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# An experimental examination of program maintainability as a function of structuredness

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## Abstract

The general ethos of producing structured programs has been, at least in theory, adopted throughout the software engineering community. By studying and measuring the structure of existing software we can estimate the benefits to be gained from changes in the structure in terms of the external attributes (perceived behaviour) of the re- structured software. [13, 2, 3, 10, 6, 7]. In this paper we report the results of two controlled experiments measuring the improvement on the maintainability of *differently structured* code. These experiments build on the experience and insights gained through an earlier experiment [5]. We discuss a strategy for re-structuring based on an improved re-engineering factor [9] and present the static measures of morphology (depth and width of module calls), coupling and cohesion and module complexity of a range of programs. By plotting these measures and adopting target values (e.g. width of call < 5) we estimate the expected improvement in the maintainability after re-engineering. We subsequently carry out the re-engineering, measure the re-structured code statically and measure the actual maintainability experimentally. The results reveal that unstructured programmes take longer to 'reveal their secrets'. An integral part of this work are the design and execution of controlled experiments as well as the use of automated tools for the static analysis of code and the recording of the experimental data.

## 1. Introduction

In the last twenty years the software engineering community has adopted structured methods for the development of software. However, it is not always obvious or certain that the methods ensure the production of structured programs. Furthermore the degree of structuredness cannot always be measured.

Several attempts have been made to define the attributes of a structured program in terms of the constructs it uses (sequence, iteration, selection). Fenton [6] provided a rigorous definition in terms of S-Structures using only sequence and nesting. When attempting to re-structure code one needs to ascertain the degree of structuredness of the given code as the re-structuring process is both time-consuming and expensive.

In an attempt to gain insights into the structure of software we examined the global attributes of morphology and coupling and we subsequently looked at the cohesion and complexity of the individual modules. We produced the static measures for a variety of programs [12] and carried out re-structuring of the original code according to established rules [7, 1, 9].

In each experiment, both versions of the program (original and re-structured) were seeded with errors and corrective maintenance was carried out under controlled conditions. Automated tools for the analysis and the monitoring of the maintenance activity were used.[14]. The automatically stored data was analysed [8] and conclusions were drawn.

Section 2 of this paper provides the hypothesis under test, and the static analysis of code in terms of global and module-based attributes. It discusses examples of the measures produced. Section 3 deals with the design and conduct of the experiments and section 4 reports the results and their interpretation. Finally Section 5 provides the conclusions and future directions of this research work.

## 2. Re-structuring Software

### 2.1 Strategy for re-structuring

The re-structuring strategy is based on analysing the code in order to identify problem areas such as high concentration of calls and high McCabe complexity measure. The code is then modularised according to established rules [1, 9]. It is expected that structured programs are easier to maintain and It is therefore the expected mean time to find and correct an error in a structured program should be smaller than the time taken for an equivalent unstructured version.

The rationale is based on the need to measure simple (internal) software attributes in order to estimate and measure the more complex ones (external attributes) such as maintainability. Measuring the maintainability of a program provides an understanding of its the quality. It is desirable to produce software of high maintainability [16, 2, 1, 17].

### 2.2 Global View : The overall structure

When judging the overall shape of a tangible object we look at its proportions and the way its constituent parts are connected. Certain shapes are pleasing to the eye either because of their symmetry or smoothness of contours. In addition, the shape of an object may be dictated by its purpose (use). Unfortunately it is not possible to judge programs in the same way. However, its is possible to model the shape of a program in terms of the inter-relationships of its modules. The shape of a program known as its *morphology* [18] is given by its call-hierarchy, the way the individual modules are inter-connected. Researchers and practitioners on this aspect have identified four attributes of morphology namely *size, depth, width and connectivity density.* All these measures can be obtained from the call-graph where each module is represented by a node and each call by an arc.

The size of the call-graph can be the number of modules and the number of calls or even the sum of the two. The depth is the longest path from the root node to a leaf node and the width is the maximum number of nodes at any one level. Finally the connectivity density is the ratio of arcs to nodes which increases as more connections (calls) between modules are added.

