Structured programming, programming teaching and the language Pascal

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1 - Introduction

This paper is a series of considerations on the three subjects stated in its title, and on their mutual relationships. Since it is a survey of the present situation in three related and evolving areas, references play a very important role. A rather extensive bibliography is thus appended to this text, and more than doubles its length.

The structure of this paper may be very simply inferred from its title: the three subjects a, b, c are examined first separately, then two by two and finally all three at once, according to the scheme:

a - b - c - ab - ac - bc - abc

2 - Structured programming

Even if we give to this somewhat fuzzy term a wider signification than is customary, this subject was still unknown a few years ago, and has today a crucial importance. Is it only a fashionable topic, or does it correspond to a real need? If a need, it is a very recent one, and some meritorious books on programming risk to be rapidly obsolete because of its importance. Even Knuth's magnum opus [Knu68,Knu69,Knu73a] is not completely irreproachable from this aspect.

To see how much mentalities have changed, it is sufficient to browse among the Collected algorithms of the A.C.M. or the algorithms published by the Computer Journal: for example, see [Flo62] (which is a pathological case), [Sin68] or even more recently [Woo70]. Books also give instructive examples, as in [Har71] or [Dav73]. Weinberg's books [Wei70,Wei71] present symptoms of a change, but still rather slight.

The oldest papers are concerned by proofs of algorithms and axiomatisation of programming; it is only recently that these matters have been related to structured programming [Nau66,Flo67,MCP67,Bur69,Hoa69,Ars71,FoH71, ClH72,Gri72,Lon72,Hoa72b,Hoa72c,Hoa73a,MNV73]. The goto controversy, because of its theoretical and paradoxical aspects, produced many papers following Dijkstra's celebrated letter to the editor of the Communications [Dij68a,Ric68,AsM71, Wul71,KnF71,Lea72,Hop72,Wul72,Ars72,Boc73,NaS73, PKT73]. The necessity for structured programming and its practical usage are advocated in more and more papers [Dij68b,Dij69,Nau69,Bau71,Mil71,Woo71, Wir71a,Dij72a,Hes72,BrH72,Hoa72a,Hoa72d,Nau72, Wir72c,DaH72,Bak72,Dij72b,Bro73,ClH73,Lec73,Sha73, ShW73]. The first books have at last just been published [DDH72,Wir73,WMY73,ChC73]. In every meeting related to programming, these different aspects take great importance, even if they were not planned in the programme [ACM71,IFIP72,ACM73]. However, some of the most fundamental ideas are far from being new, since they were exposed by Polyà [Pol48], who found them (in part) in the works of Bolzano, Descartes and even Pappus of Alexandria.

The major ideas that we group under the heading of structured programming comprise: complete or partial banishment of the goto statement, by the way of logical constructs with nested structure; a novel approach to modularity; construction of programs by stepwise refinement; top-down programming; analytic verification or proof of correctness of algorithms; and the use in program construction of a strict but freely accepted discipline.

3 - Programming teaching

This is an up-to-date subject, but also a controversial one. The different curricula which have been proposed for teaching computer science [ACM68,Baz69,Las72,AuE73] contradict each other, about the whole subject and especially about the teaching of programming. The working conference sponsored by IFIP to examine this one subject [IFIP72] saw the proposition of just about all possible solutions.

The most important reason for differences in opinion is probably the confusion between a programming language and programming (or even computer science). This confusion is maintained by employers, who request that people master the language they will use on their computer, and by the specialized institutes who seriously promise wonderful wages after three weeks of a programming course by correspondence.

Even if people agree really to teach programming (this does not seem evident when we see how much the ACM curriculum for small colleges [AuE73] moves back compared to Curriculum 68 [ACM68]), the quarrel focuses around the precise language used: a pedagogical or a real one, a machine or a high-level one, a powerful or a restrictive one, all possible combinations are proposed, and often well justified [Ada72,Lec72, Org72,Pec72,VdP72,Wei72,Wor72,Hol73]. Even if we decide to use an existing high-level language, the most currently accepted solution, must we choose it because of the number of people using

it daily, or independently of this?

