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

Tian Liang

Shandong agriculture and engineering university, Dormitory building 1-2-702, Zhudian, Licheng district, Jinan city, Shandong Province
Zip code 250100
liangtian_ngy@sina.com

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:

$$I = -log_2(P) = -log_2\left(\frac{A_S}{A_C}\right)$$

(2)

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

(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 φ, the corresponding fuzzy information content is:

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

(4)

(2) If the design feature is of maximum-type, and its corresponding fuzzy value of quantity $v = \left[v(\varphi_{x1}), v(\varphi_{x2})\right]$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-\frac{1}{2}\left(\frac{v(\varphi_{x1})+v(\varphi_{x2})}{v_{opt}}\right)} = \log_2 e^{1-\frac{1}{2}\left(\frac{v(\varphi_{x1})+v(\varphi_{x2})}{max(v(\varphi_{x2}))}\right)}$$

(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 $v = \left[v(\varphi_{x1}), v(\varphi_{x2})\right]$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-\frac{1}{2}\left(\frac{v_{opt}}{v(\varphi_{x1})}+\frac{v_{opt}}{v(\varphi_{x2})}\right)} = \log_2 e^{1-\frac{1}{2}\left(\frac{min(v(\varphi_{x1}))}{v(\varphi_{x1})}+\frac{min(v(\varphi_{x1}))}{v(\varphi_{x2})}\right)}$$

(6)

(4) If the design feature is of middle-type, and its corresponding fuzzy value of quantity $v = \left[v(\varphi_{x1}), v(\varphi_{x2})\right]$, the corresponding fuzzy information content is:

$$I = \log_2 e^{1-\frac{1}{2}\left(\frac{v(\varphi_{x1})}{v_{mid}}+\frac{v_{mid}}{v(\varphi_{x2})}\right)}$$

(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 1. Quality Analysis Index System for Computer Software System

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

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_{int} are:

$$I_{ope} = \log_2 e^{1-\frac{1}{2}\left(v_{ope}^a + v_{ope}^b\right)}$$

(8)

$$I_{int} = \log_2 e^{1-\frac{1}{2}\left(v_{int}^a + v_{int}^b\right)}$$

(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 φ_{rel}, φ_{eff} and φ_{acc} respectively, the fuzzy information content of reliability I_{rel}, execution efficiency I_{eff} and accuracy I_{acc} are:

$$I_{rel} = \log_2 e^{1-\varphi_{rel}} \tag{11}$$

$$I_{eff} = \log_2 e^{1-\varphi_{eff}} \tag{12}$$

$$I_{acc} = \log_2 e^{1-\varphi_{acc}} \tag{13}$$

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

$$I_{\cos} = \log_2 e^{1-\frac{1}{2}\left(\frac{\min\limits_{1 \le i \le m}\left(v_{\cos}^a \right)}{v_{\cos}^a} + \frac{\min\limits_{1 \le i \le m}\left(v_{\cos}^a \right)}{v_{\cos}^b} \right)} \tag{14}$$

$$I_{cyc} = \log_2 e^{1-\frac{1}{2}\left(\frac{\min\limits_{1 \le i \le m}\left(v_{cyc}^a \right)}{v_{cyc}^a} + \frac{\min\limits_{1 \le i \le m}\left(v_{cyc}^a \right)}{v_{cyc}^b} \right)} \tag{15}$$

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 $v_{mai} = \left[v_{mai}^a, v_{mai}^b \right]$, $v_{tes} = \left[v_{tes}^a, v_{tes}^b \right]$, $v_{rec} = \left[v_{rec}^a, v_{rec}^b \right]$, $v_{por} = \left[v_{por}^a, v_{por}^b \right]$, $v_{mat} = \left[v_{mat}^a, v_{mat}^b \right]$ and $v_{sca} = \left[v_{sca}^a, v_{sca}^b \right]$ respectively, the corresponding fuzzy information content are I_{mai}, I_{tes}, I_{rec}, I_{por}, I_{mat} and I_{sca}:

$$\begin{cases} I_{mai} = \log_2 e^{1-\frac{1}{2}\left(v_{mai}^a + v_{mai}^b \right)} \\ I_{tes} = \log_2 e^{1-\frac{1}{2}\left(v_{tes}^a + v_{tes}^b \right)} \\ I_{rec} = \log_2 e^{1-\frac{1}{2}\left(v_{rec}^a + v_{rec}^b \right)} \\ I_{por} = \log_2 e^{1-\frac{1}{2}\left(v_{por}^a + v_{por}^b \right)} \\ I_{mat} = \log_2 e^{1-\frac{1}{2}\left(v_{mat}^a + v_{mat}^b \right)} \\ I_{sca} = \log_2 e^{1-\frac{1}{2}\left(v_{sca}^a + v_{sca}^b \right)} \end{cases} \tag{16}$$

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 $v_{fun} = \left[v_{fun}^a, v_{fun}^b \right]$ and $v_{com} = \left[v_{com}^a, v_{com}^b \right]$, the corresponding fuzzy information content are I_{fun} and I_{com} :

$$I_{fun} = \log_2 e^{1 - \frac{1}{2}\left(v_{fun}^a + v_{fun}^b \right)} \tag{17}$$

$$I_{com} = \log_2 e^{1 - \frac{1}{2}\left(v_{com}^a + v_{com}^b \right)} \tag{18}$$

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 $v_{rob} = \left[v_{rob}^a, v_{rob}^b \right]$, its fuzzy information content is I_{rob} :

$$I_{rob} = \log_2 e^{1 - \frac{1}{2}\left(\frac{v_{rob}^a + v_{rob}^b}{\max\limits_{1 \leq i \leq m}(v_{rob}^b)} \right)} \tag{19}$$

Platform exchangeability and system safety are measured by exchangeable grade and safety grade. Suppose their value of quantity are v_{alt} and v_{saf}, the fuzzy information content are I_{alt} and I_{saf} :

$$I_{alt} = \log_2 e^{1 - \frac{v_{alt}^b}{\max\limits_{1 \leq i \leq m}(v_{alt}^b)}} \tag{20}$$

$$I_{saf} = \log_2 e^{1 - \frac{v_{saf}^b}{\max\limits_{1 \leq i \leq m}(v_{saf}^b)}} \tag{21}$$

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, A_{app}, A_{sup} and A_{bas} based on abovementioned analysis. There are:

$$A_{app} = \begin{bmatrix} I_{app}^{11} & I_{app}^{12} & L & I_{app}^{1N} \\ I_{app}^{21} & I_{app}^{22} & L & I_{app}^{2N} \\ M & M & L & M \\ I_{app}^{M1} & I_{app}^{M2} & L & I_{app}^{MN} \end{bmatrix} \tag{23}$$

$$A_{sup} = \begin{bmatrix} I_{sup}^{11} & I_{sup}^{12} & L & I_{sup}^{1N} \\ I_{sup}^{21} & I_{sup}^{22} & L & I_{sup}^{2N} \\ M & M & L & M \\ I_{sup}^{M1} & I_{sup}^{M2} & L & I_{sup}^{MN} \end{bmatrix} \tag{24}$$

$$A_{bas} = \begin{bmatrix} I_{bas}^{11} & I_{bas}^{12} & \mathrm{L} & I_{bas}^{1N} \\ I_{bas}^{21} & I_{bas}^{22} & \mathrm{L} & I_{bas}^{2N} \\ \mathbf{M} & \mathbf{M} & \mathbf{L} & \mathbf{M} \\ I_{bas}^{M1} & I_{bas}^{M2} & \mathrm{L} & I_{bas}^{MN} \end{bmatrix} \tag{25}$$

The weight sequence of quality analysis indicators is $W = (w_1, w_2, \mathrm{L}, w_N)$. So, information sequence of M design schemes of indicators in different layers are I_{app}, I_{sup} and I_{bas}. There are:

$$\begin{cases} I_{app} = W_{app}^{T} * A_{app} \\ I_{sup} = W_{sup}^{T} * A_{sup} \\ I_{bas} = W_{bas}^{T} * A_{bas} \end{cases} \tag{26}$$

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

$$I_{cri} = \begin{bmatrix} I_{app}^{11} & I_{sup}^{12} & I_{bas}^{13} \\ I_{app}^{21} & I_{sup}^{22} & I_{bas}^{23} \\ & & \\ I_{app}^{M1} & I_{sup}^{M2} & I_{bas}^{M3} \end{bmatrix} \tag{27}$$