**Fig. 1 Call Hierarchy Matrix**

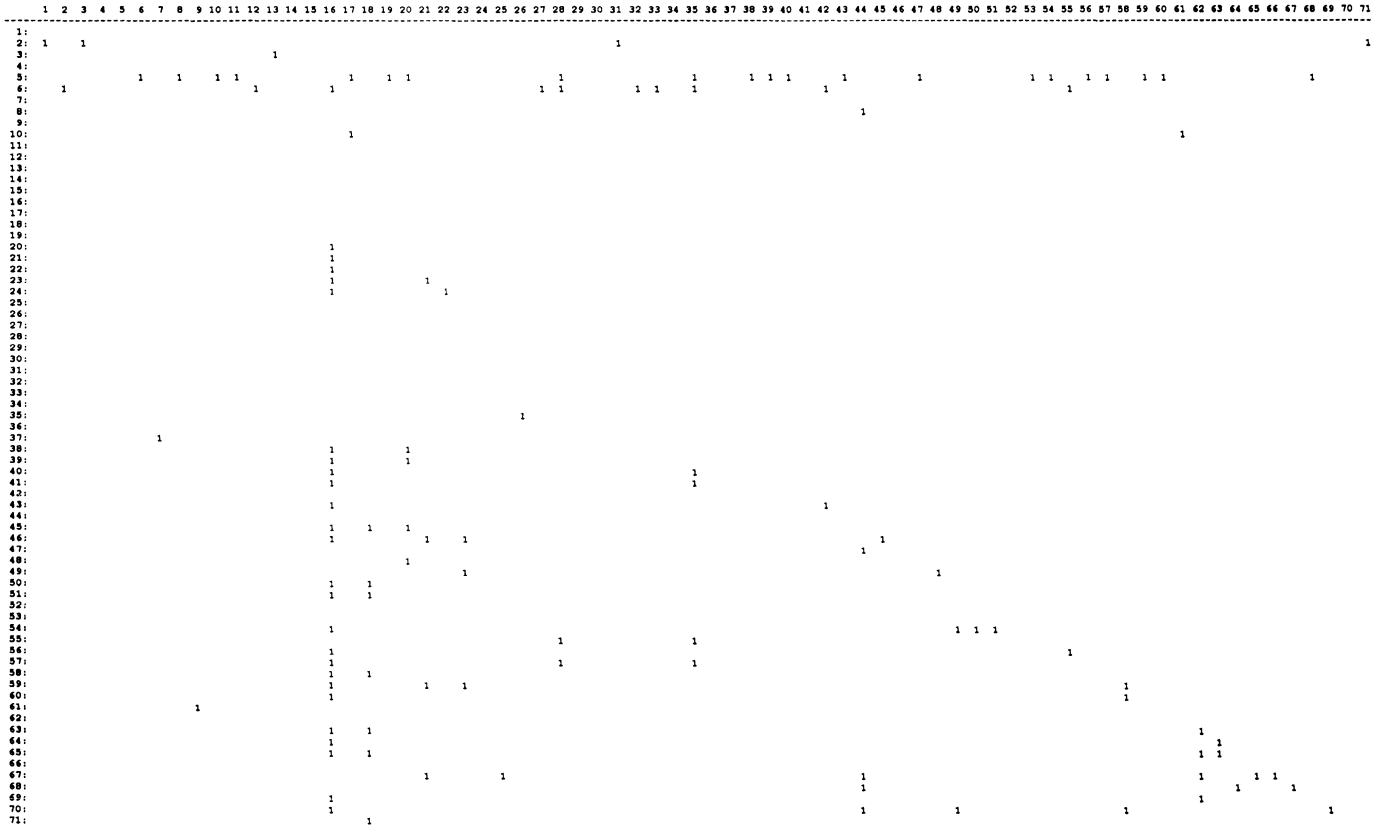
