A Quality Analysis Model of Computer Software System Based on Fuzzy Information Content

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Abstract

Developing computer software system is a crucial part of the intelligent design. In order to solve problems presented in software system quality analysis, this paper proposes a quality analysis model for computer software system based on fuzzy information content. In this model, fuzzy information content of quality analysis indicators is defined according to information axiom, and a software system quality analysis index system is constructed with the basic layer, the support layer and the application layer considered. With the index system, fuzzy information content can be computed and analyzed to obtain fuzzy information content of computer software system. This facilitates the quantitative analysis on the quality of the software system. Finally, an engineering case study is introduced to explain how the model works and proves efficacy and feasibility of the model.

Keywords: quality analysis, computer software system, fuzzy information content, information axiom, intelligent design

1. Introduction

With rapid development of computer science, computer software system, as a crucial part of intelligent design, has received widely attention by researchers and experts [1-3]. In particular, quality analysis of computer software system plays an important role to application, upgrading and maintenance of the whole software system. There is no dearth of relevant research, but quality analysis is a complicated decision-making process, in that the software system is large and factors of quality analysis are fuzzy and uncertain [8-11].

Currently, there are traditional methods and models such as Software Quality Metrics (SQM), Goal Question Metric (GQM), Quality Metrics Methodology (QMM) and ISO/IEC9126. But they are not effective enough for modern software system. For example, (1) even though features of quality analysis are taken into account, but as a lack of clear definition of these features, it is not easy to conduct effective quality analysis; (2) as quality features are fuzzy and uncertain, the completeness and consistency of fuzzy information is overlooked in the quality analysis of the software system; (3) there is no unified standard for the index system of quality analysis. Multi-faced views bring the analysis much limitation. Thus, this paper bases itself on information axiom [12-15], and proposes an optimized quality analysis of computer software system to compute fuzzy information content, aiming at providing support to the development of the computer software system.
2. Fuzzy Information Content of Quality Analysis Indicators According to Information Axiom

Information axiom is one of the two important axioms proposed by Professor. Suh from MIT. The core idea is that under the condition of independent axiom, the system that contains the least information content is the best one. Independent axiom is widely applied to decision-making and evaluation of complicated system. The information content $I$ is measured by the possibility $P$ of realizing the design features. There is:

$$I = -\log_2 (P)$$  

(1)

Under normal condition, the possibility $P$ of realizing the design features is decided by the range of system design $A_s$ and the range of public design $A_c$. So the information content $I$ of the system is:

$$I = -\log_2 \left( \frac{A_s}{A_c} \right)$$  

(2)

$$I = -\log_2 \left( \int_{\text{max}}^{\text{min}} \rho(x) dx \right)$$  

(3)

However, in real situation, it is not easy to obtain possibility $P$. So, this paper proposes an optimized model to compute fuzzy information content according to different categories of design features.

(1) If the fuzzy membership obtained by the design features $\varphi$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-P}$$  

(4)

(2) If the design feature is of maximum-type, and its corresponding fuzzy value of quantity $v = \left[ v(\varphi_{s1}), v(\varphi_{s2}) \right]$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-\frac{v_{opt} + v_{opt}}{2}} = \log_2 e^{1-\frac{v_{opt} + v_{opt}}{2}}$$  

(5)

Where $v_{opt}$ is the optimal value of quantity of the design feature.

(3) If the design feature is of minimum-type, and its corresponding fuzzy value of quantity $v = \left[ v(\varphi_{s1}), v(\varphi_{s2}) \right]$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-\frac{v_{opt} - v_{opt}}{2} \frac{v_{opt} - v_{opt}}{v_{opt} + v_{opt}}} = \log_2 e^{1-\frac{v_{opt} - v_{opt}}{2}}$$  

(6)

(4) If the design feature is of middle-type, and its corresponding fuzzy value of quantity $v = \left[ v(\varphi_{s1}), v(\varphi_{s2}) \right]$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-\frac{v_{mid} - v_{mid}}{2} \frac{v_{mid} - v_{mid}}{v_{mid} + v_{mid}}}$$  

(7)

Where $v_{mid}$ is the optimal value of quantity of the design feature.
3. Quality Analysis Model for Computer Software System based on Fuzzy Information Content

3.1. Quality Analysis Index System

This paper analyzes the quality of the computer software system from three layers, namely, the application layer, the support layer and the basic layer. Quality analysis indicators in the criterion layer are listed below. See Table 1 Quality analysis index system for computer software system.

