Software Quality Classification Model based on McCabe's Complexity Measure

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Abstract

A software quality classification model based on McCabe's complexity measure is investigated. It is experimentally shown using regression and discriminant analyses that program fault density (number of faults per 1000 source lines of code) depends on the complexity of the functional unit rather than on that of each of the modules. To identify the best model, stepwise selection method improved by AIC (Akaike Information Criterion) is applied to regression and discriminant analyses. A functional unit is the partitioning unit of the software function and consists of several modules that are combined with data that is commonly referred to or updated. This partitioning is done in the early phases of the software life cycle and experiments show that interfaced complexity among functional units is associated with software faults. The concept of an "extended cyclomatic number (S_1')" - an extension of McCabe's design complexity measure S_1 from an inner-functional-unit control structure to a between-functional-unit control structure - is proposed taking this complexity tendency into consideration and is experimentally studied. It is well known that S_1 is equal to the number of predicates + 1. In the metric S_1' , the nesting depth of predicate nodes for invoking module path selection is taken into consideration. The number of predicates whose scope is confined to a functional unit can be separately counted from the predicates whose scope extends to different functional units. This software quality classification model with the extended cyclomatic number enables project managers to control software quality.

Keywords

Software quality classification, McCabe's complexity measure, regression analysis, discriminant analysis, AIC

1 Introduction

The relationship between software quality and complexity metrics has been researched for many years [Li, Cheung, 1987]. These experiments have shown that complexity metrics are interrelated with each other and several complexity metrics are related to software quality to some degree. Taking the relationship between complexity metrics and software quality into consideration, various software quality prediction models have been developed [Takahashi, Wakayama, 1994; Munson, Khoshgoftaar,

1992; Rodriguez, Tsai, 1987].

Complexity metrics, such as the cyclomatic number for measuring the complexity of the software control structure [McCabe, 1976], are used as indicators for program modularization, revising specifications, and test coverage. In addition, they have been used in software quality prediction models, whose purposes include predicting fault numbers through multivariate regression analysis and identification of error-prone modules based on discriminant analysis. Those models, however, are based on metric data and quality data contained in the program modules themselves and do not sufficiently take the functional relations between modules into consideration. Here, a module is defined as the lowest level unit of hierarchical functional partitioning [De Marco, 1986] and corresponds to a function in C-coding [Richie, Kernighan, 1978], and module's size was experientially shown to be of the order of $10^1 \sim 10^2$ SLOC (source lines of code).

In our experiments, on the contrary, the relationship between complexity metrics and software quality were investigated using multivariate regression analysis. The results show that program fault density (fault number per 1000 SLOC), which we use as a measure of software quality, does not depend on the complexity density (ex. cyclomatic number per 1000 SLOC) of every fault module but on the complexity of the functional unit with modules functionally related to the fault module. In other words, variance analysis shows that program fault density is mostly characterized by functional units. A functional unit is a program unit partitioned in the early phases of software development from the standpoints of data structure or process and corresponds to a certain hierarchical level of partitioning software. Each unit consists of several modules (coincident with functions in C-coding) and functional unit's size is experientially shown to be of the order of 10^3 SLOC, which is suitable for a programmer to design, to code and to test. Since a software quality control unit should be a manageable comprehensible evaluation unit, it generally accords with a functional unit.

