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(54) COMPUTER ARCHITECTURE AND METHOD OF OPERATION FOR MULTI-COMPUTER DISTRIBUTED PROCESSING WITH INITIALIZATION OF OBJECTS

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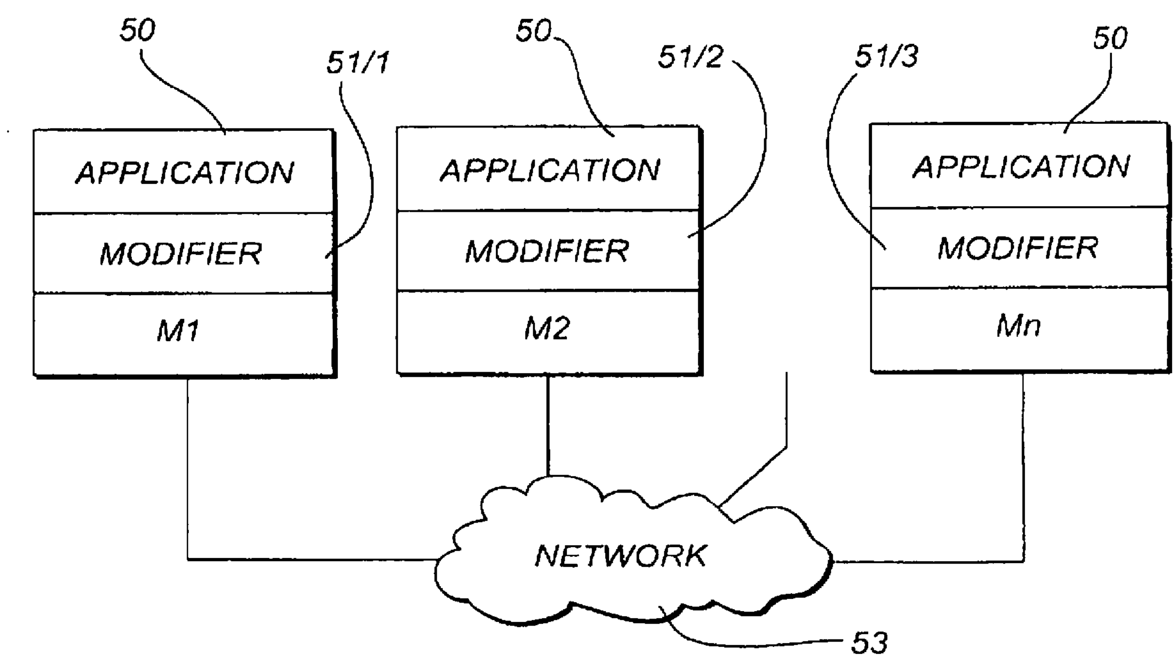
(57) **ABSTRACT**

The present invention discloses a modified computer architecture which (**50**, **71**, **72**) enables an applications program (**50**) to be run simultaneously on a plurality of computers (M**1**, . . . Mn). Shared memory at each computer is updated with amendments and/or overwrites so that all memory read requests are satisfied locally. During initial program loading (**75**), or similar, instructions which result in memory being re-written or manipulated are identified (**92**). Additional instructions are inserted (**103**) to cause the equivalent memory locations at all computers to be updated. In particular, the initialisation of JAVA language classes and objects is disclosed (**162**, **163**) so all memory locations for all computers are initialized in the same manner.



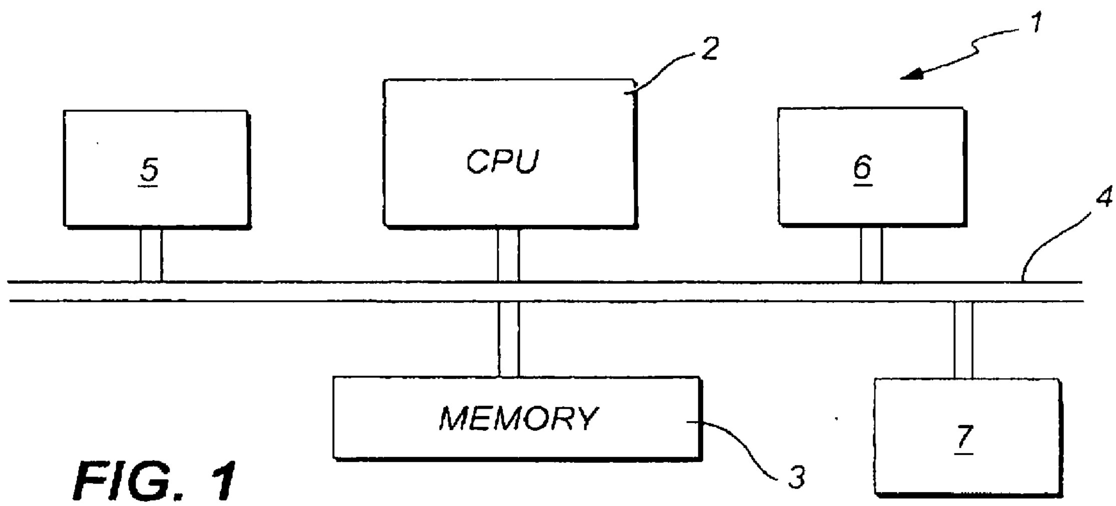


FIG. 1
PRIOR ART

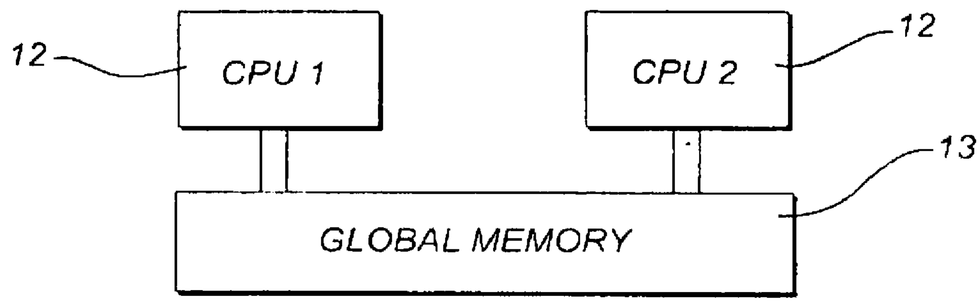


FIG. 2
PRIOR ART

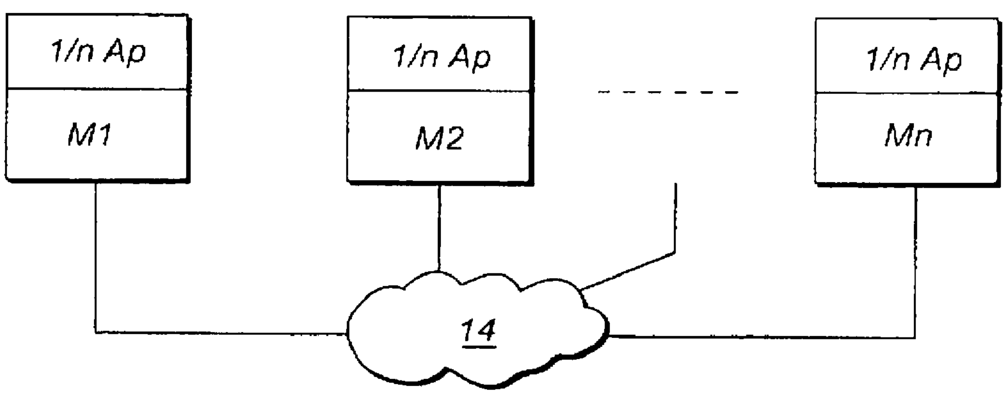


FIG. 3
PRIOR ART

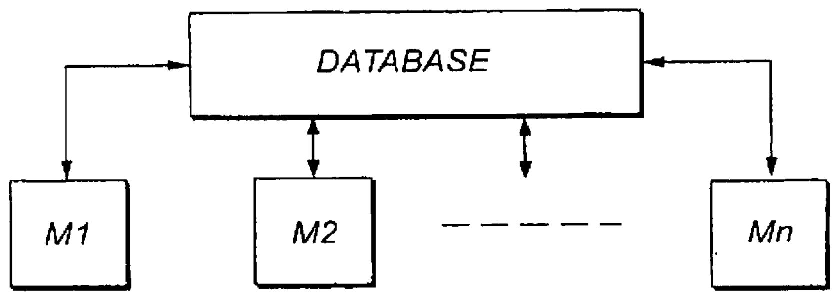


FIG. 4
PRIOR ART

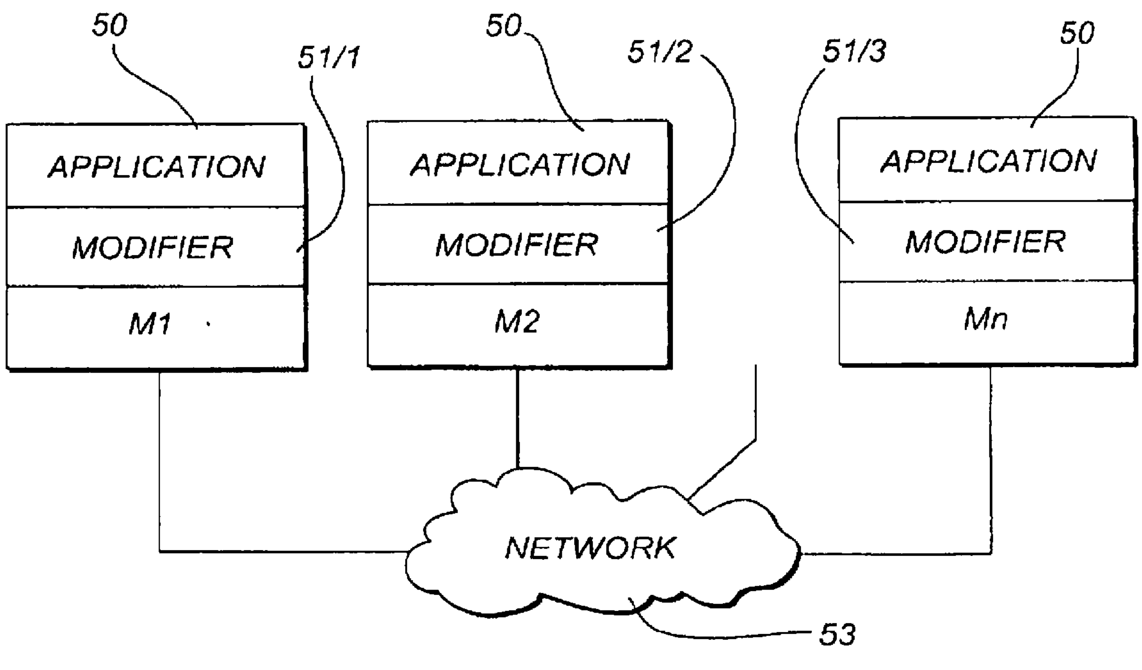


FIG. 5

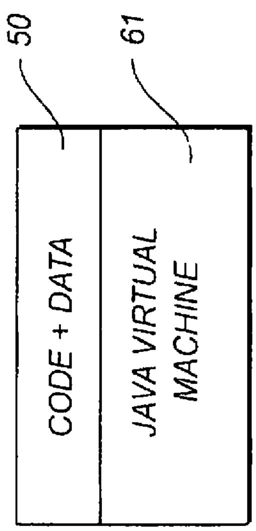


FIG. 6
PRIOR ART

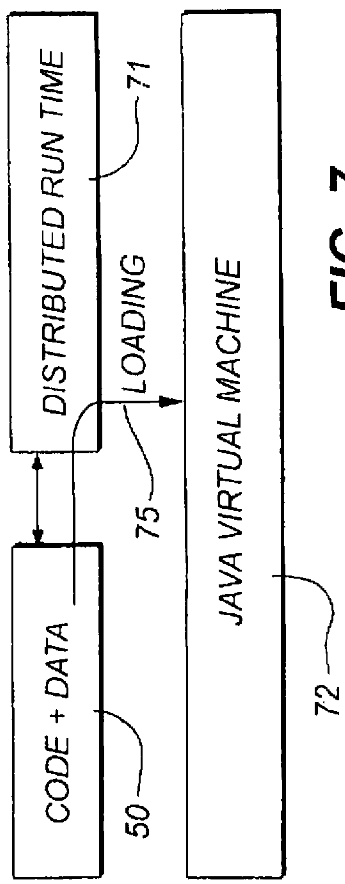


FIG. 7

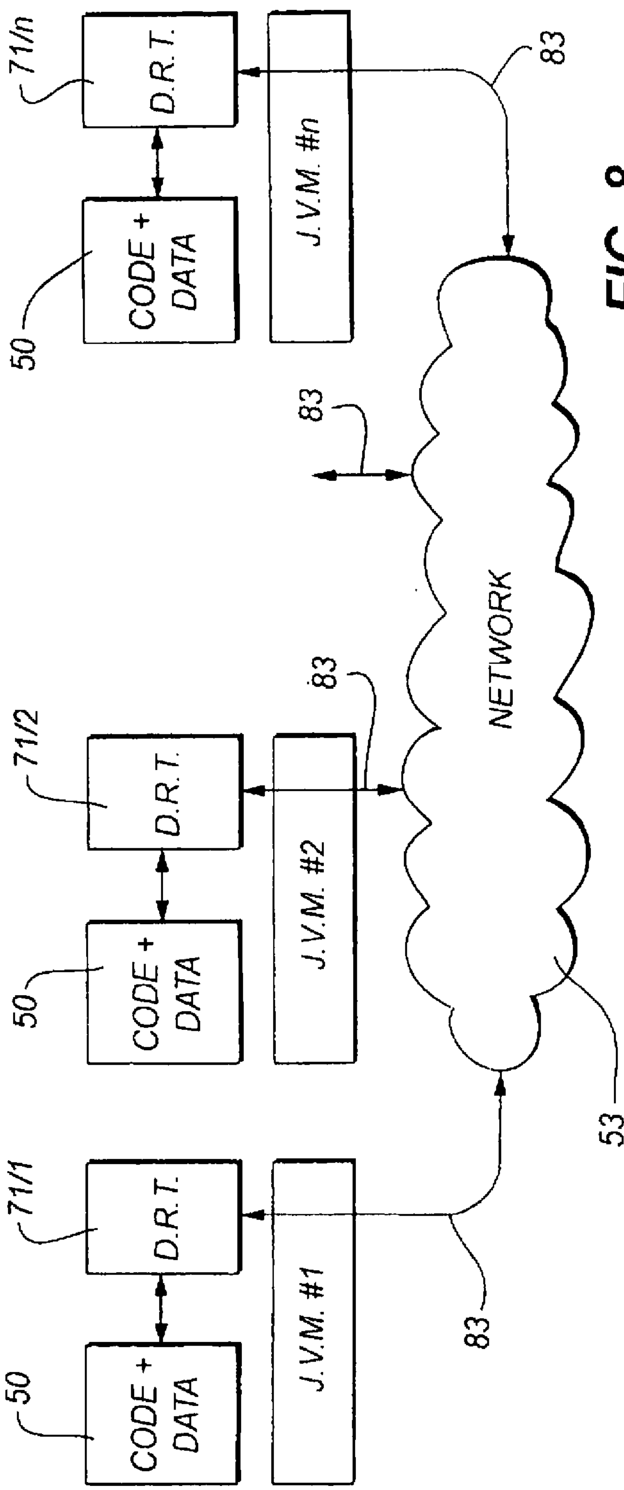


FIG. 8

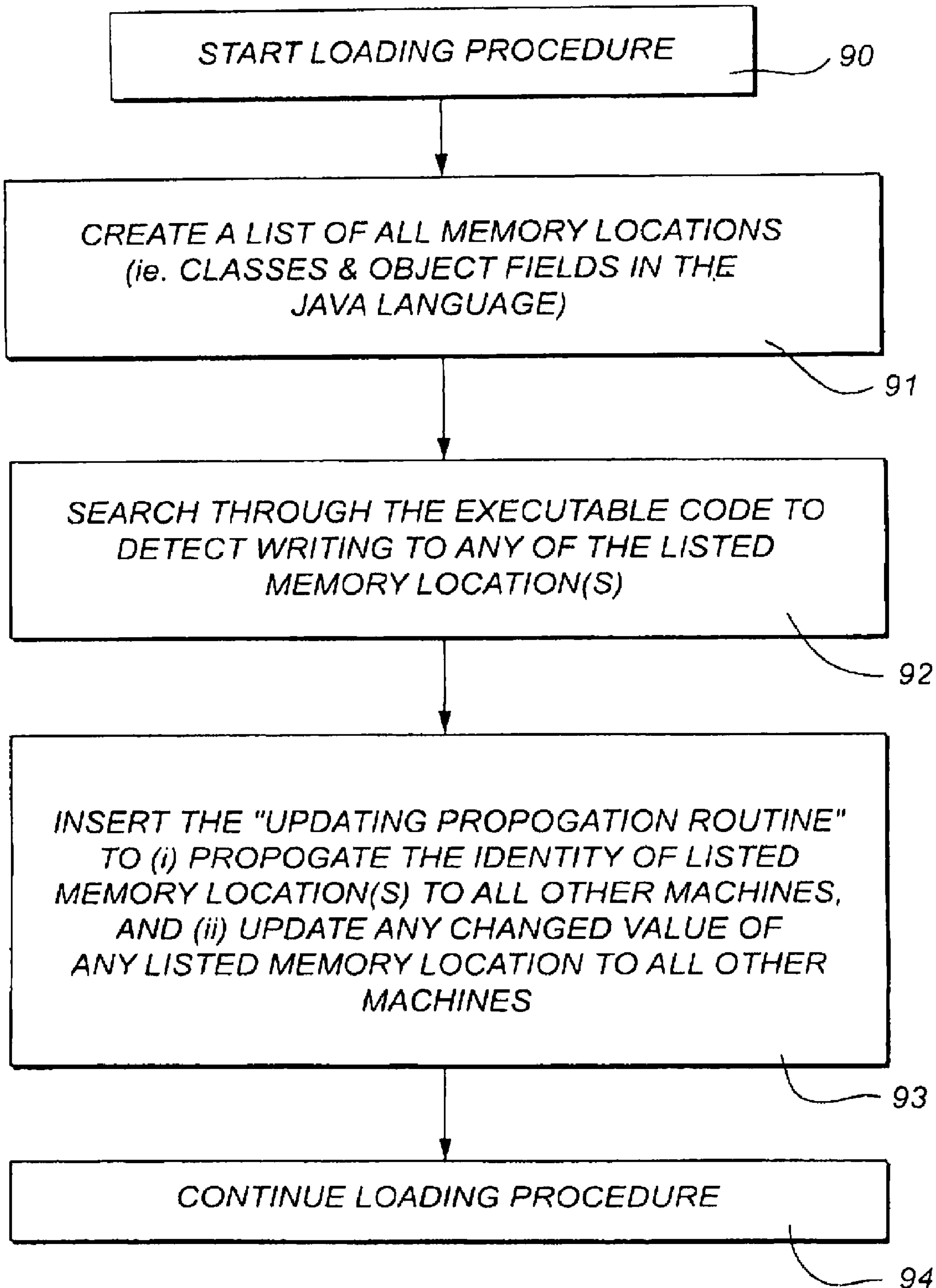

START LOADING PROCEDURE
90
CREATE A LIST OF ALL MEMORY LOCATIONS (ie. CLASSES & OBJECT FIELDS IN THE JAVA LANGUAGE)
91
SEARCH THROUGH THE EXECUTABLE CODE TO DETECT WRITING TO ANY OF THE LISTED MEMORY LOCATION(S)
92
INSERT THE "UPDATING PROPOGATION ROUTINE" TO (i) PROPOGATE THE IDENTITY OF LISTED MEMORY LOCATION(S) TO ALL OTHER MACHINES, AND (ii) UPDATE ANY CHANGED VALUE OF ANY LISTED MEMORY LOCATION TO ALL OTHER MACHINES
93
CONTINUE LOADING PROCEDURE
94