<table>
<thead>
<tr>
<th>Systematic layer</th>
<th>Criterion layer</th>
<th>Indicator layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality analysis system for the software system</td>
<td>Application</td>
<td>Software operability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software reliability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software access normativity</td>
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<tr>
<td></td>
<td></td>
<td>Software execution efficiency</td>
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<td>Development cost of software</td>
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<td>Development cycle of software</td>
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<tr>
<td></td>
<td></td>
<td>Software accuracy</td>
</tr>
<tr>
<td></td>
<td>Support layer</td>
<td>Software maintainability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software testability</td>
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<tr>
<td></td>
<td></td>
<td>Software configurability</td>
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<tr>
<td></td>
<td></td>
<td>Software portability</td>
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<td></td>
<td></td>
<td>Software maturity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software extensibility</td>
</tr>
<tr>
<td></td>
<td>Basic layer</td>
<td>System functionality</td>
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<td></td>
<td></td>
<td>System compatibility</td>
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<td>System robustness</td>
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<td></td>
<td></td>
<td>Platform exchangeability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System safety</td>
</tr>
</tbody>
</table>

3.2. Fuzzy Information Content of Quality Analysis Indicators in the Criterion Layer for the Software System

Fuzzy information content model is constructed. The systematic layer, the criterion layer and the indicator layer are analyzed to get information content.

3.2.1. Fuzzy Information Content of Indicators in the Application Layer: Operability of the software system can be measured by convenience and practicability. Access normativity refers to standardization and normativity of the software access, both of which are fuzzy description and need to be transformed to fuzzy value of quantity in [0, 1].

Fuzzy information content of operability $I_{ope}$ and access normativity $I_{ntr}$ are:

$$I_{ope} = \log_2 e^{\frac{1}{2}[r_{ope} - r_{ope}']}$$  \hspace{1cm} (8)

$$I_{ntr} = \log_2 e^{\frac{1}{2}[r_{ntr} - r_{ntr}']}$$  \hspace{1cm} (9)
Reliability, execution efficiency and accuracy can be measured by whether the software system is reliable, in high efficiency and functions accurately. If the fuzzy memberships are $\phi_{rel}$, $\phi_{eff}$ and $\phi_{acc}$ respectively, the fuzzy information content of reliability $I_{rel}$, execution efficiency $I_{eff}$ and accuracy $I_{acc}$ are:

$$I_{rel} = \log_2 e^{1-\phi_{rel}}$$

(11)

$$I_{eff} = \log_2 e^{1-\phi_{eff}}$$

(12)

$$I_{acc} = \log_2 e^{1-\phi_{acc}}$$

(13)

Software development cost and development cycle are minimum-type indicators. Suppose their value of quantity is $v_{cos} = [v_{cos}^a, v_{cos}^b]$ and $v_{cyc} = [v_{cyc}^a, v_{cyc}^b]$ respectively, then the fuzzy information content $I_{cos}$ and $I_{cyc}$ are:

$$I_{cos} = \log_2 e \frac{1}{2} \frac{\min (v_{cos}^a) - \max (v_{cos}^b)}{v_{cos}^a - v_{cos}^b}$$

(14)

$$I_{cyc} = \log_2 e \frac{1}{2} \frac{\min (v_{cyc}^a) - \max (v_{cyc}^b)}{v_{cyc}^a - v_{cyc}^b}$$

(15)

