

2. The method of claim 1, wherein the respective lengths assigned to a link are determined based on a function of the number of outgoing links from the source page of the link.

3. The method of claim 2, wherein the function is a monotonic non-decreasing function of the number of outgoing links from the source page, so that the length of the link increases as the number of outgoing links from the source page increases.

4. The method of claim 2, wherein determining the length of a link from a source page q to a target page p includes adding a term $(\alpha+\log(|q|_{out}))$ to the length of the link, wherein a is a non-negative value, and wherein $|q|_{out}$ is the number of outgoing links from the source page q.

5. The method of claim 4, wherein $\alpha=-\log(d)$, wherein d is a damping factor.

6. The method of claim 2, wherein the function for the length of the link is also a function of a weight of the link.

7. The method of claim 1, wherein determining a shortest distance from a seed page to a given page includes summing lengths of individual links along a shortest path from the seed page to the given page.

8. The method of claim 1,

wherein a seed page s_i in the set of seed pages is associated with a predetermined weight w_i, wherein $0<i\leq 1$; and

wherein the seed page s_i is associated with an initial distance d_i, wherein $d_i=-\log(w_i)$.

9. The method of claim 8, wherein the determined shortest distance from the seed page s_i to a given page includes the initial distance d_i.

10. The method of claim 1, wherein the ranking score for the given page can be proportional to $e^{-D(p)}$, wherein D(p) is the kth shortest distance.

11. The method of claim 1, further comprising including each link in a shortest path from the kth-closest seed page to the first web page in a reduced link-graph, wherein the shortest path is a path having the shortest distance from the kth-closest seed page to the first web page.

12. A non-transitory computer-readable storage medium storing instructions that when executed by one or more computers cause the one or more computers to perform operations comprising:

obtaining data identifying a set of pages to be ranked, wherein each page in the set of pages is connected to at least one other page in the set of pages by a page link;

obtaining data identifying a set of n seed pages that each include at least one outgoing link to a page in the set of pages, wherein n is greater than one;

accessing respective lengths assigned to one or more of the page links and one or more of the outgoing links; and

for each page in the set of pages:

identifying a kth-closest seed page to the page according to the respective lengths, wherein k is greater than one and less than n,

determining a shortest distance from the kth-closest seed page to the page; and

determining a ranking score for the page based on the determined shortest distance, wherein the ranking score is a measure of a relative quality of the page relative to other pages in the set of pages.

13. The computer-readable storage medium of claim 12, wherein the respective lengths assigned to a link are determined based on a function of the number of outgoing links from the source page of the link.

14. The computer-readable storage medium of claim 13, wherein the function is a monotonic non-decreasing function of the number of outgoing links from the source page, so that the length of the link increases as the number of outgoing links from the source page increases.

15. The computer-readable storage medium of claim 13, wherein determining the length of a link from a source page q to a target page p includes adding a term $(\alpha+\log(|q|_{out}))$ to the length of the link, wherein a is a non-negative constant value, and wherein $|q|_{out}$ is the number of outgoing links from the source page q.

16. The computer-readable storage medium of claim 15, wherein $\alpha=-\log(d)$, wherein d is a damping factor.

17. The computer-readable storage medium of claim 12, wherein determining a shortest distance from a seed page to a given page involves summing lengths of individual links along a shortest path from the seed page to the given page.

18. The computer-readable storage medium of claim 12,

wherein a seed page s_i in the set of seed pages is associated with a predetermined weight w_i, wherein $0<w_i\leq 1$; and

wherein the seed page s_i is associated with an initial distance d_i, wherein $d_i=-\log(w_i)$.

19. The computer-readable medium of claim 12, the operations further comprising:

using the ranking score in ranking one or more of the pages in response to a received search query.

20. A system comprising:

one or more data processing apparatus; and

one or more computer-readable storage devices having stored thereon instructions that, when executed by the one or more data processing apparatus, cause the one or more data processing apparatus to perform operations comprising:

obtaining data identifying a set of pages to be ranked, wherein each page in the set of pages is connected to at least one other page in the set of pages by a page link;

obtaining data identifying a set of n seed pages that each include at least one outgoing link to a page in the set of pages, wherein n is greater than one;

accessing respective lengths assigned to one or more of the page links and one or more of the outgoing links; and for each page in the set of pages:

identifying a kth-closest seed page to the page according to the respective lengths, wherein k is greater than one and less than n,

determining a shortest distance from the kth-closest seed page to the page; and

determining a ranking score for the page based on the determined shortest distance, wherein the ranking score is a measure of a relative quality of the page relative to other pages in the set of pages.

21. The method of claim **1**, further comprising:

using the ranking score in ranking one or more of the pages in response to a received search query.

22. The system of claim **20**, the operations further comprising:

using the ranking score in ranking one or more of the pages in response to a received search query.

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