# Website Complexity Metrics for Measuring Navigability

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## Abstract

*In recent years, navigability has become the pivot of website designs. Existing works fall into two categories. The first is to evaluate and assess a website's navigability against a set of criteria or check list. The second is to analyse usage data of the website, such as the server log files. This paper investigates a metric approach to website navigability measurement. In comparison with existing assessment and analysis methods, navigability metrics have the advantages of objectiveness and the possibility of using automated tools to evaluate large-scale websites. This paper proposes a number of metrics for website navigability measurement based on measuring website structural complexity. We will validate these metrics against Weyuker's software complexity axioms, and report the results of empirical studies of the metrics.*

## 1. Introduction

The rapid advancement of the Internet and World Wide Web has created new lifestyles, such as searching for information and browsing through various products by using the World Wide Web as a universal tool. However, users often experience severe difficulties in the uses of the web, especially to navigate on a complicated website [4].

Generally speaking, navigation is the process of determine a path to be travelled through a chosen environment [6]. Nielsen claimed that the navigation design of a website should help users answer three fundamental questions when browsing the site. They are: 'Where am I?', 'Where have I been?' and 'Where can I go?' [17].

By 1997, much of the existing navigation research literature deals with virtual reality [1]. Until recently, usability engineering has put web users at the centre of focus. The Web therefore has become a major concern of navigation research as users become frustrated with poor designs. In fact, the navigation is such an important feature that Krug stated "navigation is not just a part of the websites; It *is* the website" [14].

We are concerned with the measurement of the quality of websites related to navigation. We define website navigability as the easiness that the users find the required piece of information by moving through a website.

The remainder of the paper is organised as follows. Section 2 summarises the related works. Section 3 defines a group of four metrics of website structural complexity. Section 4 assesses the metrics against Weyuker's axiom system of software complexity. Section 5 evaluates the metrics via empirical study based on user-centred questionnaire. Section 6 concludes the paper with a discussion of further work.

## 2. Related works

Navigability design is one of the trickiest areas of website development. It is tricky because it is so subjective – everyone seems to have a different opinion of what works [9]. Furnas stated that usability focused navigability testing is by no means a simple issue. This is because usability itself is a vast complex concept, while navigability is only one attribute of usability. In addition, the Web has to cater for different types of users each with an individual style of preference. Web navigation is a challenge because of the need to manage billions of information objects [17], which makes the measuring of navigability extremely difficult.

The breadth versus depth issue in web design has been widely studied. Results from several studies have suggested that a web page with many links, a means to reduce the depth, is the optimal condition for user performance [10, 13]]. Zaphris and Mtei found that in a site of 64 links, the design with 8 links per page and two levels resulted in fastest response time and lowest navigation efforts [23]. For web-design, a widely quoted heuristic rule of navigation design is the "three-click rule", which states that the user should be able to get from homepage to any other page on the site within three clicks of the mouse.

McGovern believes that the strength of navigation is how quickly users can find what they are looking for [15]. A good navigability design should include a variety of navigation attributes. A questionnaire was produced to assess web navigability with 14 questions like "How easily can you identify where you are within the website?", "how similar are the navigational elements to the other websites?", "how correct are your expectations from links?" etc. Web navigability was tested with a rating from one to five of the above questions. McGovern's study was usability focused. McGovern emphasized the importance to have a baseline statistics against which to compare the results obtained from an analysis.

Another approach to measuring Web navigability is to analyze the server log files. In [3], real data of web usages, such as Visitors-per-Page, Pages-per-Visitor Average-Duration-of-visitor-session, are gathered from server log files and analyzed to derive the user's feelings and perceptive of websites. Sullivan investigated four aspects when measuring navigability using server log files [21]:

1. how do people arrive at the site? (leaf page, or main page?)
2. how do they hit various portions of the site? (identifying frequently used navigational devices)
3. are there any portions of the site unexplored? (this would suggest a need to improve visibility)
4. users' reaction to page load time

The result of Sullivan's study was that most users used Topical Tour to navigate the site. In addition, a surprising result was that once the users encountered the Tour pages, on average they would visit other 14 additional pages. With the result Sullivan made several changes to his site, mainly with the Topical more accessible. Consequently, the number of high-traffic visitors increased by 14%.