The next phase of our investigation was characterization of functional units with complexity metrics, using the techniques of discriminant analysis with stepwise selection method improved by AIC (Akaike Information Criterion) estimates [Takahashi, Wakayama, 1994; Akaike, 1974], but unfortunately the ratio of correct classification-ratio was not very high. In the work reported here, we used 12 complexity metrics obtained from the viewpoints of source lines of code [Yu, Smith, Huang, 1991], the cyclomatic number that measures the number of predicates [McCabe, 1976], the fan-in and fan-out that measures the complexity of information flow [Henry, Kafura, 1981], the number of external variables [Halstead, 1977], and comment lines [Woodfield, Dunsmore, Shen, 1981]. The main reason the missclassification ratio was high in the previous work is probably that these 12 complexity metrics could not sufficiently represent the functional relationship among the modules that compose a functional unit. Agresti has measured the interfaced complexity among modules by the "context-coupling" metric [Agresti, Evanco, 1992] and "relative complexity" metric [Card, Agresti, 1988]. The former metric counts the number of data commonly used among modules to measure the interconnection of modules and the latter metric counts the number of invoking modules and I/O variables. But data obtained by using these metrics represent interfaced complexity from every module's viewpoint and can't sufficiently represent the complexity of a functional unit. On the other hand, McCabe proposed integration complexity measure S_1 [McCabe, Butler, 1989] to measure complexity of an inner-func-

tional - unit control structure in the design phase and to count the number of predicates that select the invoking module path. But our experiments using regression analysis have shown that the correlation coefficient between S_1 and program fault density is not so high ($R^2=0.10$) and only the interfaced complexity among modules in a functional unit is not thorough enough to represent the complexity tendency of a functional unit.

To solve this problem, the "extended cyclomatic number" S_1' is proposed, considering the relationship among functional units, and the validation of this metric is empirically and statistically studied. The proposed cyclomatic number extends the concepts of integration complexity measure S_1 . The applied area of McCabe's complexity metric is extended from an inner-functional-unit control structure to a between-functional-unit control structure. A functional unit control structure is represented by a graph. In the graph, S_1 is defined as number of edges - number of nodes + 2, where nodes correspond to invoking functions or invoking predicates and edges correspond to executing sequences of nodes. It is well known that S_1 is equal to the number of predicates + 1. In the metric S_1' , nesting depth of predicate nodes for invoking module path selection is taken into consideration. In it, the number of predicates whose scope is confined to a functional unit can be separately counted from those predicates whose scope extends to different functional units. Consequently, the interfaced complexity among different functional units can be obtained using the metric S_1' and the accuracy of software quality evaluation model can be increasingly improved. In fact, our experiments on regression analysis applied to a small scale program (about 10 thousand of SLOC) have shown that the correlation coefficient between S_1' and the program fault density is very high ($R^2=0.70$). This software quality classification model with the extended cyclomatic number that shows the interfaced complexity among functional units enables project managers to control software quality.

2 The extended cyclomatic number

2.1 The applied area of the metric S_1'

Fig. 1. Background

The applied area of the extended cyclomatic number S_1' is shown in Fig. 1. S_1' is expressed as the thin hatched areas. To measure interfaced complexity among software quality evaluation units of a certain hierarchical level partitioning, complexity metrics are divided into three classes: an inner-module level complexity metric (to measure complexities of an inner module whose size is of the order of $10^1 \sim 10^2$ SLOC and McCabe's original complexi-

ity metric is part of this class), an inner-functional-unit level complexity metric (to measure complexities of an inner functional unit that has the size of the order of 10^3 SLOC, where a functional unit consists of several modules and McCabe's design complexity measure S_1 belongs to this class), and an inner-subsystem level complexity metric (to measure complexities of an inner subsystem that has the size of the order of 10^4 SLOC, where a subsystem consists of several functional units). The metric S_1' is an inner-subsystem level metric that measures interfaced complexity among functional units. In S_1' , nesting depth of predicate nodes for invoking module path selection is taken into consideration. This metric extends the concepts of integration complexity measure S_1 proposed by McCabe. The purpose of S_1 is to measure the complexity of an inner functional unit control structure and it is well known that it is equal to the number of predicates + 1. With S_1 , inner logic of every module is not taken into consideration; a path that does not influence the interrelationship between modules is eliminated. The metric S_1 itself is an extended metric of McCabe's original cyclomatic number V from an inner-module-control structure to a between-module-control structure. In this research, the applied area of McCabe's complexity metric is extended from an inner-functional-unit control structure to a between-functional-unit control structure. In the metric S_1' , the number of predicates whose scope is confined to a functional unit can be separately counted from those predicates whose scope extends to different functional units. A software control unit corresponds to a software functional unit, and a software functional unit corresponds to a subtree of a hierarchical module control structure [De Marco, 1986]. We call this tree call & called module tree. The partitioning function corresponds to a call & called module tree decomposed into several subtrees.