### 3.2.2 Fuzzy Information Content of Indicators in the Support Layer:

Software maintainability and testability can be analyzed from the view of maintenance and repair. Software configurability and portability can be analyzed from the view of design reuse. Software maturity and extensibility can be analyzed from the view of design service and system upgrading. Indicators in this layer are all of maximum-type and qualitative fuzzy description. Thus, we need to transform the indicators to fuzzy value of quantity in [0, 1]. Suppose the fuzzy value of quantity for software maintainability, testability, configurability, portability, maturity and extensibility are $v_{mat} = [v_{mat}^a, v_{mat}^b]$, $v_{test} = [v_{test}^a, v_{test}^b]$, $v_{rec} = [v_{rec}^a, v_{rec}^b]$, $v_{port} = [v_{port}^a, v_{port}^b]$, $v_{sca} = [v_{sca}^a, v_{sca}^b]$ respectively, the corresponding fuzzy information content are $I_{mat}$, $I_{test}$, $I_{rec}$, $I_{port}$, $I_{sca}$ and $I_{sca}$:

$$\begin{align*}
I_{mat} &= \log_2 e \frac{1}{2} \frac{v_{mat}^a + v_{mat}^b}{v_{mat}^a + v_{mat}^b} \\
I_{test} &= \log_2 e \frac{1}{2} \frac{v_{test}^a + v_{test}^b}{v_{test}^a + v_{test}^b} \\
I_{rec} &= \log_2 e \frac{1}{2} \frac{v_{rec}^a + v_{rec}^b}{v_{rec}^a + v_{rec}^b} \\
I_{port} &= \log_2 e \frac{1}{2} \frac{v_{port}^a + v_{port}^b}{v_{port}^a + v_{port}^b} \\
I_{sca} &= \log_2 e \frac{1}{2} \frac{v_{sca}^a + v_{sca}^b}{v_{sca}^a + v_{sca}^b} \\
I_{sca} &= \log_2 e \frac{1}{2} \frac{v_{sca}^a + v_{sca}^b}{v_{sca}^a + v_{sca}^b}
\end{align*}$$

(16)

### 3.2.3 Fuzzy Information Content in the Basic Layer:

System functionality and compatibility reflect whether the modules of the software are set up reasonably and whether the software system is compatible. Usually, customers’ requirements are
standards for judgment. This paper turns fuzzy judgment to fuzzy value of quantity in [0, 1]. Suppose the value of quantity of functionality and compatibility are

\[ \mathbf{v}^{fu}_{fu} = \begin{bmatrix} v^{a}_{fu} \\ v^{b}_{fu} \end{bmatrix} \quad \text{and} \quad \mathbf{v}^{co}_{co} = \begin{bmatrix} v^{a}_{co} \\ v^{b}_{co} \end{bmatrix}, \]

the corresponding fuzzy information content are \( I^{fu} \) and \( I^{co} \):

\[
I^{fu} = \log_2 e^{1 - \frac{1}{2} \left( \frac{v^{a}_{fu} + v^{b}_{fu}}{\max_{1 \leq i \leq M} (v^{a}_{fu}, v^{b}_{fu})} \right)} \quad \text{(17)}
\]

\[
I^{co} = \log_2 e^{1 - \frac{1}{2} \left( \frac{v^{a}_{co} + v^{b}_{co}}{\max_{1 \leq i \leq M} (v^{a}_{co}, v^{b}_{co})} \right)} \quad \text{(18)}
\]

System robustness reflects the stability of the system. Small disturbance quantity of parameters under certain conditions reflects whether the system can maintain its function. System robustness is a maximum-type indicator. Suppose the value of quantity is

\[ \mathbf{v}^{ro}_{ro} = \begin{bmatrix} v^{a}_{ro} \\ v^{b}_{ro} \end{bmatrix}, \]

its fuzzy information content is \( I^{ro} \):

\[
I^{ro} = \log_2 e^{1 - \frac{1}{2} \left( \frac{v^{a}_{ro} + v^{b}_{ro}}{\max_{1 \leq i \leq M} (v^{a}_{ro}, v^{b}_{ro})} \right)} \quad \text{(19)}
\]

Platform exchangeability and system safety are measured by exchangeable grade and safety grade. Suppose their value of quantity are \( v^{alt}_{alt} \) and \( v^{saf}_{saf} \), the fuzzy information content are \( I^{alt} \) and \( I^{saf} \):

\[
I^{alt} = \log_2 e^{1 - \frac{v^{b}_{alt}}{\max_{1 \leq i \leq M} (v^{a}_{alt})}} \quad \text{(20)}
\]

\[
I^{saf} = \log_2 e^{1 - \frac{v^{b}_{saf}}{\max_{1 \leq i \leq M} (v^{a}_{saf})}} \quad \text{(21)}
\]