4 - The language Pascal

This programming language has a surprising history, which puts it apart from its celebrated predecessors and contemporaries. It is a very recent language [Wir70], officially described in the first number of a new non-American journal [Wir71b], by a quite difficult paper, so condensed that one must find the newest aspects of the language "between the lines" (Haberman [Hab73] makes a spiteful and unfair criticism of Pascal because he was not able to read the report in such a way). It is not the work of a users' group, nor of an international committee, nor of an important computer manufacturer. The first implementation [Wir71c,Wir72b] was done on a costly and not widespread machine, using a method which seems a priori worrying. No useful implementation is presently available on an IBM machine. The language revision, made after two years of use [Wir72a, WiJ73], includes no extension, no new feature, and even suppresses some details, which seems a unique case in the history of programming languages.

All these facts seemed to sentence the language to a definitive obscurity. In fact, it has already a descendance [C1H71,IRH73,Jen73,McK73, Des74], and one says "Pascal-like language" as one said "Algol-like language". Numerous implementations are in progress [Des73,ThM73,Lyn73] or already completed [WeQ72]. During the Sigplan-Sigops interface workshop [ACM73], Pascal was the most quoted language. It is probably the only programming language of comparable power whose formal semantic description uses only twenty-six typed pages [HoW72] (compare to those of PL/1 [IBM69] or even Basic [Lee72]).

Pascal still has some weaknesses, which seem to arise especially from the fact that its author did not want to make its definition grow bigger with ill-formalized features, too machine-dependent or operating system-dependent, or too expensive to implement. The major reason for Pascal's success seems to be the fact that it corresponds exactly to what Dijkstra [Dij72b] requires: "I see a great future for very systematic and very modest programming languages."

5 - Teaching of structured programming

The question is not to teach structured programming as a particular programming technique, alongside other techniques, but to make it the basis of a programming course. The course descriptions which use this notion [Wei72,Ros72, Ros73] are however somewhat fuzzy about this point. They are rather courses "about programming" (as Rosin says), where a series of methods, habits and rules of behavior are taught.

These courses are often offered at an advanced level, i.e. to the few best students, as if one said: "Let us begin by giving people bad habits, then we shall correct them for people who deserve it". However, in an interval of a few months, there have been published the latest development of Dijkstra's celebrated "Notes" [Dij72a], and above all Wirth's book [Wir72c, Wir73], which both suggest making structured programming the basis of programming teaching.

This seems to be evident: if we are convinced that it is not only efficient and useful [Bak72], but even necessary if we do not want to fall into catastrophe [Dij72b], we must teach structured programming to everybody (even to those people who seem to be unrecoverable), immediately, and as soon as at the beginning of programming teaching.

6 - The language Pascal and structured programming

Is it possible to write structured programs (this has not to be confused with programming in a structured way) in any language? The answer is certainly no, and this has already been said several times [WGW71,Pec72,C1H73,Hol73]. However, if we eliminate the machine languages, Cobol and Fortran (there exists however, what is hardly credible, an attempt of extension to Fortran to allow structured programming [Mil73]), the different points of view begin to diverge. Many people indeed are interested only in structuring the program itself, and forget the data. The debate is then centered around that "obscene goto" (Laski in [IFIP72]), that "forbidden fruit" [Wei72], and on the means to prevent the programmer from using it, by completely removing it [C1H71,WRH71] or hiding from him that it exists [Wei72,Hol73]. To replace the goto, the most tricky and unnatural methods are used [C1H71,WRH71,Ars72,IRH73,Boc73], a fact which proves that the true question was left aside, and that people remain influenced by flowcharts [NAS73] and Fortran, since after having ignominously driven away the goto they try to reintroduce it in concealment.

However, the question of data structuring is equally important, and Hoare's papers [Hoa72a, Hoa72c] deal with it in a probably final way. The greatest strength of the language Pascal is precisely to be suggested by [Hoa72a], and to have borrowed from it all that can be realized at a moderate cost (the language LIS alone [IRH73] seems to go a step further in that sense). Besides that, the language offers the statement structures identified as necessary (if...then... else, while...do and the compound statement) or useful (repeat...until and for...do). As for the goto, it is present, even if in an ultra-restrictive form: only this statement (at least presently) allows a clear processing of error situations [Lan66,Lea72,Hop72], without using such powerful and complicated tools as the ones proposed for exit from nested constructs. In fact, the language Pascal, despite its simplicity (or better, because of it), supplies one with all the tools necessary for structured programming, if one is not the slave of flowcharts and not (or no longer) infected by Fortran [Lec73].

