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(54) **METHOD AND APPARATUS FOR RESOLVING DATA REFERENCES IN GENERATED CODE**

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(52) **U.S. Cl.** **717/140**; 717/106; 717/136; 717/139; 717/142; 717/146

(58) **Field of Search** 717/2, 5, 7, 8, 717/106–108, 114, 116, 146–147

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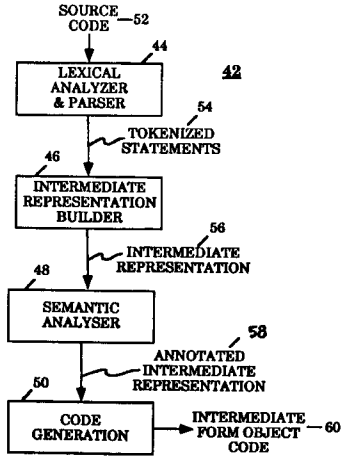
(57) **ABSTRACT**

A hybrid compiler-interpreter comprising a compiler for "compiling" source program code, and an interpreter for interpreting the "compiled" code, is provided to a computer system. The compiler comprises a code generator that generates code in intermediate form with data references made on a symbolic basis. The interpreter comprises a main interpretation routine, and two data reference handling routines, a dynamic field reference routine for handling symbolic references, and a static field reference routine for handling numeric references. The dynamic field reference routine, when invoked, resolves a symbolic reference and rewrites the symbolic reference into a numeric reference. After re-writing, the dynamic field reference routine returns to the main interpretation routine without advancing program execution to the next instruction, thereby allowing the rewritten instruction with numeric reference to be reexecuted. The static field reference routine, when invoked, obtain data for the program from a data object based on the numeric reference. After obtaining data, the static field reference routine advances program execution to the next instruction before returning to the interpretation routine. The main interpretation routine selectively invokes the two data reference handling routines depending on whether the data reference in an interaction in a symbolic or a numeric reference.

31 Claims, 5 Drawing Sheets



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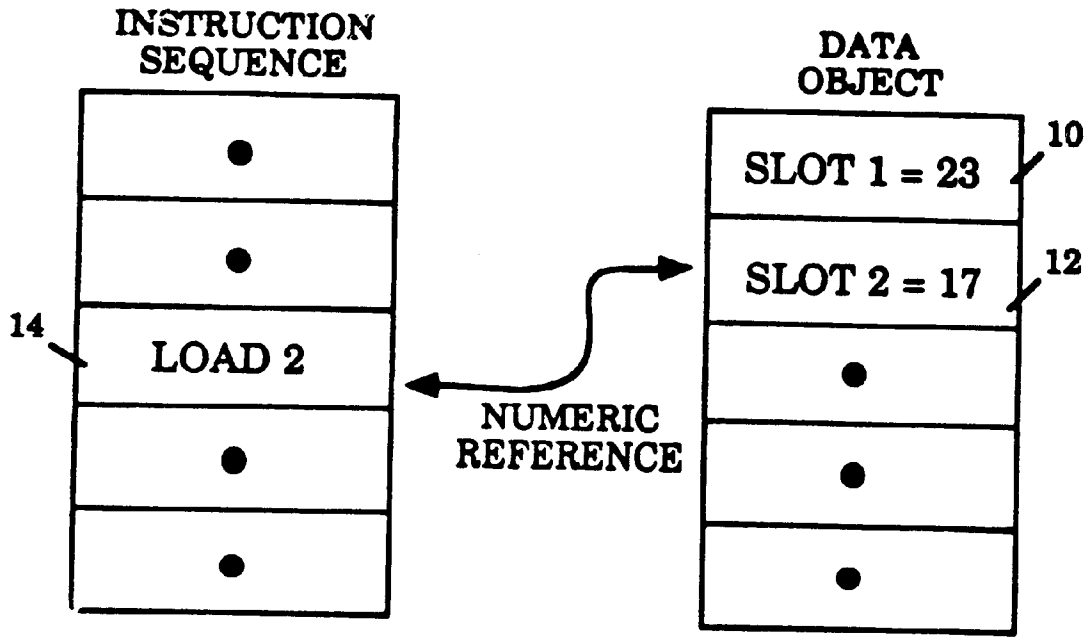