### 3.3. Comprehensive Information Content and the Realization of the Algorithm

Suppose there are \( M \) design schemes, we can get the information content matrices for different layers, namely, \( \mathbf{A}_{app} \), \( \mathbf{A}_{sup} \) and \( \mathbf{A}_{bas} \) based on abovementioned analysis. There are:

\[
\mathbf{A}_{app} = \begin{bmatrix}
I^{11}_{app} & I^{12}_{app} & L & I^{1N}_{app} \\
I^{21}_{app} & I^{22}_{app} & L & I^{2N}_{app} \\
M & M & L & M \\
I^{M1}_{app} & I^{M2}_{app} & L & I^{MN}_{app}
\end{bmatrix}
\]

\[
\mathbf{A}_{sup} = \begin{bmatrix}
I^{11}_{sup} & I^{12}_{sup} & L & I^{1N}_{sup} \\
I^{21}_{sup} & I^{22}_{sup} & L & I^{2N}_{sup} \\
M & M & L & M \\
I^{M1}_{sup} & I^{M2}_{sup} & L & I^{MN}_{sup}
\end{bmatrix}
\]

\[
\mathbf{A}_{bas} = \begin{bmatrix}
I^{11}_{bas} & I^{12}_{bas} & L & I^{1N}_{bas} \\
I^{21}_{bas} & I^{22}_{bas} & L & I^{2N}_{bas} \\
M & M & L & M \\
I^{M1}_{bas} & I^{M2}_{bas} & L & I^{MN}_{bas}
\end{bmatrix}
\]
The weight sequence of quality analysis indicators is \( W = (w_1, w_2, \ldots, w_N) \). So, information sequence of \( M \) design schemes of indicators in different layers are \( I_{app} \) and \( I_{bas} \). There are:

\[
egin{align*}
I_{app} &= W_{app}^T \ast A_{app} \\
I_{sup} &= W_{sup}^T \ast A_{sup} \\
I_{bas} &= W_{bas}^T \ast A_{bas}
\end{align*}
\]  

(26)

The information content matrix \( I_{cri} \) of indicators in the criterion layer is:

\[
I_{cri} = \begin{bmatrix}
I_{app}^{11} & I_{app}^{12} & I_{bas}^{11} \\
I_{sup}^{21} & I_{sup}^{22} & I_{bas}^{21} \\
I_{bas}^{31} & I_{bas}^{32} & I_{bas}^{33}
\end{bmatrix}
\]

(27)

In the same way, we can get the weight sequence corresponding to different criteria layers. So the fuzzy information content sequence \( I_{sys} \) of \( M \) design schemes is:

\[
I_{sys} = W_{cri}^T \ast I_{cri} = (I_{sys}^1, I_{sys}^2, \ldots, I_{sys}^M)
\]

(28)

According to the information axiom, the optimal system \( i \) has the minimum information content. There is:

\[
I_{sys}^i = min\{I_{sys}^1, I_{sys}^2, \ldots, I_{sys}^M\}
\]

(29)