7 - The language Pascal and programming teaching

Laski [Las72] gave the best reasons for teaching programming using an algorithmic language, or rather to teach the development of algorithms and their expression by means of a programming language (we paraphrase): "Very few computers are von Neumann machines. Very few programs are written in machine language. A programming language has an a priori meaning; its translation into machine language does not give it an a posteriori meaning, it has only to be correct. Numerical analysis is not computer science. The object of computer science is to represent, store, retrieve, transform and interpret some information."

The advantage of Pascal, in these circumstances, is that it is machine-independent, but not too much: it never refers to the manner in which information is represented in memory, but it allows this to be done reasonably. Besides that, its principal advantage is that it is a simple and concise language, of which the clear and complete description, illustrated by examples, occupies less than a hundred pages. This is the only way for the programming language not to be the subject of the course but only its support, and one has only to browse through some of the innumerable books of introduction to programming, to see that by using Fortran or a subset (even a tiny one) of PL/I, this goal can never be attained.

It is evident that Pascal is not a language for doing everything, but its qualities make it usable in a great variety of problems (and not only in numerical calculations), with fair efficiency, and without frustrating restrictions [Lec72]. As Peck says [Pec72], "it is particularly distressing to think of the vast unfortunate herd of programmers whose only means of communication with the computer is the Fortran language".

8 - Teaching structured programming with the language Pascal

Structured programming must be taught at the time of the initiation to computer science, and the language Pascal is an excellent support for such a course. Is there a better choice? Holt [Hol73] is favourable to Pascal, but cannot use it and deems it to be too young; he is consequently reduced to the "fatal disease" [Dij72b], that is PL/I, which he tries to make innocuous thank to innumerable cuts. Weinberg, on the other hand, preaches the use of PL/I as a universal language [Wei70]. Besides the fact that a universal language is evidently a fruitless lure, it is particularly informing to compare his books [Wei70, WMY73] with Wirth's [Wir72c,Wir73], who evidently advocates the use of Pascal. Whereas the name of the language used as a support in the Wirth's book is quoted once only, in a footnote, a very short syntactic description being put in an appendix, in [WMY73] it is not only the name of the language used which appears in the title, but moreover the name of the precise compiler that must be used! This simple fact seems very significant of the difference of approach between the two books: while one can forget Pascal and concentrate on programming itself, this is completely impossible with PL/I.

Aside from the programming language, the teaching of these two books is easily condensed. Contrary to the opinion of most professional programmers, a good program is the result of 5% inspiration and 95% perspiration. The best means to obtain an error-free program is to manage to not put them into it, since if program testing may be used to show the presence of bugs, it can never prove their absence [Dij69,Dij72b,Wir73]. There is no miracle recipe, and the only thing to do is to work in a systematic manner and to apply the methods identified as good in other areas [Pol48,Nau69,Nau72].

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THE SCOPE OF VARIABLE CONCEPT: THE KEY TO STRUCTURED PROGRAMMING?

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During the past several months, there have been a number of articles, short notes, letters to the editors, etc., addressing the subject of structured programming. In general, those articles purporting to explain structured programming begin by introducing Bohm and Jacopine's basic structures [1] - the sequence block, the two-branch conditional (IF-THEN-ELSE) and the repetitive loop, (DO-LOOP, FOR-WHILE, PERFORM-UNTIL) and continuing in such a manner as to elicit the response from the experienced practioner - heck, that's nothing but modular programming! A technique that these people have been practicing for some time.

I contend that structured programming is a lot more than modular programming. For with regard to the latter: On what basis are modules defined? Can the rule(s) be applied consistently? Repetitively? By different people in different companies with equivalent results? For structured programming, all answers are yes.

I propose that the key to understanding structured programming is to understand the concept of the "scope of the variable". The scope of a variable may be defined to be that group of programming statements over which the variable has a constant interpretation. Note that a variable which is used as a control variable in two disjoint loops, has two disjoint scopes. This is a situation commonly encountered in FORTRAN and COBOL. The basis for this proposal is two-fold: (1) it appears to work nicely, and (2) the earlier work of the two major contributors: E. W. Dijkstra and C. Bohm involved programming systems in which the scope of variable concept was basic. It is difficult not to assume that this earlier work influenced their approach to structured programming.

1. E. W. Dijkstra has long been associated with the ALGOL effort. Removing the GOTO from ALGOL yields a language very similar to P. J. Landin's ISWIM language. ISWIM is a linguistic treatment of Church's lambda calculus. In the lambda calculus, the scope of all variables are explicity defined. [4, 5].