2.2 Concepts of the metric S_1'

(1) Re-definition of integration complexity metric $S_1(G)$

Before we describe the concepts of S_1' , the concepts of McCabe's design complexity measure S_1 are reviewed. The metric S_1 is an extension of McCabe's original complexity metric from an inner-module control structure to a between-module (an inner-functional-unit) control structure. A module is assumed to correspond to a function in C coding. The metric $S_1(G)$ measures the complexity of a functional unit graph G . A node in G not only corresponds to a function in C-coding but also to a predicate for invoking function path selection. An edge in G corresponds to an invoking function or invoking function path selection. $S_1(G)$ does not reflect the inner logic complexity of every function. Hence, $S_1(G)$ is defined as

$$S_1(G) = e_1 - n_1 + 2,$$

where e_1 is the number of edges and n_1 is the number of nodes in graph G . On the other hand, the purpose of the original McCabe's complexity metric [McCabe, 1976] $V(F)$ is to measure the complexity of the inner-logic of every function F , and $V(F)$ is defined as $e - n + 2$, where e is the number of edges and n is the number of nodes in graph F . In graph F , a node corresponds to an instruction statement or a decision statement in C-coding, and an edge signifies the execution of sequences of nodes. It is well known that $V(F)$ is equal to the number of predicates plus one in structured programming, and is equal to the number of regions (Euler's formula in a connected plane graph). The

Fig. 2. McCabe's integration measure $S_1(G)$.

Then $S_1(G) = \text{number of edges} - \text{number of nodes} + 2 = 13 - 11 + 2 = 4$ and is equal to the number of predicates (3) + 1. Furthermore, as you can see in the graph, $S_1(G)$ is equal to the number of regions (①~④). You can also see that S_1 in a reduced graph G' is consistent with S_1 in the original graph G , where a reduced graph G' includes predicate nodes but not function nodes.

(2) Definition of the extended cyclomatic number S_i'

The extended cyclomatic number S_i' extends the concepts of integration complexity measure S_i , considering the effects of interfaced complexity among functional units. The metric $S_i'(G)$ classifies predicate nodes into $S_{i_0}(G)$ and $S_{i_1}(G)$, taking the nesting depth (i.e. scope) of predicate nodes for invoking module path selection into consideration [Howatt, Baker, 1989]. The number of predicates whose scope is confined to a functional unit can be separately counted from those predicates whose scope extends to different functional units. The scope of predicate node X includes a set of functions whose executions are controlled by decision statement X , where nesting of predicate nodes is taken into consideration. When a predicate node Y is directly or indirectly controlled by predicate node X , not only functions whose executions are directly controlled by predicate X , but also functions whose executions are controlled by predicate Y are included in the scope of X .

[Definition of S_i']

The metric S_i' is divided into two metrics.

- (A) $S_{i_0}(G)$: The extended cyclomatic number of inner quality control unit subtrees • • This class consists of predicates in G whose scope is confined to functions defined in a functional unit G . $S_{i_0}(G)$ is the number of predicates (plus + 1) belonging to this class.
- (B) $S_{i_1}(G)$: The extended cyclomatic number among different quality control unit subtrees • • • This class consists of two sets of predicates. The first set consists of predi-

graph theory is also applicable to a between-module control structure S_i , so the metric S_i is considered to be an extension of McCabe's original complexity metric V and it is proved that $S_i(G)$ equals the number of predicates (plus 1) for invoking function path selection.