Figure 1A

Prior Art

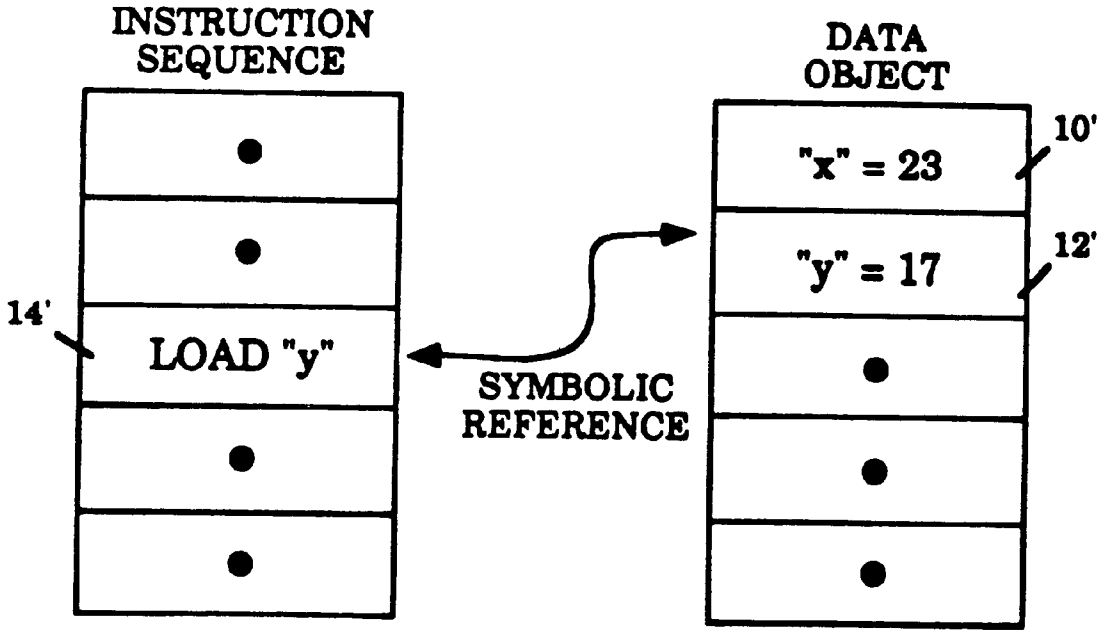

Figure 1B

Prior Art

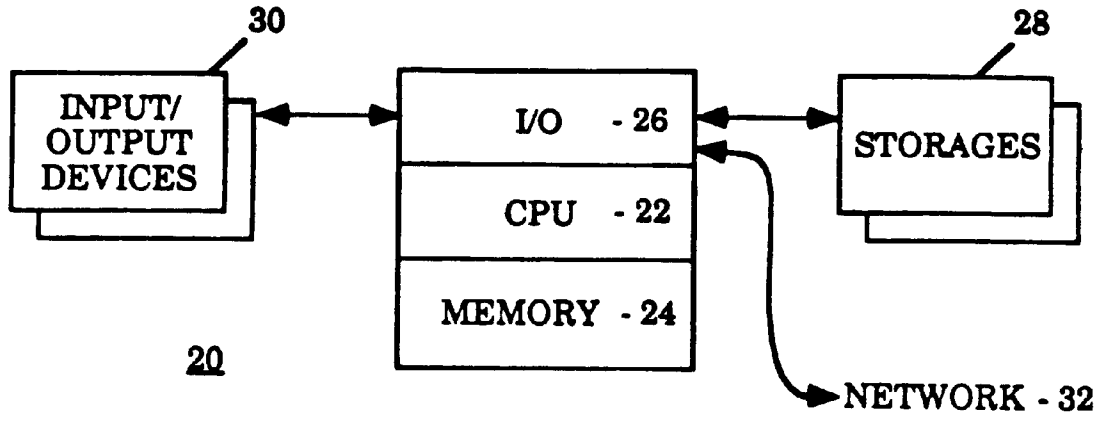

Figure 2

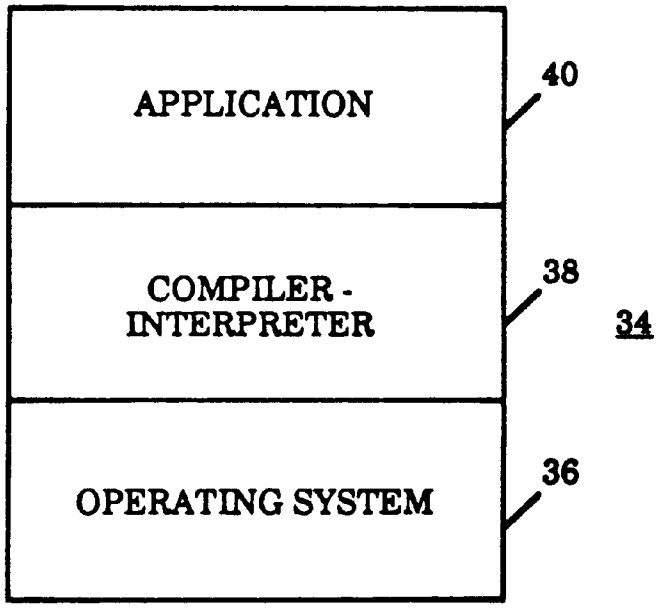

Figure 3

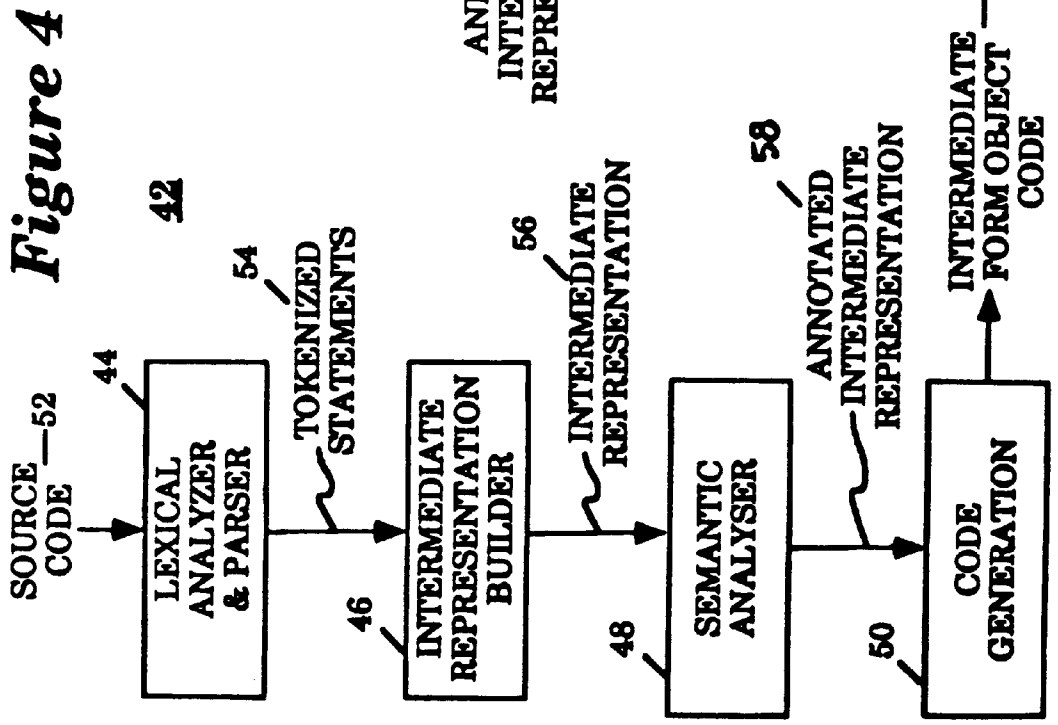

Figure 4

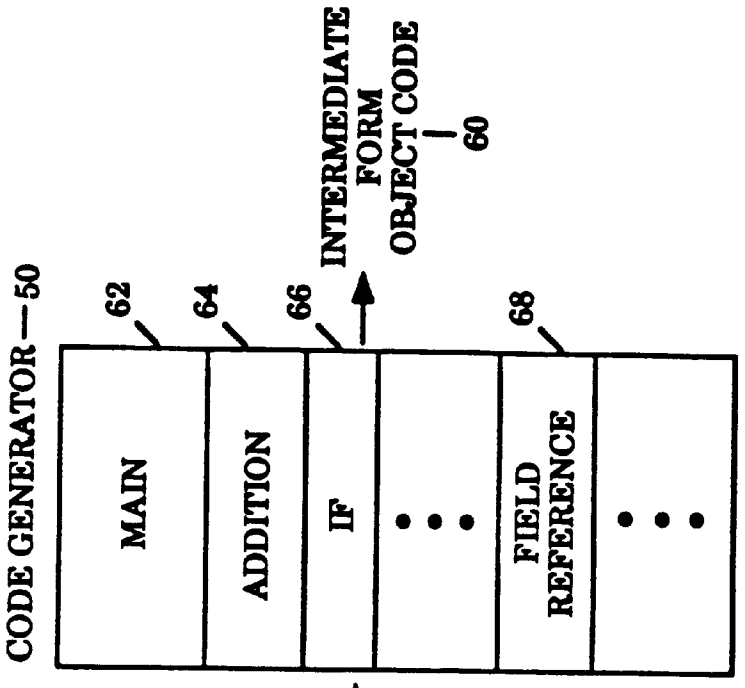

Figure 5

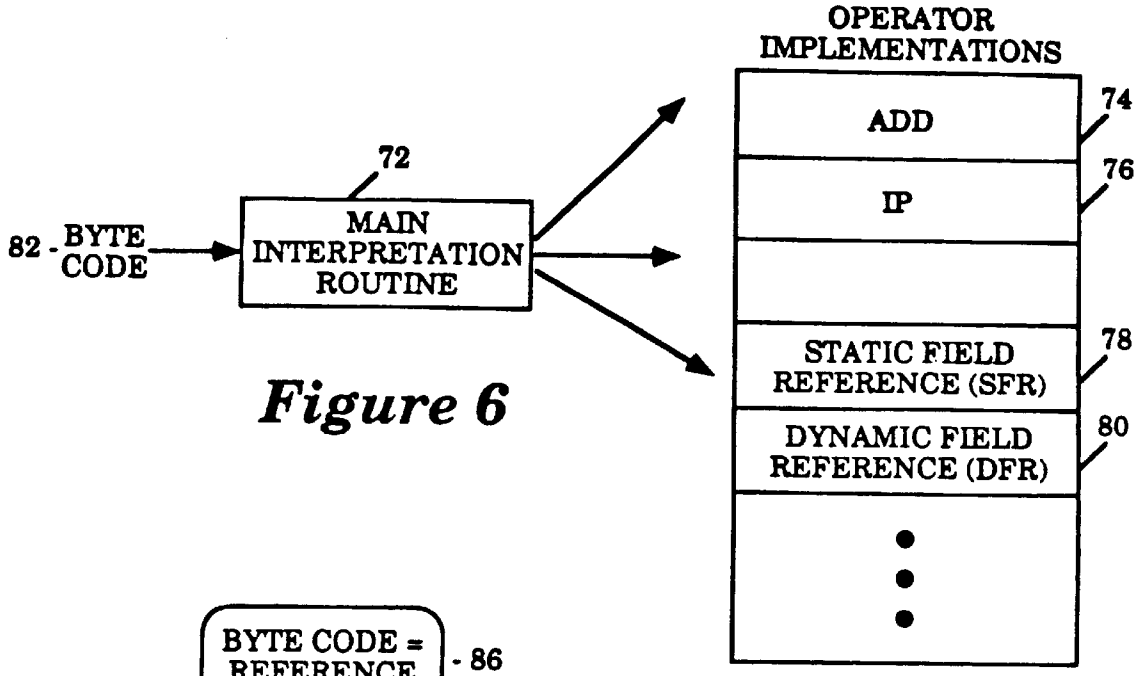

Figure 6

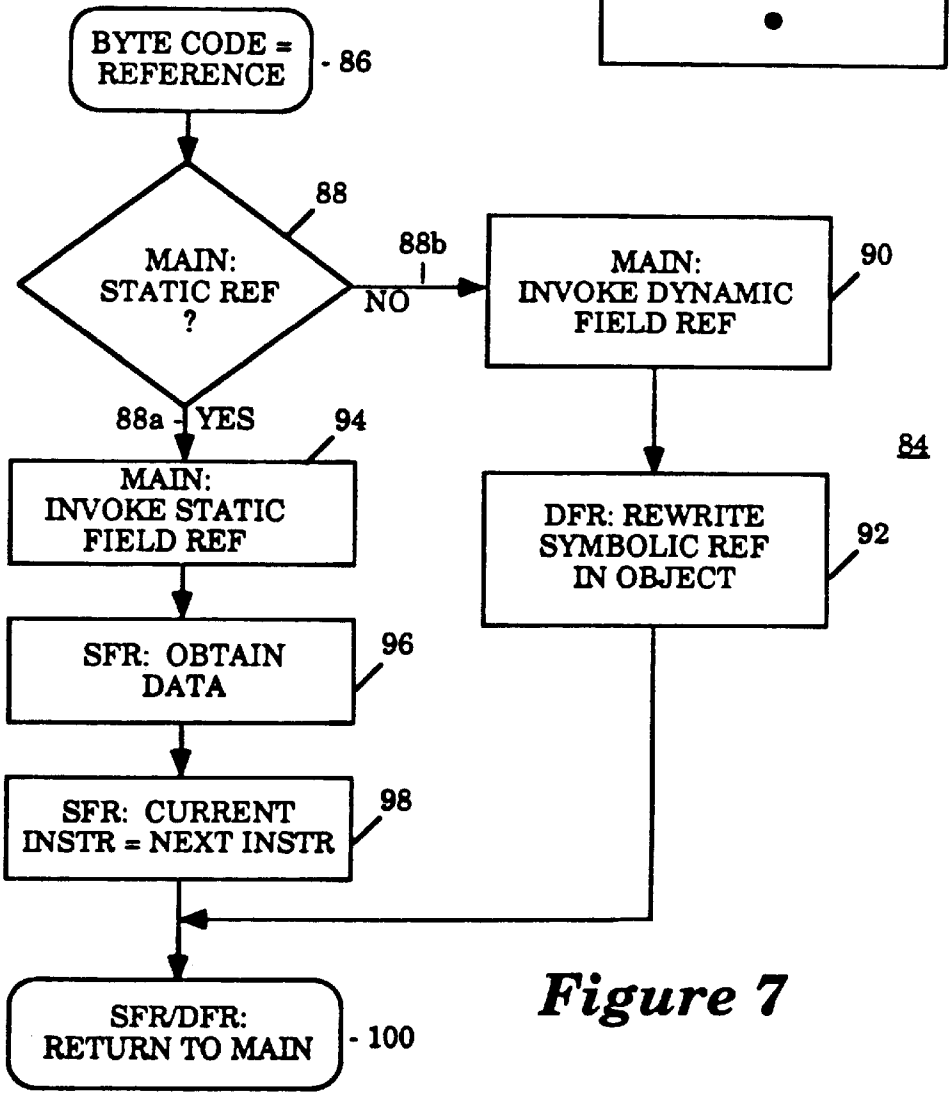

Figure 7

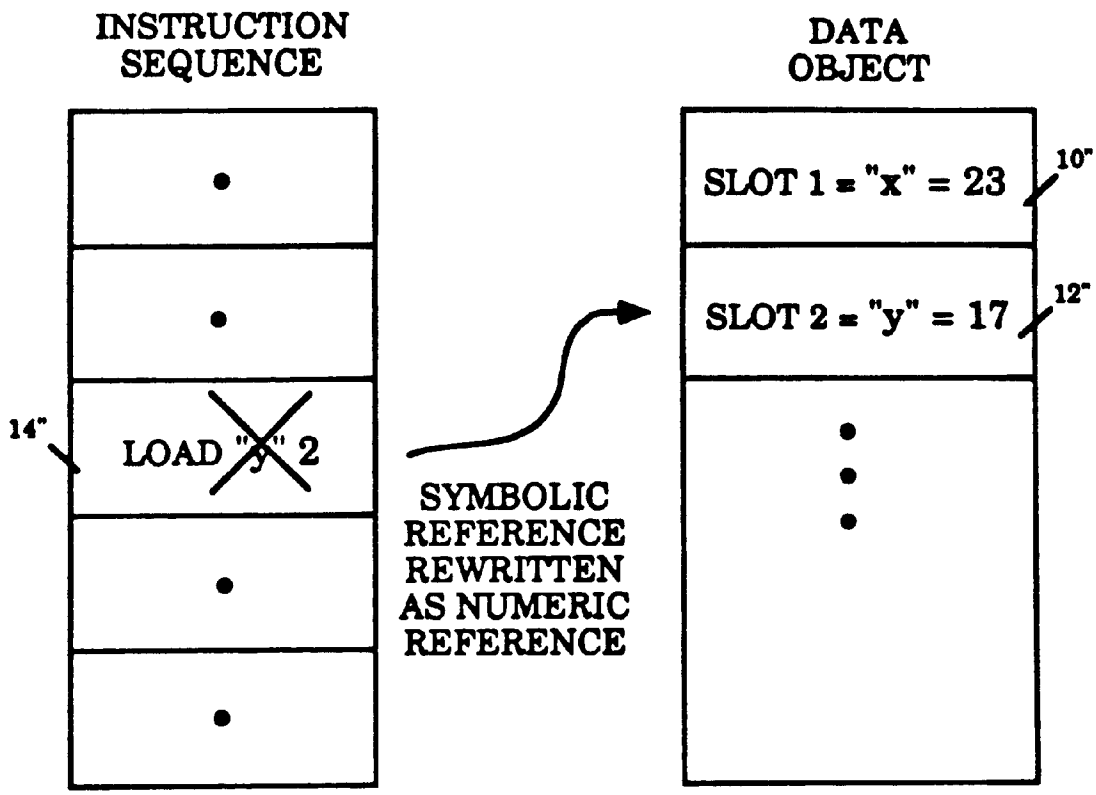
INSTRUCTION SEQUENCE
DATA OBJECT
SLOT 1 = "x" = 23
10"
SLOT 2 = "y" = 17
12"
14"
LOAD "y" 2
SYMBOLIC REFERENCE REWRITTEN AS NUMERIC REFERENCE

Figure 8

METHOD AND APPARATUS FOR RESOLVING DATA REFERENCES IN GENERATED CODE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This is a continuation of reissue application Ser. No. 08/755,764, filed Nov. 21, 1996, now U.S. Pat. Re. No. 36,204, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of computer systems, in particular, programming language compilers and interpreters of these computer systems. More specifically, the present invention relates to resolving references in compiler generated object code.

2. Background

The implementation of modern programming languages, including object oriented programming languages, are generally grouped into two categories: compiled and interpreted.

In a compiled programming language, a computer program (called a compiler) compiles the source program and generates executable code for a specific computer architecture. References to data in the generated code are resolved prior to execution based on the layout of the data objects that the program deals with, thereby, allowing the executable code to reference data by their locations. For example, consider a program that deals with a point data object containing two variables x and y, representing the x and y coordinates of a point, and