2. The three basic structures proposed by C. Bohm and G. Jacopine, when considered in terms of ALGOL have the property that the scope of all variables is known upon entry into the structure. Some of Bohm's earlier work was with his CUCH language, a language strongly influenced by the lambda calculus. [2].

It is understandable that in general, we are unaware of the scope of variable concept. I believe that it is safe to say that with but few expections, programming in the U.S.A. is accomplished using either FORTRAN or COBOL. In both cases, the "scope of variable" is no problem. All variables are global! As a result, the average programmer rarely gives it any thought.

To establish the viability of the concept, please re-consider two generalizations offered in a recent article [4]. (1) The generalization of the IF-THEN-ELSE conditional from a two-valued to a multi-valued operation and, (2) The generalization to allow abnormal termination (exit) from a repetition loop by relaxing the single-entry/single-exit rule.

In the case of the multi-valued operation (nested IF-THEN-ELSE) the "generalization" can be viewed more strongly, such as, as a theorem. The variables upon which the if-clause decision is made is known upon entry into the block and exists for the scope of either True or False blocks. Figure 1 is offered as a pictorial proof of the "theorem".

An interesting observation can be made. The structured flowchart need not be a decision-for-decision representation of the program code. Rather, it can be a description of the approach, such as a "black box" diagram in engineering. Local conventions would establish how the representation would be encoded, i.e. in FORTRAN using the Computed GOTO assuming the availability of a suitable function g(A), or using sequential IF statements, see Figure 2.

The re-examination of the generalization of the repetition block in which an abnormal exit is allowed, e.g. relaxing the single-entry/single-exit rule, cannot be treated so briefly.

Two cases are of interest:

Case 1: The subsequent processing from the abnormal exit and the normal exit merge at some later point in the program, see Figure 3. A special case is where they do not; all subsequent processing is independent. See Figure 3a.

Case 2: Subsequent to the processing from the abnormal exit, control loops back to a point, prior to the repetition block without merging with the control stream from the normal exit. See Figure 5.

Figure 4 represents an alternative approach to the logic depicted in Figure 3. By introducing a control variable, in this case C1, and including the subsequent processing S3 and S4, it is possible to realize the program logic of 3 using the basic block components of Bohm and Jacopine. Since the control variable C1 exists only internal to the block, containing variables A and B, then to

implement the logic of Figure 3 in terms of the logic of Figure 4 might be considered as "academic". Figure 4, then may be viewed as the "proof" of Figure 3. It is important to note that the block of Figure 3 has the property of single-entry/single-exit and that it is non-reducible. Although complex, it is a complete, albeit irreducible module; the blocks: S1, S2, S3, and S4 are integral members of the "repetition with abnormal exit" block.

Figure 5 depicts the second case where the abnormal exit loops back eventually to a point prior to the repetition block. Figure 6 depicts the logic of Figure 5 in terms of the basic blocks.

Again, as above, it has been necessary to introduce a new control variable C2 as well as consider the subsequent processing S3 and S4. In addition, it is now necessary to consider the previous processing S5. Note, however, that while the scope of the control variable C1 began with the repetition block in the previous example, it contains the repetition block in the second. Furthermore, the logic shows nested repetition blocks! Figure 6 constitutes the "proof" of the logic of Figure 5. It should be noted that much of the program logic is hidden, namely that the scope of the variable C2 begins previous to the current block, i.e. it may contain the scope of the variables A and B.

Thus, if the properties of structured programming are desired to be retained it is not possible to generalize the repetition loop to allow abnormal termination simply by relaxing the single-entry/single-exit rule. One may obtain the desired efficiencies only by defining a more complex, well structured module.

The program logic of Figure 5 is often encountered. For example, in using some of the package software systems now available, such as generalized data base management systems, it is necessary to test for a successful system operation prior to continuing the processing of the data. In earlier years, a similar example was the testing for successful I/O operation. In many cases the program logic for processing the system operation is intermixed with that for processing the data. To attempt to do this in structured programming will be difficult (possibly impossible, but at least very frustrating). An alternative approach is to partition the program logic according to the data and processing objectives, i.e. stratify the control and program logic. Then within each level of stratification, structured programming principles can be applied.

By these examples, it is hoped that the role played by the scope of variable concept is apparent. By the introduction of appropriate variables any program should be definable in terms of the basic, axiomatic modules. To be able to do it, thus "proves" the original program and answers affirmatively the questions: On what basis are modules defined? Can the rule(s) be applied consistently? Repetitively? By different people in different companies with equivalent results?