FIG. 9

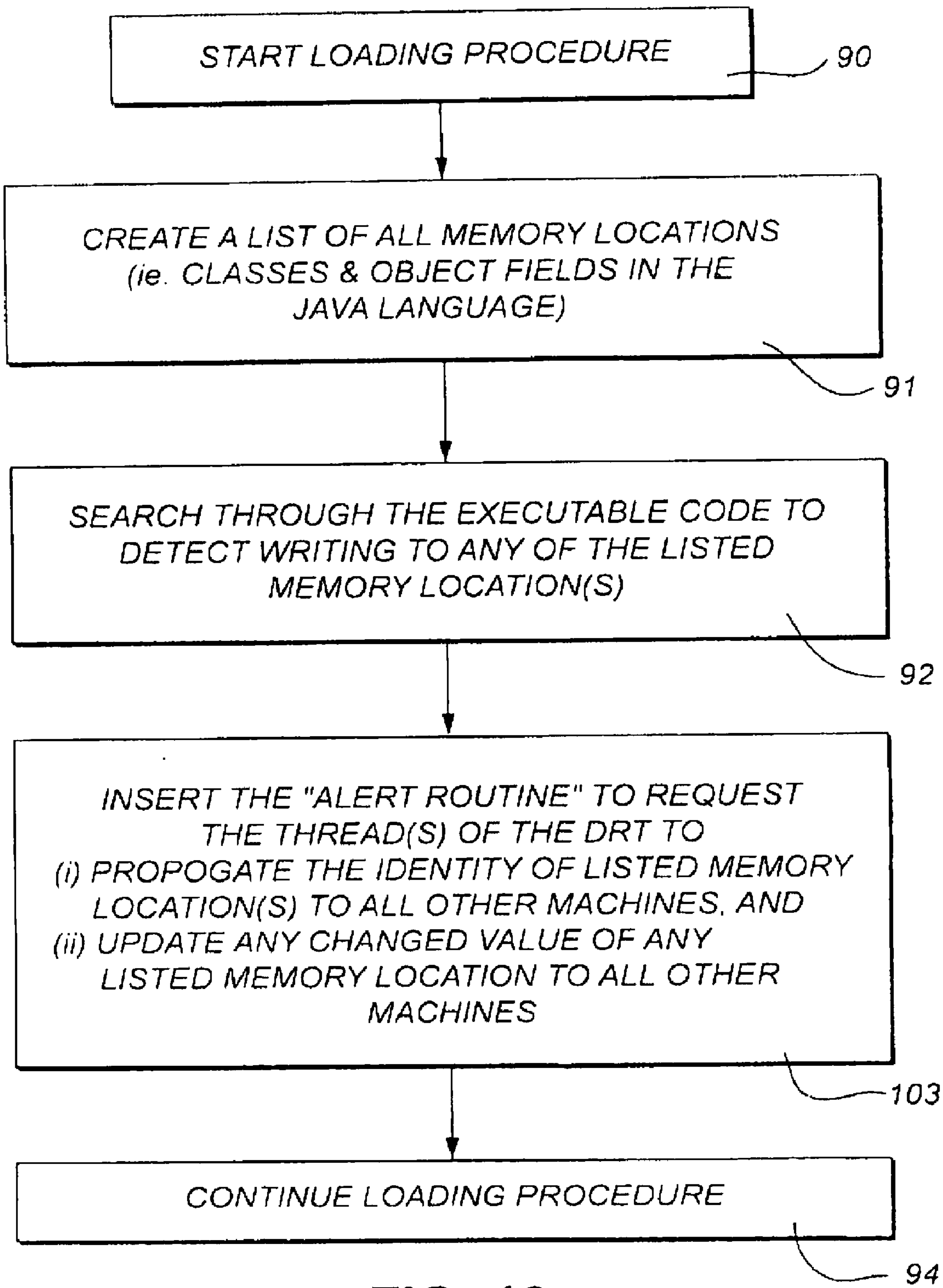

START LOADING PROCEDURE
90
CREATE A LIST OF ALL MEMORY LOCATIONS (ie. CLASSES & OBJECT FIELDS IN THE JAVA LANGUAGE)
91
SEARCH THROUGH THE EXECUTABLE CODE TO DETECT WRITING TO ANY OF THE LISTED MEMORY LOCATION(S)
92
INSERT THE "ALERT ROUTINE" TO REQUEST THE THREAD(S) OF THE DRT TO (i) PROPOGATE THE IDENTITY OF LISTED MEMORY LOCATION(S) TO ALL OTHER MACHINES, AND (ii) UPDATE ANY CHANGED VALUE OF ANY LISTED MEMORY LOCATION TO ALL OTHER MACHINES
103
CONTINUE LOADING PROCEDURE
94

FIG. 10

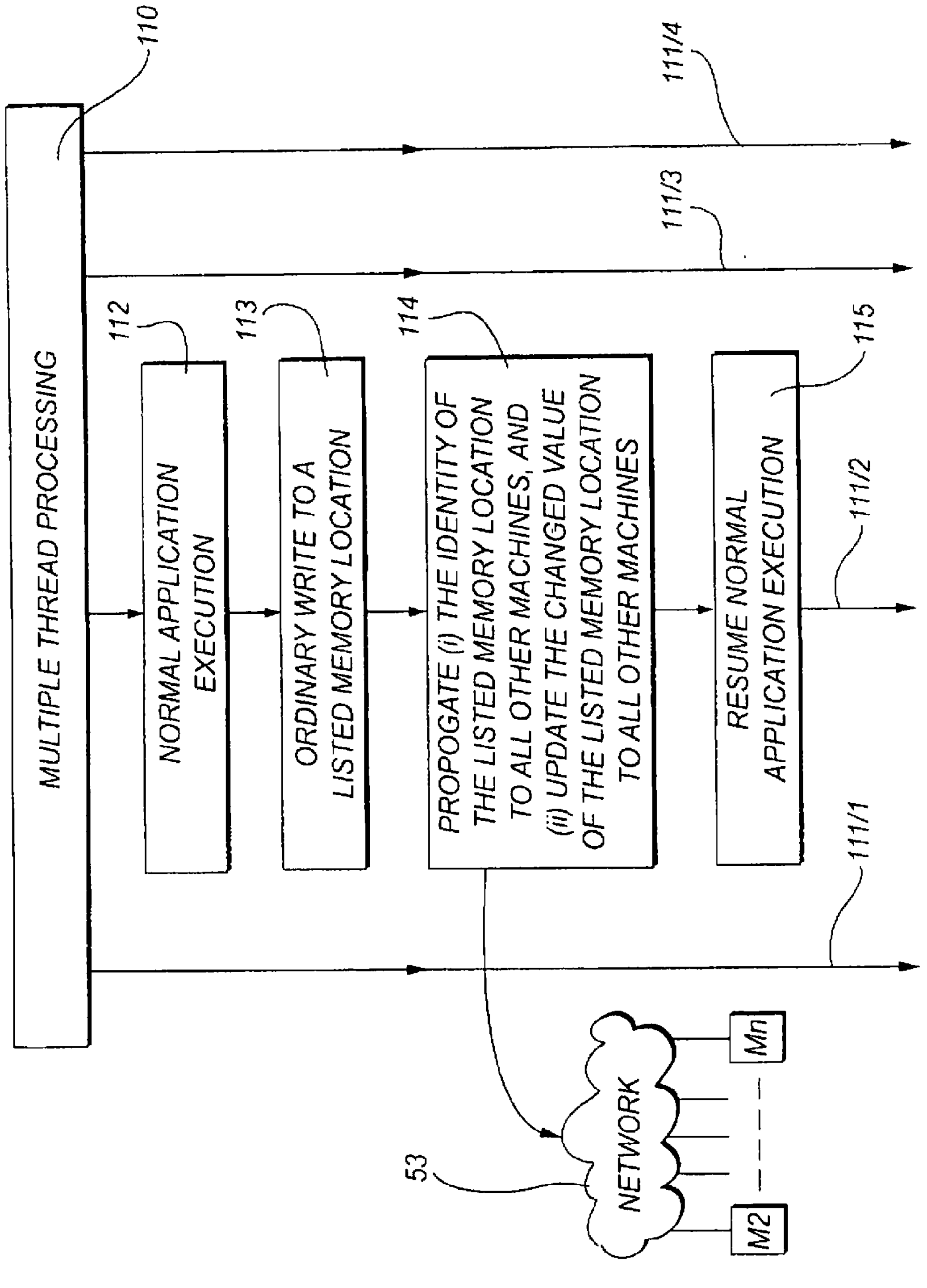

110
MULTIPLE THREAD PROCESSING
111/4
111/3
112
NORMAL APPLICATION EXECUTION
113
ORDINARY WRITE TO A LISTED MEMORY LOCATION
114
PROPOGATE (i) THE IDENTITY OF THE LISTED MEMORY LOCATION TO ALL OTHER MACHINES, AND (ii) UPDATE THE CHANGED VALUE OF THE LISTED MEMORY LOCATION TO ALL OTHER MACHINES
115
RESUME NORMAL APPLICATION EXECUTION
111/2
111/1
53
NETWORK
M2
Mn

FIG.11

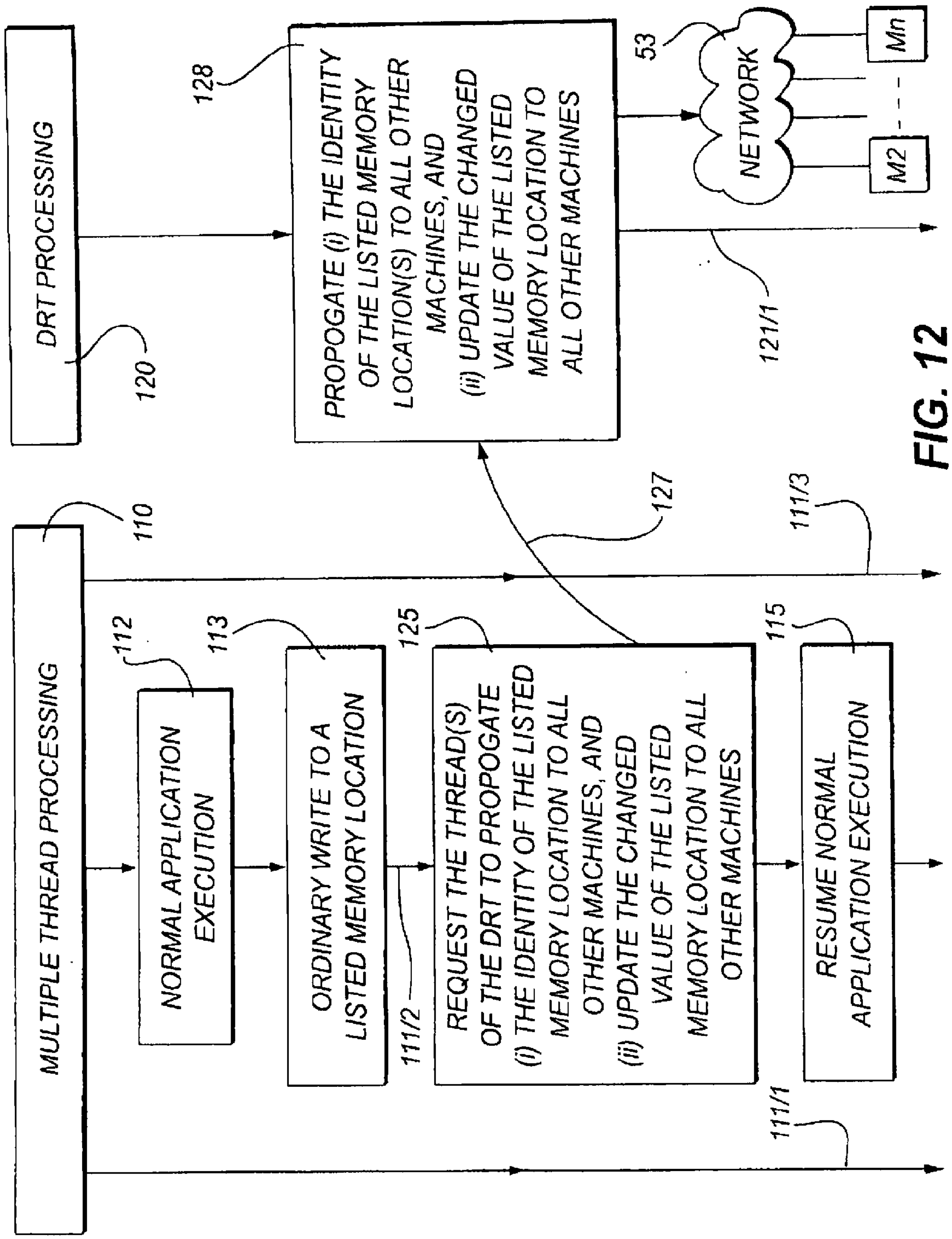

MULTIPLE THREAD PROCESSING
110
NORMAL APPLICATION EXECUTION
112
ORDINARY WRITE TO A LISTED MEMORY LOCATION
113
REQUEST THE THREAD(S) OF THE DRT TO PROPOGATE (i) THE IDENTITY OF THE LISTED MEMORY LOCATION TO ALL OTHER MACHINES, AND (ii) UPDATE THE CHANGED VALUE OF THE LISTED MEMORY LOCATION TO ALL OTHER MACHINES
125
RESUME NORMAL APPLICATION EXECUTION
115
111/1
111/2
111/3
127
DRT PROCESSING
120
PROPOGATE (i) THE IDENTITY OF THE LISTED MEMORY LOCATION(S) TO ALL OTHER MACHINES, AND (ii) UPDATE THE CHANGED VALUE OF THE LISTED MEMORY LOCATION TO ALL OTHER MACHINES
128
121/1
NETWORK
53
M2
Mn

FIG. 12

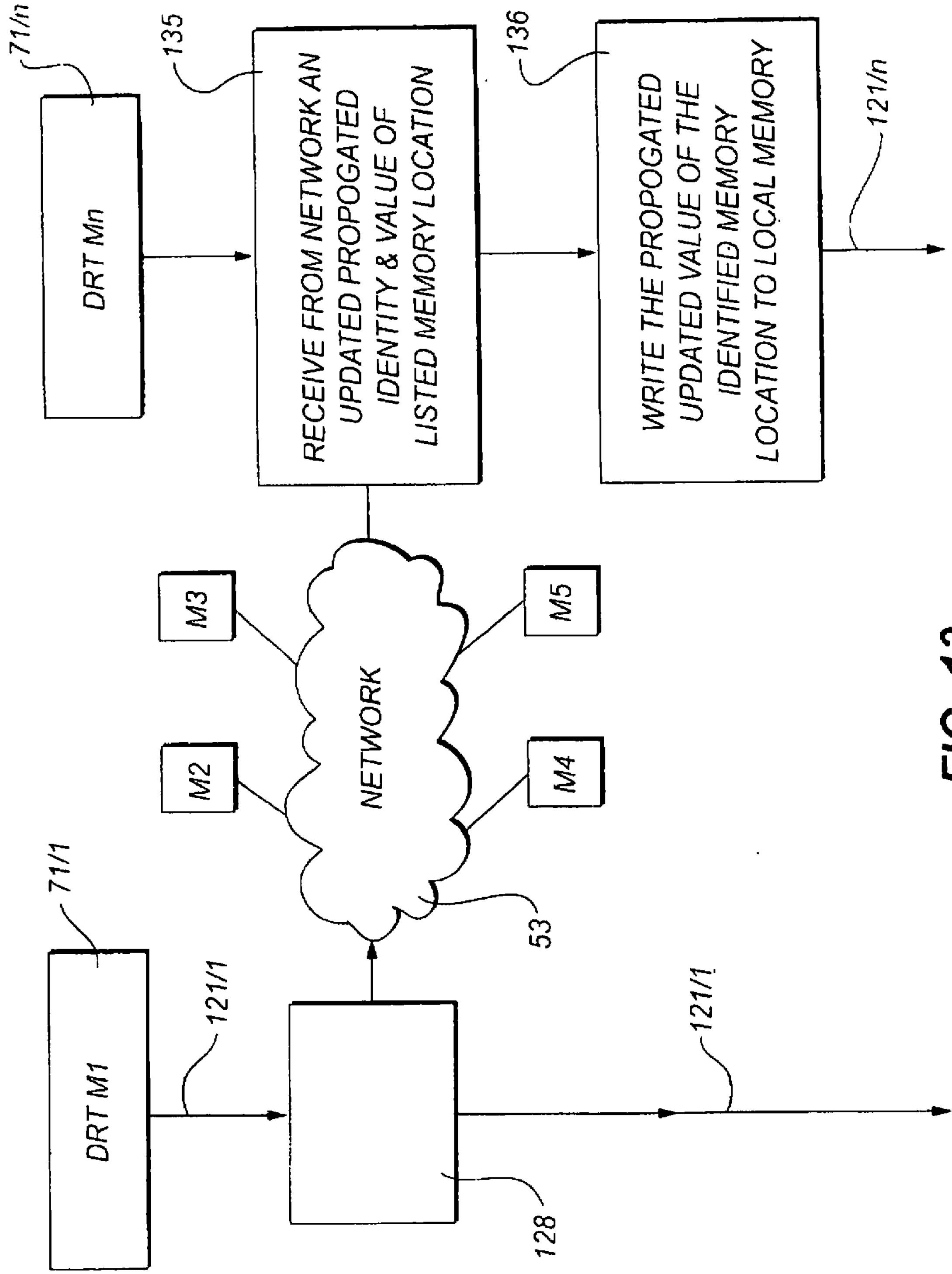

71/n
DRT Mn
135
RECEIVE FROM NETWORK AN UPDATED PROPOGATED IDENTITY & VALUE OF LISTED MEMORY LOCATION
136
WRITE THE PROPOGATED UPDATED VALUE OF THE IDENTIFIED MEMORY LOCATION TO LOCAL MEMORY
121/n
M3
M5
NETWORK
M2
M4
53
71/1
DRT M1
121/1
121/1
128