In [18], Rodriguez, *et al* stated that applying classic usability testing to navigability has proven to be slow, expensive and inaccurate. Navigability testing in their view "requires high precision and permanent observation of the users." They developed a tool called the Automatic Navigability Testing System (ANTS). It was designed to study user behaviour without having to observe the user and testing out which type of navigational facilities were the most effective. ANTS was able to record the exact position of the user on a navigational map as well as record the duration of how long a user spends on each page. Although the tool could be useful for future information retrieval concerning navigability, it is still at a starting point, as the results showed little distinctive relationship between user behaviour and navigability [19].

In [12], Jin, Zhu and Hall proposed an abstract model of hypertext application systems as a directed graph (see e.g. Fig. 1), which is equally applicable to websites. In this model, a website can be modeled as a pair $< G, S >$, where $G = (V, E)$ is a directed graph representing the website; $V$ is the set of nodes representing web pages; $E$ is the set of edges representing links between web pages; and $S$ is the start node of the graph, i.e. the home page of the website. The directed graph must also satisfy the condition that all nodes $v$ in $V$ are reachable, i.e. there is at least one path from the home page to node $v$. They suggested the use of the Number of Independent Paths (NOIP) as a measure of hypertext navigation complexity. The larger the NOIP, the more complex the website structure is, the easier for a user to get lost in the network, and the poor navigability.

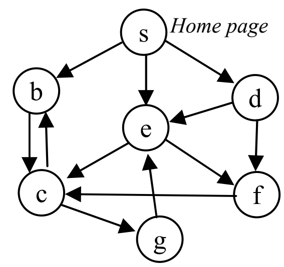


Figure 1. An graph model of a website W

This idea was further investigated in [24]. A metric for website structure complexity was defined as the sum of the number of simple paths from the home page to each page. A simple path contains no duplicated occurrences of any node, hence represents a navigation process in which no page is viewed more than once. The metric was evaluated against Weyuker's axiom system [22] of software complexity, but no empirical studies on real websites were conducted. A number of other metrics of website complexity have also been proposed and investigated in the literature; see, e.g. [7] for a survey. In comparison with assessment methods and analysis methods, navigability metrics have the advantages of objectiveness and the possibility of using automated tools to evaluate large-scale websites efficiently. Therefore, this paper takes this approach. It proposes a number of metrics for website navigability measurement based on measuring website structural complexity. We will validate these metrics against Weyuker's software complexity axioms, and report the results of empirical studies of the metrics.

## 3. Definition of metrics

Structural complexity emerges from the relationships among the pages of the website. The most basic and important relationship is that a page is linked to another through hyperlinks. The hyperlinks between web pages of a website form the navigational paths through which users browse the website to find the information that they want. The more complex that the web pages are inter-linked, the more likely that a user becomes lost in the information ocean, and hence, the more difficult to navigate. Our structural complexity metrics are therefore based on the study of website links.

The structurally simplest system consists of a single page with no links. For more complex systems, structural complexity depends on the structure of the graph model of the website. For a given web page, we distinguish the number of in coming links and out going links from the page. In-link is the count of links to a page, and out-link is the count of links from a given page. For example, in Figure 2, the in-link of page A is 1 and the out-link is 3.

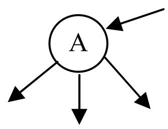


Figure 2. In-link and Out-link

Intuitively, in-link, i.e. the number of in coming links, indicates how easy to get to a page. A large in-link is generally confined to pages that performed simple functions reused throughout the website. Consequently, a large in-link does not prove to be an important complexity indicator. On the other hand, out-link, i.e. the number of out going links, indicates how easy it is to get lost since each out going link represents a choice for the next step in navigation. For that reason, out-link is an important indicator. Therefore, the first candidate formula for measuring website structural complexity is the following.

$$WSC_1 = \sum_{i=1}^{n} outlink(i) \qquad \text{Eq1}$$

where: *out-link*($i$): out-link of a given page $i$, $n$: number of pages in a website. From graph theory, for all directed graphs, the sum of in-links of all nodes is equal to the sum of out-links, which is equal to the total number of clickable links. Therefore, we have that

$$WSC_1 = \sum_{i=1}^{n} inlink(i) = total\ number\ of\ links$$

$WSC_1$ catches the intuition that a small website with fewer pages and links are less complex than a large web site that has hundreds even thousands of pages and links. However, for comparison purposes, it is desirable to know its relative complexity taking into consideration of the size. Dividing the overall complexity by the number of pages gives a normalized complexity.

$$WSC_2 = WSC_1 / n = \sum_{i=1}^{n} outlink(i) \Big/ n \qquad \text{Eq2}$$

Informally, Eq2 defines structural complexity as the average number of links per page.