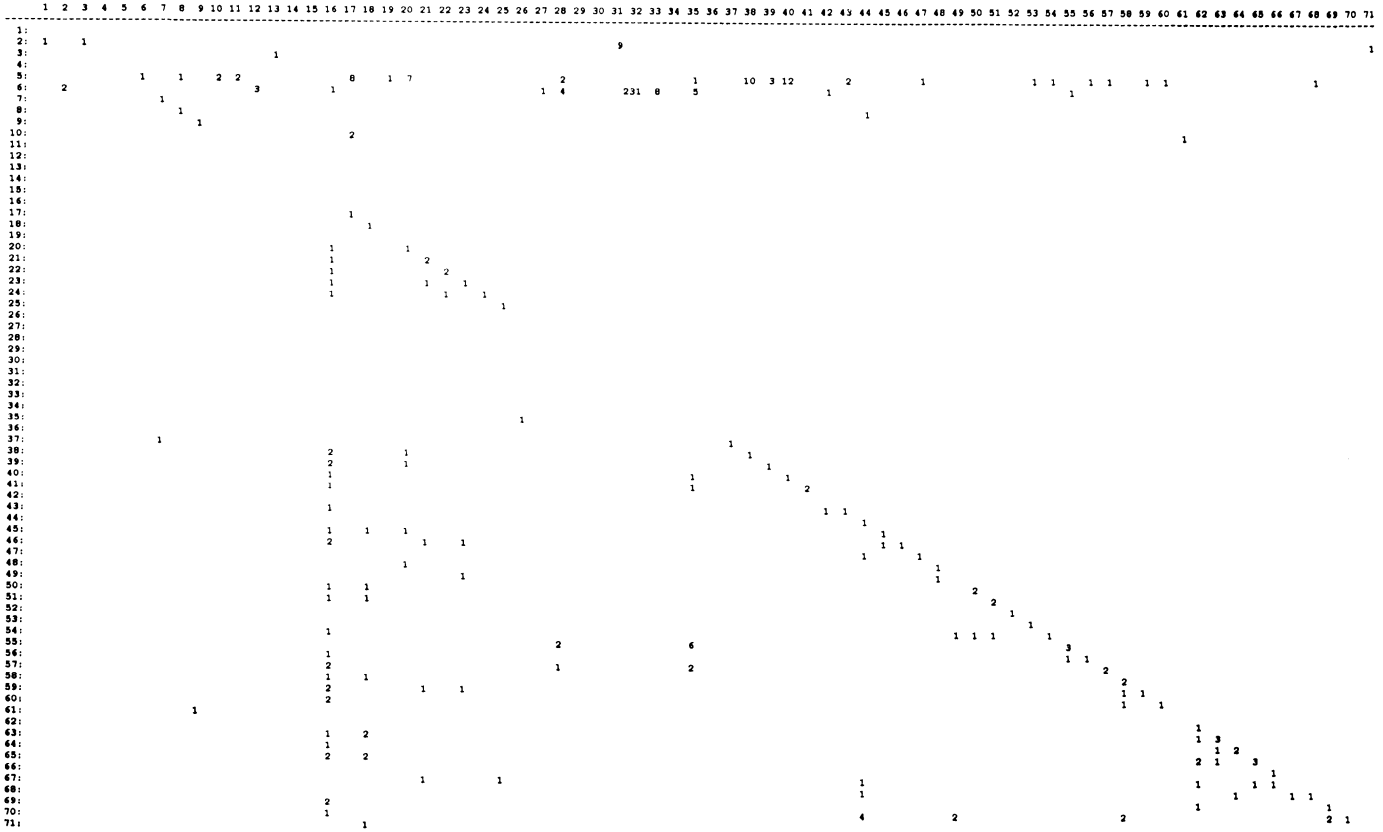