In general, strict adherence to the structured programming approach will yield tree-structured programs. [6]. The above discussion shows one method for simplifying the programming and gaining a degree of efficiency. Another method is to recognize and minimize the occurrence of identically functional modules. Two cases are of interest:

Case 1. For a given subset of occurrences of the common module, the subsequent program to be executed is identical. In this case, the common module and subsequent program can be factored out and identified as a module to which control is transferred.

Case 2. For a given subset of occurrences of the common module, the subsequent program is different. In this case, the common module can be factored out and identified as a subroutine.

The degree of application of these rules appear to be heuristic in as much as they represent a compromise between program length, execution speed and control path complexity. To an extent, it would seem that they could be performed mechanically.

From the above discussion, it is possible to outline a programming approach:

1) Synthesize a program to solve the defined problem, using previously defined or axiomatic modules, interconnecting them following structured programming concepts.

2) Test the synthesized solution against the objectives of the defined problem.

3) If the program satisfies the problem, simplify it by:

a) defining new modules in those cases when trivial use has been made of control variables.

b) factor out common modules either as subroutines or a subsequent, sequentially executed module.

The extent to which the application of this approach provides positive answers to the above questions would appear to be no less than what is provided by the traditional engineering approaches in the respective disciplines.

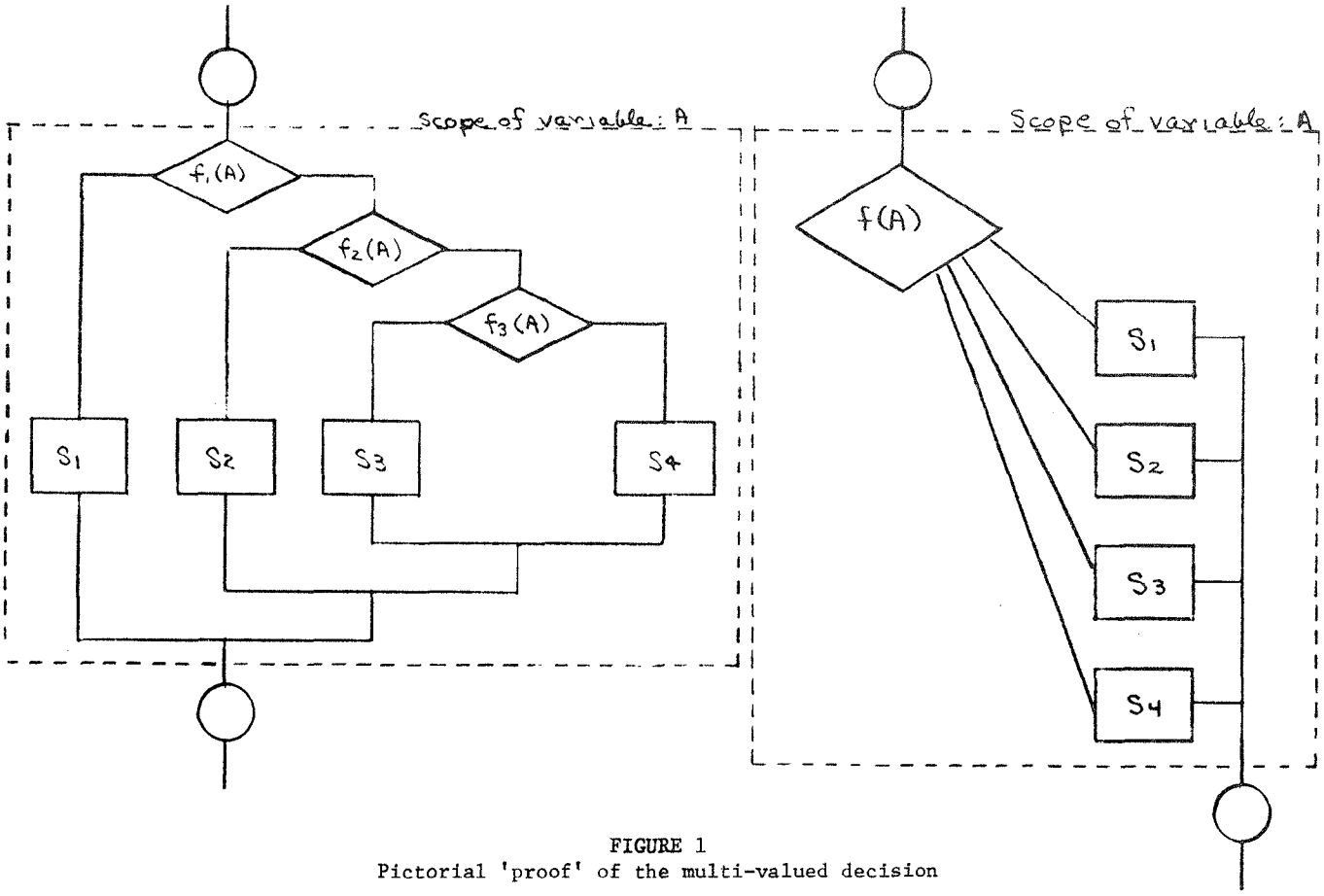

FIGURE 1
Pictorial 'proof' of the multi-valued decision

```
BEGIN
   Control variable A;
   IF f1(A) THEN S1 ELSE
   IF f2(A) THEN S2 ELSE
   IF f3(A) THEN S3 ELSE
                 S4    ;
END
```

Figure 2a - ALGOL

```
      IF (f1(A)) GO TO l1
      IF (f2(A)) GO TO l2
      IF (f3(A)) GO TO l3
l4    S4
      GO TO l0
l3    S3
      GO TO l0
l2    S2
      GO TO l0
l1    S1
l0    CONITINUE
```