As suggested in [12], the number of independent paths in a hyperlinked network of web pages can be used as a complexity metrics. Let $NOIP(G)$ denote the number of independent paths in a graph model $G$. We define the following metrics.

$$WSC_3 = NOIP(G)$$

According to graph theory, the number of independent paths in a directed graph G can be calculated by the following formula [8, 25].

$$NOIP(G) = e - n + d + 1$$

where $e$ is the total number of links in the graph, $n$ is the number of nodes in the graph and $d$ is the number of dead end nodes in the graph. We define that

$$WSC_3 = e - n + d + 1. \qquad \text{Eq3}$$

We can also define a relative complexity metric based on the number of independent paths as follows.

$$WSC_4 = WSC_3 / n = (e - n + d + 1) / n \qquad \text{Eq4}$$

Because $e = \sum_{i=1}^{n} outlink(i) = \sum_{i=1}^{n} inlink(i)$, and usually $d << n$, we have the following relationship between $WSC_2$, $WSC_3$ and $WSC_4$.

$$WSC_4 \approx WSC_2 - 1 \quad \text{and} \quad WSC_2 \approx WSC_3 / n + 1$$

Not only does the number of out-links and in-links affect structural complexity, but also the distribution of the links within a website [11]. For a fixed number of links, a website in which links are concentrated in a few pages is more complex than one in which links are mostly evenly distributed. In the discussion of software structural complexity measurement, Belady and Evangelisti applied interconnection matrix representation of partition [2] and suggested that complexity increases as the square of connections (fanout), where fanout is number of the calls from a given module. In website designs, all pages are connected by hyperlinks. This leads to the following metrics, $WSC_5$.

$$WSC_5 = \sum_{i=1}^{n} out\_link^2(i) \Big/ n \qquad \text{Eq5}$$

## 4. Axiomatic assessment

A number of properties of software complexity have been proposed in the literature to validate the correctness and meaningfulness of software complexity measurement. Although being criticized for inadequacy, Weyuker's axioms of software complexity [22] have been commonly applied as an approach to validating analytically the measurement of software complexity [5]. In this section, we assess the metrics defined in the previous section against Weyuker's axioms of software complexity.

Weyuker's axioms, shown in Table 1, were proposed to characterize ideal complexity metrics of computer programs. No similar axioms have been proposed for web-based systems. Here, we regard the web-based applications as a special kind of software systems. However, some properties of Weyuker's axioms are not directly applicable to website complexity metrics, hence must be adapted.

As shown in Table 1, Weyuker's axioms are based on a number of operators and relations on programs. These operators and relations must be modified according to the features of websites. The following formally defines these operators and relations in the context of websites.

Table 1. Weyuker's axioms of complexity metrics

| | |
|---|---|
| Axiom 1 | There exist $P$ and $Q$ such that $M(P) \neq M(Q)$. |
| Axiom 2 | If $c$ is a non-negative number, then there exist only finitely many $P$ such that $M(P) = c$. |
| Axiom 3 | There exist distinct $P$ and $Q$ such that $M(P) = M(Q)$. |
| Axiom 4 | There exist functionally equivalent $P$ and $Q$ such that $M(P) \neq M(Q)$. |
| Axiom 5 | For any $P$ and $Q$, we have $M(P;Q) \geq M(P)$ and $M(P;Q) \neq M(Q)$. |
| Axiom 6 | There exist $P$, $Q$ and $R$ such that $M(P) = M(Q)$ and $M(P;R) \neq M(Q;R)$. |
| Axiom 7 | There exist $P$ and $Q$ such that $Q$ is formed by permuting the order of the statements of $P$ and $M(P) \neq M(Q)$. |
| Axiom 8 | If $P$ is a renaming of $Q$, then $M(P) = M(Q)$. |
| Axiom 9 | There exist $P$ and $Q$ such that $M(P)+M(Q) < M(P;Q)$. |

**Definition 1. (Functionally Equivalence)**

Let $S_1$=<($V_1$, $E_1$), $s_1$> and $S_2$=<($V_2$, $E_2$), $s_2$> be two graph models of websites. They are functionally equivalent if, and only if, that $V_1 = V_2$ and $s_1 = s_2$. □

Informally, two website are functionally equivalent, if they contain the same information, but may be inter-linked differently.