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:

$$I_{SYS} = W_{cri}^{T} * I_{cri} = (I_{SYS}^{1}, I_{SYS}^{2}, \mathrm{L}, I_{SYS}^{M}) \tag{28}$$

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

$$I_{SYS}^{i} = min(I_{SYS}^{1}, I_{SYS}^{2}, \mathrm{L}, I_{SYS}^{M}) \tag{29}$$

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 2. Initial Data of Quality Analysis of the Software System

System layer	Criterion layer	Weight	Indicator layer	Weight	Initial value		
					System A	System B	System C
Quality analysis system for the software system	Application	0.30	Software operability	0.10	0.93-0.97	0.83-0.87	0.85-0.95
			Software reliability	0.20	0.93	0.90	0.90
			Software access normativity	0.15	0.91-0.95	0.88-0.94	0.91-0.95
			Software execution efficiency	0.15	0.90	0.93	0.95
			Development cost of software	0.10	75-85	105-115	120-130
			Development cycle of software	0.10	6.50	8.76	4.50
			Software accuracy	0.20	1.00	1.00	0.95
	Support layer	0.40	Software maintainability	0.25	0.91-0.95	0.90-0.94	0.85-0.95
			Software testability	0.15	0.85-0.95	0.85-0.95	0.93-0.97
			Software configurability	0.15	0.91-0.95	0.85-0.95	0.93-0.97
			Software portability	0.10	0.93-0.97	0.80-0.90	0.80-0.90
			Software maturity	0.25	0.85-0.95	0.93-0.97	0.80-0.90
			Software extensibility	0.10	0.93-0.97	0.80-0.90	0.80-0.90
	Basic layer	0.30	System functionality	0.25	0.93-0.97	0.80-0.90	0.85-0.95
			System compatibility	0.15	0.85-0.95	0.80-0.90	0.91-0.95
			System robustness	0.20	0.83-0.87	0.83-0.87	0.91-0.95
			Platform exchangeability	0.15	0.90	0.90	0.85
			System safety	0.25	0.95	0.95	0.90

Information content of quality analysis indicators for different systems are computed based on the information content model, as is shown in Table 3.

Table 3. Information Content of Quality Analysis Indicators of the Software System

System layer	Criterion layer	Indicator layer	Information content		
			System A	System B	System C
Quality analysis system for the software system	Application	Software operability	0.072	0.216	0.144
		Software reliability	0.101	0.144	0.144
		Software access normativity	0.101	0.216	0.101
		Software execution efficiency	0.144	0.101	0.072
		Development cost of software	0	0.394	0.519
		Development cycle of software	0.375	0.701	0
		Software accuracy	0	0	0.072
	Support layer	Software maintainability	0.101	0.115	0.144
		Software testability	0.144	0.144	0.072
		Software configurability	0.101	0.144	0.072
		Software portability	0.072	0.216	0.216
		Software maturity	0.144	0.072	0.216
		Software extensibility	0.072	0.216	0.216
	Basic layer	System functionality	0.072	0.216	0.144
		System compatibility	0.144	0.216	0.101
		System robustness	0.216	0.216	0.101
		Platform exchangeability	0.144	0.144	0.216
		System safety	0.072	0.072	0.144

In the same way, we can get the information content in the criterion layer for different systems. Details are shown in Table 4.

Table 4. Information Content of Indicators in the Criterion Layer

System layer	Criterion layer	Indicator layer		
		System A	System B	System C
Quality analysis system for the software system	Application layer	0.10165	0.20745	0.13545
	Support layer	0.1124	0.13315	0.1548
	Basic layer	0.1224	0.1758	0.13975

Thus, we can get the information content for the software system. $I_{sys}^{A} = 0.1122$, $I_{sys}^{B} = 0.1682$ and $I_{sys}^{C} = 0.1445$. 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.

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Author

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.

Scientific interest: She research interest fields include Computer application, Software engineering.

Publications: more than four papers published in various journals.

Experience: She has teaching experience of eight years, has completed three scientific research projects.