FIG. 13

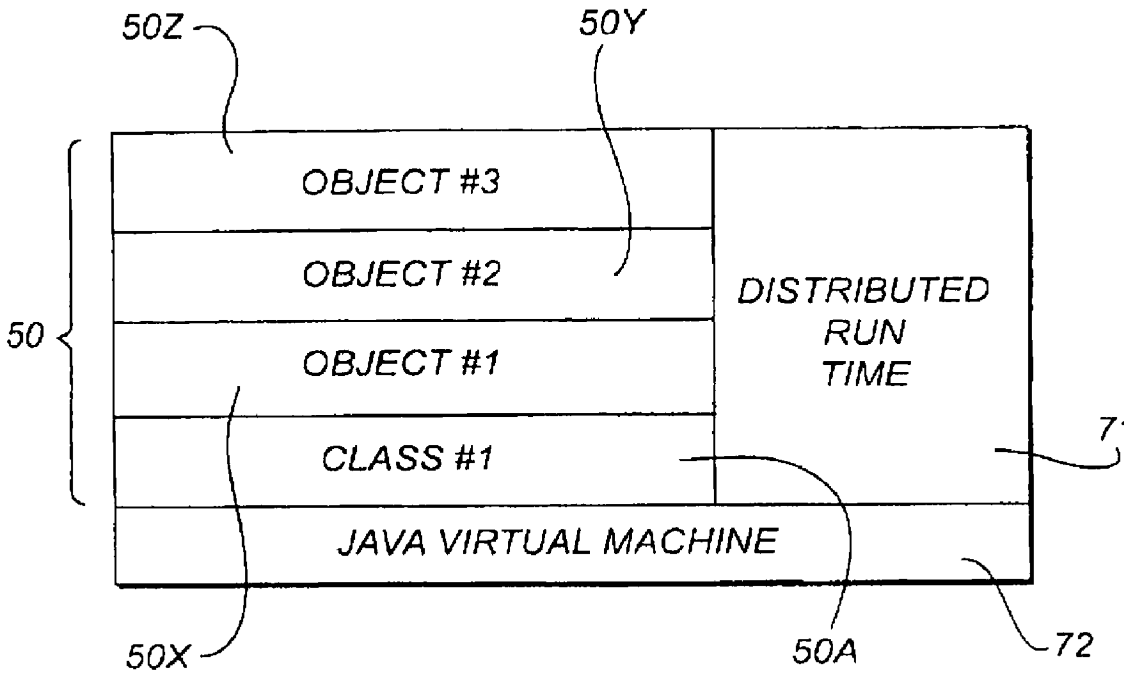


FIG. 14
PRIOR ART

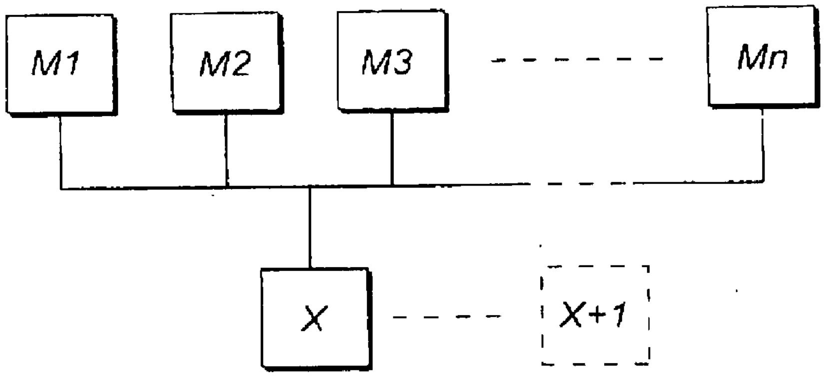

M1
M2
M3
Mn
X
X+1

FIG. 15

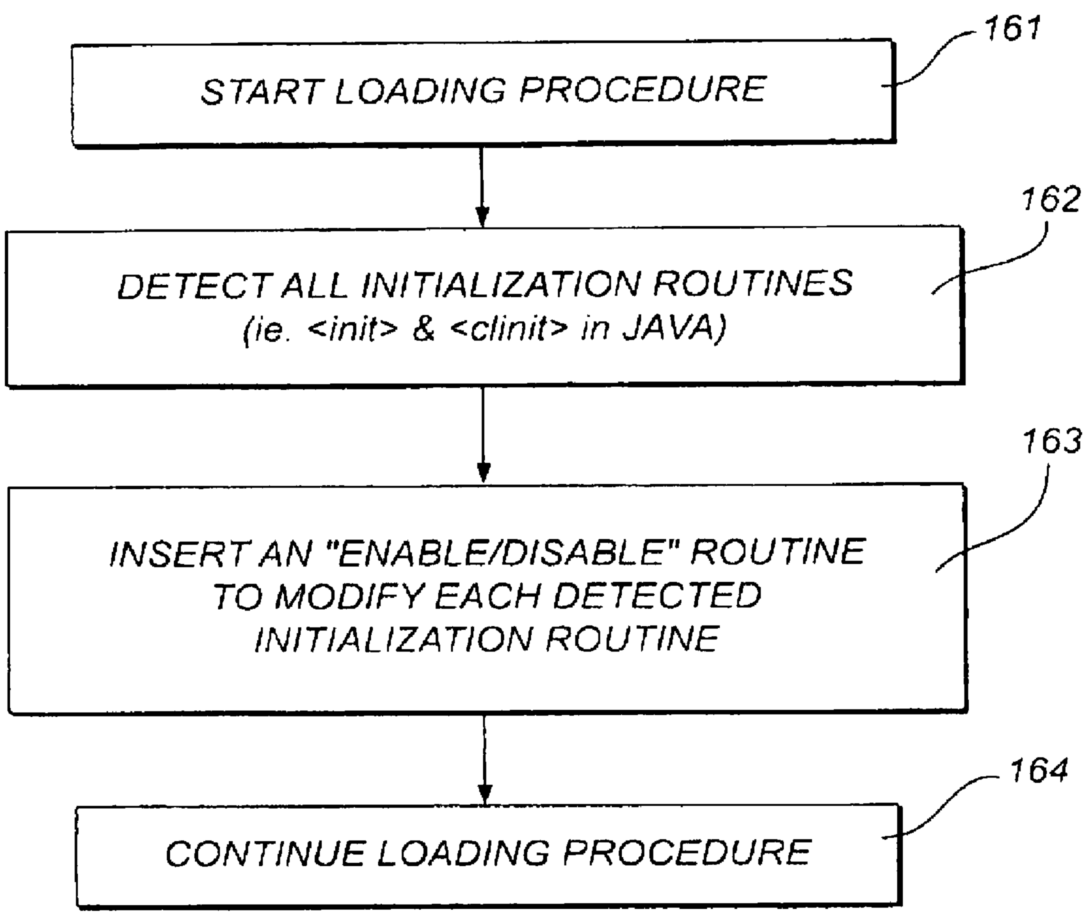

161
START LOADING PROCEDURE
162
DETECT ALL INITIALIZATION ROUTINES
(ie. <init> & <clinit> in JAVA)
163
INSERT AN "ENABLE/DISABLE" ROUTINE
TO MODIFY EACH DETECTED
INITIALIZATION ROUTINE
164
CONTINUE LOADING PROCEDURE

FIG. 16

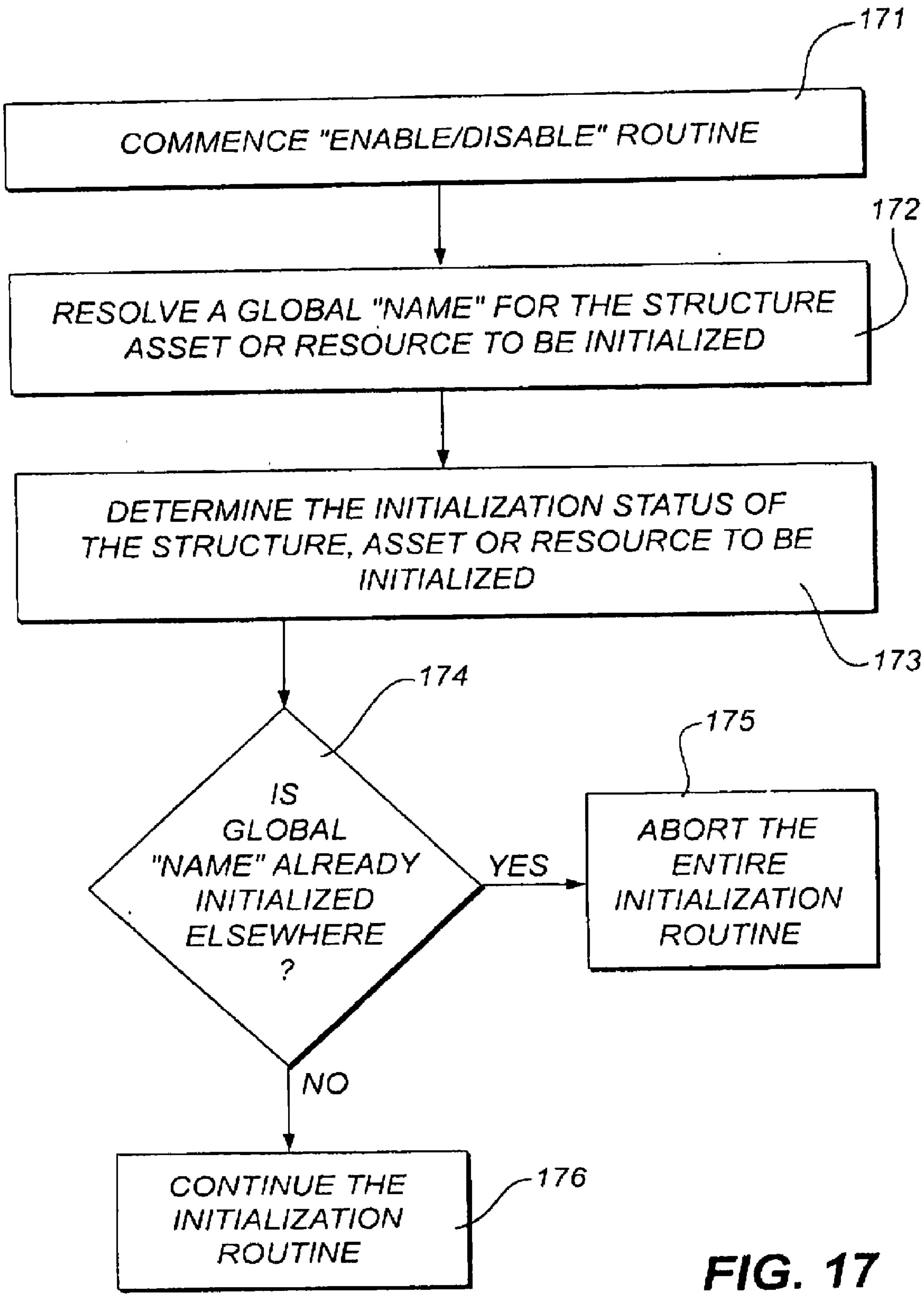

171
COMMENCE "ENABLE/DISABLE" ROUTINE
172
RESOLVE A GLOBAL "NAME" FOR THE STRUCTURE ASSET OR RESOURCE TO BE INITIALIZED
DETERMINE THE INITIALIZATION STATUS OF THE STRUCTURE, ASSET OR RESOURCE TO BE INITIALIZED
173
174
IS GLOBAL "NAME" ALREADY INITIALIZED ELSEWHERE ?
YES
175
ABORT THE ENTIRE INITIALIZATION ROUTINE
NO
CONTINUE THE INITIALIZATION ROUTINE
176

FIG. 17

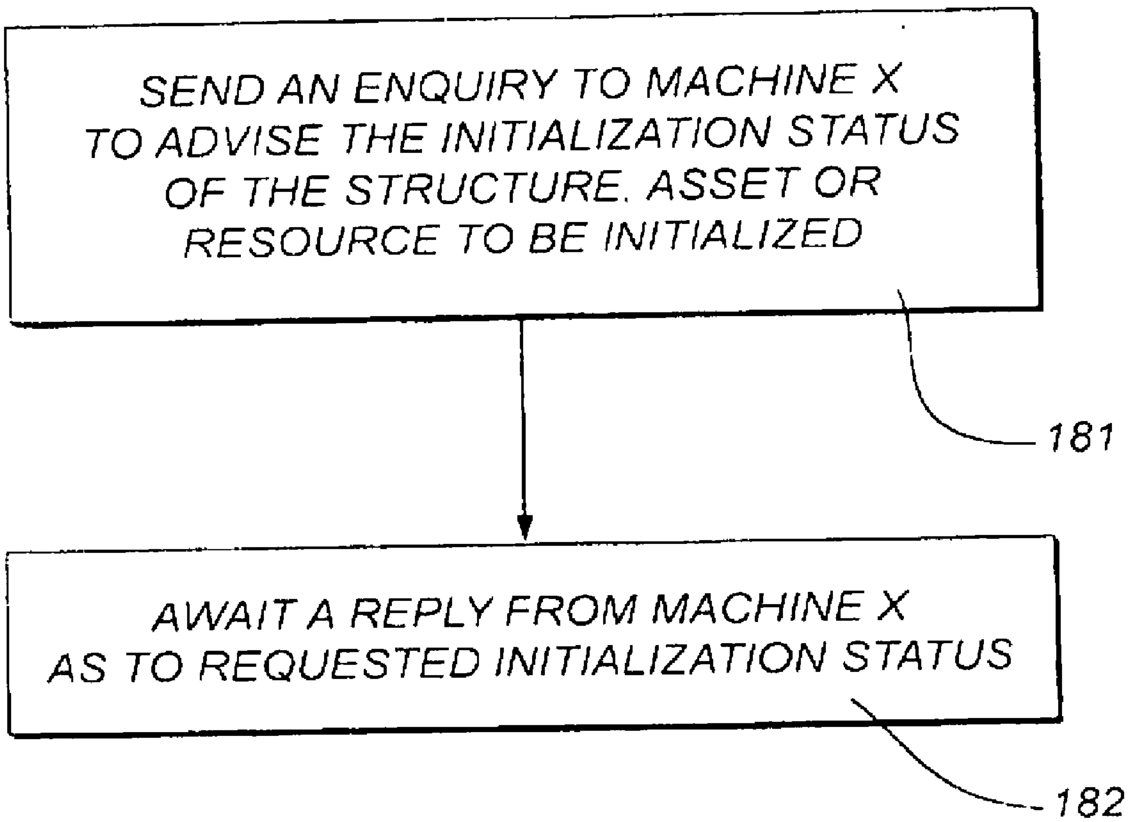

SEND AN ENQUIRY TO MACHINE X TO ADVISE THE INITIALIZATION STATUS OF THE STRUCTURE, ASSET OR RESOURCE TO BE INITIALIZED
181
AWAIT A REPLY FROM MACHINE X AS TO REQUESTED INITIALIZATION STATUS
182

FIG. 18

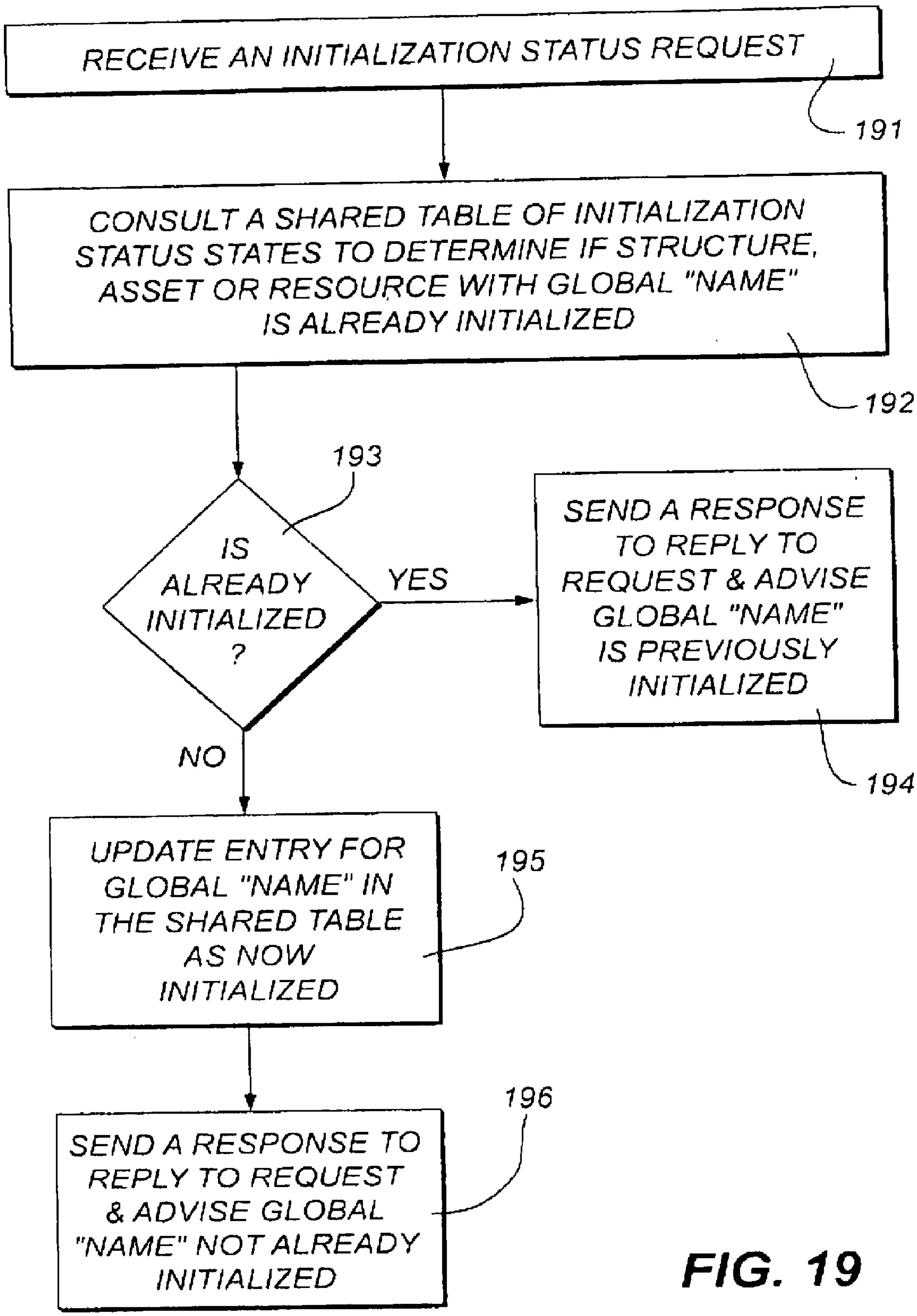

RECEIVE AN INITIALIZATION STATUS REQUEST
191
CONSULT A SHARED TABLE OF INITIALIZATION STATUS STATES TO DETERMINE IF STRUCTURE, ASSET OR RESOURCE WITH GLOBAL "NAME" IS ALREADY INITIALIZED
192
193
IS ALREADY INITIALIZED ?
YES
SEND A RESPONSE TO REPLY TO REQUEST & ADVISE GLOBAL "NAME" IS PREVIOUSLY INITIALIZED
194
NO
UPDATE ENTRY FOR GLOBAL "NAME" IN THE SHARED TABLE AS NOW INITIALIZED
195
196
SEND A RESPONSE TO REPLY TO REQUEST & ADVISE GLOBAL "NAME" NOT ALREADY INITIALIZED

FIG. 19

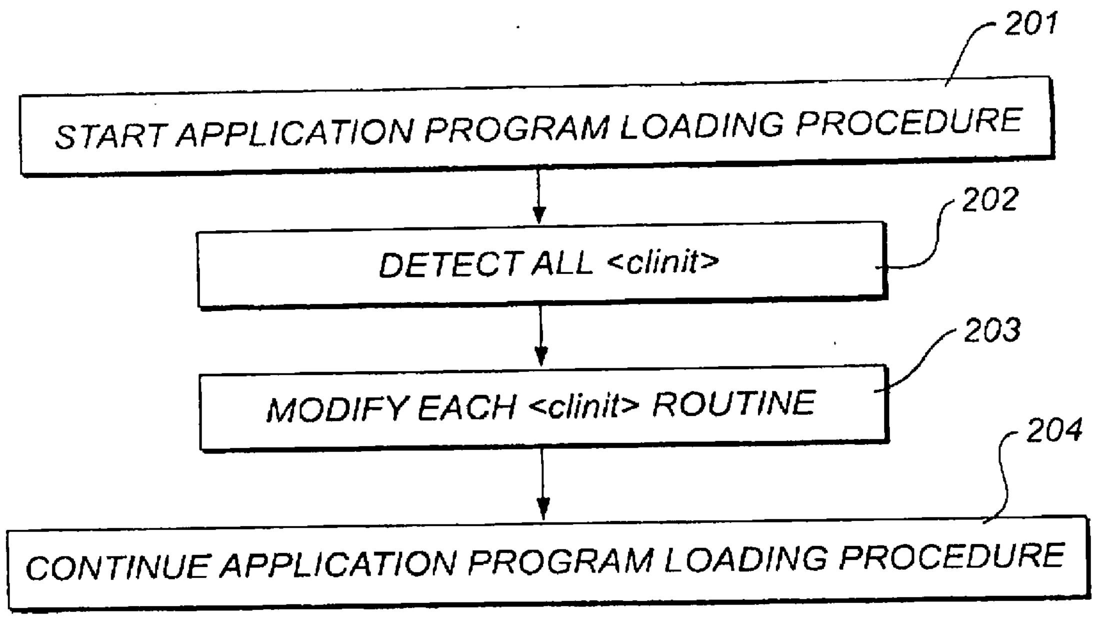

201
START APPLICATION PROGRAM LOADING PROCEDURE
202
DETECT ALL <clinit>
203
MODIFY EACH <clinit> ROUTINE
204
CONTINUE APPLICATION PROGRAM LOADING PROCEDURE