**Definition 2. (Composition of websites: P;Q)**

Let $S_1$=<($V_1$, $E_1$), $s_1$> and $S_2$=<($V_2$, $E_2$), $s_2$> be two graph models of websites, and $V_1 \cap V_2 = \varnothing$. $S_1;S_2$ is defined as <($V_1 \cup V_2$, $E_1 \cup E_2 \cup \{(p, s_2)\}$), $s_1$>, where $p \in V_1$. □

Informally, the composition of two websites is to link these two websites by a hyperlink. Of course, in general, we often add a number of links between the websites. For the sake of simplicity, we assume one hyperlink is added. This assumption will not change the result of the assessment of the metrics.

**Definition 3. (Permutation of orders)**

Let $S_1$=<($V_1$, $E_1$), $s_1$> and $S_2$=<($V_2$, $E_2$), $s_2$> be two graph models of websites and $V_1 = V_2$. $S_2$ is obtained by permuting the representation order of $S_1$ if $\|E_1\| = \|E_2\|$. □

Informally, permuting the order of the representation of information means change the links between the pages, but without adding additional links. Therefore, the number of links between the websites must keep unchanged.

**Definition 4. (Renaming)**

A website $W_1$ is obtained from website $W_2$ by renaming, if $W_1$ is obtained by change the texts associated to the hyperlinks and the titles of the pages of $W_2$. □

Obviously, we have the following property of renaming.

**Proposition 1**.

Let $W_1$ is obtained from $W_2$ by renaming, and $S_1$ and $S_2$ are the graph models of $W_1$ and $W_2$, respectively. We have that $S_1 \approx S_2$. □

In the following, we evaluate the structure complexity metrics by examining the axioms one by one.

## 4.1. Properties of $WSC_1$

From the definition of the $WSC_1$, it is ease to see that it satisfies axiom 1, axiom 3, axiom 4, axiom 5, axiom 8 and axiom 9. It does not satisfy axiom 6 and axiom 7. It also satisfies axiom 2 because for all connected graphs, the number of links must be greater than or equal to the number of nodes −1. Therefore, if $WSC_1(P) = c$, $P$ can contain at most $c$+1 pages. There can only be a finite number of connected graphs of $c$+1 or less nodes and $c$ links.

## 4.2. Properties of $WSC_2$

From the definitions, it is ease to see that $WSC_2$ satisfies axiom 1, axiom 3, axiom 4 and axiom 8. It obviously does not satisfy axiom 7. $WSC_2$ satisfies axiom 6. To prove this, consider the graphs in Figure 3. By definition, we have that $WSC_2$(P) = $WSC_2(Q)$ = 5/3, $WSC_2(P;R)$ =11/7, and $WSC_2(Q;R)$.= 6/4. That is, $WSC_2(Q;R) \neq WSC_2(Q;R)$.

It does not satisfy axiom 2. As a counter example, consider the graphs in Figure 4. All these graph's complexity under $WSC_2$ are 1, because there are $n$

nodes and n arcs for all $n>1$. Therefore, there are infinite number of graphs $G$ such that $WSC_2(G)=1$.