[An application of S_i]

An example of $S_i(G)$ is illustrated in Fig. 2. This graph consists of six functions denoted A, B, C, D, E, F, an end node, and 3 predicates, $\gamma 1$, $\gamma 2$, and $\gamma 3$. A invokes C when $\gamma 1$ is satisfied, and invokes B when $\gamma 1$ is not satisfied. B invokes F when $\gamma 2$ is satisfied, and invokes D when $\gamma 2$ is not satisfied. D invokes F when $\gamma 3$ is satisfied, and invokes E when $\gamma 3$ is not satisfied. E invokes B recursively.

Then $S_i(G) = \text{number of edges} - \text{number of nodes} + 2 = 13 - 11 + 2 = 4$ and is equal to the number of predicates (3) + 1. Furthermore, as you can see in the graph, $S_i(G)$ is equal to the number of regions (①~④). You can also see that S_i in a reduced graph G' is consistent with S_i in the original graph G , where a reduced graph G' includes predicate nodes but not function nodes.

cates in G whose scope includes functions defined in another functional unit G' . $S_{i_0}: 4$. $S_{i_1}: 2$. The second set consists of predicates in another functional unit G' whose scope includes functions defined in G itself. $S_{i_1}(G)$ is the summation of the number of predicates that belong to the first set and the number of predicates that belong to the second set.

$S_{i_0}(G)$ measures the complexity of an inner-functional-unit control structure and $S_{i_1}(G)$ measures the complexity of a between-functional-unit (i.e. an inner-subsystem-unit) control structure.

[An application of $S_{i'}$]

An example of $S_{i'}$ (S_{i_0}, S_{i_1}) is shown in Fig. 3, where

the graph indicates information flow among functions including predicates for invoking function path selection, and $\rightarrow$ denotes the invoking function or invoking predicate in an inner-quality-control subtree, and $\cdots \rightarrow$ denotes the invoking function among different quality control-unit subtrees. This example has three software quality control units, A, B, and C. In the graph the end node of every quality control unit is also shown. Subtree A is connected with subtree C by arc $A6 \rightarrow C1$, where $A6$ and $C1$ are functions. Subtree B is connected with subtree A by arc $\beta 2 \rightarrow A6$ and is also connected with subtree C by arc $B4 \rightarrow C1$, where $\beta 2$ is an executing condition (predicate) of function $A6$ and $B4$ is a function. From subtree C's standpoint, as the scope of three predicates $\gamma 1$, $\gamma 2$, $\gamma 3$ includes only functions $C2$, $C3$, $\dots$ $C7$ defined in C itself, it follows that $S_{i_0}(C)=3+1=4$. In addition, as the execution of function $C1$ is controlled by predicates $\alpha 1$, $\alpha 3$, $\beta 1$, and $\beta 2$ in functional units A, and B, it follows that $S_{i_1}(C)=4$. Similarly from subtree A's standpoint, predicates $\alpha 2$ and $\alpha 4$ ($\alpha 4$ has three branches so the number of predicates of $\alpha 4$ is 2) only control execution of functions $A4$, $A7$, and $A8$ defined in A itself, so it follows that $S_{i_0}(A)=3+1=4$. Since the scope of predicates $\alpha 1$, $\alpha 3$ not only includes functions defined in A itself but also includes function $C1$ defined in functional unit C, it follows that $S_{i_1}(A)=2$. Similarly, $S_{i_0}(B), S_{i_1}(B)$ are counted. The calculation is summarized as follows:

- $S_{i_0}(A) = 4 = \{\alpha 2, \alpha 4^*\} + 1$, $S_{i_1}(A) = 2 = \{\alpha 1, \alpha 3\}$
- $S_{i_0}(B) = 4 = \{\beta 3, \beta 4, \beta 5\} + 1$, $S_{i_1}(B) = 2 = \{\beta 1, \beta 2\}$
- $S_{i_0}(C) = 4 = \{\gamma 1, \gamma 2, \gamma 3\} + 1$, $S_{i_1}(C) = 4 = \{\alpha 1, \alpha 3, \beta 1, \beta 2\}$.