FIG. 20

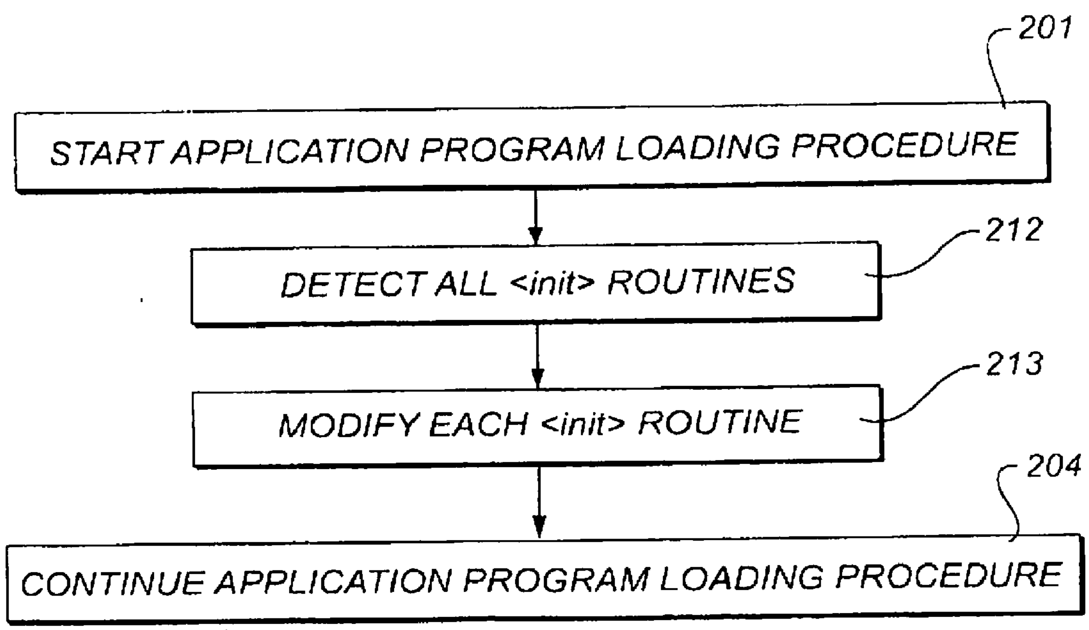

201
START APPLICATION PROGRAM LOADING PROCEDURE
212
DETECT ALL <init> ROUTINES
213
MODIFY EACH <init> ROUTINE
204
CONTINUE APPLICATION PROGRAM LOADING PROCEDURE

FIG. 21

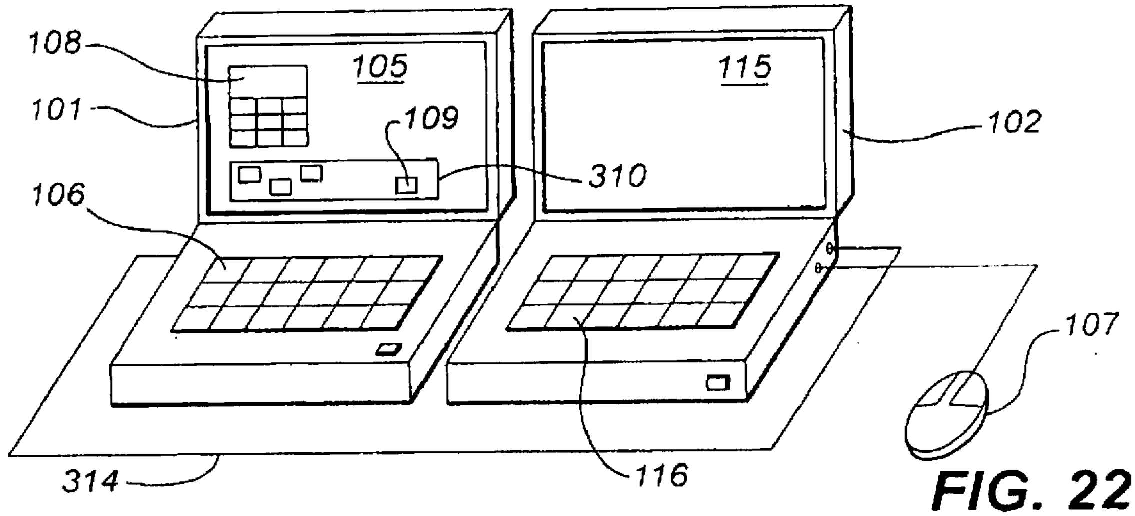


FIG. 22

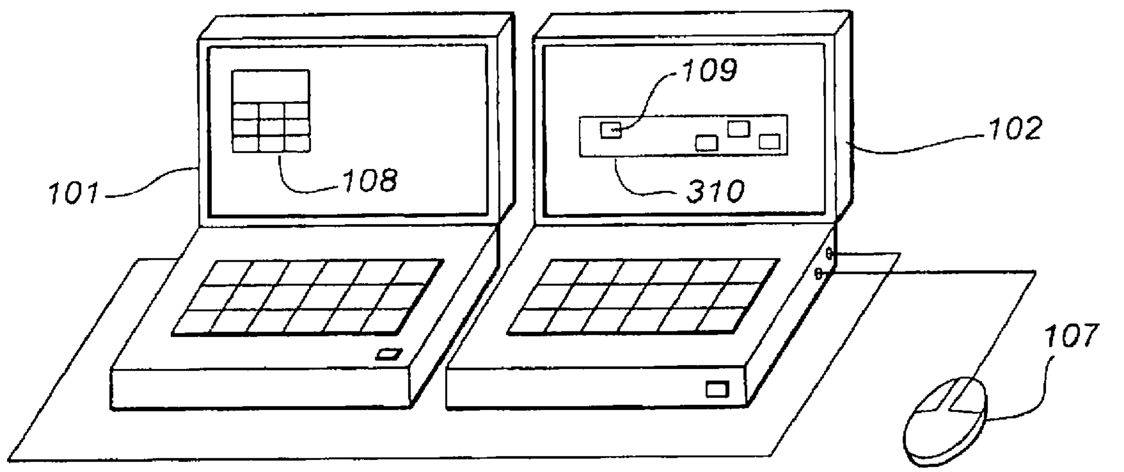


FIG. 23

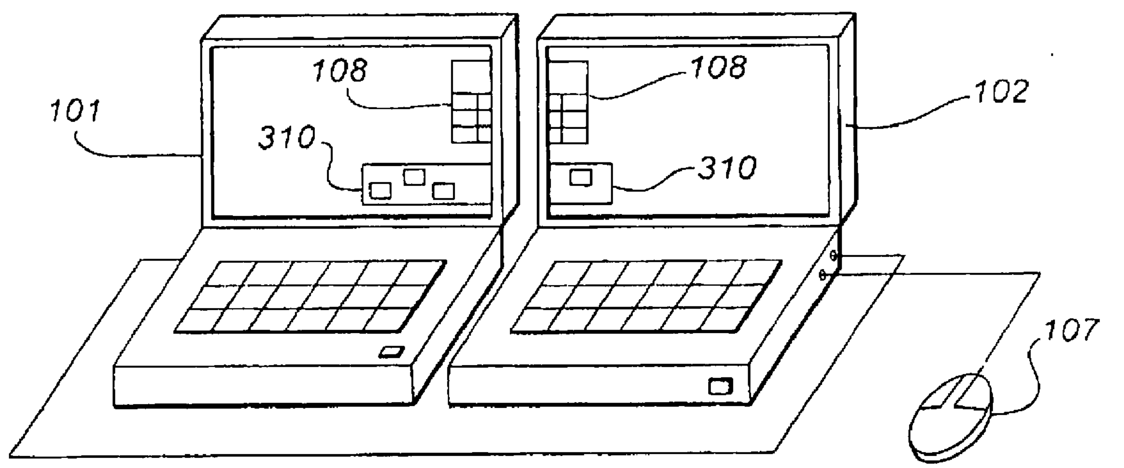


FIG. 24

COMPUTER ARCHITECTURE AND METHOD OF OPERATION FOR MULTI-COMPUTER DISTRIBUTED PROCESSING WITH INITIALIZATION OF OBJECTS

PRIORITY

[0001] This application is a continuation application and claims the benefit of priority of U.S. patent application Ser. No. 11/259,744, filed Oct. 25, 2005, entitled "COMPUTER ARCHITECTURE AND METHOD OF OPERATION FOR MULTI-COMPUTER DISTRIBUTED PROCESSING WITH INITIALIZATION OF OBJECTS", which is hereby incorporated by this reference.

RELATED APPLICATIONS

[0002] This application claims the benefit of priority under ore or more of 35 U.S.C. 119 and/or 35 U.S.C. 120 to the following Australian Patent Applications, U.S. Utility patent applications and PCT International Patent Applications, each of which is also a related application and each is incorporated herein by reference in its entirety:

[0003] U.S. patent application Ser. No. 11/259,634 filed 25 Oct. 2005 entitled "Computer Architecture And Method Of Operation For Multi-Computer Distributed Processing With Replicated Memory";

[0004] U.S. patent application Ser. No. 11/259,744 filed 25 Oct. 2005 entitled "Computer Architecture And Method Of Operation For Multi-Computer Distributed Processing With Initialization Of Objects";

[0005] U.S. patent application Ser. No. 11/259,762 filed 25 Oct. 2005 entitled "Computer Architecture And Method Of Operation For Multi-Computer Distributed Processing With Finalization Of Objects";

[0006] U.S. patent application Ser. No. 11/259,761 filed 25 Oct. 2005 entitled "Computer Architecture And Method Of Operation For Multi-Computer Distributed Processing With Synchronization";

[0007] U.S. patent application Ser. No. 11/259,895 filed 25 Oct. 2005 entitled "Computer Architecture And Method Of Operation For Multi-Computer Distributed Processing And Coordinated Memory And Asset Handling";

[0008] Australian Provisional Patent Application No. 2005 902 023 filed 21 Apr. 2005 entitled "Multiple Computer Architecture with Replicated Memory Fields";

[0009] Australian Provisional Patent Application No. 2005 902 024 filed 21 Apr. 2005 entitled "Modified Computer Architecture with Initialization of Objects"; Australian Provisional Patent Application No. 2005 902 025 filed 21 Apr. 2005 entitled "Modified Computer Architecture with Finalization of Objects";

[0010] Australian Provisional Patent Application No. 2005 902 026 filed 21 Apr. 2005 entitled "Modified Computer Architecture with Synchronization of Objects";

[0011] Australian Provisional Patent Application No. 2004 902 027 filed 21 Apr. 2005 entitled "Modified Computer Architecture with Coordinated Objects";

[0012] U.S. patent application Ser. No. 11/111,757 filed 22 Apr. 2005 entitled "Multiple Computer Architecture with Replicated Memory Fields";

[0013] U.S. patent application Ser. No. 11/111,781 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Initialization of Objects";

[0014] U.S. patent application Ser. No. 11/111,778 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Finalization of Objects";

[0015] U.S. patent application Ser. No. 11/111,779 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Synchronization of Objects";

[0016] U.S. patent application Ser. No. 11/111,946 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Coordinated Objects";

[0017] PCT International Application No. PCT/AU05/000/5B2 filed 22 Apr. 2005 entitled "Multiple Computer Architecture with Replicated Memory Fields";

[0018] PCT International Application No. PCT/AU05/000/578 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Initialization of Objects";

[0019] PCT International Application No. PCT/AU05/000/581 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Finalization of Objects";

[0020] PCT International Application No. PCT/AU05/000/579 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Synchronization of Objects"; and

[0021] PCT International Application No. PCT/AU05/000/580 filed 22 Apr. 2005 entitled "Modified Computer Architecture with Coordinated Objects".

[0022] A further related patent application that is hereby incorporated by reference is U.S. patent application Ser. No. 10/830,042 filed 23 Apr. 2004 entitled "Modified Computer Architecture".

FIELD OF THE INVENTION

[0023] The present invention relates to computers and other computing machines and information appliances, in particular, to a modified computer architecture and program structure which enables the operation of an application program concurrently or simultaneously on a plurality of computers interconnected via a communications link using a distributed runtime and enables improved performance to be achieved.

BACKGROUND OF THE INVENTION

[0024] Ever since the advent of computers, and computing, software for computers has been written to be operated upon a single machine. As indicated in FIG. **1**, that single prior art machine **1** is made up from a central processing unit, or CPU, **2** which is connected to a memory **3** via a bus **4**. Also connected to the bus **4** are various other functional units of the single machine **1** such as a screen **5**, keyboard **6** and mouse **7**.

[0025] A fundamental limit to the performance of the machine **1** is that the data to be manipulated by the CPU **2**, and the results of those manipulations, must be moved by the bus **4**. The bus **4** suffers from a number of problems including so called bus "queues" formed by units wishing to gain an access to the bus, contention problems, and the like. These problems can, to some extent, be alleviated by various stratagems including cache memory, however, such stratagems invariably increase the administrative overhead of the machine **1**.

[0026] Naturally, over the years various attempts have been made to increase machine performance. One approach is to use symmetric multi-processors. This prior art approach has been used in so called "super" computers and is schematically indicated in FIG. **2**. Here a plurality of CPU's **12** are connected to global memory **13**. Again, a bottleneck arises in the communications between the CPU's **12** and the memory **13**. This process has been termed "Single System Image". There is only one application and one whole copy of the memory for the application which is distributed over the global memory. The single application can read from and write to, (i.e. share) any memory location completely transparently.

[0027] Where there are a number of such machines interconnected via a network, this is achieved by taking the single application written for a single machine and partitioning the required memory resources into parts. These parts are then distributed across a number of computers to form the global memory **13** accessible by all CPU's **12**. This procedure relies on masking, or hiding, the memory partition from the single running application program. The performance degrades when one CPU on one machine must access (via a network) a memory location physically located in a different machine.

[0028] Although super computers have been technically successful in achieving high computational rates, they are not commercially successful in that their inherent complexity makes them extremely expensive not only to manufacture but to administer. In particular, the single system image concept has never been able to scale over "commodity" (or mass produced) computers and networks. In particular, the Single System Image concept has only found practical application on very fast (and hence very expensive) computers interconnected by very fast (and similarly expensive) networks.

[0029] A further possibility of increased computer power through the use of a plural number of machines arises from the prior art concept of distributed computing which is schematically illustrated in FIG. **3**. In this known arrangement, a single application program (Ap) is partitioned by its author (or another programmer who has become familiar with the application program) into various discrete tasks so as to run upon, say, three machines in which case n in FIG. **3** is the integer 3. The intention here is that each of the machines M**1** . . . M**3** runs a different third of the entire application and the intention is that the loads applied to the various machines be approximately equal. The machines communicate via a network **14** which can be provided in various forms such as a communications link, the internet, intranets, local area networks, and the like. Typically the speed of operation of such networks **14** is an order of magnitude slower than the speed of operation of the bus **4** in each of the individual machines M**1**, M**2**, . . . , Mn.

[0030] Distributed computing suffers from a number of disadvantages. Firstly, it is a difficult job to partition the application and this must be done manually. Secondly, communicating data, partial results, results and the like over the network **14** is an administrative overhead. Thirdly, the need for partitioning makes it extremely difficult to scale upwardly by utilising more machines since the application having been partitioned into, say three, does not run well upon four machines. Fourthly, in the event that one of the machines should become disabled, the overall performance of the entire system is substantially degraded.

[0031] A further prior art arrangement is known as network computing via "clusters" as is schematically illustrated in FIG. **4**. In this approach, the entire application is loaded onto each of the machines M**1**, M**2**, . . . , Mn. Each machine communicates with a common database but does not communicate directly with the other machines. Although each machine runs the same application, each machine is doing a different "job" and uses only its own memory. This is somewhat analogous to a number of windows each of which sell train tickets to the public. This approach does operate, is scalable and mainly suffers from the disadvantage that it is difficult to administer the network.

[0032] In computer languages such as for example JAVA and MICROSOFT.NET there are two major types of constructs with which programmers deal. In the JAVA language these are known as objects and classes. More generally they may be referred to as assets. Every time an object (or other asset) is created there is an initialization routine run known as an object initialization (e.g., "<init>") routine. Similarly, every time a class is loaded there is a class initialization routine known as "<clinit>". Other languages use different terms but utilize a similar concept. In either case, however, there is no equivalent "clean up" or deletion routine to delete an object or class (or other asset) once it is no longer required. Instead, this "clean up" happens unobtrusively in a background mode.

[0033] Furthermore, in any computer environment it is necessary to acquire and release a lock to enable the use of such objects, classes, assets, resources or structures to avoid different parts of the application program from attempting to use the same objects, classes, assets, resources or structures at the one time. In the JAVA environment this is known as synchronization. Synchronization more generally refers to the exclusive use of an object, class, resource, structure, or other asset to avoid contention between and among computers or machines. This is achieved in JAVA by the "monitor enter" and "monitor exit" instructions or routines. Other languages use different terms but utilize a similar concept.

[0034] Unfortunately, conventional computing systems, architectures, and operating schemes do not provide for computing environments and methods in which an application program can operate simultaneously on an arbitrary plurality of computers where the environment and operating scheme ensure that the abovementioned memory management, initialization, clean up and synchronization procedures operate in a consistent and coordinated fashion across all the computing machines.

SUMMARY

[0035] The present invention discloses a computing environment in which an application program operates simultaneously on a plurality of computers. In such an environment it is advantageous to ensure that the abovementioned asset initialization, clean-up and synchronization procedures operate in a consistent and coordinated fashion across all the machines.

[0036] The present invention further discloses a computing environment in which an application program operates simultaneously on a plurality of computers. In such an environment it is advantageous to ensure that the abovementioned initialization routines operate in a consistent fashion across all the machines. It is this goal of consistent initialization that is the genesis of the present invention.

[0037] In accordance with a first aspect of the present invention there is disclosed a multiple computer system having at least one application program each written to operate on only a single computer but running simultaneously on a plurality of computers interconnected by a communications network, wherein different portions of said application program (s) execute substantially simultaneously on different ones of said computers and for each said portion a like plurality of substantially identical objects are created, each in the corresponding computer and each having a substantially identical name, and wherein the initial contents of each of said identically named objects is substantially the same.

[0038] In accordance with a second aspect of the present invention there is disclosed a plurality of computers interconnected via a communications link and simultaneously operating at least one application program each written to operation on only a single computer wherein each said computer substantially simultaneously executes a different portion of said application program(s), each said computer in operating its application program portion creates objects only in local memory physically located in each said computer, the contents of the local memory utilized by each said computer are fundamentally similar but not, at each instant, identical, and every one of said computers has distribution update means to distribute to all other said computers objects created by said one computer.