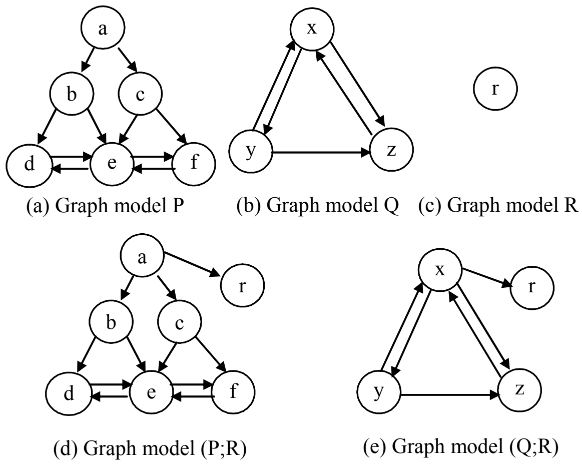


Figure 3. Explanation of Axiom 6 for WSC2

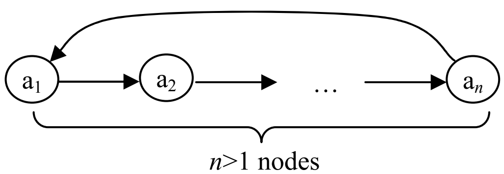


Figure 4. Explanation of Axiom 2 for WSC2

It also does not satisfy axiom 5. In Figure 5, $WSC_2(P) = 1$, $WSC_2(Q) = 4/3$, $WSC_2(P;Q) = 4/3$. $WSC_2(P;Q) = WSC_2(Q)$.

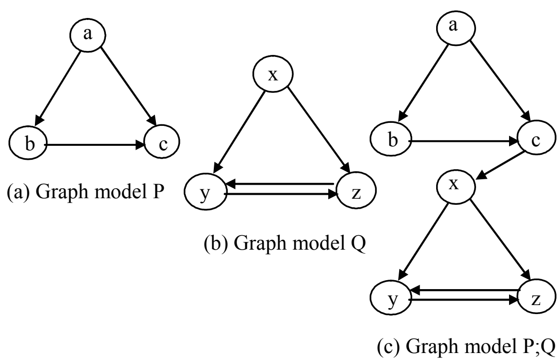


Figure 5. Explanation of Axiom 5 for WSC2/5

The metric does not satisfy Axiom 9. Let $e_p$ and $n_p$ be the number of edges and nodes in a graph $P$ and $e_q$ and $n_q$ be the number of edges and nodes in graph $Q$, respectively. By definition 2, the graph $P;Q$ has $e_p+e_q+1$ edges, and $n_p+n_q$ nodes. It is easy to prove that for all natural numbers $e_p$, $e_q$, $n_p$, and $n_q$, we have that

$$e_p / n_p + e_q/n_q \geq (e_p+e_q+1)/(n_p+n_q).$$

That is, for all graphs $P$ and $Q$, we have that

$$WSC_2(P) + WSC_2(Q) \geq WSC_2(P;Q).$$

## 4.3. Properties of $WSC_3$

From the definition of independent paths and the axioms, it is ease to see that $WSC_3$ satisfies axiom 1, axiom 3, axiom 4, axiom 7 and axiom 8, but does not satisfy axiom 6. It does not satisfy axiom 5, which can be easily proved using Figure 6. Notice that for all graphs $G$ in Figure 4, $WSC_3(G) = 1$. Hence, it does not satisfy axiom 2.

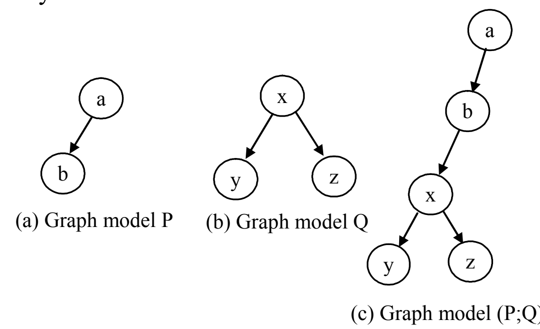


Figure 6. Explanation of Axiom 5 for WSC3

It does not satisfy axiom 9. Let $e_p$, $n_p$ and $d_p$ be the number of edges, nodes and dead end nodes in a graph $P$; $e_q$, $n_q$ and $d_q$ be the number of edges, nodes and dead end nodes in graph $Q$, respectively. By definition 2, the graph $P;Q$ has $e_p+e_q+1$ edges, $n_p+n_q$ nodes and $d_p+d_q$ -1 dead end nodes. We therefore have $WSC_4(P;Q) = WSC_4(P) + WSC_4(Q)$.

## 4.4. Properties of $WSC_4$

From the definition of independent paths and the axioms, it is ease to see that $WSC_4$ satisfies axiom 1, axiom 3, and axiom 4. Similar to the proofs given in (C), we can prove that $WSC_4$ also satisfies axiom 6, axiom 7 and axiom 8. However, it does not satisfy axiom 5. Notice that for all graphs $G$ in Figure 4, $WSC_4(G) = 1$. Hence, it does not satisfy axiom 2.