further assume that the variables x and y are assigned slots **1** and **2** respectively, in each instance of the point data object. Thus, an instruction that accesses or fetches y, such as the Load instruction **14** illustrated in FIG. **1**, is resolved to reference the variable y by the assigned slot **2** before the instruction sequence is executed. Particular examples of programming language compilers that generate code and resolve data references in the manner described above include C and C++ compilers.

This "compiled" approach presents problems when a program is constructed in pieces, which happens frequently under object oriented programming. For example, a program may be constructed from a library and a main program. If a change is made to the library, such that the layout of one of the data objects it implements is changed, then clients of that library, like the main program, need to be recompiled. Continuing the preceding example, if the point data object had a new field added at the beginning called name, which contains the name of the point, then the variables x and y could be reassigned to slots **2** and **3**. Existing programs compiled assuming that the variables x and y and are in slots **1** and **2** will have to be recompiled for them to execute correctly.

In an interpreted language, a computer program (called a translator) translates the source statements of a program into some intermediate form, typically independent of any computer instruction set. References to data in the intermediate form are not fully resolved before execution based on the layout of the data objects that the program deals with. Instead, references to data are made on a symbolic basis. Thus, an instruction that accesses or fetches y, such as the Load instruction **14'** illustrated in FIG. **1**, references the variable y by the symbolic name "y". The program in

intermediate form is executed by another program (called an interpreter) which scans through the code in intermediate form, and performs the indicated actions. Each of the symbolic references is resolved during execution each time the instruction comprising the symbolic reference is interpreted. A particular example of a programming language interpreter that translates source code into intermediate form code and references data in the manner described above is the BASIC interpreter.

The "interpreted" approach avoids the problems encountered with the "compiled" approach, when a program is constructed in pieces. However, because of the extra level of interpretation at execution time, each time an instruction comprising a symbolic reference is interpreted, execution is slowed significantly.

Thus, it is desirable if programming languages can be implemented in a manner that provides the execution performance of the "compiled" approach, and at the same time, the flexibility of the "interpreted" approach for altering data objects, without requiring the compiled programs to be recompiled. As will be disclosed, the present invention provides a method and apparatus for resolving data references in compiler generated object code that achieves the desired results.

SUMMARY OF THE INVENTION

A method and apparatus for generating executable code and resolving data references in the generated code is disclosed. The method and apparatus provides execution performance substantially similar to the traditional compiled approach, as well as the flexibility of altering data objects like the traditional interpreted approach. The method and apparatus has particular application to implementing object oriented programming languages in computer systems.