[0039] In accordance with a third aspect of the present invention there is disclosed a method of running simultaneously on a plurality of computers at least one application program each written to operate on only a single computer, said computers being interconnected by means of a communications network, said method comprising the steps of: (i) executing different portions of said application program(s) on different ones of said computers and for each said portion creating a like plurality of substantially identical objects each in the corresponding computer and each having a substantially identical name, and (ii) creating the initial contents of each of said identically named objects substantially the same.

[0040] In accordance with a fourth aspect of the present invention there is disclosed a method of compiling or modifying an application program written to operate on only a single computer to have different portions thereof to execute substantially simultaneously on different ones of a plurality of computers interconnected via a communications link, said method comprising the steps of: (i) detecting instructions which create objects utilizing one of said computers, (ii) activating an initialization routine following each said detected object creation instruction, said initialization routine forwarding each created object to the remainder of said computers.

[0041] In accordance with a fifth aspect of the present invention there is disclosed a multiple thread processing computer operation in which individual threads of a single application program written to operate on only a single computer are simultaneously being processed each on a different corresponding one of a plurality of computers interconnected via a communications link, the improvement comprising communicating objects created in local memory physically associated with the computer processing each thread to the local memory of each other said computer via said communications link.

[0042] In accordance with a sixth aspect of the present invention there is disclosed a method of ensuring consistent initialization of an application program written to operate on only a single computer but different portions of which are to be executed simultaneously each on a different one of a plurality of computers interconnected via a communications network, said method comprising the steps of: (i) scrutinizing or analysing said application program at, or prior to, or after loading to detect each program step defining an initialization routine, and (ii) modifying said initialization routine to ensure consistent operation of all said computers.

[0043] In accordance with a twenty-sixth aspect of the present invention there is disclosed a computer program product comprising a set of program instructions stored in a storage medium and operable to permit a plurality of computers to carry out the abovementioned methods.

[0044] In accordance with a twenty-seventh aspect of the invention there is disclosed a distributed run time and distributed run time system adapted to enable communications between a plurality of computers, computing machines, or information appliances.

[0045] In accordance with a twenty-eighth aspect of the invention there is disclosed a modifier, modifier means, and modifier routine for modifying an application program written to execute on a single computer or computing machine at a time to execute simultaneously on a plurality of networked computers or computing machines, distributed run time and distributed run time system adapted to enable communications between a plurality of computers, computing machines, or information appliances.

[0046] In accordance with a twenty-ninth aspect of the present invention there is disclosed a computer program and computer program product written to operate on only a single computer but product comprising a set of program instructions stored in a storage medium and operable to permit a plurality of computers to carry out the abovementioned procedures, routines, and methods.

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] Embodiments of the present invention are now described with reference to the drawings in which:

[0048] FIG. **1** is a schematic view of the internal architecture of a conventional computer;

[0049] FIG. **2** is a schematic illustration showing the internal architecture of known symmetric multiple processors;

[0050] FIG. **3** is a schematic representation of prior art distributed computing;

[0051] FIG. **4** is a schematic representation of a prior art network computing using clusters;

[0052] FIG. **5** is a schematic block diagram of a plurality of machines operating the same application program in accordance with a first embodiment of the present invention;

[0053] FIG. **6** is a schematic illustration of a prior art computer arranged to operate JAVA code and thereby constitute a JAVA virtual machine;

[0054] FIG. **7** is a drawing similar to FIG. **6** but illustrating the initial loading of code in accordance with the preferred embodiment;

[0055] FIG. **8** is a drawing similar to FIG. **5** but illustrating the interconnection of a plurality of computers each operating JAVA code in the manner illustrated in FIG. **7**;

[0056] FIG. **9** is a flow chart of the procedure followed during loading of the same application on each machine in the network;

[0057] FIG. **10** is a flow chart showing a modified procedure similar to that of FIG. **9**;

[0058] FIG. **11** is a schematic representation of multiple thread processing carried out on the machines of FIG. **8** utilizing a first embodiment of memory updating;

[0059] FIG. **12** is a schematic representation similar to FIG. **11** but illustrating an alternative embodiment;

[0060] FIG. **13** illustrates multi-thread memory updating for the computers of FIG. **8**;

[0061] FIG. **14** is a schematic illustration of a prior art computer arranged to operate in JAVA code and thereby constitute a JAVA virtual machine;

[0062] FIG. **15** is a schematic representation of n machines running the application program and serviced by an additional server machine X;

[0063] FIG. **16** is a flow chart of illustrating the modification of initialization routines;

[0064] FIG. **17** is a flow chart illustrating the continuation or abortion of initialization routines;

[0065] FIG. **18** is a flow chart illustrating the enquiry sent to the server machine X;

[0066] FIG. **19** is a flow chart of the response of the server machine X to the request of FIG. **18**;

[0067] FIG. **20** is a flowchart illustrating a modified initialization routine for the class initialization <clinit> instruction:

[0068] FIG. **21** is a flowchart illustrating a modified initialization routine for the object initialization <init> instruction;

[0069] FIG. **22** is a schematic representation of two laptop computers interconnected to simultaneously run a plurality of applications, with both applications running on a single computer;

[0070] FIG. **23** is a view similar to FIG. **22** but showing the FIG. **22** apparatus with one application operating on each computer; and

[0071] FIG. **24** is a view similar to FIGS. **22** and **23** but showing the FIG. **22** apparatus with both applications operating simultaneously on both computers.

[0072] The specification includes Annexures A and B which provide actual program fragments which implement various aspects of the described embodiments. Annexure A relates to fields and Annexure B relates to initialization.

REFERENCE TO ANNEXES

[0073] Although the specification provides a complete and detailed description of the several embodiments of the invention such that the invention may be understood and implemented without reference to other materials, the specification does includes Annexures A and B which provide exemplary actual program or code fragments which implement various aspects of the described embodiments. Although aspects of the invention are described throughout the specification including the Annexes, drawings, and claims, it may be appreciated that Annexure A relates primarily to fields, and Annexure B relates primarily to initialization.

[0074] More particularly, the accompanying Annexures are provided in which:

[0075] Annexures A**1**-A**10** illustrate exemplary code to illustrate embodiments of the invention in relation to fields.

[0076] Annexure B**1** is an exemplary typical code fragment from an unmodified class initialization <clinit> instruction, Annexure B**2** is an equivalent in respect of a modified class initialization <clinit> instruction. Annexure B**3** is a typical code fragment from an unmodified object initialization <init> instruction. Annexure B**4** is an equivalent in respect of a modified object initialization <init> instruction. In addition, Annexure B**5** is an alternative to the code of Annexure B**2** for an unmodified class initialization instruction, and Annexure B**6** is an alternative to the code of Annexure B**4** for a modified object initialization <init> instruction. Furthermore, Annexure B**7** is exemplary computer program source-code of InitClient, which queries an "initialization server" for the initialization status of the relevant class or object. Annexure B**8** is the computer program source-code of InitServer, which receives an initialization status query by InitClient and in response returns the corresponding status. Similarly, Annexure B**9** is the computer program source-code of the example application used in the before/after examples of Annexure B**1**-B**6**.

[0077] It will be appreciated in light of the description provided here that the categorization of the Annexures as well as the use of other headings and subheadings in this description is intended as an aid to the reader and is not to be used to limit the scope of the invention in any way.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0078] The present invention discloses a modified computer architecture which enables an applications program to be run simultaneously on a plurality of computers in a manner that overcomes the limitations of the aforedescribed conventional architectures, systems, methods, and computer programs.

[0079] In one aspect, shared memory at each computer may be updated with amendments and/or overwrites so that all memory read requests are satisfied locally. Before, during or after program loading, but before execution of relevant portions of the program code are executed, or similar, instructions which result in memory being re-written or manipulated are identified. Additional instructions are inserted into the program code (or other modification made) to cause the equivalent memory locations at all computers to be updated. While the invention is not limited to JAVA language or virtual machines, exemplary embodiments are described relative to the JAVA language and standards.

[0080] In another aspect, the initialization of JAVA language classes and objects (or other assets) are provided for so all memory locations for all computers are initialized in the same manner. In another aspect, the finalization of JAVA language classes and objects is also provide so finalization only occurs when the last class or object present on all machines is no longer required. In still another aspect, synchronization is provided such that instructions which result in the application program acquiring (or releasing) a lock on a particular asset (synchronization) are identified. Additional instructions are inserted (or other code modifications performed) to result in a modified synchronization routine with which all computers are updated.

[0081] As will become more apparent in light of the further description provided herein, one of the features of the invention is to make it appear that one common application program or application code and its executable version (with likely modification) is simultaneously or concurrently executing across a plurality of computers or machines M**1**, . . . , Mn. As will be described in considerable detail hereinafter, the instant invention achieves this by running the same application program (for example, Microsoft Word or Adobe Photoshop CS2) on each machine, but modifying the executable code of that application program on each machine as necessary such that each executing instance ('copy') on each machine coordinates its local operations on any particular machine with the operations of the respective instances on the other machines such that they all function together in a consistent, coherent and coordinated manner and give the appearance of being one global instance of the application (i.e., a "meta-application").

[0082] In accordance with embodiments of the present invention a single application code **50** (sometimes more informally referred to as the application or the application program) can be operated simultaneously on a number of machines M1, M2 . . . Mn interconnected via a communications network or other communications link or path 53. The communications network or path may be any electronic signaling, data, or digital communications network or path and may advantageously be a relatively slow speed communications path, such as a network connection over the Internet or any common networking configurations known or available as of the date or this applications, and extensions and improvements, thereto.

[0083] By way of example but not limitation, one application code or program **50** may be a single application on the machines, such as Microsoft Word, as opposed to different applications on each machine, such as Microsoft Word on machine M1, and Microsoft PowerPoint on machine M2, and Netscape Navigator on machine M3 and so forth. Therefore the terminology "one" application code or program and a "common" application code or program is used to try and capture this situation where all machines M1, . . . , Mn are operating or executing the same program or code and not different (and unrelated) programs. In other words copies or replicas of same or substantially the same application code is loaded onto each of the interoperating and connected machines or computers. As the characteristics of each machine or computer may differ, the application code **50** may be modified before loading, during the loading process, and with some restrictions after the loading process to provide a customization or modification of the code on each machine. Some dissimilarity between the programs may be permitted so long as the other requirements for interoperability, consistency, and coherency as described herein can be maintain. As it will become apparent hereafter, each of the machines M1, M2 . . . Mn operates with the same application code **50** on each machine M1, M2 . . . Mn and thus all of the machines M1, M2, . . . , Mn have the same or substantially the same application code **50** usually with a modification that may be machine specific.

[0084] Similarly, each of the machines M1, M2, . . . , Mn operates with the same (or substantially the same or similar) modifier **51** (in some embodiments implemented as a distributed run time or DRT **71**) on each machine M1, M2, . . . , Mn and thus all of the machines M1, M2 . . . Mn have the same (or substantially the same or similar) modifier **51** for each modification required. Different modification for example may be required for memory management and replication, initialization, finalization, and/or synchronization (though not all of these modification types may be required for all embodiments).

[0085] In addition, during the loading of, or at any time preceding the execution of, the application code **50** (or relevant portion thereof) on each machine M1, M2 . . . Mn, each application code **50** has been modified by the corresponding modifier **51** according to the same rules (or substantially the same rules since minor optimizing changes are permitted within each modifier **51/1**, **51/2**, . . . , **51/*n***).

[0086] With reference to any initialisation modifier that may be present, such initialisation modifier **51**-I or DRT **71**-I or other code modifying means component of the overall modifier or distributed run time means is responsible for modifying the application code **50** so that it may execute initialisation routines or other initialization operations, such as for example class and object initialization methods or routines in the JAVA language and virtual machine environment, in a coordinated, coherent, and consistent manner across the plurality of individual machines M1, M2 . . . Mn

[0087] These structures and procedures when applied in combination when required, maintain a computing environment where memory locations, address ranges, objects, classes, assets, resources, or any other procedural or structural aspect of a computer or computing environment are where required created, maintained, operated, and deactivated or deleted in a coordinated, coherent, and consistent manner across the plurality of individual machines M1, M2 . . . Mn.

[0088] Attention is now directed to the particulars of several aspects of the invention that may be utilised alone or in any combination.

[0089] In connection with FIG. **5**, in accordance with a preferred embodiment of the present invention a single application code **50** (sometimes more informally referred to as the application or the application program) can be operated simultaneously on a number of machines M1, M2 . . . Mn interconnected via a communications network or other communications link or path **53**. By way of example but not limitation, one application code or program **50** would be a single common application program on the machines, such as Microsoft Word, as opposed to different applications on each machine, such as Microsoft Word on machine M1, and Microsoft PowerPoint on machine M2, and Netscape Navigator on machine M3 and so forth. Therefore the terminology "one", "single", and "common" application code or program is used to try and capture this situation where all machines M1, . . . , Mn are operating or executing the same program or code and not different (and unrelated) programs. In other words copies or replicas of same or substantially the same application code is loaded onto each of the interoperating and connected machines or computers. As the characteristics of each machine or computer may differ, the application code **50** may be modified before loading, during the loading process, or after the loading process to provide a customization or modification of the code on each machine. Some dissimilarity between the programs may be permitted so long as the other requirements for interoperability, consistency, and coherency as described herein can be maintain. As it will become apparent hereafter, each of the machines M1, M2 . . . Mn operates with the same application code **50** on each machine M1, M2 . . . Mn and thus all of the machines M1, M2, . . . , Mn have the same or substantially the same application code **50** usually with a modification that may be machine specific.

[0090] Similarly, each of the machines M1, M2, . . . , Mn operates with the same (or substantially the same or similar) modifier **51** on each machine M1, M2 . . . , Mn and thus all of the machines M1, M2 . . . Mn have the same (or substantially the same or similar) modifier **51** with the modifier of machine M1 being designated **51/1** and the modifier of machine M2 being designated **51/2**, etc. In addition, before or during the loading of, or preceding the execution of, or even after execution has commenced, the application code **50** on each machine M1, M2 . . . Mn is modified by the corresponding modifier **51** according to the same rules (or substantially the same rules since minor optimizing changes are permitted within each modifier **51/1**, **51/2**, . . . , **51/*n***).

[0091] As will become more apparent in light of the further description provided herein, one of the features of the invention is to make it appear that one application program instance of application code **50** is executing simultaneously across all of the plurality of machines M1, M2, . . . , Mn. As will be described in considerable detail hereinafter, the instant invention achieves this by running the same application program code (for example, Microsoft Word or Adobe Photoshop CS2) on each machine, but modifying the executable code of that application program on each machine such that each executing occurrence (or 'local instance') on each one of the machines M1 . . . Mn coordinates its local operations with the operations of the respective occurrences on each one of the other machines such that each occurrence on each one of the plurality of machines function together in a consistent, coherent and coordinated manner so as to give the appearance of being one global instance (or occurrence) of the application program and program code (i.e., a "meta-application").

[0092] As a consequence of the above described arrangement, if each of the machines **M1**, **M2**, . . . , Mn has, say, an internal memory capability of 10 MB, then the total memory available to each application code **50** is not necessarily, as one might expect the number of machines (n) times 10 MB, or alternatively the additive combination of the internal memory capability of all n machines, but rather or still may only be 10 MB. In the situation where the internal memory capacities of the machines are different, which is permissible, then in the case where the internal memory in one machine is smaller than the internal memory capability of at least one other of the machines, then the size of the smallest memory of any of the machines may be used as the maximum memory capacity of the machines when such memory (or a portion thereof) is to be treated as a 'common' memory (i.e. similar equivalent memory on each of the machines M1 . . . Mn) or otherwise used to execute the common application code.

[0093] However, even though the manner that the internal memory of each machine is treated may initially appear to be a possible constraint on performance, how this results in improved operation and performance will become apparent hereafter. Naturally, each machine **M1**, **M2** . . . Mn has an private (i.e. 'non-common') internal memory capability. The private internal memory capability of the machines **M1**, **M2**, . . . , Mn are normally approximately equal but need not be. It may also be advantageous to select the amounts of internal memory in each machine to achieve a desired performance level in each machine and across a constellation or network of connected or coupled plurality of machines, computers, or information appliances **M1**, **M2**, . . . , Mn. Having described these internal and common memory considerations, it will be apparent in light of the description provided herein that the amount of memory that can be common between machines is not a limitation of the invention.

[0094] It is known from the prior art to operate a single computer or machine (produced by one of various manufacturers and having an operating system operating in one of various different languages) in a particular language of the application, by creating a virtual machine as schematically illustrated in FIG. **6**. The code and data and virtual machine configuration or arrangement of FIG. **6** takes the form of the application code **50** written in the Java language and executing within a Java Virtual Machine **61**. Thus, where the intended language of the application is the language JAVA, a JAVA virtual machine is used which is able to operate code in JAVA irrespective of the machine manufacturer and internal details of the machine. For further details see "The JAVA Virtual Machine Specification" 2nd Edition by T. Lindholm & F. Yellin of Sun Microsystems Inc. of the USA, which is incorporated by reference herein.

[0095] This conventional art arrangement of FIG. **6** is modified in accordance with embodiments of the present invention by the provision of an additional facility which is conveniently termed "distributed run time" or "distributed run time system" DRT **71** and as seen in FIG. **7**.

[0096] In FIG. **7**, the application code **50** is loaded onto the Java Virtual Machine **72** in cooperation with the distributed runtime system **71**, through the loading procedure indicated by arrow **75**. As used herein the terms distributed runtime and the distributed run time system are essentially synonymous, and by means of illustration but not limitation are generally understood to include library code and processes which support software written in a particular language running on a particular platform. Additionally, a distributed runtime system may also include library code and processes which support software written in a particular language running within a particular distributed computing environment. The runtime system typically deals with the details of the interface between the program and the operation system such as system calls, program start-up and termination, and memory management. For purposes of background, a conventional Distributed Computing Environment (DCE) that does not provide the capabilities of the inventive distributed run time or distributed run time system **71** required in the invention is available from the Open Software Foundation. This Distributed Computing Environment (DCE) performs a form of computer-to-computer communication for software running on the machines, but among its many limitations, it is not able to implement the modification or communication operations of this invention. Among its functions and operations, the inventive DRT **71** coordinates the particular communications between the plurality of machines **M1**, **M2**, . . . , Mn. Moreover, the inventive distributed runtime **71** comes into operation during the loading procedure indicated by arrow **75** of the JAVA application **50** on each JAVA virtual machine **72** of machines JVM#**1**, JVM#**2**, . . . JVM#n. The sequence of operations during loading will be described hereafter in relation to FIG. **9**. It will be appreciated in light of the description provided herein that although many examples and descriptions are provided relative to the JAVA language and JAVA virtual machines so that the reader may get the benefit of specific examples, the invention is not restricted to either the JAVA language or JAVA virtual machines, or to any other language, virtual machine, machine, or operating environment.

[0097] FIG. **8** shows in modified form the arrangement of FIG. **5** utilising JAVA virtual machines, each as illustrated in FIG. **7**. It will be apparent that again the same application code **50** is loaded onto each machine **M1**, **M2** . . . Mn. However, the communications between each machine **M1**, **M2**, . . . , Mn, and indicated by arrows **83**, although physically routed through the machine hardware, are advantageously controlled by the individual DRT's **71/1** . . . **71/*n*** within each machine. Thus, in practice this may be conceptionalised as the DRT's **71/1**, . . . , **71/*n*** communicating with each other via the network or other communications link **73** rather than the machines **M1**, **M2**, . . . , Mn communicating directly with themselves or each other. Actually, the invention contemplates and included either this direct communication between machines **M1**, **M2**, . . . , Mn or DRTs **71/1**, **71/2**, . . . , **71/*n*** or a combination of such communications. The inventive DRT **71** provides communication that is transport, protocol, and link independent.