Here $\{ \}$ is a set of predicates, $\alpha 4^*$ has 3 branches and is counted as two

Fig. 3. An application of $S_{i'}$.

predicates, $S_1_0(X)$ = number of elements of set X plus one, and $S_1_1(X)$ = number of elements of a set X .

3 A case study

3.1 Sample spaces

Metric and quality data were obtained from the DBMS (Database Management System) maintenance program developed by NTT Information and Communication Systems Laboratories. This program is a subsystem of the DBMS. Our program is written in C and consists of 10 KDSI (thousands of delivered source instructions). Its function is to change DB attributes and directories during online operations. It consists of seven excluded software quality control units. Each quality control unit consists of several routines, and a routine coincides with a compiled file designated by *.c in UNIX. Each file consists of several functions in C coding. Overall, the DB maintenance program consists of 50 routines, and 144 functions. The sample spaces of the seven units are scribed as follows: the 1st group (the initializer/terminator is designated by ● in Figures 4, 5, and 7) and consists of 7 routines, 21 functions, 1.4 KDSI (shortened to (●,7,21,1.4) hereafter); the 2nd group (the SQL analyzer) consists of (○,9,39,2.8); the 3rd group (the garbage collector), (×,7,3,0.5); the 4th (the data transporter) of (△,42,10,2.4); the 5th (the SQL parameter generator), (□,19,8,1.6); the 6th (the SG parameter reformatizer), (■,6,6,0.6); and the 7th (common modules), (▲,10,7,0.9).

3.2 Complexity metrics

In this investigation, we used 12 complexity metrics obtained from the viewpoints of source lines of code [Yu, Smith, Huang, 1991], the cyclomatic number that counts the number of predicates [McCabe, 1976], the fan-in and fan-out that measures the complexity of information flow [Henry, Kafura, 1981], the number of external and static variables [Halstead, 1977], and comment lines [Woodfield, Dunsmore, Shen, 1981]. A summary is given in Table 1.

Table 1. Summary of complexity metrics used in the case study

Complexity metrics class and its subclasses		abbreviation: Definition in C [8]
McCabe's complexity measure		CC0: cyclomatic number without case CC1: cyclomatic number with case
fan-in & fan-out	subsystem level evaluation (includes debug-macro & common module)	FA1: (call to * call from) ²
		FA2: (to num * from num) ²
	subsystem level evaluation (excludes debug-macro & common module)	FA3: (call to * call from) ²
		FA4: (to num * from num) ²
	functional level evaluation (excludes debug-macro & common module)	FA5: (call to * call from) ²
		FA6: (to num * from num) ²
source lines of code		EXEC: instruction lines + declare lines + SQL lines DEB: debug lines
global variables		REF: occurrence of external and static variables
comment lines		COM: comment lines + blank lines

[The metric "fan-in & fan-out"]

The metric "fan-in & fan-out" investigated in this study is not consistent with what Henry & Kafura originally proposed. In this paper, "fan-in & fan-out" is confined to the local flow [Henry, Kafura, 1981] of function invoking, and is classified into 6 patterns by the combination of three conditions: whether common modules or debug macros are excluded or not in every quality control unit, whether invoking functions among different functional units are taken into consideration or not, and whether total occurrences of invoking functions are taken into consideration or not. In the table,

- call to = number of distinct functions that call to other functions
- call from = number of distinct functions that are called from other functions
- to num = total numbers of function calling
- from num = total numbers of function called

3.3 Relationship between program fault density and module complexity density

The software control units were the 50 routines mentioned in section 3.1. Experiments show that correlation coefficients between fault number and software complexity metrics are high, and the complexity metrics are interrelated [Takahashi, Wakayama, 1994]. Faults are detected and corrected after the implementation phase of the software cycle. However, a relationship between program fault density (fault number per 1000 source lines of code) and program module complexity density was not found. As a typical example, the cyclomatic number without case (CC0) per 1000 source lines of code versus program fault density is shown in Fig. 4. The determinant coefficients R^2 of the model was low ($=0.07$).