Under the present invention, a hybrid compiler-interpreter comprising a compiler for "compiling" source program code, and an interpreter for interpreting the "compiled" code, is provided to a computer system. The compiler comprises a code generator that generates code in intermediate form with data references made on a symbolic basis. The interpreter comprises a main interpretation routine, and two data reference handling routines, a static field reference routine for handling numeric references and a dynamic field reference routine for handling symbolic references. The dynamic field reference routine, when invoked, resolves a symbolic reference and rewrites the symbolic reference into a numeric reference. After rewriting, the dynamic field reference routine returns to the interpreter without advancing program execution to the next instruction, thereby allowing the rewritten instruction with numeric reference to be reexecuted. The static field reference routine, when invoked, obtain data for the program from a data object based on the numeric reference. After obtaining data, the static field reference routine advances program execution to the next instruction before returning to the interpreter. The main interpretation routine selectively invokes the two data reference handling routines depending on whether the data reference in an instruction is a symbolic or a numeric reference.

As a result, the "compiled" intermediate form object code of a program achieves execution performance substantially similar to that of the traditional compiled object code, and yet it has the flexibility of not having to be recompiled when the data objects it deals with are altered like that of the traditional translated code, since data reference resolution is performed at the first execution of a generated instruction comprising a data reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features, and advantages of the present invention will be apparent from the following detailed description of the presently preferred and alternate embodiments of the invention with references to the drawings in which:

FIG. **1** shows the prior art compiled approach and the prior art interpreted approach to resolving data reference.

FIG. **2** illustrates an exemplary computer system incorporated with the teachings of the present invention.

FIG. **3** illustrates the software elements of the exemplary computer system of FIG. **2**.

FIG. **4** illustrates one embodiment of the compiler of the hybrid compiler-interpreter of the present invention.

FIG. **5** illustrates one embodiment of the code generator of the compiler of FIG. **4**.

FIG. **6** illustrates one embodiment of the interpreter and operator implementations of the hybrid compiler-interpreter of the present invention.

FIG. **7** illustrates the cooperative operation flows of the main interpretation routine, the static field reference routine and the dynamic field reference routine of the present invention.

FIG. **8** illustrates an exemplary resolution and rewriting of a data reference under the present invention.

DETAILED DESCRIPTION PRESENTLY PREFERRED AND ALTERNATE EMBODIMENTS

A method and apparatus for generating executable code and resolving data references in the generated code is disclosed. The method and apparatus provides execution performance substantially similar to the traditional compiled approach, as well as the flexibility of altering data objects like the traditional interpreted approach. The method and apparatus has particular application to implementing object oriented programming languages. In the following description for purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well known systems are shown in diagrammatical or block diagram form in order not to obscure the present invention unnecessarily.

Referring now to FIGS. **2** and **3**, two block diagrams illustrating an exemplary computer system incorporated with the teachings of the present invention are shown. As shown in FIG. **2**, the exemplary computer system **20** comprises a central processing unit (CPU) **22**, a memory **24**, and an I/O module **26**. Additionally, the exemplary computer system **20** also comprises a number of input/output devices **30** and a number of storage devices **28**. The CPU **22** is coupled to the memory **24** and the I/O module **26**. The input/output devices **30**, and the storage devices **28** are also coupled to the I/O module **26**. The I/O module **26** in turn is coupled to a network **32**.

Except for the manner they are used to practice the present invention, the CPU **22**, the memory **24**, the I/O module **26**, the input/output devices **30**, and the storage devices **28**, are intended to represent a broad category of these hardware elements found in most computer systems. The constitutions and basic functions of these elements are well known and will not be further described here.

As shown in FIG. **3**, the software elements of the exemplary computer system of FIG. **2** comprises an operating system **36**, a hybrid compiler-interpreter **38** incorporated with the teachings of the present invention, and applications compiled and interpreted using the hybrid compiler-interpreter **38**. The operating system **36** and t he applications **40** are intended to represent a broad categories of these software elements found in many computer systems. The constitutions and basic functions of these elements are also well known and will not be described further. The hybrid compiler-interpreter **38** will be described in further detail below with references to the remaining figures.

Referring now to FIGS. **4** and **5**, two block diagrams illustrating the compiler of the hybrid compiler-interpreter of the present invention are shown. Shown in FIG. **4** is one embodiment of the compiler **42** comprising a lexical analyzer and parser **44**, an intermediate representation builder **46**, a semantic analyzer **48**, and a code generator **50**. These elements are sequentially coupled to each other. Together, they transform program source code **52** into tokenized statements **54**, intermediate representations **56**, annotated intermediate representations **58**, and ultimately intermediate form code **60** with data references made on a symbolic basis. The lexical analyzer and parser **44**, the intermediate representation builder **46**, and the semantic analyzer **48**, are intended to represent a broad category of these elements found in most compilers. The constitutions and basic functions of these elements are well known and will not be otherwise described further here. Similarly, a variety of well known tokens, intermediate representations, annotations, and intermediate forms may also be used to practice the present invention.

As shown in FIG. **5**, the code generator **50** comprises a main code generation routine **62**, a number of complimentary operator specific code generation routines for handling the various operators, such as the ADD and the IF code generation routines, **64** and **66**, and a data reference handling routine **68**. Except for the fact that generated coded **60** are in intermediate form and the data references in the generated code are made on a symbolic basis, the main code generation routine **62**, the operator specific code generation routines, e.g. **64** and **66**, and the data reference handling routine **68**, are intended to represent a broad category of these elements found in most compilers. The constitutions and basic functions of these elements are well known and will not be otherwise described further here.

For further descriptions on various parsers, intermediate representation builders, semantic analyzers, and code generators, see A. V. Aho, R. Sethi, and J. D. Ullman, Compilers Principles, Techniques and Tools. Addision-Wesley, 1986, pp. 25–388, and 463–512.