[0098] It will be appreciated in light of the description provided herein that there are alternative implementations of the modifier **51** and the distributed run time **71**. For example, the modifier **51** may be implemented as a component of or within the distributed run time **71**, and therefore the DRT **71** may implement the functions and operations of the modifier **51**. Alternatively, the function and operation of the modifier **51** may be implemented outside of the structure, software, firmware, or other means used to implement the DRT **71**. In one embodiment, the modifier **51** and DRT **71** are implemented or written in a single piece of computer program code that provides the functions of the DRT and modifier. The modifier function and structure therefore maybe subsumed into the DRT and considered to be an optional component. Independent of how implemented, the modifier function and structure is responsible for modifying the executable code of the application code program, and the distributed run time function and structure is responsible for implementing communications between and among the computers or machines. The communications functionality in one embodiment is implemented via an intermediary protocol layer within the computer program code of the DRT on each machine. The DRT may for example implement a communications stack in the JAVA language and use the Transmission Control Protocol/Internet Protocol (TCP/IP) to provide for communications or talking between the machines. Exactly how these functions or operations are implemented or divided between structural and/or procedural elements, or between computer program code or data structures within the invention are less important than that they are provided.

[0099] However, in the arrangement illustrated in FIG. **8**, (and also in FIGS. **31**-**32**), a plurality of individual computers or machines M**1**, M**2**, . . . Mn are provided, each of which are interconnected via a communications network **53** or other communications link and each of which individual computers or machines provided with a modifier **51** (See in FIG. **5**) and realised by or in for example the distributed run time (DRT) **71** (See FIG. **8**) and loaded with a common application code **50**. The term common application program is to be understood to mean an application program or application program code written to operate on a single machine, and loaded and/or executed in whole or in part on each one of the plurality of computers or machines M**1**, M**2** . . . Mn, or optionally on each one of some subset of the plurality of computers or machines M**1**, M**2** . . . Mn. Put somewhat differently, there is a common application program represented in application code **50**, and this single copy or perhaps a plurality of identical copies are modified to generate a modified copy or version of the application program or program code, each copy or instance prepared for execution on the plurality of machines. At the point after they are modified they are common in the sense that they perform similar operations and operate consistently and coherently with each other. It will be appreciated that a plurality of computers, machines, information appliances, or the like implementing the features of the invention may optionally be connected to or coupled with other computers, machines, information appliances, or the like that do not implement the features of the invention.

[0100] Essentially in at least one embodiment the modifier **51** or DRT **71** or other code modifying means is responsible for modifying the application code **50** so that it may execute memory manipulation operations, such as memory putstatic and putfield instructions in the JAVA language and virtual machine environment, in a coordinated, consistent, and coherent manner across and between the plurality of individual machines M**1** . . . Mn. It follows therefore that in such a computing environment it is necessary to ensure that each of memory location is manipulated in a consistent fashion (with respect to the others).

[0101] In some embodiments, some or all of the plurality of individual computers or machines may be contained within a single housing or chassis (such as so-called "blade servers" manufactured by Hewlett-Packard Development Company, Intel Corporation, IBM Corporation and others) or implemented on a single printed circuit board or even within a single chip or chip set.

[0102] A machine (produced by any one of various manufacturers and having an operating system operating in any one of various different languages) can operate in the particular language of the application program code **50**, in this instance the JAVA language. That is, a JAVA virtual machine **72** is able to operate application code **50** in the JAVA language, and utilize the JAVA architecture irrespective of the machine manufacturer and the internal details of the machine.

[0103] When implemented in a non-JAVA language or application code environment, the generalized platform, and/or virtual machine and/or machine and/or runtime system is able to operate application code **50** in the language(s) (possibly including for example, but not limited to any one or more of source-code languages, intermediate-code languages, object-code languages, machine-code languages, and any other code languages) of that platform, and/or virtual machine and/or machine and/or runtime system environment, and utilize the platform, and/or virtual machine and/or machine and/or runtime system and/or language architecture irrespective of the machine manufacturer and the internal details of the machine. It will also be appreciated in light of the description provided herein that platform and/or runtime system may include virtual machine and non-virtual machine software and/or firmware architectures, as well as hardware and direct hardware coded applications and implementations.

[0104] For a more general set of virtual machine or abstract machine environments, and for current and future computers and/or computing machines and/or information appliances or processing systems, and that may not utilize or require utilization of either classes and/or objects, the inventive structure, method, and computer program and computer program product are still applicable. Examples of computers and/or computing machines that do not utilize either classes and/or objects include for example, the x86 computer architecture manufactured by Intel Corporation and others, the SPARC computer architecture manufactured by Sun Microsystems, Inc and others, the PowerPC computer architecture manufactured by International Business Machines Corporation and others, and the personal computer products made by Apple Computer, Inc., and others. For these types of computers, computing machines, information appliances, and the virtual machine or virtual computing environments implemented thereon that do not utilize the idea of classes or objects, may be generalized for example to include primitive data types (such as integer data types, floating point data types, long data types, double data types, string data types, character data types and Boolean data types), structured data types (such as arrays and records) derived types, or other code or data structures of procedural languages or other languages and environments such as functions, pointers, components, modules, structures, references and unions.

[0105] Turning now to FIGS. **7** and **9**, during the loading procedure **75**, the application code **50** being loaded onto or into each JAVA virtual machine **72** is modified by DRT **71**.

This modification commences at Step **90** in FIG. **9** and involves the initial step **91** of preferably scrutinizing or analysing the code and detecting all memory locations addressable by the application code **50**, or optionally some subset of all memory locations addressable by the application code **50**; such as for example named and unnamed memory locations, variables (such as local variables, global variables, and formal arguments to subroutines or functions), fields, registers, or any other address space or range of addresses which application code **50** may access. Such memory locations in some instances need to be identified for subsequent processing at steps **92** and **93**. In some embodiments, where a list of detected memory locations is required for further processing, the DRT **71** during the loading procedure **75** creates a list of all the memory locations thus identified. In one embodiment, the memory locations in the form of JAVA fields are listed by object and class, however, the memory locations, fields, or the like may be listed or organized in any manner so long as they comport with the architectural and programming requirements of the system on which the program is to be used and the principles of the invention described herein. This detection is optional and not required in all embodiments of the invention. It may be noted that the DRT is at least in part fulfilling the roll of the modifier **51**.

[0106] The next phase (designated Step **92** in FIG. **9**) [Step **92**] of the modification procedure is to search through the application code **50** in order to locate processing activity or activities that manipulate or change values or contents of any listed memory location (for example, but not limited to JAVA fields) corresponding to the list generated at step **91** when required. Preferably, all processing activities that manipulate or change any one or more values or contents of any one or more listed memory locations, are located.

[0107] When such a processing activity or operation (typically "putstatic" or "putfield" in the JAVA language, or for example, a memory assignment operation, or a memory write operation, or a memory manipulation operation, or more generally operations that otherwise manipulate or change value (s) or content(s) of memory or other addressable areas), is detected which changes the value or content of a fisted or detected memory location, then an "updating propagation routine" is inserted by step **93** in the application code **50** corresponding to the detected memory manipulation operation, to communicate with all other machines in order to notify all other machines of the identity of the manipulated memory location, and the updated, manipulated or changed value(s) or content(s) of the manipulated memory location. The inserted "updating propagation routine" preferably takes the form of a method, function, procedure, or similar subroutine call or operation to a network communications library of DRT **71**. Alternatively, the "updating propagation routine" may take the optional form of a code-block (or other inline code form) inserted into the application code instruction stream at, after, before, or otherwise corresponding to the detected manipulation instruction or operation. And preferably, in a multi-tasking or parallel processing machine environment (and in some embodiments inclusive or exclusive of operating system), such as a machine environment capable of potentially simultaneous or concurrent execution of multiple or different threads or processes, the "updating propagation routine" may execute on the same thread or process or processor as the detected memory manipulation operation of step **92**. Thereafter, the loading procedure continues, by loading the modified application code **50** on the machine **72** in place of the unmodified application code **50**, as indicated by step **94** in FIG. **9**.

[0108] An alternative form of modification during loading is illustrated in the illustration of FIG. **10**. Here the start and listing steps **90** and **91** and the searching step **92** are the same as in FIG. **9**. However, rather than insert the "updating propagation routine" into the application code **50** corresponding to the detected memory manipulation operation identified in step **92**, as is indicated in step **93**, in which the application code **50**, or network communications library code **71** of the DRT executing on the same thread or process or processor as the detected memory manipulation operation, carries out the updating, instead an "alert routine" is inserted corresponding to the detected memory manipulation operation, at step **103**. The "alert routine" instructs, notifies or otherwise requests a different and potentially simultaneously or concurrently executing thread or process or processor not used to perform the memory manipulation operation (that is, a different thread or process or processor than the thread or process or processor which manipulated the memory location), such as a different thread or process allocated to the DRT **71**, to carry out the notification, propagation, or communication of all other machines of the identity of the manipulated memory location, and the updated, manipulated or changed value(s) or content (s) of the manipulated memory location.

[0109] Once this modification during the loading procedure has taken place and execution begins of the modified application code **50**, then either the steps of FIG. **11** or FIG. **12** take place. FIG. **11** (and the steps **112**, **113**, **114**, and **115** therein) correspond to the execution and operation of the modified application code **50** when modified in accordance with the procedures set forth in and described relative to FIG. **9**. FIG. **12** on the other hand (and the steps **112**, **113**, **125**, **127**, and **115** therein) set forth therein correspond to the execution and operation of the modified application code **50** when modified in accordance with FIG. **10**.

[0110] This analysis or scrutiny of the application code **50** can may take place either prior to loading the application program code **50**, or during the application program code **50** loading procedure, or even after the application program code **50** loading procedure. It may be likened to an instrumentation, program transformation, translation, or compilation procedure in that the application code may be instrumented with additional instructions, and/or otherwise modified by meaning-preserving program manipulations, and/or optionally translated from an input code language to a different code language (such as for example from source-code language or intermediate-code language to object-code language or machine-code language), and with the understanding that the term compilation normally or conventionally involves a change in code or language, for example, from source code to object code or from one language to another language. However, in the present instance the term "compilation" (and its grammatical equivalents) is not so restricted and can also include or embrace modifications within the same code or language. For example, the compilation and its equivalents are understood to encompass both ordinary compilation (such as for example by way of illustration but not limitation, from source-code to object-code), and compilation from source-code to source-code, as well as compilation from object-code to object-code, and any altered combinations therein. It is also inclusive of so-called "intermediary-code languages" which are a form of "pseudo object-code".

[0111] By way of illustration and not limitation, in one embodiment, the analysis or scrutiny of the application code **50** may take place during the loading of the application program code such as by the operating system reading the application code from the hard disk or other storage device or source and copying it into memory and preparing to begin execution of the application program code. In another embodiment, in a JAVA virtual machine, the analysis or scrutiny may take place during the class loading procedure of the java.lang.ClassLoader loadClass method (e.g., "java.lang.ClassLoader.loadClass( )").

[0112] Alternatively, the analysis or scrutiny of the application code **50** may take place even after the application program code loading procedure, such as after the operating system has loaded the application code into memory, or optionally even after execution of the relevant corresponding portion of the application program code has started, such as for example after the JAVA virtual machine has loaded the application code into the virtual machine via the "java.lang.ClassLoader.loadClass( )" method and optionally commenced execution.

[0113] As seen in FIG. **11**, a multiple thread processing machine environment **110**, on each one of the machines M**1**, . . . , Mn and consisting of threads **111/1** . . . **111/4** exists. The processing and execution of the second thread **111/2** (in this example) results in that thread **111/2** manipulating a memory location at step **113**, by writing to a listed memory location. In accordance with the modifications made to the application code **50** in the steps **90-94** of FIG. **9**, the application code **50** is modified at a point corresponding to the write to the memory location of step **113**, so that it propagates, notifies, or communicates the identity and changed value of the manipulated memory location of step **113** to the other machines M**2**, . . . , Mn via network **53** or other communication link or path, as indicated at step **114**. At this stage the processing of the application code **50** of that thread **111/2** is or may be altered and in some instances interrupted at step **114** by the executing of the inserted "updating propagation routine", and the same thread **111/2** notifies, or propagates, or communicates to all other machines M**2**, . . . , Mn via the network **53** or other communications link or path of the identity and changed value of the manipulated memory location of step **113**. At the end of that notification, or propagation, or communication procedure **114**, the thread **111/2** then resumes or continues the processing or the execution of the modified application code **50** at step **115**.

[0114] In the alternative arrangement illustrated in FIG. **12**, a multiple thread processing machine environment **110** comprising or consisting of threads **111/1**, . . . , **111/3**, and a simultaneously or concurrently executing DRT processing environment **120** consisting of the thread **121/1** as illustrated, or optionally a plurality of threads, is executing on each one of the machines M**1**, . . . Mn. The processing and execution of the modified application code **50** on thread **111/2** results in a memory manipulation operation of step **113**, which in this instance is a write to a listed memory location. In accordance with the modifications made to the application code **50** in the steps **90**, **91**, **92**, **103**, and **94** of FIG. **9**, the application code **50** is modified at a point corresponding to the write to the memory location of step **113**, so that it requests or otherwise notifies the threads of the DRT processing environment **120** to notify, or propagate, or communicate to the other machines M**2**, . . . , Mn of the identity and changed value of the manipulated memory location of step **113**, as indicated at steps **125** and **128** and arrow **127**. In accordance with this modification, the thread **111/2** processing and executing the modified application code **50** requests a different and potentially simultaneously or concurrently executing thread or process (such as thread **121/1**) of the DRT processing environment **120** to notify the machines M**2**, . . . , Mn via network **53** or other communications link or path of the identity and changed value of the manipulated memory location of step **113**, as indicated in step **125** and arrow **127**. In response to this request of step **125** and arrow **127**, a different and potentially simultaneously or concurrently executing thread or process **121/1** of the DRT processing environment **120** notifies the machines M**2**, . . . , Mn via network **53** or other communications link or path of the identity and changed value of the manipulated memory location of step **113**, as requested of it by the modified application code **50** executing on thread **111/2** of step **125** and arrow **127**.

[0115] When compared to the earlier described step **114** of thread **111/2** of FIG. **11**, step **125** of thread **111/2** of FIG. **12** can be carried out quickly, because step **114** of thread **111/2** must notify and communicate with machines M**2** . . . , Mn via the relatively slow network **53** (relatively slow for example when compared to the internal memory bus **4** of FIG. **1** or the global memory **13** of FIG. **2**) of the identity and changed value of the manipulated memory location of step **113**, whereas step **125** of thread **111/2** does not communicate with machines M**2**, . . . , Mn via the relatively slow network **53**. Instead, step **125** of thread **111/2** requests or otherwise notifies a different and potentially simultaneously or concurrently executing thread **121/1** of the DRT processing environment **120** to perform the notification and communication with machines M**2**, . . . , Mn via the relatively slow network **53** of the identify and changed value of the manipulated memory location of step **113**, as indicated by arrow **127**. Thus thread **111/2** carrying out step **125** is only interrupted momentarily before the thread **111/2** resumes or continues processing or execution of modified application code in step **115**. The other thread **121/1** of the DRT processing environment **120** then communicates the identity and changed value of the manipulated memory location of step **113** to machines M**2**, . . . , Mn via the relatively slow network **53** or other relatively slow communications link or path.

[0116] This second arrangement of FIG. **12** makes better utilisation of the processing power of the various threads **111/1** . . . **111/3** and **121/1** (which are not, in general, subject to equal demands). Irrespective of which arrangement is used, the identity and change value of the manipulated memory location(s) of step **113** is (are) propagated to all the other machines M**2** . . . Mn on the network **53** or other communications link or path.

[0117] This is illustrated in FIG. **13** where step **114** of FIG. **11**, or the DRT **71/1** (corresponding to the DRT processing environment **120** of FIG. **12**) and its thread **121/1** of FIG. **12** (represented by step **128** in FIG. **13**), send, via the network **53** or other communications link or path, the identity and changed value of the manipulated memory location of step **113** of FIGS. **11** and **12**, to each of the other machines M**2**, . . . , Mn.

[0118] With reference to FIG. **13**, each of the other machines M**2**, . . . , Mn carries out the action of receiving from the network **53** the identity and changed value of, for example, the manipulated memory location of step **113** from machine M**1**, indicated by step **135**, and writes the value received at step **135** to the local memory location corresponding to the identified memory location received at step **135**, indicated by step **136**.

[0119] In the conventional arrangement in FIG. **3** utilising distributed software, memory access from one machine's software to memory physically located on another machine is permitted by the network interconnecting the machines. However, because the read and/or write memory access to memory physically located on another computer require the use of the slow network **14**, in these configurations such memory accesses can result in substantial delays in memory read/write processing operation, potentially of the order of 10^6-10^7 cycles of the central processing unit of the machine, but ultimately being dependent upon numerous factors, such as for example, the speed, bandwidth, and/or latency of the network **14**. This in large part accounts for the diminished performance of the multiple interconnected machines in the prior art arrangement of FIG. **3**.

[0120] However, in the present arrangement as described above in connection with FIG. **8**, it will be appreciated that all reading of memory locations or data is satisfied locally because a current value of all (or some subset of all) memory locations is stored on the machine carrying out the processing which generates the demand to read memory.

[0121] Similarly, in the present arrangement as described above in connection with FIG. **8**, it will be appreciated that all writing of memory locations or data may be satisfied locally because a current value of all (or some subset of all) memory locations is stored on the machine carrying out the processing which generates the demand to write to memory.

[0122] Such local memory read and write processing operation as performed according to the invention can typically be satisfied within 10^2-10^3 cycles of the central processing unit. Thus, in practice, there is substantially less waiting for memory accesses which involves reads than the arrangement shown and described relative to FIG. **3**. Additionally, in practice, there may be less waiting for memory accesses which involve writes than the arrangement shown and described relative to FIG. **3**

[0123] It may be appreciated that most application software reads memory frequently but writes to memory relatively infrequently. As a consequence, the rate at which memory is being written or re-written is relatively slow compared to the rate at which memory is being read. Because of this slow demand for writing or re-writing of memory, the memory locations or fields can be continually updated at a relatively low speed via the possibly relatively slow and inexpensive commodity network **53**, yet this possibly relatively slow speed is sufficient to meet the application program's demand for writing to memory. The result is that the performance of the FIG. **8** arrangement is superior to that of FIG. **3**. It may be appreciated in light of the description provided herein that while a relatively slow network communication link or path **53** may advantageously be used because it provides the desired performance and low cost, the invention is not limited to a relatively low speed network connection and may be used with any communication link or path. The invention is transport, network, and communications path independent, and does not depend on how the communication between machines or DRTs takes place. In one embodiment, even electronic mail (email) exchanges between machines or DRTs may suffice for the communications.

[0124] In a further optional modification in relation to the above, the identity and changed value pair of a manipulated memory location sent over network **53**, each pair typically sent as the sole contents of a single packet, frame or cell for example, can be grouped into batches of multiple pairs of identities and changed values corresponding to multiple manipulated memory locations, and sent together over network **53** or other communications link or path in a single packet, frame, or cell. This further modification further reduces the demands on the communication speed of the network **53** or other communications link or path interconnecting the various machines, as each packet, cell or frame may contain multiple identity and changed value pairs, and therefore fewer packets, frames, or cells require to be sent.