3.4 Analysis of program fault density variance from the program function viewpoint

To identify the most suitable regression model, stepwise selection method [SPSS, 1991] improved by AIC (Akaike Information Criterion) [Akaike, 1974] was applied to

Fig. 4. Complexity density versus program fault density.

Fig. 5. Analysis of fault density variance.

select the main complexity - metric factors (the procedure to select complexity - metric factors is based on AIC estimates and details are explained in section 3.5, because the idea is the same between regression analysis and discriminant analysis). The AIC procedures are based on the maximum likelihood estimation method and the least number of complexity metrics. The results of the minimum AIC estimated model were as follows: R^2 was 0.44. The F - test value was 10.52 for the "software function", 7.04 for the "distinct functions number density", 6.28 for the "comment lines (COM) density", 3.12 for the "global variables (REF) density", and 2.56 for the "cyclomatic number with case's (CC1) density". The item "software function" has the highest F - test value, indicating it is the primary factor affecting program density. These results mean we need a complexity metric that can distinguish software functional units. The results of regression analysis is illustrated in Fig. 5. The y - axis is for program fault density. The x - axis represents software quality control unit "difficulty", whose values are item scores obtained from the minimum AIC regression model. The item score of "software function" agrees with a partial regression coefficient. If the item score increases, program fault density tends to increase, which is why we call this item "difficulty". Each sample item score is equal if the sample belongs to the same functional unit. The set (1,2, ..., 7) in the Fig. 5 signifies the functional units, and each functional unit's mean fault density value curve is also presented.

3.5 Discriminant analysis to classify software functional units by complexity metrics

The most suitable software quality classification model can be obtained by the stepwise selection method [SPSS, 1991] with AIC estimates [Akaike, 1974]. This method, which takes the number of complexity metrics into consideration [Takahashi & Wakayama, 1994], is thought to be an improvement on the Wilks Λ criteria [Rao, 1973]. The relationship between the AIC estimate and Wilks Λ is discussed in detail in [Takahashi, Wakayama, 1994]. The procedure begins with the selection of the metric with which the lowest AIC estimated discriminant model M1 can be constructed. Then, the second metric is selected among the residual metrics, and by adding it to M1, the lowest AIC estimated model M2 can be obtained. The AIC estimate of M2 is smaller than that of M1. This procedure of locating the next added metric continues until metrics can no longer be added or until the adding of any residual metric to the last model AIC estimate no longer gets smaller. The most suitable discriminant model obtained in this study was with an F - test value of 7.42, an AIC estimate of 364, and a ratio of correct classification of 0.16=(23/144), where 23 F - test (AIC estimate) trials were performed with the stepwise selection method, and the last selected complexity metric was "fan - in & fan - out (FA1)". The complexity metrics are interrelated (multicollineality), so we could not establish the unique contribution of every metric to the discriminant model. As a consequence, only the "fan - in & fan - out number FA1" was selected among the 12 complexity metrics. The main reason the missclassification ratio was high is probably that these 12 complexity metrics can not sufficiently represent the functional relationship among the modules that compose a functional unit. In an attempt to solve this problem, we applied our extended cyclomatic number and the validity of the metric was experimentally verified as described in section 3.6. The result shown in this section, i.e., that functional units can be classified by the metric "fan - in -

Fig. 6. S_1 in the case study.