4. Empirical Studies

Bidding schemes for software integration system of warehouse logistics of an electronic device company are studied in order to prove the efficacy of the quality analysis model for computer software system. These bidding schemes are subject to analysis and evaluation. We have consulted with designers of the software system from candidate software technology companies, experts in the IT industry and technicians in relevant research institutions. Production requirement of the company is also taken into account. Data of bidding schemes are shown in Table 2.
<table>
<thead>
<tr>
<th>System layer</th>
<th>Criterion layer</th>
<th>Weight</th>
<th>Indicator layer</th>
<th>Weight</th>
<th>Initial value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>System A</td>
</tr>
<tr>
<td>Quality analysis system for the software system</td>
<td>Application</td>
<td>0.30</td>
<td>Software operability</td>
<td>0.10</td>
<td>0.93-0.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software reliability</td>
<td>0.20</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software access normativity</td>
<td>0.15</td>
<td>0.91-0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software execution efficiency</td>
<td>0.15</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Development cost of software</td>
<td>0.10</td>
<td>75-85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Development cycle of software</td>
<td>0.10</td>
<td>6.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software accuracy</td>
<td>0.20</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Support layer</td>
<td>0.40</td>
<td>Software maintainability</td>
<td>0.25</td>
<td>0.91-0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software testability</td>
<td>0.15</td>
<td>0.85-0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software configurability</td>
<td>0.15</td>
<td>0.91-0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software portability</td>
<td>0.10</td>
<td>0.93-0.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software maturity</td>
<td>0.25</td>
<td>0.85-0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Software extensibility</td>
<td>0.10</td>
<td>0.93-0.97</td>
</tr>
<tr>
<td></td>
<td>Basic layer</td>
<td>0.30</td>
<td>System functionality</td>
<td>0.25</td>
<td>0.93-0.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>System compatibility</td>
<td>0.15</td>
<td>0.85-0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>System robustness</td>
<td>0.20</td>
<td>0.83-0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Platform exchangeability</td>
<td>0.15</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>System safety</td>
<td>0.25</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Information content of quality analysis indicators for different systems are computed based on the information content model, as is shown in Table 3.
<table>
<thead>
<tr>
<th>System layer</th>
<th>Criterion layer</th>
<th>Indicator layer</th>
<th>Information content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Software operability</td>
<td>0.072  0.216  0.144</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software reliability</td>
<td>0.101  0.144  0.144</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software access normativity</td>
<td>0.101  0.216  0.101</td>
</tr>
<tr>
<td></td>
<td>Application</td>
<td>Software execution efficiency</td>
<td>0.144  0.101  0.072</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Development cost of software</td>
<td>0  0.394  0.519</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Development cycle of software</td>
<td>0.375  0.701  0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software accuracy</td>
<td>0  0  0.072</td>
</tr>
<tr>
<td>Quality analysis system for the software system</td>
<td>Support layer</td>
<td>Software maintainability</td>
<td>0.101  0.115  0.144</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software testability</td>
<td>0.144  0.144  0.072</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software configurability</td>
<td>0.101  0.144  0.072</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software portability</td>
<td>0.072  0.216  0.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software maturity</td>
<td>0.144  0.072  0.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software extensibility</td>
<td>0.072  0.216  0.216</td>
</tr>
<tr>
<td></td>
<td>Basic layer</td>
<td>System functionality</td>
<td>0.072  0.216  0.144</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System compatibility</td>
<td>0.144  0.216  0.101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System robustness</td>
<td>0.216  0.216  0.101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Platform exchangeability</td>
<td>0.144  0.144  0.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System safety</td>
<td>0.072  0.072  0.144</td>
</tr>
</tbody>
</table>

In the same way, we can get the information content in the criterion layer for different systems. Details are shown in Table 4.
Thus, we can get the information content for the software system. $I^A_{sys} = 0.1122$, $I^B_{sys} = 0.1682$ and $I^C_{sys} = 0.1445$. Obviously, software integration system A of warehousing logistics provided by the bidder is the best.

5. Conclusion

This paper studies problems and limitations of the quality analysis in the development of software system and proposes a quality analysis model for computer software system based on fuzzy information content. It is innovative in the following 3 aspects. 1. It constructs an optimized quality analysis index system for computer software system. 2. It draws merits from the information axiom and the fuzzy theory and constructs a fuzzy information content model for computer software system. 3. It takes an engineering case study and proves the efficacy of the model. Compared to traditional analysis, this model is comprehensive, accurate and operable, and easy to achieve on the computer. It is worthy of application. Limitation is that quality analysis indicators can be more detailed and fuzzy information content can be further optimized.

References


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Tian Liang. Current position, grades: the A lecturer of Shandong Agriculture and Engineering University, China.
University studies: received his Software engineering from Shandong University in China. She received her M.Sc. from Shandong University in China.
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Experience: She has teaching experience of eight years, has completed three scientific research projects.