Figure 2b - FORTRAN

```
GO TO (l1, l2, l3, l4) g(A)
```

Figure 2c - FORTRAN

FIGURE 2
Various program logic for the multi-valued decision

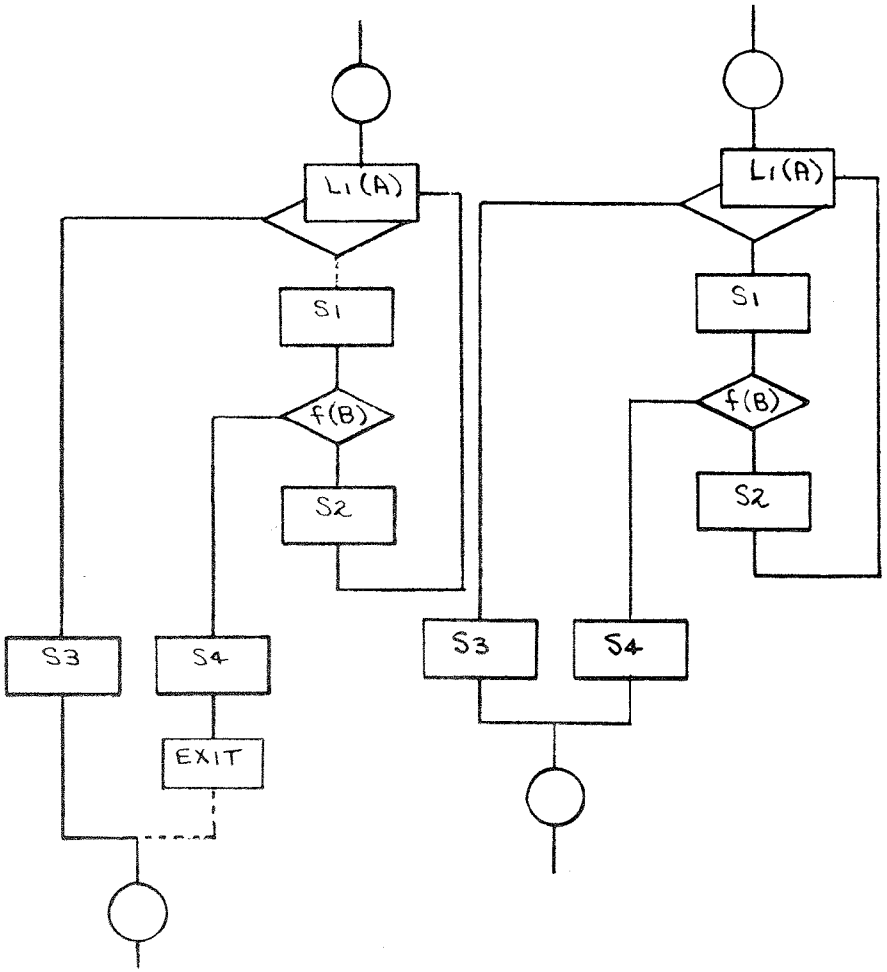

FIGURE 3