Referring now to FIGS. **6** and **7**, two block diagrams illustrating one embodiment of the interpreter of the hybrid compiler-interpreter of the present invention and its operation flow for handling data references is shown. As shown in FIG. **6**, the interpreter **70** comprises a main interpretation routine **72**, a number of complimentary operator specific interpretations routines, such as the ADD and the IF interpretation routines, **74** and **76**, and two data reference interpretation routines, a static field reference routine (SFR) and a dynamic field reference routine (DFR), **78** and **80**. The main interpreter routine **72** receives the byte codes **82** of the intermediate form object code as inputs, and interprets them, invoking the operator specific interpretations routines, e.g. **74** and **76**, and the data reference routines, **78** and **80**, as necessary. Except for the dynamic field reference routine **80**, and the manner in which the main interpretation routine **72**

and the state field reference routine **78** cooperates with the dynamic field reference routine **80** to handle data references, the main interpretation routine **72**, the operator specific interpretation routines, e.g. **74** and **76**, and the static field reference routine **78**, are intended to represent a broad category of these elements found in most compilers and interpreters. The constitutions and basic functions of these elements are well known and will not be otherwise described further here.

As shown in FIG. **7**, upon receiving a data reference byte code, block **86**, the main interpretation routine determines if the data reference is static, i.e. numeric, or dynamic, i.e. symbolic, block **88**. If the data reference is a symbolic reference, branch **88**b, the main interpretation routine invokes the dynamic field reference routine, block **90**. Upon invocation, the dynamic field reference routine resolves the symbolic reference, and rewrites the symbolic reference in the intermediate form object code as a numeric reference, block **92**. Upon rewriting the data reference in the object code, the dynamic field reference routine returns to the main interpretation routine, block **100**, without advancing the program counter. As a result, the instruction with the rewritten numeric data reference gets reexecuted again.

On the other hand, if the data reference is determined to be a numeric reference, branch **88**a, the main interpretation routine invokes the static field reference routine, block **94**. Upon invocation, the static field reference routine obtain the data reference by the numeric reference, block **96**. Upon obtaining the data, the static field reference routine advances the program counter, block **98**, and returns to the main interpretation routine, block **100**.

Referring now to FIG. **8**, a block diagram illustrating the alteration and rewriting of data references under the present invention in further detail is shown. As illustrated, a data referencing instruction, such as the LOAD instruction **14**", is initially generated with a symbolic reference, e.g. "y". Upon its first interpretation in execution, the data referencing instruction, e.g. **14**, is dynamically resolved and rewritten with a numeric reference, e.g. slot **2**. Thus, except for the first execution, the extra level of interpretation to resolve the symbolic reference is no longer necessary. Therefore, under the present invention, the "compiled" intermediate form object code of a program achieves execution performance substantially similar to that of the traditional compiled object code, and yet it has the flexibility of not having to be recompiled when the data objects it deals with are altered like that of the traditional translated code, since data reference resolution is performed at the first execution of a generated instruction comprising a symbolic reference.

While the present invention has been described in terms of presently preferred and alternate embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The method and apparatus of the present invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting on the present invention.

What is claimed is:

[1. In a computer system comprising a program in source code form, a method for generating executable code for said program and resolving data references in said generated code, said method comprising the steps of:

a) generating executable code in intermediate form for said program in source code form with data references being made in said generated code on a symbolic basis, said generated code comprising a plurality of instructions of said computer system;

b) interpreting said instructions, one at a time, in accordance to a program execution control;

c) resolving said symbolic references to corresponding numeric references, replacing said symbolic references with their corresponding numeric references, and continuing interpretation without advancing program execution, as said symbolic references are encountered while said instructions are being interpreted; and

d) obtaining data in accordance to said numeric references, and continuing interpretation after advancing program execution, as said numeric references are encountered while said instruction are being interpreted;

said steps b) through d) being performed iteratively and interleaving.**]**

[2. The method as set forth in claim **1**, wherein, said program in source code form is implemented in source code form of an object oriented programming language.**]**

[3. The method as set forth in claim **2**, wherein said programming language is C.**]**

[4. The method as set forth in claim **2**, wherein, said programming language is C++.**]**

[5. The method as set forth in claim **1**, wherein, said program execution control is a program counter said continuing interpretation in step c) is achieved by performing said step b) after said c) without incrementing said program counter; and

said continuing interpretation in said step d) is achieved by performing said step b) after said d) after incrementing said program counter.**]**

[6. In a computer system comprising a program in source code form, an apparatus for generating executable code for said program and resolving data references in said generated code, said apparatus comprising:

a) compilation means for receiving said program in source code form and generating executable code in intermediate form for said program in source code form with data references being made in said generated code on a symbolic basis, said generated code comprising a plurality of instructions of said computer system;

b) interpretation means for receiving said generated code and interpreting said instructions, one at a time;

c) dynamic reference handling means coupled to said interpretation means for resolving said symbolic references to corresponding numeric references, replacing said symbolic references with their corresponding numeric references, and continuing interpretation by said interpretation means without advancing program execution, as said symbolic references are encountered while said instructions are being interpreted by said interpretation means; and

d) static reference handling means coupled to said interpretation means for obtaining data in accordance to said numeric references, and continuing interpretation by said interpretation means after advancing program execution, as said numeric references are encountered while said instruction are being interpreted by said interpretation means;

said interpretation means, said dynamic reference handling means, and said static reference handling means performing their corresponding functions iteratively and interleavingly.**]**

[7. The apparatus as set forth in claim **6**, wherein, said program in source code form is implemented in source code form of an object oriented programming language.**]**

[8. The apparatus as set forth in claim **7**, wherein, said programming language is C.**]**

[9. The apparatus as set forth in claim 7, wherein, said programming language is C++.]

[10. The apparatus as set forth in claim 6, wherein, and program execution control is a program counter.]

11. An apparatus comprising:

a memory containing intermediate form object code constituted by a set of instructions, certain of said instructions containing one or more symbolic references; and

a processor configured to execute said instructions containing one or more symbolic references by determining a numerical reference corresponding to said symbolic reference, storing said numerical references, and obtaining data in accordance to said numerical references.

12. A computer-readable medium containing instructions for controlling a data processing system to perform a method for interpreting intermediate form object code comprised of instructions, certain of said instructions containing one or more symbolic references, said method comprising the steps of:

interpreting said instructions in accordance with a program execution control; and

resolving a symbolic reference in an instruction being interpreted, said step of resolving said symbolic reference including the substeps of:

determining a numerical reference corresponding to said symbolic reference, and

storing said numerical reference in a memory.

13. A computer-implemented method for executing instructions, certain of said instructions containing one or more symbolic references, said method comprising the steps of:

resolving a symbolic reference in an instruction, said step of resolving said symbolic reference including the substeps of:

determining a numerical reference corresponding to said symbolic reference, and

storing said numerical reference in a memory.

14. The method of claim 3, wherein said substep of storing said numerical reference comprises the substep of replacing said symbolic reference with said numerical reference.