**Fig. 2 Connectivity density matrix**



We present one example program which was analysed to produce measures of inter-modular and intra-modular attributes. Figure 1 shows the Call Hierarchy Matrix which together with the levelling information (Table 1) provide the architecture of the whole program. Furthermore, figure 2 shows the density of module calls also in matrix form. It can be seen that the program has 71 modules.

The total number of calls was found to be equal to 493 giving an average connectivity density of 7. In this particular example about one third of the calls are made from module 6 to module 32. This high concentration of calls rather distorts the overall result. In fact it is a call to a library routine which for the sake of this calculation we can ignore obtaining a more realistic average connectivity density of 4. This means that on average each module is called four times. It is important to examine the reasons why one of the modules is called so many times and ensure it is tested exhaustively. A well balanced graph tends to be an indication of a "balanced' design.

**Table 1 : Levelling of Program Modules**

| level | width |
|---|---|
| 0 | 14 |
| 1 | 21 |
| 2 | 15 |
| 3 | 13 |
| 4 | 5 |
| 5 | 3 |

max width = 21 (level 1)

max number of calls = 231 on module 32

## 2.3 Coupling of modules

Coupling is a measure of module interdependence and it involves two modules. The global coupling is the overall connectivity of the system represented by a directed graph showing all the connections (calls between modules) including multiple connections between two modules. Low coupling is desirable.

The global coupling can be obtained from the median value of the set of pairwise coupling values c(m1, m2) which are calculated using formula 1 and the coupling classification shown in table 2 [6]. where m1 and m2 are the connected modules, i the worst type of coupling between them and n the total number of interconnections between m1 and m2.

$$c(m1, m2) = i + [n / (n+1)] \quad [1]$$

**Table 2: Coupling Classification**

| Coupling identification | Description | Quality level |
|---|---|---|
| 5 | Content Coupling | bad |
| 4 | Common Coupling | \| |
| 3 | Control Coupling | \| |
| 2 | Stamp Coupling | \| |
| 1 | Data Coupling | V |
| 0 | No Coupling | good |

In this example the global coupling is equal to 2.95. The local coupling between modules 6 and 32 is c(6, 32) = 1 + (231/232) = 1.987 (aprox. = 2).

## 2. 4 Intra-modular view

One fundamental attribute of program modules is that of cohesion. Another word describing module cohesion is module strength which is the extent to which the module components are needed to perform the same task. High cohesion is desirable and a rough idea about its value can be obtained if the purpose of a module can be stated in a single sentence. If this is impossible then the module is likely to perform many tasks which means that it possesses sequential or communicational cohesion. It is believed that programs made up of modules with functional cohesion are highly maintainable.

In the example presented here the cohesion ratio of the number of modules with functional cohesion to the total number of modules is equal to 0.7 which means that this program is expected to be highly maintainable.

## 2.5 Re-engineering factor

Before embarking onto the difficult and resource hungry activity of re-structuring we can obtain an estimate of each programs re-engineering potential by calculating its re-engineering factor which provides an indication of the amount of re-structuring required for a specific program if a certain target is to be achieved [9]. Following the static analysis we have measures of the code's attributes. The re-engineering factor can be calculated using formula 2 where the ti's are the target values and the ai's are the actual values and

t1 = Target Local Variables a1 = Actual Local Variables
t2 = Target Granularity a2 = Actual Granularity
t3 = Target McCabe a3 = Actual McCabe
t4 = Target Information Flow a4 = Actual Information Flow

$$r = \{[a1+|a3|]*[a2+|a4|] - [t1+|t3|]*[t2+|t4|]\}/[a1 +|a3|]*[a2+|a4|] \quad [2]$$

When the value of r is high (nearly 1) then the program is a strong candidate for re-structuring. Adopting the target values of Granularity <= 50, McCabe < = 5 , Information Flow < = 5 and Number of identifiers < 5 we calculated the re-engineering factors of 6 programs (Table 3).

It can be seen that Programs B and D are already well structured which in fact will suffer deterioration if they undergo re-structuring according to the target. Program C is a good candidate for re-structuring whilst the improvement expected for Program A is minimal. Similarly Programs E and F can be re-structured to a 27% and 54% level.

**Table 3**

| | McCabe | Granularity | Information Flow | Local Variables | Re-engineering Factor |
|---|---|---|---|---|---|
| Prog A | 8 | 33 | 14 | 6 | 0.08 |
| Prog B | 2 | 7 | 7 | 2 | -9.80 |
| Prog C | 26 | 91 | 1 | 17 | **0.81** |
| Prog D | 3 | 9 | 2 | 2 | -10 |
| Prog E | 8 | 31 | 21 | 8 | **0.27** |
| Prog F | 10 | 70 | 8 | 7 | **0.54** |
| **Target Measures** | **5** | **50** | **5** | **6** | **0** |

## 2.6 Additional Static Measures

A reasonably large program written in C was analysed using MLT [12] to produce static measures some of which are listed below [3, 10]. In addition, Table 4 shows the number of local variables for each module. with the granularity of each module shown in brackets.