It does not satisfy axiom 9. Let $e_p$, $n_p$ and $d_p$ be the number of edges, nodes and dead end nodes in a graph $P$; $e_q$, $n_q$ and $d_q$ be the number of edges, nodes and dead end nodes in graph $Q$, respectively. By definition 2, the graph $P;Q$ has $e_p+e_q+1$ edges, $n_p+n_q$ nodes and $d_p+d_q-1$ dead end nodes. It is easy to prove that

$$WSC_4(P;Q) - WSC_4(P) - WSC_4(Q)$$
$$= (e_p+e_q+1-n_p-n_q+d_p+d_q-1+1)/(n_p+n_q) - (e_p-n_p+d_p+1)/n_p - (e_q-n_q+d_q+1)/n_q \leq 0$$

## 4.5. Properties of $WSC_5$

It is ease to see that $WSC_5$ satisfies axiom 1, axiom 3, and axiom 8. It does not satisfy axiom 2 because we have that for all graphs $G$ in Figure 4, $WSC_5(G) = 1$.

It does not satisfy axiom 5. A counterexample is given in Figure 5, where $WSC_5(P) = 5/3$, $WSC_5(Q) = 2$, $WSC_5(P;Q) = 2$. Hence, $WSC_5(P;Q) = WSC_5(Q)$.

It satisfies Axiom 4. To prove this property, consider the graphs in Figure 7. We have that $WSC_5(a) = 15/7$; $WSC_5(b) = 3$, although graph *a* and *b* are functionally equivalent.

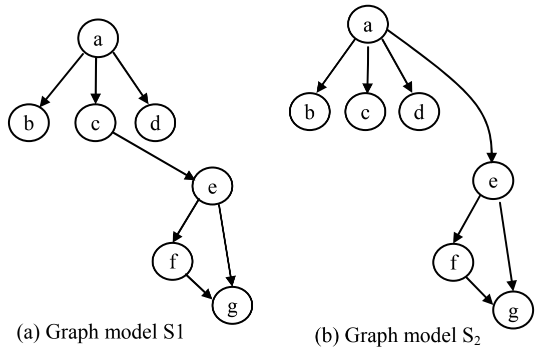


Figure 7. Explanation of Axiom 4 for WSC5

It satisfies Axiom 6. To prove this, consider the graphs given in Figure 8. We have that $WSC_5(P) = WSC_5(Q) = 9/4$, $WSC_5(P;R) = 2$, $WSC_5(Q;R)=14/5$, i.e. $WSC_5(P;R) \neq WSC_5(Q;R)$.

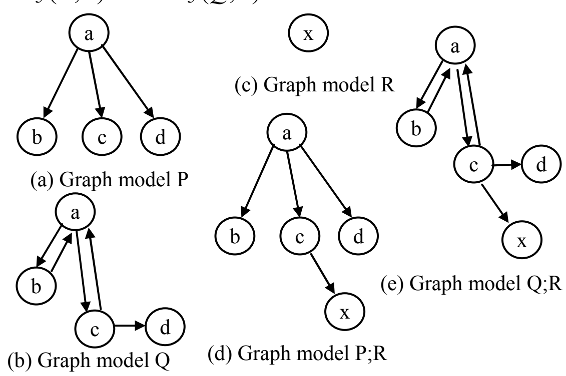


Figure 8. Explanation of Axiom 6 for WSC5

It satisfies Axiom 7. Figure 9 is an counterexample, where *Q* is a permutation of *P*, but $WSC_5(P)=2/3$, $WSC_5(Q)= 4/3$, i.e. $WSC_5(P) \neq WSC_5(Q)$.