Fig. 7. S_1 -1 versus program fault density

& fan-out” that measures the interfaced complexity among modules is consistent to the result represented in section 3.6, i.e., that program fault density has a high correlation with extended cyclomatic number S_1 that measures the interfaced complexity among functional units, although the classification ratio of the most suitable discriminant model is not very high and the evaluation level of software quality is different between the model in this section and that in section 3.6.

3.6 Extended cyclomatic number S_1' and program fault density

The correlation between McCabe’s integration complexity metric S_1 and program fault density (fault number per 1000 SLOC, where fault number is the summation of each module’s fault number and SLOC is the summation of each module’s SLOC) is not very high (R^2 of the model was 0.10). We assume that program fault density mainly stems from interfaced complexity among functional units. The measurement of interfaced complexity among seven software quality control units is summarized in Fig. 6, where $\bigcirc$ s represent quality control units (QUs), and values on the arrows denote the degree of the effects of the predicates (i.e. number of predicates) in a certain QU whose scope occupies functions defined in another QU. In this sample, not only predicates that give effects directly (denoted by $\longrightarrow$, which indicates interfaced complexity between two QUs) but also predicates that give effects indirectly (denoted by $\dashrightarrow$, which indicates interfaced complexity among more than two QUs) are taken into consideration. $S_1_1(X)$ is the summation of values on input arrows to a certain quality control unit X and values on output arrows from X and can be thought as an indicator of the total interfaced complexity of X. Through Fig. 6, it has been seen that group-id 7 (a group is a functional unit) has the highest interfaced complexity among the seven functional units. The relationship between program fault density and the metric S_1_1 is shown in Fig. 7. The determinant coefficient R^2 between program fault density and S_1_1 was very high ($R^2=0.70$), indicating that the more accurate software quality classification model could be obtained by taking nesting of predicates nodes into consideration. But, the correlation coefficient between program fault density and S_1_0 was low -

($R^2=0.0006$) in this case study.

4. Conclusion

The extended cyclomatic metric S_1' for measuring the interfaced complexity among functional units has been proposed for the purpose of evaluating software quality (program fault density) and its validity has been experimentally verified. S_1' is an extension of McCabe's integration metric S_1 from an inner-functional control structure to a between-functional control structure, taking the scope (nesting depth) of predicate nodes among functional units into consideration. The metric S_1' was applied to a DBMS maintenance program developed by NTT whose volume is about 10 thousand source lines of code (KSLOC) written in C language. The results of our experiments are summarized as follows:

- (1) The correlation coefficient between program fault density and cyclomatic complexity density is not very high, where the software evaluation unit is a module, (i.e., the function or routine with the size of the order of $10^1 \sim 10^2$ SLOC) which is the lowest level of hierarchical partitioning of software functions.
- (2) It has been shown using the minimum AIC estimate regression model that the "software function" is the main factor that causes program faults, where "software function" is classified into several categories coincident to the above functional units. A functional unit consists of several interrelated modules and has the size of the order of 10^3 SLOC and is a certain hierarchical-level partitioning unit of the software function.
- (3) Even with the minimum AIC estimate discriminant model, the "software function" could not be characterized by complexity metrics that measure module-level complexity.
- (4) Although classification ratio of the most suitable discriminant model is not very high, the metric "fan-in & fan-out", which measures the interfaced complexity among modules, is the most effective factor for the discrimination of the "software function".
- (5) The correlation between McCabe's integration complexity metric S_1 and program fault density is not very high.
- (6) The determinant coefficient R^2 between program fault density and our extended cyclomatic number $S_1'_{-1}$ was very high ($R^2=0.70$), indicating that a more accurate software quality classification model can be obtained by taking the scope of predicate nodes among functional units into consideration.

To construct a more accurate software quality classification model, it is necessary to extend sample spaces in order to confirm model validity, to investigate the conditional variable complexity (i.e., these variables are used for invoking function paths [McClure, 1978]), and to evaluate stepwise selection method to reach the minimum AIC estimate discriminant model. All of these remain for future work.

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