Total number of statements = 2228 Number of modules = 71
Maximum Granularity 1079 (on yyparse) Average granularity = 31

*The experimental material* for each experiment consisted of two versions of a program (written in C) carrying out the same tasks, using the same input and producing the same output which differs from the required output due to seeded logic errors. Other materials were hard copies of the program, its actual output, its required output and simple user instructions on the interface.

The subjects were required to carry out a series of *tasks* starting with the loading of the allocated version of the program and continuing with corrective maintenance in order to produce the required output.

## 3 The experiments

### 3.1 The parameters

All the experiments in this series have been designed using the 4ET guidelines [4, 15].The hypothesis under test was : *"Maintainability is a function of the program structuredness"* and more specifically *" Programs with a high degree of structuredness take shorter time to maintain"*.

The *experimental subjects* were beginners in programming having studied principles of programming and the syntax of C for 8 weeks. They were familiar with the fundamentals of the UNIX operating system.

### 3.2 The environment and recording the experimental data

The maintenance activity was carried out using the interface environment INTER [14] running under UNIX. This is a non-obtrusive Open Windows environment which logs the activity of the subject and the time of their actions. In particular the interface carries out a comparison between the required output and the actual output every time the program is executed and it logs exactly which errors have been rectified.

### 3.3 The experimental procedures

Corrective maintenance is carried out on code which is behaving in a different manner to the expected one. The maintainers are provided with a listing of the program, a printout of the required output and a printout of the actual output. The differences in output are caused by carefully seeded errors which need to be located and rectified.