DO-WHILE block with abnormal exit - Case I

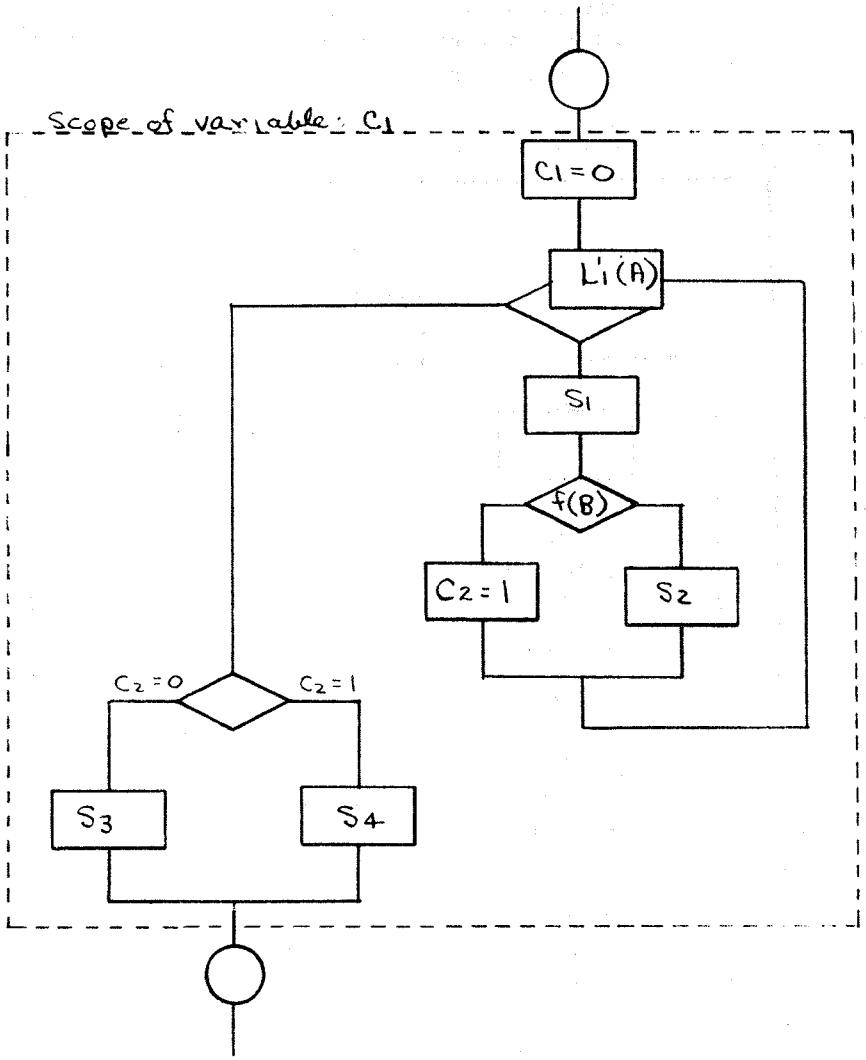

FIGURE 4
Proof of DO-WHILE block with abnormal exit - Case I

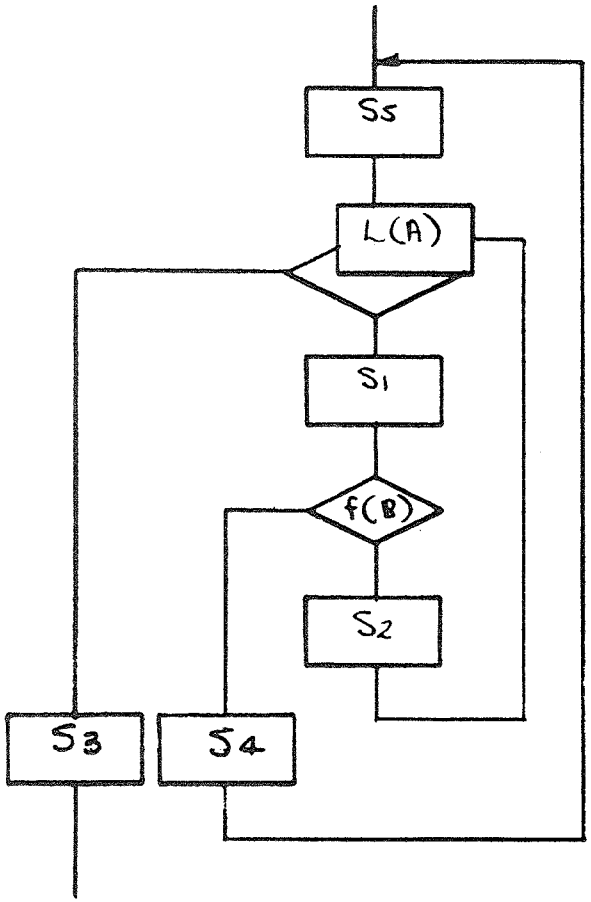

FIGURE 5
DO-WHILE with abnormal exit