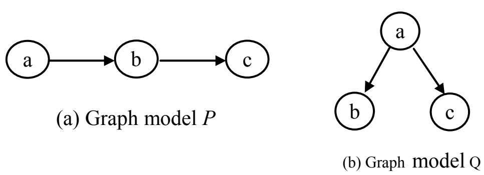


Figure 9. Explanation of Axiom 7 for WSC5

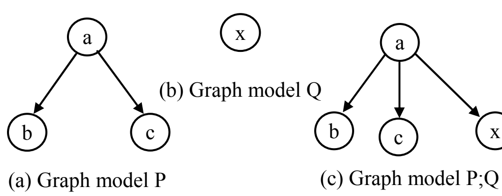


Figure 10. Explanation of Axiom 10 for WSC5

It satisfies Axiom 9. To prove this, consider the graphs given in Figure 10. We have that $WSC_4(P) = 4/3$; $WSC_5(Q) = 0$; $WSC_5(P;Q) = 9/4$. Therefore, we have that $WSC_5(P;Q) > WSC_5(P) + WSC_5(Q)$.

Table 2 summaries the analysis above. From Table 2, we can see that $WSC_1$ and $WSC_5$ comply with the Weyuker's axiom system best, but other metrics can still be successful candidates.

Table 2. Assessment against Weyuker's axioms

| Metrics / Axioms | $WSC_1$ | $WSC_2$ | $WSC_3$ | $WSC_4$ | $WSC_5$ |
|---|---|---|---|---|---|
| Axiom 1 | Yes | Yes | Yes | Yes | Yes |
| Axiom 2 | Yes | No | No | No | No |
| Axiom 3 | Yes | Yes | Yes | Yes | Yes |
| Axiom 4 | Yes | Yes | Yes | Yes | Yes |
| Axiom 5 | Yes | No | No | No | No |
| Axiom 6 | No | Yes | No | Yes | Yes |
| Axiom 7 | No | No | Yes | Yes | Yes |
| Axiom 8 | Yes | Yes | Yes | Yes | Yes |
| Axiom 9 | Yes | No | No | No | Yes |

## 5. Empirical evaluation

To further evaluate the metrics, we choose four websites of the same nature as the subject of evaluation. Measurements of the navigability of the websites are calculated using the metrics. Experiments with human users' access to the websites are design, and carried out with 3 repetitions. The experiment results are compared with the data calculated using the metrics. This section reports our empirical evaluations of the metrics.

### 5.1. The Subjects of Empirical Study

The websites used in the empirical study are all university portals. The universities are geographically located in the same city in England. In the sequel, they are referred to as U1, U2, U3 and U4, respectively.

The empirical study was carried out in 2003. 122 students from different universities were selected at random to participate in the empirical study. All the students who participated in the empirical study were from computing fields and fluent in the use of web to find the required information. They all use university websites to obtain their daily study information, etc.

### 5.2. Calculation of Navigability

A simple software tool was developed to calculate the navigability of chosen websites using the metrics defined in section 3. The tool consists three parts:

1. *Site Download Agent.* It downloads the whole site. A simple Perl scrip from CPAN (http://www.perl.org/CPAN) is used to generate an HTML site map from a given URL. It traverses the website using a breadth first algorithm starting from the home page. It

extracts the hyperlinks from HTML files, retrieves all pages linked to the website recursively. It outputs the structure of the website as a tree with the home page as the root. If a page is linked from more than one page, it is show in the highest place in the tree that it is linked from, which guarantees that no file will be downloaded more than once.
2. *Filter*. It removes the multimedia files (audio, video, animation…) but keeps the markup text files (html, shtml, htm, php, php3, asp, xml…) because only these markup text files contribute to the structural complexity.
3. *Metrics calculation and report agents.* They calculate the metrics according to the equations and stores the results in a database.

The results are given in Table 3 below.

Table 3. Navigability according to the metrics

| Site | *#Pages* | $WSC_1$ | $WSC_2$ | $WSC_3$ | $WSC_4$ | $WSC_5$ |
|---|---|---|---|---|---|---|
| U1 | 5842 | 107493 | 18.4 | 103403 | 17.7 | 6215888 |
| U2 | 6824 | 128974 | 18.9 | 124197 | 18.2 | 8257040 |
| U3 | 3685 | 85861 | 23.3 | 82913 | 22.5 | 4543605 |
| U4 | 4608 | 131789 | 28.6 | 128563 | 27.9 | 8451072 |

To compare the complexity, we applied relative complexity indicators, $WSC_2$, $WSC_4$ and $WSC_5$. We can see that all these metrics showed that the U1's web site gained the highest mark, and the U4's website was the most complex one in structure. $U_2$ and $U_3$ are similar. It can be also seen that $WSC_1$ and $WSC_3$ illustrated the same behaviour.