**Table 4 : Local Variables per module.**

1 ... ( st: 1 ) (env.-ids: 0 ) yywrap
2 ... ( st: 477 ) (env.-ids: 2 ) yylex
3 ... ( st: 122 ) (env.-ids: 12 ) yylook
4 ... ( st: 1 ) (env.-ids: 0 ) yyinput
5 ... ( st: 85 ) (env.-ids: 19 ) main
6 ... ( st: 1079 ) (env.-ids: 2 ) yyparse
7 ... ( st: 18 ) (env.-ids: 5 ) alldis
8 ... ( st: 6 ) (env.-ids: 0 ) prlev
9 ... ( st: 5 ) (env.-ids: 0 ) whereinx
10 ... ( st: 14 ) (env.-ids: 12 ) tablecalls
11 ... ( st: 14 ) (env.-ids: 2 ) prtable
12 ... ( st: 3 ) (env.-ids: 0 ) yyerror
13 ... ( st: 7 ) (env.-ids: 0 ) yyback
14 ... ( st: 1 ) (env.-ids: 0 ) yyoutput
15 ... ( st: 6 ) (env.-ids: 0 ) yyunput
16 ... ( st: 4 ) (env.-ids: 1 ) consgen
17 ... ( st: 3 ) (env.-ids: 0 ) length
18 ... ( st: 5 ) (env.-ids: 0 ) isstrin
19 ... ( st: 11 ) (env.-ids: 2 ) snocgen
20 ... ( st: 3 ) (env.-ids: 0 ) appgen
21 ... ( st: 5 ) (env.-ids: 0 ) delstr
22 ... ( st: 5 ) (env.-ids: 0 ) delastr
23 ... ( st: 3 ) (env.-ids: 0 ) noreplst
24 ... ( st: 3 ) (env.-ids: 0 ) norepalist
25 ... ( st: 3 ) (env.-ids: 0 ) llast
26 ... ( st: 5 ) (env.-ids: 2 ) locit
27 ... ( st: 2 ) (env.-ids: 1 ) lobj
28 ... ( st: 3 ) (env.-ids: 1 ) lsel
29 ... ( st: 3 ) (env.-ids: 1 ) ltpnts
30 ... ( st: 3 ) (env.-ids: 1 ) lrmk
31 ... ( st: 9 ) (env.-ids: 3 ) keep
32 ... ( st: 14 ) (env.-ids: 6 ) MKstr
33 ... ( st: 7 ) (env.-ids: 3 ) MKy
34 ... ( st: 3 ) (env.-ids: 1 ) get_y
35 ... ( st: 3 ) (env.-ids: 1 ) readit
36 ... ( st: 8 ) (env.-ids: 1 ) mark
37 ... ( st: 35 ) (env.-ids: 5 ) mrkdis
38 ... ( st: 25 ) (env.-ids: 7 ) pick
39 ... ( st: 25 ) (env.-ids: 7 ) pickall
40 ... ( st: 4 ) (env.-ids: 0 ) getitlist
41 ... ( st: 7 ) (env.-ids: 1 ) getitsel
42 ... ( st: 5 ) (env.-ids: 2 ) strfromy
43 ... ( st: 4 ) (env.-ids: 0 ) getstrlist
44 ... ( st: 4 ) (env.-ids: 0 ) prlst
45 ... ( st: 21 ) (env.-ids: 7 ) pickifin
46 ... ( st: 3 ) (env.-ids: 1 ) findsubs
47 ... ( st: 6 ) (env.-ids: 0 ) pralist
48 ... ( st: 3 ) (env.-ids: 0 ) xcalled
49 ... ( st: 1 ) (env.-ids: 0 ) called
50 ... ( st: 6 ) (env.-ids: 0 ) topfolds
51 ... ( st: 6 ) (env.-ids: 0 ) lowfolds
52 ... ( st: 4 ) (env.-ids: 0 ) prlst2
53 ... ( st: 4 ) (env.-ids: 0 ) prlstcn
54 ... ( st: 5 ) (env.-ids: 1 ) manifolds
55 ... ( st: 21 ) (env.-ids: 1 ) dd_ident_one
56 ... ( st: 4 ) (env.-ids: 0 ) dd_ident
57 ... ( st: 6 ) (env.-ids: 0 ) sel_dd
58 ... ( st: 5 ) (env.-ids: 0 ) lcommon
59 ... ( st: 5 ) (env.-ids: 1 ) subs
60 ... ( st: 5 ) (env.-ids: 1 ) subs2
61 ... ( st: 1 ) (env.-ids: 0 ) wherein
62 ... ( st: 3 ) (env.-ids: 0 ) listcalls
63 ... ( st: 9 ) (env.-ids: 0 ) isclose
64 ... ( st: 8 ) (env.-ids: 0 ) isrecur
65 ... ( st: 8 ) (env.-ids: 0 ) findcycle
66 ... ( st: 3 ) (env.-ids: 0 ) nodeastr
67 ... ( st: 9 ) (env.-ids: 4 ) rmcycle
68 ... ( st: 11 ) (env.-ids: i ) nomr
69 ... ( st: 3 ) (env.-ids: 0 ) recons
70 ... ( st: 12 ) (env.-ids: 1 ) relocate
71 ... ( st: 3 ) (env.-ids: 0 ) dftype

The whole process is monitored by a program which provides the interface through which the maintainers load, compile and run the program. Each time the program is executed the output is compared to the correct (expected) output without the programmer knowing it. When the programmer is happy or indeed when the time runs out or the programmer gives up (!) they log out.

The interface records all the activities. Two experiments were designed, planned and conducted in two consecutive weeks. The reason for doing this was to ensure familiarity with the environment and as a contingency in case of unforeseen circumstances (power cut, system failure, fire).

## 4. Analysis of the data

### 4.1 Logistic regression

The data were analysed in two different ways. Firstly the number of errors found was treated as a response variable in a logistic regression with binomial errors. The appropriate model was fitted using GLIM4 [ 8] to investigate whether the probability of detecting and correcting an error was higher in the case of the structured version of the program than in the case of the unstructured version. The resulting probabilities from the fitted model are shown in Table 5.

**Table 5: Probability of error detection**

| | unstructured | structured |
|---|---|---|
| 1st experiment | 0.3182 | 0.4091 |
| 2nd experiment | 0.2500 | 0.7083 |

The probability for detecting an error for the structured program is higher in both experiments. This confirms the hypothesis. In the case of the first experiment the difference in probability is statistically significant at a 0.05 significant level whilst the same applies to the second experiment at a lower significant level.