Case II

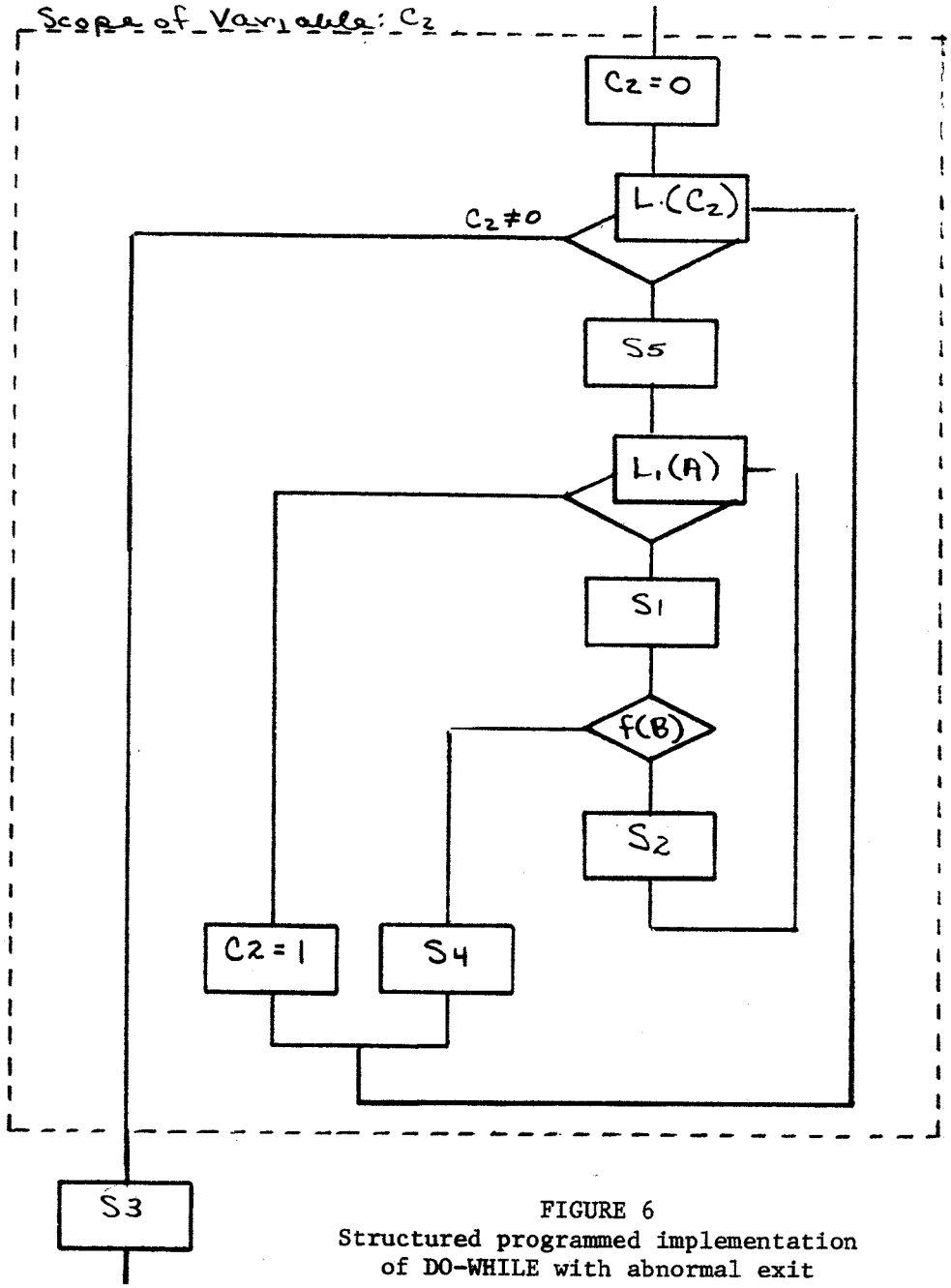

FIGURE 6
Structured programmed implementation
of DO-WHILE with abnormal exit
Case II

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