[0125] It may be apparent that in an environment where the application program code writes repeatedly to a single memory location, the embodiment illustrated of FIG. **11** of step **114** sends an updating and propagation message to all machines corresponding to every performed memory manipulation operation. In a still further optimal modification in relation to the above, the DRT thread **121/1** of FIG. **12** does not need to perform an updating and propagation operation corresponding to every local memory manipulation operation, but instead may send fewer updating and propagation messages than memory manipulation operations, each message containing the last or latest changed value or content of the manipulated memory location, or optionally may only send a single updating and propagation message corresponding to the last memory manipulation operation. This further improvement reduces the demands on the network **53** or other communications link or path, as fewer packets, frames, or cells require to be sent.

[0126] It will also be apparent to those skilled in the art in light of the detailed description provided herein that in a table or list or other data structure created by each DRT **71** when initially recording or creating the list of all, or some subset of all, memory locations (or fields), for each such recorded memory location on each machine M**1**, . . . , Mn there is a name or identity which is common or similar on each of the machines M**1**, . . . , Mn. However, in the individual machines the local memory location corresponding to a given name or identity (listed for example, during step **91** of FIG. **9**) will or may vary over time since each machine may and generally will store changed memory values or contents at different memory locations according to its own internal processes. Thus the table, or list, or other data structure in each of the DRTs will have, in general, different local memory locations corresponding to a single memory name or identity, but each global "memory name" or identity will have the same "memory value" stored in the different local memory locations.

[0127] It will also be apparent to those skilled in the art in light of the description provided herein that the abovementioned modification of the application program code **50** during loading can be accomplished in many ways or by a variety of means. These ways or means include, but are not limited to at least the following five ways and variations or combinations of these five, including by:

(i) re-compilation at loading,

(ii) by a pre-compilation procedure prior to loading,

(iii) compilation prior to loading,

(iv) a "just-in-time" compilation, or

(v) re-compilation after loading (but, or for example, before execution of the relevant or corresponding application code in a distributed environment).

[0128] Traditionally the term "compilation" implies a change in code or language, for example, from source to object code or one language to another. Clearly the use of the term "compilation" (and its grammatical equivalents) in the present specification is not so restricted and can also include or embrace modifications within the same code or language

[0129] Given the fundamental concept of modifying memory manipulation operations to coordinate operation between and amongst a plurality of machines **M1**, . . . Mn, there are several different ways or embodiments in which this coordinated, coherent and consistent memory state and manipulation operation concept, method, and procedure may be carried out or implemented.

[0130] In the first embodiment, a particular machine, say machine **M2**, loads the asset (such as class or object) inclusive of memory manipulation operation(s), modifies it, and then loads each of the other machines **M1**, **M3**, . . . , Mn (either sequentially or simultaneously or according to any other order, routine or procedure) with the modified object (or class or other asset or resource) inclusive of the new modified memory manipulation operation. Note that there may be one or a plurality of memory manipulation operations corresponding to only one object in the application code, or there may be a plurality of memory manipulation operations corresponding to a plurality of objects in the application code. Note that in one embodiment, the memory manipulation operation(s) that is (are) loaded is binary executable object code. Alternatively, the memory manipulation operation(s) that is (are) loaded is executable intermediary code.

[0131] In this arrangement, which may be termed "master/slave" each of the slave (or secondary) machines **M1**, **M3**, . . . , Mn loads the modified object (or class), and inclusive of the new modified memory manipulation operation(s), that was sent to it over the computer communications network or other communications link or path by the master (or primary) machine, such as machine **M2**, or some other machine such as a machine X of FIG. **15**. In a slight variation of this "master/slave" or "primary/secondary" arrangement, the computer communications network can be replaced by a shared storage device such as a shared file system, or a shared document/file repository such as a shared database.

[0132] Note that the modification performed on each machine or computer need not and frequently will not be the same or identical. What is required is that they are modified in a similar enough way that in accordance with the inventive principles described herein, each of the plurality of machines behaves consistently and coherently relative to the other machines to accomplish the operations and objectives described herein. Furthermore, it will be appreciated in light of the description provided herein that there are a myriad of ways to implement the modifications that may for example depend on the particular hardware, architecture, operating system, application program code, or the like or different factors. It will also be appreciated that embodiments of the invention may be implemented within an operating system, outside of or without the benefit of any operating system, inside the virtual machine, in an EPROM, in software, in firmware, or in any combination of these.

[0133] In a still further embodiment, each machine **M1**, . . . , Mn receives the unmodified asset (such as class or object) inclusive of one or more memory manipulation operation(s), but modifies the operations and then loads the asset (such as class or object) consisting of the now modified operations. Although one machine, such as the master or primary machine may customize or perform a different modification to the memory manipulation operation(s) sent to each machine, this embodiment more readily enables the modification carried out by each machine to be slightly different and to be enhanced, customized, and/or optimized based upon its particular machine architecture, hardware, processor, memory, configuration, operating system, or other factors, yet still similar, coherent and consistent with other machines with all other similar modifications and characteristics that may not need to be similar or identical.

[0134] In all of the described instances or embodiments, the supply or the communication of the asset code (such as class code or object code) to the machines **M1**, . . . , Mn, and optionally inclusive of a machine X of FIG. **15**, can be branched, distributed or communicated among and between the different machines in any combination or permutation; such as by providing direct machine to machine communication (for example, **M2** supplies each of **M1**, **M3**, **M4**, etc. directly), or by providing or using cascaded or sequential communication (for example, **M2** supplies **M1** which then supplies **M3** which then supplies **M4**, and so on), or a combination of the direct and cascaded and/or sequential.

[0135] Reference is made to the accompanying Annexure A in which: Annexure A**5** is a typical code fragment from a memory manipulation operation prior to modification (e.g., an exemplary unmodified routine with a memory manipulation operation), and Annexure A**6** is the same routine with a memory manipulation operation after modification (e.g., an exemplary modified routine with a memory manipulation operation). These code fragments are exemplary only and identify one software code means for performing the modification in an exemplary language. It will be appreciated that other software/firmware or computer program code may be used to accomplish the same or analogous function or operation without departing from the invention.

[0136] Annexures A**5** and A**6** (also reproduced in part in Table VI and Table VII below) are exemplary code listings that set forth the conventional or unmodified computer program software code (such as may be used in a single machine or computer environment) of a routine with a memory manipulation operation of application program code **50** and a post-modification excerpt of the same routine such as may be used in embodiments of the present invention having multiple machines. The modified code that is added to the routine is highlighted in bold text.

TABLE I

Summary Listing of Contents of Annexure A Annexure A includes exemplary program listings in the JAVA language to further illustrate features, aspects, methods, and procedures of described in the detailed description
A1. This first excerpt is part of an illustration of the modification code of the modifier 51 in accordance with steps 92 and 103 of FIG. 10. It searches through the code array of the

TABLE I-continued

Summary Listing of Contents of Annexure A Annexure A includes exemplary program listings in the JAVA language to further illustrate features, aspects, methods, and procedures of described in the detailed description
application program code 50, and when it detects a memory manipulation instruction (i.e. a putstatic instruction (opcode 178) in the JAVA language and virtual machine environment) it modifies the application program code by the insertion of an "alert" routine. A2. This second excerpt is part of the DRT.alert( ) method and implements the step of 125 and arrow of 127 of FIG. 12. This DRT.alert( ) method requests one or more threads of the DRT processing environment of FIG. 12 to update and propagate the value and identity of the changed memory location corresponding to the operation of Annexure A1. A3. This third excerpt is part of the DRT 71, and corresponds to step 128 of FIG. 12. This code fragment shows the DRT in a separate thread, such as thread 121/1 of FIG. 12, after being notified or requested by step 125 and array 127, and sending the changed value and changed value location/identity across the network 53 to the other of the plurality of machines M1 . . . Mn. A4. The fourth excerpt is part of the DRT 71, and corresponds to steps 135 and 136 of FIG. 13. This is a fragment of code to receive a propagated identity and value pair sent by another DRT 71 over the network, and write the changed value to the identified memory location. A5. The fifth excerpt is an disassembled compiled form of the example.java application of Annexure A7, which performs a memory manipulation operation (putstatic and putfield). A6. The sixth excerpt is the disassembled compiled form of the same example application in Annexure A5 after modification has been performed by FieldLoader.java of Annexure A11, in accordance with FIG. 9 of this invention. The modifications are highlighted in bold. A7. The seventh excerpt is the source-code of the example.java application used in excerpt A5 and A6. This example application has two memory locations (staticValue and instanceValue) and performs two memory manipulation operations. A8. The eighth excerpt is the source-code of FieldAlert.java which corresponds to step 125 and arrow 127 of FIG. 12, and which requests a thread 121/1 executing FieldSend.Java of the "distributed run-time" 71 to propagate a changed value and identity pair to the other machines M1 . . . Mn. A9. The ninth excerpt is the source-code of FieldSend.java which corresponds to step 128 of FIG. 12, and waits for a request/notification generated by FieldAlert.java of A8 corresponding to step 125 and arrow 127, and which propagates a changed value/identity pair requested of it by FieldAlert.java, via network 53. A10. The tenth excerpt is the source-code of FieldReceive.java, which corresponds to steps 135 and 136 of FIG. 13, and which receives a propagated changed value and identity pair sent to it over the network 53 via FieldSend.java of annexure A9. A11. FieldLoader.java. This excerpt is the source-code of FieldLoader.java, which modifies an application program code, such as the example.java application code of Annexure A7, as it is being loaded into a JAVA virtual machine in accordance with steps 90, 91, 92, 103, and 94 of FIG. 10. FieldLoader.java makes use of the convenience classes of Annexures A12 through to A36 during the modification of a compiled JAVA A12. Attribute_info.java Convience class for representing attribute_info structures within ClassFiles. A13. ClassFile.java Convience class for representing ClassFile structures. A14. Code_attribute.java Convience class for representing Code_attribute structures within ClassFiles. A15. CONSTANT_Class_info.java Convience class for representing CONSTANT_Class_info structures within ClassFiles. A16. CONSTANT_Double_info.java Convience class for representing CONSTANT_Double_info structures within ClassFiles. A17. CONSTANT_Fieldref_info.java Convience class for representing CONSTANT_Fieldref_info structures within ClassFiles. A18. CONSTANT_Float_info.java Convience class for representing CONSTANT_Float_info structures within ClassFiles. A19. CONSTANT_Integer_info.java Convience class for representing CONSTANT_Integer_info structures within ClassFiles. A20. CONSTANT_InterfaceMethodref_info.java Convience class for representing CONSTANT_InterfaceMethodref_info structures within ClassFiles. A21. CONSTANT_Long_info.java Convience class for representing CONSTANT_Long_info structures within ClassFiles. A22. CONSTANT_Methodref_info.java Convience class for representing CONSTANT_Methodref_info structures within ClassFiles. A23. CONSTANT_NameAndType_info.java Convience class for representing CONSTANT_NameAndType_info structures within ClassFiles. A24. CONSTANT_String_info.java Convience class for representing CONSTANT_String_info structures within ClassFiles. A25. CONSTANT_Utf8_info.java Convience class for representing CONSTANT_Utf8_info structures within ClassFiles.

TABLE I-continued

Summary Listing of Contents of Annexure A
Annexure A includes exemplary program listings in the JAVA language to further illustrate features, aspects, methods, and procedures of described in the detailed description

A26. ConstantValue__attribute.java
Convience class for representing ConstantValue__attribute structures within ClassFiles.
A27. cp__info.java
Convience class for representing cp__info structures within ClassFiles.
A28. Deprecated__attribute.java
Convience class for representing Deprecated__attribute structures within ClassFiles.
A29. Exceptions__attribute.java
Convience class for representing Exceptions__attribute structures within ClassFiles.
A30. field__info.java
Convience class for representing field__info structures within ClassFiles.
A31. InnerClasses__attribute.java
Convience class for representing InnerClasses__attribute structures within ClassFiles.
A32. LineNumberTable__attribute.java
Convience class for representing LineNumberTable__attribute structures within ClassFiles.
A33. LocalVariableTable__attribute.java
Convience class for representing LocalVariableTable__attribute structures within ClassFiles.
A34. method__info.java
Convience class for representing method__info structures within ClassFiles.
A35. SourceFile__attribute.java
Convience class for representing SourceFile__attribute structures within ClassFiles.
A36. Synthetic__attribute.java
Convience class for representing Synthetic__attribute structures within ClassFiles.

TABLE II

Exemplary code listing showing embodiment of modified code.

A1. This first excerpt is part of an illustration of the modification code of the modifier 51 in accordance with steps 92 and 103 of FIG. 10. It searches through the code array of the application program code 50, and when it detects a memory manipulation instruction (i.e. a putstatic instruction (opcode 178) in the JAVA language and virtual machine environment) it modifies the application program code by the insertion of an "alert" routine.

```
// START
byte[ ] code = Code__attribute.code;        // Bytecode of a given method in a
                                            // given classfile.
int code__length = Code__attribute.code__length;
int DRT = 99;        // Location of the CONSTANT__Methodref__info for the
                     // DRT.alert( ) method.
for (int i=0; i<code__length; i++){
   if ((code[i] & 0xff) == 179){     // Putstatic instruction.
      System.arraycopy(code, i+3, code, i+6, code__length−(i+3));
      code[i+3] = (byte) 184;         // Invokestatic instruction for the
                                      // DRT.alert( ) method.
      code[i+4] = (byte)    ((DRT >>> 8) & 0xff);
      code[i+5] = (byte)    (DRT & 0xff);
   }
}
// END
```

TABLE III

Exemplary code listing showing embodiment of code for alert method

A2. This second excerpt is part of the DRT.alert( ) method and implements the step of 125 and arrow of 127 of FIG. 12. This DRT.alert( ) method requests one or more threads of the DRT processing environment of FIG. 12 to update and propagate the value and identity of the changed memory location corresponding to the operation of Annexure A1.

```
// START
public static void alert( ){
   synchronized (ALERT__LOCK){
      ALERT__LOCK.notify( ); // Alerts a waiting DRT
      thread in the background.
```

TABLE III-continued

Exemplary code listing showing embodiment of code for alert method

```
   }
}
// END
```

TABLE IV

Exemplary code listing showing embodiment of code for DRT

A3. This third excerpt is part of the DRT 71, and corresponds to step 128 of FIG. 12. This code fragment shows the DRT in a separate thread, such as thread 121/1 of FIG. 12, after being notified or requested by

TABLE IV-continued

Exemplary code listing showing embodiment of code for DRT

step 125 and array 127, and sending the changed value and changed value location/identity across the network 53 to the other of the plurality of machines M1...Mn.

```
// START
MulticastSocket ms = DRT.getMulticastSocket( );   // The multicast socket
                                                  // used by the DRT for
                                                  // communication.
byte nameTag = 33;   // This is the "name tag" on the network for this
                     // field.
Field field = modifiedClass.getDeclaredField("myField1");   // Stores
                                                            // the field
                                                            // from the
                                                            // modified
                                                            // class.
// In this example, the field is a byte field.
while (DRT.isRunning( )){
   synchronized (ALERT_LOCK){
      ALERT_LOCK.wait( );   // The DRT thread is waiting for the alert
                            // method to be called.
      byte[ ] b = new byte[ ]{nameTag, field.getByte(null)};   // Stores
                                                               // the
                                                               // nameTag
                                                               // and the
                                                               // value
                                                               // of the
                                                               // field from
                                                               // the
                                                               // modified
                                                               // class in a
                                                               // buffer.
      DatagramPacket dp = new DatagramPacket(b, 0, b.length);
      ms.send(dp);   // Send the buffer out across the network.
   }
}
// END
```

TABLE V

Exemplary code listing showing embodiment of code for DRT receiving.

A4. The fourth excerpt is part of the DRT 71, and corresponds to steps 135 and 136 of FIG. 13. This is a fragment of code to receive a propagated identity and value pair sent by another DRT 71 over the network, and write the changed value to the identified memory location.

```
// START
MulticastSocket ms = DRT.getMulticastSocket( );   // The multicast socket
                                                  // used by the DRT for
                                                  // communication.
DatagramPacket dp = new DatagramPacket(new byte[2], 0, 2);
byte nameTag = 33;   // This is the "name tag" on the network for this
                     // field.
Field field = modifiedClass.getDeclaredField("myField1");   // Stores the
                                                            // field from
                                                            // the
                                                            // modified
                                                            // class.
// In this example, the field is a byte field.
while (DRT.isRunning){
   ms.receive(dp);   // Receive the previously sent buffer from
   the network.
   byte[ ] b = dp.getData( );
   if (b[0] == nameTag){   // Check the nametags match.
      field.setByte(null, b[1]);   // Write the value from the network packet
                                   // into the field location in memory.
   }
}
// END
```

TABLE VI

Exemplary code listing showing embodiment of application before modification is made.
A5. The fifth excerpt is an disassembled compiled form of the example.java application of Annexure A7, which performs a memory manipulation operation (putstatic and putfield).

```
Method void setValues(int, int)
   0 iload_1
   1 putstatic #3 <Field int staticValue>
   4 aload_0
   5 iload_2
   6 putfield #2 <Field int instanceValue>
   9 return
```

TABLE VII

Exemplary code listing showing embodiment of application after modification is made.
A6. The sixth excerpt is the disassembled compiled form of the same example application in Annexure A5 after modification has been performed by FieldLoader.java of Annexure A11, in accordance with FIG. 9 of this invention. The modifications are highlighted in bold.

```
Method void setValues(int, int)
   0 iload_1
   1 putstatic #3 <Field int staticValue>
   4 ldc #4 <String "example">
   6 iconst_0
   7 invokestatic #5 <Method void alert(java.lang.Object, int)>
  10 aload_0
  11 iload_2
  12 putfield #2 <Field int instanceValue>
  15 aload_0
  16 iconst_1
  17 invokestatic #5 <Method void alert(java.lang.Object, int)>
  20 return
```

TABLE VIII

Exemplary code listing showing embodiment of source-code of the example application.

A7. The seventh excerpt is the source-code of the example.java application used in excerpt A5 and A6. This example application has two memory locations (staticValue and instanceValue) and performs two memory manipulation operations.

```
import java.lang.*;
public class example{
   /** Shared static field. */
   public static int staticValue = 0;
   /** Shared instance field. */
   public int instanceValue = 0;
   /** Example method that writes to memory (instance field). */
   public void setValues(int a, int b){
      staticValue = a;
      instanceValue = b;
   }
}
```

TABLE IX

Exemplary code listing showing embodiment of the source-code of FieldAlert.

A8. The eighth excerpt is the source-code of FieldAlert.java which corresponds to step 125 and arrow 127 of FIG. 12, and which requests a thread 121/1 executing FieldSend.java of the "distributed run-time" 71 to propagate a changed value

TABLE IX-continued

Exemplary code listing showing embodiment of the source-code of FieldAlert.

```
and identity pair to the other
machines M1...Mn.
import java.lang.*;
import java.util.*;
import java.net.*;
import java.io.*;
public class FieldAlert{
   /** Table of alerts. */
   public final static Hashtable alerts = new Hashtable( );
   /** Object handle. */
   public Object reference = null;
   /** Table of field alerts for this object. */
   public boolean[ ] fieldAlerts = null;
   /** Constructor. */
   public FieldAlert(Object o, int initialFieldCount){
      reference = o;
      fieldAlerts = new boolean[initialFieldCount];
   }
   /** Called when an application modifies a value. (Both objects and
      classes) */
   public static void alert(Object o, int fieldID){
      // Lock the alerts table.
      synchronized (alerts){
         FieldAlert alert = (FieldAlert) alerts.get(o);
         if (alert == null){    // This object hasn't been alerted already,
                                // so add to alerts table.
            alert = new FieldAlert(o, fieldID + 1);
            alerts.put(o, alert);
         }
         if (fieldID >= alert.fieldAlerts.length){
            // Ok, enlarge fieldAlerts array.
            boolean[ ] b = new boolean[fieldID+1];
            System.arraycopy(alert.fieldAlerts, 0, b, 0,
               alert.fieldAlerts.length);
            alert.fieldAlerts = b;
         }
         // Record the alert.
         alert.fieldAlerts[fieldID] = true;
         // Mark as pending.
         FieldSend.pending = true;      // Signal that there is one or more
                                        // propagations waiting.
         // Finally, notify the waiting FieldSend thread(s)
         if (FieldSend.waiting){
            FieldSend.waiting = false;
            alerts.notify( );
         }
      }
   }
}
```

[0137] It is noted that the compiled code in the annexure and portion repeated in the table is taken from the source-code of the file "example java" which is included in the Annexure A7 (Table VIII). In the procedure of Annexure A5 and Table VI, the procedure name "Method void setvalues(int, int)" of Step **001** is the name of the displayed disassembled output of the setValues method of the compiled application code of "example.java". The name "Method void setValues(int, int)" is arbitrary and selected for this example to indicate a typical JAVA method inclusive of a memory manipulation operation. Overall the method is responsible for writing two values to two different memory locations through the use of an memory manipulation assignment statement (being "putstatic" and "putfield" in this example) and the steps to accomplish this are described in turn.