### 5.3 Questionnaire

In the preparation of the questionnaire, an initially list of attributes of navigability were selected based on the literature on website designs, especially the guidelines and heuristics. Eight site-frequent users were also interviewed to obtain the end-users point of view on the most concerned attributes on navigability. Finally, the questionnaire incorporates a subset of the attributes taken from the IEEE standards regarding usability.

The questionnaire consists of eight sections. Each section is concerned with one particular aspect of web navigability. It contains a number of tests for the participants to perform and to give an objective or subjective rating on the attribute, as well as a comment.

Given the differences in the nature of the tests and ranking contained in the sections, the results of the sections have different formats. Some are subjective preferences; some are numerical data. For example, answers to Section 1 are the numbers of clicks, whereas answers to Section 5 are 'yes' or 'no'. To enable statistic data analysis, we used Likert scale, rating from 1 (worst) to 5 (best), to normalize the results. The following summarizes the tests and their meanings of the ratings in each section of the questionnaire.

Section 1 is concerned with the minimal paths to find a specific piece of information on the website. Section 2 is about the availability of alternative paths to find a piece of information. Section 3 is concerned with navigational structure taxonomy. Section 4 tests link visibility, such as link layout, cursor changes and colour changes before and after visited. Section 5 tests the availability and effectiveness of the search facility. Section 6 is concerned with the labels associated to the links in terms of meaningfulness and predictability. Section 7 tests navigational errors. Section 8 is concerned with the availability of supportive mechanism for disabled people, such as large font for weak-sighted people. The results of each section are normalized into a scale from 1 (the worst) to 5 (the best). The results are shown in Table 4.

Table 4 shows that, from participants' subjective point of view, U1 website gained the highest mark on navigability, and U4 the lowest. This matches Table 1 well. This is consistent with all metrics defined in section 3. When deciding the 2nd and 3rd place, $WSC_2$ and $WSC_5$ seem to be the most appropriate metrics for navigability measurement.

Table 4. Questionnaire results of navigability

| **Section** | U1 | U2 | U3 | U4 |
|---|---|---|---|---|
| 1. Minimal path | 4.3 | 3.0 | 3.0 | 2.1 |
| 2. Alternative path | 4.2 | 3.5 | 2.9 | 3.0 |
| 3. Structure taxonomy suitability | 4.2 | 4.8 | 4.2 | 4.1 |
| 4. Link visibility | 4.4 | 4.2 | 4.3 | 3.2 |
| 5. Search facility availability | 4.5 | 3.3 | 4.2 | 3.3 |
| 6. Navigational predictability | 3.2 | 2.8 | 3.1 | 2.6 |
| 7. Navigational errors | 4.8 | 4.6 | 4.2 | 3.6 |
| 8. Supportive mechanism | 1.4 | 1.3 | 1.3 | 1.1 |
| **Total mark** | 31.0 | 27.5 | 27.2 | 23.0 |

## 6. Conclusion and future work

In this paper, we investigated five metrics of website structural complexity. Our empirical study shows that structural complexity plays a significant role in Web navigability. Hence, website structural complexity metrics can be used to measure web navigability indirectly.

There are still some limitations to the metrics approach studied in this paper. For example, the metrics ignore the taxonomy within a page. Other properties, such as layout of links, will also affect navigability. In Figure 11, for example, the left column showed Dan's e-commerce site with hyperlinks arranged alphabetically, the right column organizes hyperlinks according to the topics. Although the number of links is the same, the navigability is apparently different. The results of our empirical study should be understood under the assumption that if both websites are well designed in terms of the taxonomy, etc., the more complex means the less navigable.


Figure 11. Link taxonomy vs. navigability

In the literature of web navigation study, there are several reports on the negative correlation between the number of links and web navigation c.f. [16, 20]. One may argue that if adding some ad hoc links between existing pages, the navigability may be improved although complexity increases. However, from our findings, the metrics of web complexity are proved to be effective measurements of navigability.

For future work, we will investigate the measurements of the cognitive complexity of website, which is more user-centered. Secondly, we will conduct further empirical studies to show the adequacy and appropriateness of our metrics.

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