15. The method of claim 3, wherein said step of resolving said symbolic reference further comprises the substep of executing said instruction containing said symbolic reference using the stored numerical reference.

16. The method of claim 3, wherein said step of resolving said symbolic reference further comprises the substep of advancing program execution control after said substep of executing said instruction containing said symbolic reference.

17. In a computer system comprising a program, a method for executing said program comprising the steps of:

receiving intermediate form object code for said program with symbolic data references in certain instructions of said intermediate form object code; and

converting the instructions of the intermediate form object code having symbolic data references, said converting step comprising the substeps of:

resolving said symbolic references to corresponding numerical references,

storing said numerical references, and

obtaining data in accordance to said numerical references.

18. A computer-implemented method for executing program operations, each operation being comprised of a set of instructions, certain of said instructions containing one or more symbolic references, said method comprising the steps of:

receiving a set of instructions reflecting an operation; and

performing the operation corresponding to the received set of instructions, wherein at least one of said symbolic references is resolved by determining a numerical reference corresponding to said symbolic reference, storing said numerical reference, and obtaining data in accordance to said stored numerical reference.

19. A memory for use in executing a program by a processor, the memory comprising:

intermediate form code containing symbolic field references associated with an intermediate representation of source code for the program,

the intermediate representation having been generated by lexically analyzing the source code and parsing output of said lexical analysis, and

wherein the symbolic field references are resolved by determining a numerical reference corresponding to said symbolic reference, and storing said numerical reference in a memory.

20. A computer-implemented method comprising:

receiving a program that comprises a set instructions written in an intermediate form code;

replacing each instruction in the program with a symbolic data reference with a new instruction containing a numeric reference resulting from invocation of a dynamic field reference routine to resolve the symbolic data reference; and

executing the program by performing an operation in accordance with each instruction or new instruction, depending upon whether an instruction has been replaced with a new instruction in accordance with the replacing step.

21. A data processing system, comprising:

a processor; and

a memory comprising a control program for causing the processor to (i) receive a program that comprises a set instructions written in an intermediate form code, (ii) replace each instruction in the program with a symbolic data reference with a new instruction containing a numeric reference resulting from invocation of a dynamic field reference routine to resolve the symbolic data reference, and (iii) execute the program by performing an operation in accordance with each instruction or new instruction, depending upon whether an instruction has been replaced with a new instruction in accordance with the replacing step.

22. An apparatus comprising:

a memory containing a compiled program in intermediate form object code constituted by a set of instructions, at least one of the instructions containing a symbolic reference; and

a processor configured to execute the instruction by determining a numerical reference corresponding to the symbolic reference, and performing an operation in accordance with the instruction and data obtained in accordance with the numerical reference without recompiling the program or any portion thereof.

23. A computer-implemented method, comprising:

receiving a program with a set instructions written in an intermediate form code;

analyzing each instruction of the program to determine whether the instruction contains a symbolic reference to a data object; and

executing the program, wherein when it was determined that an instruction contains a symbolic reference, data

from a storage location identified by a numeric reference correspoding to the symbolic reference is used thereafter to perform an operation corresponding to that instruction.

24. A computer-implemented method for executing a program comprised of bytecodes, the method comprising:

determining immediately prior to execution whether a bytecode of the program contains a symbolic data reference;

when it is determined that the bytecode of the program contains a symbolic data reference, invoking a dynamic field reference routine to resolve the symbolic data reference; and

executing thereafter the bytecode using stored data located using a numeric reference resulting from the resolution of the symbolic reference.

25. A data processing system, comprising:

a processor; and

a memory comprising a program comprised of bytecodes and instructions for causing the processor to (*i*) determine immediately prior to execution of the program whether a bytecode of the program contains a symbolic data reference, (*ii*) when it is determined that the bytecode of the program contains a symbolic data reference, invoke a dynamic field reference routine to resolve the symbolic data reference, and (*iii*) execute thereafter the bytecode using stored data located using a numeric reference resulting from the resolution of the symbolic reference.

26. A computer program product containing instructions for causing a computer to perform a method for executing a program comprised of bytecodes, the method comprising:

determining immediately prior to execution whether a bytecode of the program contains a symbolic data reference;

when it is determined that the bytecode of the program contains a symbolic data reference, invoking a dynamic field reference routine to resolve the symbolic data reference; and

executing thereafter the bytecode using stored data located using a numeric reference resulting from the resolution of the symbolic reference.

27. A computer-implemented method comprising:

receiving a program with a set of original instructions written in an intermediate form code;

generating a set of new instructions for the program that contain numeric references resulting from invocation of a routine to resolve any symbolic data references in the set of original instructions; and

executing the program using the set of new instructions.

28. A data processing system, comprising:

a processor; and

a memory comprising a control program for causing the processor to (*i*) receive a program with a set of original instructions written in an intermediate form code, (*ii*) generate a set of new instructions for the program that contain numeric references resulting from invocation of a routine to resolve any symbolic data references in the set of original instructions, and (*iii*) executing the program using the set of new instructions.

29. A computer program product containing instructions for causing a computer to perform a method, the method comprising:

receiving a program with a set of original instructions written in an intermediate form code;

generating a set of new instructions for the program that contain numeric references resulting from invocation of a routine to resolve any symbolic data references in the set of original instructions; and

executing the program using the set of new instructions.

30. A computer-implemented method comprising:

receiving a program that comprises a set instructions written in an intermediate form code;

replacing each instruction in the program with a symbolic data reference with a new instruction containing a numeric reference resulting from invocation of a dynamic field reference routine to resolve the symbolic data reference; and

executing the program by performing an operation in accordance with each instruction or new instruction, depending upon whether an instruction has been replaced with a new instruction in accordance with the replacing step.

31. A data processing system, comprising:

a processor; and

a memory comprising a control program for causing the processor to (*i*) receive a program that comprises a set instructions written in an intermediate form code, (*ii*) replace each instruction in the program with a symbolic data reference with a new instruction containing a numeric reference resulting from invocation of a dynamic field reference routing to resolve the symbolic data reference, and (*iii*) execute the program by performing an operation in accordance with each instruction or new instruction, depending upon whether an instruction has been replaced with a new instruction in accordance with the replacing step.

32. A computer program product containing control instructions for causing a computer to perform a method, the method comprising:

receiving a program that comprises a set instructions written in an intermediate form code;

replacing each instruction in the program with a symbolic data reference with a new instruction containing a numeric reference resulting from invocation of a dynamic field reference routine to resolve the symbolic data reference; and

executing the program by performing an operation in accordance with each instruction or new instruction, depending upon whether an instruction has been replaced with a new instruction in accordance with the replacing step.