### 4.2 Time taken to correct errors

The second analysis is based on the time taken to find and correct an error in the two program versions and the two experiments. Figures 3 and 4 show the total time taken against the number of errors found. It can be seen that the structured versions have, in general, lower values than the unstructured ones. This is more obvious in the second experiment. Table 6 below confirms this observation . It shows the average time taken to find and correct an error in the two program versions and the two experiments (no errors found are excluded). The exclusion of the non hits is necessary but likely to distort the results especially in experiment one where the success rate was lower. Nevertheless the table shows a significant difference in the second experiment.

**Table 6: Time taken to correct errors (in seconds)**

| | unstructured | structured |
|---|---|---|
| 1st experiment | 4121 | 4089 |
| 2nd experiment | 5708 | 2262 |

**Figure3 & 4 : Time in seconds versus Number of errors**

In the first experiment the programs contained 2 errors therefore the possibilities are 0, 1 or 2 errors. Similarly in experiment 2 the number of errors was equal to 4 giving rise to 5 possibilities namely 0, 1, 2, 3 or 4.

**Fig. 3 Error corrections (Program 1)**

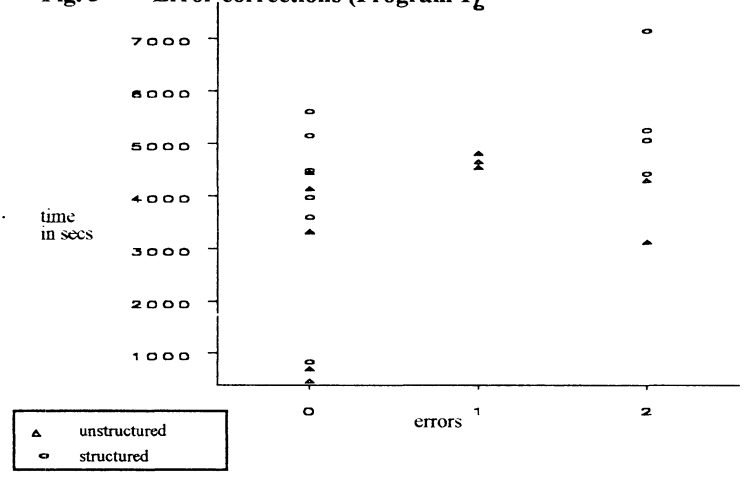
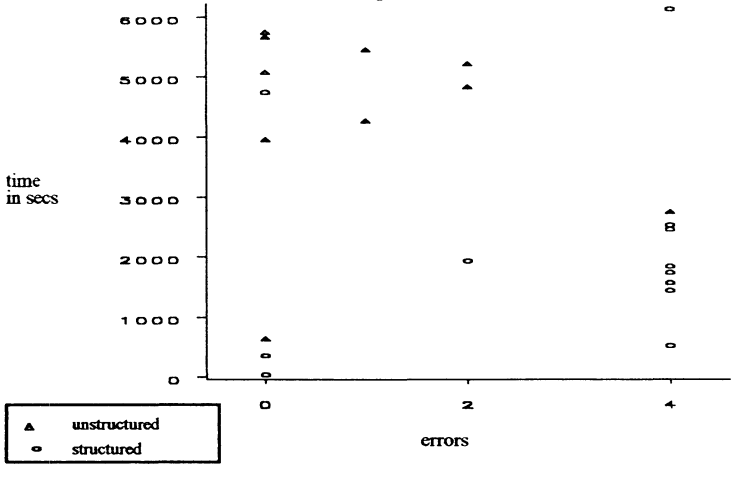



**Fig. 4 Error corrections (Program 2)**



# 5. Postscript

## 5.1 Conclusions

The experimental results suggest that the original hypothesis is true. Programs with a high degree of structuredness take shorter time to maintain. Existing code can be analysed and re-structured provided it has a high re-engineering factor. Static analysis tools indicate the problem areas which can then be isolated and improved.

## 5.2 The future

Further experiments have been planned to carry out adaptive maintenance. If any industrial sponsors become available we aim to run the same experiments in industry where the programs can be large. In addition the subjects can be experienced programmers. Finally we intend to test the same hypotheses using other languages (Pascal and C++).

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