33. A computer-implemented method, comprising:

receiving a program with a set instructions written in an intermediate form code;

analyzing each instruction of the program to determine whether the instruction contains a symbolic reference to a data object; and

executing the program, wherein when it was determined that an instruction contains a symbolic reference, data from a storage location identified by a numeric reference corresponding to the symbolic reference is used thereafter to perform an operation corresponding to that instruction.

34. A data processing system, comprising:

a processor; and

a memory comprising a control program for causing the processor to (*i*) receive a program with a set instructions written in an intermediate form code, (*ii*) analyze each instruction of the program to determine whether

the instruction contains a symbolic reference to a data object, and (iii) execute the program, wherein when it was determined that an instruction contains a symbolic reference, data from a storage location identified by a numeric reference corresponding to the symbolic reference is used thereafter to perform an operation corresponding to that instruction.

35. A computer program product containing control instructions for causing a computer to perform a method, the method comprising:

receiving a program with a set instructions written in an intermediate form code;

analyzing each instruction of the program to determine whether the instruction contains a symbolic reference to a data object; and

executing the program, wherein when it was determined that an instruction contains a symbolic reference, data from a storage location identified by a numeric reference corresponding to the symbolic reference is used thereafter to perform an operation corresponding to that instruction.

36. A computer-implemented method for executing a program comprised of bytecodes, the method comprising:

determining whether a bytecode of the program contains a symbolic reference;

when it is determined that the bytecode contains a symbolic reference, invoking a dynamic field reference routine to resolve the symbolic reference; and

performing an operation identified by the bytecode thereafter using data from a storage location identified by a numeric reference resulting from the invocation of the dynamic field reference routine.

37. A data processing system, comprising:

a processor; and

a memory comprising a program comprised of bytecodes and instructions for causing the processor to (i) determine whether a bytecode of the program contains a symbolic reference, (ii) when it is determined that the bytecode contains a symbolic reference, invoke a dynamic field reference routine to resolve the symbolic reference, and (iii) perform an operation identified by the bytecode thereafter using data from a storage location identified by a numeric reference resulting from the invocation of the dynamic field reference routine.

38. A computer program product containing instructions for causing a computer to perform a method for executing a program comprised of bytecodes, the method comprising:

determining whether a bytecode of the program contains a symbolic reference;

when it is determined that the bytecode contains a symbolic reference, invoking a dynamic field reference routine to resolve the symbolic reference; and

performing an operation identified by the bytecode therafter using data from a storage location identified by a numeric reference resulting from the invocation of the dynamic field reference routine.

39. A computer-implemented method comprising:

receiving a program formed of instructions written in an intermediate form code compiled from source code;

analyzing each instruction to determine whether it contains a symbolic field reference; and

executing the program by performing an operation identified by each instruction, wherein data from a storage location identified by a numeric reference is thereafter used for the operation when the instruction contains a symbolic field reference, the numeric reference having been resolved from the symbolic field reference.

40. A data processing system, comprising:

a processor; and

a memory comprising a control program for causing the processor to (i) receive a program formed of instructions written in an intermediate form code compiled from source code, (ii) analyze each instruction to determine whether it contains a symbolic field reference, and (iii) execute the program by performing an operation identified by each instruction, wherein data from a storage location identified by a numeric reference is thereafter used for the operation when the instruction contains a symbolic field reference, the numeric reference having been resolved from the symbolic field reference.

41. A computer program product containing control instructions for causing a computer to perform a method, the method comprising:

receiving a program formed of instructions written in an intermediate form code compiled from source code;

analyzing each instruction to determine whether it contains a symbolic field reference; and

executing the program by performing an operation identified by each instruction, wherein data from a storage location identified by a numeric reference is used thereafter for the operation when the instruction contains a symbolic field reference, the numeric reference having been resolved from the symbolic field reference.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : RE 38,104 E
DATED : April 29, 2003
INVENTOR(S) : James Gosling

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page,
Item (57), **ABSTRACT**,
Line 24, please replace "interaction in" with -- instruction is --.

Column 6,
Line 15, please replace "interleaving" with -- interleavingly --.
Line 18, after "wherein", please insert a comma.
Line 23, after "counter", please insert a semicolon.
Line 25, please replace "said c)" with -- said step c) --.

Column 7,
Lines 3-4, please replace "and program execution" with -- said program execution --.
Lines 38, 41 and 45, please replace " 3" with -- 13 --.

Column 8,
Lines 20-33, delete the claim in its entirety and insert therefore:

--20. A computer-implemented method for executing a compiled program containing instructions in an intermediate form code, at least one of the instructions containing a symbolic reference, said method comprising the steps of:

resolving the symbolic reference in the instruction by determining a numerical reference corresponding to the symbolic reference; and

performing an operation in accordance with the instruction and data obtained in accordance with the numerical reference without recompiling the program or any portion thereof.--.

Lines 34-47, delete the claim in its entirety and insert therefore:

--21. A memory encoded with a compiled program, the memory comprising:

intermediate form code containing symbolic field references associated with an intermediate representation of source code for the program,

the intermediate representation having been generated by lexically analyzing the source code and parsing output of said lexical analysis,

such that when the program is executed by a processor each symbolic field reference is resolved by determining a numerical reference corresponding to the symbolic field reference and data is obtained in accordance with the numerical reference without recompiling the program or any portion thereof.--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : RE 38,104 E
DATED : April 29, 2003
INVENTOR(S) : James Gosling

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 8, line 60 - Column 9, line 4,
Delete the claim in its entirety and insert therefore:

-- 23. A computer-readable medium containing instructions for controlling a data processing system to perform a method for interpreting a compiled program in intermediate form object code comprised of instructions, at least one of the instructions containing a symbolic reference, said method comprising the steps of:

resolving the symbolic reference in the instruction by determining a numerical reference corresponding to the symbolic reference; and

performing an operation in accordance with the instruction and data obtained in accordance with the numerical reference without recompiling the program or any portion thereof. --.

Column 10,
Lines 7, 23-24, 37, 50 and 65-66, please replace "*a set instructions*" with -- *a set of instructions* --.
Line 28, please replace "*routing*" with -- *routine* --.

Column 11,
Line 11, please replace "*a set instructions*" with -- *a set of instructions* --.

Column 12,
Line 7, please replace "*therafter*" with -- *thereafter* --.

Signed and Sealed this

Sixteenth Day of September, 2003

JAMES E. ROGAN
Director of the United States Patent and Trademark Office