[0138] First (Step **002**), the Java Virtual Machine instruction "iload_**1**" causes the Java Virtual Machine to load the integer value in the local variable array at index **1** of the current method frame and store this item on the top of the stack of the current method frame and results in the integer value passed to this method as the first argument and stored in the local variable array at index **1** being pushed onto the stack.

[0139] The Java Virtual Machine instruction "putstatic #**3** <Field int staticValue>" (Step **003**) causes the Java Virtual Machine to pop the topmost value off the stack of the current method frame and store the value in the static field indicated by the CONSTANT_Fieldref_info constant-pool item stored in the 3^{rd} index of the classfile structure of the application program containing this example setvalues( ) method and results in the topmost integer value of the stack of the current method frame being stored in the integer field named "staticValue".

[0140] The Java Virtual Machine instruction "aload_**0**" (Step **004**) causes the Java Virtual Machine to load the item in the local variable array at index **0** of the current method frame and store this item on the top of the stack of the current method frame and results in the 'this' object reference stored in the local variable array at index **0** being pushed onto the stack.

[0141] First (Step **005**), the Java Virtual Machine instruction "iload_**2**" causes the Java Virtual Machine to load the integer value in the local variable array at index **2** of the current method frame and store this item on the top of the stack of the current method frame and results in the integer value passed to this method as the first argument and stored in the local variable array at index **2** being pushed onto the stack.

[0142] The Java Virtual Machine instruction "putfield #**2** <Field int instanceValue>" (Step **006**) causes the Java Virtual Machine to pop the two topmost values off the stack of the current method frame and store the topmost value in the object instance field of the second popped value, indicated by the CONSTANT_Feldref_info constant-pool item stored in the 2^{nd} index of the classfile structure of the application program containing this example setValues method and results in the integer value on the top of the stack of the current method frame being stored in the instance field named "instanceValue" of the object reference below the integer value on the stack.

[0143] Finally, the JAVA virtual machine instruction "return" (Step **007**) causes the JAVA virtual machine to cease executing this setValues( ) method by returning control to the previous method frame and results in termination of execution of this setValues( ) method.

[0144] As a result of these steps operating on a single machine of the conventional configurations in FIG. **1** and FIG. **2**, the JAVA virtual machine manipulates (i.e. writes to) the staticValue and instanceValue memory locations, and in executing the setValues( ) method containing the memory manipulation operation(s) is able to ensure that memory is and remains consistent between multiple threads of a single application instance, and therefore ensure that unwanted behaviour, such as for example inconsistent or incoherent memory between multiple threads of a single application instance (such inconsistent or incoherent memory being for example incorrect or different values or contents with respect to a single memory location) does not occur. Were these steps to be carried out on the plurality of machines of the configurations of FIG. **5** and FIG. **8** by concurrently executing the application program code **50** on each one of the plurality of machines M**1** . . . Mn, the memory manipulation operations of each concurrently executing application program occurrence on each one of the machines would be performed without coordination between any other machine(s), such coordination being for example updating of corresponding memory locations on each machine such that they each report a same content or value. Given the goal of consistent, coordinated and coherent memory state and manipulation and updating operation across a plurality of a machines, this prior art arrangement would fail to perform such consistent, coherent, and coordinated memory state and manipulation and updating operation across the plurality of machines, as each machine performs memory manipulation only locally and without any attempt to coordinate or update their local memory state and manipulation operation with any other similar memory state on any one or more other machines. Such an arrangement would therefore be susceptible to inconsistent and incoherent memory state amongst machines M**1** . . . Mn due to uncoordinated, inconsistent and/or incoherent memory manipulation and updating operation. Therefore it is the goal of the present invention to overcome this limitation of the prior art arrangement.

[0145] In the exemplary code in Table VII (Annexure A**6**), the code has been modified so that it solves the problem of consistent, coordinated memory manipulation and updating operation for a plurality of machines M**1** . . . Mn, that was not solved in the code example from Table VI (Annexure A**5**). In this modified setvalues( ) method code, an "Idc #**4** <String "example">" instruction is inserted after the "putstatic #**3**" instruction in order to be the first instruction following the execution of the "putstatic #**3**" instruction. This causes the JAVA virtual machine to load the String value "example" onto the stack of the current method frame and results in the String value of "example" loaded onto the top of the stack of the current method frame. This change is significant because it modifies the setvalues( ) method to load a String identifier corresponding to the classname of the class containing the static field location written to by the "putstatic #**3**" instruction onto the stack.

[0146] Furthermore, the JAVA virtual machine instruction "iconst_**0**" is inserted after the "Idc #**4**" instruction so that the JAVA virtual machine loads an integer value of "0" onto the stack of the current method frame and results in the integer value of "0" loaded onto the top of the stack of the current method frame. This change is significant because it modifies the setValues( ) method to load an integer value, which in this example is "0", which represents the identity of the memory location (field) manipulated by the preceding "putstatic #**3**" operation. It is to be noted that the choice or particular form of the memory identifier used for the implementation of this invention is for illustration purposes only. In this example, the integer value of "0" is the identifier used of the manipulated memory location, and corresponds to the "staticvalue" field as the first field of the "example.java" application, as shown in Annexure A**7**. Therefore, corresponding to the "putstatic #**3**" instruction, the "iconst_**0**" instruction loads the integer value "0" corresponding to the index of the manipulated field of the "putstatic #**3**" instruction, and which in this case is the first field of "example.java" hence the "0" integer index value, onto the stack.

[0147] Additionally, the JAVA virtual machine instruction "invokestatic #**5** <Method boolean alert(java.lang.Object, int)>" is inserted after the "iconst_**0**" instruction so that the JAVA virtual machine pops the two topmost items off the stack of the current method frame (which in accordance with the preceding "Idc #**4**" instruction is a reference to the String object with the value "example" corresponding to the name of the class to which manipulated field belongs, and the integer "0" corresponding to the index of the manipulated field in the example.java application) and invokes the "alert" method, passing the two topmost items popped off the stack to the new method frame as its first two arguments. This change is significant because it modifies the setvalues( ) method to execute the "alert" method and associated operations, corresponding to the preceding memory manipulation operation (that is, the "putstatic #**3**" instruction) of the setvalues( ) method.

[0148] Likewise, in this modified setvalues( ) method code, an "aload_**0**" instruction is inserted after the "putfield #**2**" instruction in order to be the first instruction following the execution of the "putfield #**2**" instruction. This causes the JAVA virtual machine to load the instance object of the example class to which the manipulated field of the preceding "puffield #**2**" instruction belongs, onto the stack of the current method frame and results in the object reference corresponding to the instance field written to by the "putfield #**2**" instruction, loaded onto the top of the stack of the current method frame. This change is significant because it modifies the setvalues( ) method to load a reference to the object corresponding to the manipulated field onto the stack.

[0149] Furthermore, the JAVA virtual machine instruction "iconst_**1**" is inserted after the "aload_**0**" instruction so that the JAVA virtual machine loads an integer value of "1" onto the stack of the current method frame and results in the integer value of "1" loaded onto the top of the stack of the current method frame. This change is significant because it modifies the setValues( ) method to load an integer value, which in this example is "1", which represents the identity of the memory location (field) manipulated by the preceding "putfield #**2**" operation. It is to be noted that the choice or particular form of the identifier used for the implementation of this invention is for illustration purposes only. In this example, the integer value of "1" corresponds to the "instanceValue" field as the second field of the "example.java" application, as shown in Annexure A**7**. Therefore, corresponding to the "putfield #**2**" instruction, the "iconst_**1**" instruction loads the integer value "1" corresponding to the index of the manipulated field of the "putfield #**2**" instruction, and which in this case is the second field of "example.java" hence the "1" integer index value, onto the stack.

[0150] Additionally, the JAVA virtual machine instruction "invokestatic #**5** <Method boolean alert(java.lang.Object, int)>" is inserted after the "iconst_**1**" instruction so that the JAVA virtual machine pops the two topmost item off the stack of the current method frame (which in accordance with the preceding "aload_**0**" instruction is a reference to the object corresponding to the object to which the manipulated instance field belongs, and the integer "1" corresponding to the index of the manipulated field in the example.java application) and invokes the "alert" method, passing the two topmost items popped off the stack to the new method frame as its first two arguments. This change is significant because it modifies the setValues( ) method to execute the "alert" method and associated operations, corresponding to the preceding memory manipulation operation (that is, the "putfield #**2**" instruction) of the setValues( ) method.

[0151] The method void alert(java.lang.Object, int), part of the FieldAlert code of Annexure A**8** and part of the distributed runtime system (DRT) **71**, requests or otherwise notifies a DRT thread **121/1** executing the FieldSend.java code of

Annexure A9 to update and propagate the changed identity and value of the manipulated memory location to the plurality of machines M . . . Mn.

[0152] It will be appreciated that the modified code permits, in a distributed computing environment having a plurality of computers or computing machines, the coordinated operation of memory manipulation operations so that the problems associated with the operation of the unmodified code or procedure on a plurality of machines M1 . . . Mn (such as for example inconsistent and incoherent memory state and manipulation and updating operation) does not occur when applying the modified code or procedure.

[0153] Turning to FIG. **14**, there is illustrated a schematic representation of a single prior art computer operated as a JAVA virtual machine. In this way, a machine (produced by any one of various manufacturers and having an operating system operating in any one of various different languages) can operate in the particular language of the application program code **50**, in this instance the JAVA language. That is, a JAVA virtual machine **72** is able to operate application code **50** in the JAVA language, and utilize the JAVA architecture irrespective of the machine manufacturer and the internal details of the machine.

[0154] When implemented in a non-JAVA language or application code environment, the generalized platform, and/or virtual machine and/or machine and/or runtime system is able to operate application code **50** in the language(s) (possibly including for example, but not limited to any one or more of source-code languages, intermediate-code languages, object-code languages, machine-code languages, and any other code languages) of that platform, and/or virtual machine and/or machine and/or runtime system environment, and utilize the platform, and/or virtual machine and/or machine and/or runtime system and/or language architecture irrespective of the machine manufacturer and the internal details of the machine. It will also be appreciated in light of the description provided herein that the platform and/or runtime system may include virtual machine and non-virtual machine software and/or firmware architectures, as well as hardware and direct hardware coded applications and implementations.

[0155] Returning to the example of the JAVA language virtual machine environment, in the JAVA language, the class initialization routine <clinit> happens only once when a given class file **50**A is loaded. However, the object initialization routine <init> typically happens frequently, for example the object initialization routine may usually occur every time a new object (such as an object **50**X, **50**Y or **50**Z) is created. In addition, within the JAVA environment and other machine or other runtime system environments using classes and object constructs, classes (generally being a broader category than objects) are loaded prior to objects (which are the narrower category and wherein the objects belong to or are identified with a particular class) so that in the application code **50** illustrated in FIG. **14**, having a single class **50**A and three objects **50**X, **50**Y, and **50**Z, the first class **50**A is loaded first, then first object **50**X is loaded, then second object **50**Y is loaded and finally third object **50**Z is loaded.

[0156] Where, as in the embodiment illustrated relative to FIG. **14**, there is only a single computer or machine **72** (and not a plurality of connected or coupled computers or machines), then no conflict or inconsistency arises in the running of the initialization routines (such as class and object initialization routines) intended to operate during the loading procedure because for conventional operation each initialization routine is executed only once by the single virtual machine or machine or runtime system or language environment as needed for each of the one or more classes and one or more objects belonging to or identified with the classes, or equivalent where the terms classes and object are not used.

[0157] For a more general set of virtual machine or abstract machine environments, and for current and future computers and/or computing machines and/or information appliances or processing systems, and that may not utilize or require utilization of either classes and/or objects, the inventive structure, method, and computer program and computer program product are still applicable. Examples of computers and/or computing machines that do not utilize either classes and/or objects include for example, the x86 computer architecture manufactured by Intel Corporation and others, the SPARC computer architecture manufactured by Sun Microsystems, Inc and others, the PowerPC computer architecture manufactured by International Business Machines Corporation and others, and the personal computer products made by Apple Computer, Inc., and others. For these types of computers, computing machines, information appliances, and the virtual machine or virtual computing environments implemented thereon that do not utilize the idea of classes or objects, the terms 'class' and 'object' may be generalized for example to include primitive data types (such as integer data types, floating point data types, long data types, double data types, string data types, character data types and boolean data types), structured data types (such as arrays and records) derived types, or other code or data structures of procedural languages or other languages and environments such as functions, pointers, components, modules, structures, references and unions.

[0158] Returning to the example of the JAVA language virtual machine environment, in the JAVA language, the class initialization routine <clinit> happens only once when a given class file **50**A is loaded. However, the object initialization routine <init> typically happens frequently, for example the object initialization routine will occur every time a new object (such as an object **50**X, **50**Y and **50**Z) is created. In addition, within the JAVA environment and other machine or other runtime system environments using classes and object constructures, classes (being the broader category) are loaded prior to objects (which are the narrower category and wherein the objects belong to or are identified with a particular class) so that in the application code **50** illustrated in FIG. **14**, having a single class **50**A and three objects **50**X-**50**Z, the first class **50**A is loaded first, then the first object **50**X is loaded, then second object **50**Y is loaded and finally third object **50**Z is loaded.

[0159] Where, as in the embodiment illustrated relative to FIG. **14**, there is only a single computer or machine **72** (not a plurality of connected or coupled machines), then no conflict or inconsistency arises in the running of the initialization routines (i.e. the class initialization routine <clinit> and the object initialisation routine <init>) intended to operate during the loading procedure because for conventional operation each initialisation routine is executed only once by the single virtual machine or machine or runtime system or language environment as needed for each of the one or more classes and one or more objects belonging to or identified with the classes.

[0160] However, in the arrangement illustrated in FIG. **8**, (and also in FIGS. **31-33**), a plurality of individual computers or machines M1, M2, . . . , Mn are provided, each of which are interconnected via a communications network **53** or other communications link and each of which individual computers or machines provided with a modifier **51** (See in FIG. **5**) and realised by or in for example the distributed runtime system (DRT) **71** (See FIG. **8**) and loaded with a common application code **50**. The term common application program is to be understood to mean an application program or application program code written to operate on a single machine, and loaded and/or executed in whole or in part on each one of the plurality of computers or machines M**1**, M**2** . . . Mn, or optionally on each one of some subset of the plurality of computers or machines M**1**, M**2** . . . Mn. Put somewhat differently, there is a common application program represented in application code **50**, and this single copy or perhaps a plurality of identical copies are modified to generate a modified copy or version of the application program or program code, each copy or instance prepared for execution on the plurality of machines. At the point after they are modified they are common in the sense that they perform similar operations and operate consistently and coherently with each other. It will be appreciated that a plurality of computers, machines, information appliances, or the like implementing the features of the invention may optionally be connected to or coupled with other computers, machines, information appliances, or the like that do not implement the features of the invention.

[0161] In some embodiments, some or all of the plurality of individual computers or machines may be contained within a single housing or chassis (such as so-called "blade servers" manufactured by Hewlett-Packard Development Company, Intel Corporation, IBM Corporation and others) or implemented on a single printed circuit board or even within a single chip or chip set.

[0162] Essentially the modifier **51** or DRT **71** or other code modifying means is responsible for modifying the application code **50** so that it may execute initialisation routines or other initialization operations, such as for example class and object initialization methods or routines in the JAVA language and virtual machine environment, in a coordinated, coherent, and consistent manner across and between the plurality of individual machines M**1**, M**2** . . . Mn. It follows therefore that in such a computing environment it is necessary to ensure that the local objects and classes on each of the individual machines M**1**, M**2** . . . Mn is initialized in a consistent fashion (with respect to the others).

[0163] It will be appreciated in light of the description provided herein that there are alternative implementations of the modifier **51** and the distributed run time **71**. For example, the modifier **51** may be implemented as a component of or within the distributed run time **71**, and therefore the DRT **71** may implement the functions and operations of the modifier **51**. Alternatively, the function and operation of the modifier **51** may be implemented outside of the structure, software, firmware, or other means used to implement the DRT **71**. In one embodiment, the modifier **51** and DRT **71** are implemented or written in a single piece of computer program code that provides the functions of the DRT and modifier. The modifier function and structure therefore maybe subsumed into the DRT and considered to be an optional component. Independent of how implemented, the modifier function and structure is responsible for modifying the executable code of the application code program, and the distributed run time function and structure is responsible for implementing communications between and among the computers or machines. The communications functionality in one embodiment is implemented via an intermediary protocol layer within the computer program code of the DRT on each machine. The DRT may for example implement a communications stack in the JAVA language and use the Transmission Control Protocol/Internet Protocol (TCP/IP) to provide for communications or talking between the machines. Exactly how these functions or operations are implemented or divided between structural and/or procedural elements, or between computer program code or data structures within the invention are less important than that they are provided.

[0164] In order to ensure consistent class and object (or equivalent) initialisation status and initialisation operation between and amongst machines M**1**, M**2**, . . . , Mn, the application code **50** is analysed or scrutinized by searching through the executable application code **50** in order to detect program steps (such as particular instructions or instruction types) in the application code **50** which define or constitute or otherwise represent an initialization operation or routine (or other similar memory, resource, data, or code initialization routine or operation). In the JAVA language, such program steps may for example comprise or consist of some part of, or all of, a "<init>" or "<clinit>" method of an object or class, and optionally any other code, routine, or method related to a "<init>" or "<clinit>" method, for example by means of a method invocation from the body of the "<init>" of "<clinit>" method to a different method.

[0165] This analysis or scrutiny of the application code **50** may take place either prior to loading the application program code **50**, or during the application program code **50** loading procedure, or even after the application program code **50** loading procedure. It may be likened to an instrumentation, program transformation, translation, or compilation procedure in that the application code may be instrumented with additional instructions, and/or otherwise modified by meaning-preserving program manipulations, and/or optionally translated from an input code language to a different code language (such as for example from source-code language or intermediate-code language to object-code language or machine-code language), and with the understanding that the term compilation normally or conventionally involves a change in code or language, for example, from source code to object code or from one language to another language. However, in the present instance the term "compilation" (and its grammatical equivalents) is not so restricted and can also include or embrace modifications within the same code or language. For example, the compilation and its equivalents are understood to encompass both ordinary compilation (such as for example by way of illustration but not limitation, from source-code to object-code), and compilation from source-code to source-code, as well as compilation from object-code to object-code, and any altered combinations therein. It is also inclusive of so-called "intermediary-code languages" which are a form of "pseudo object-code".

[0166] By way of illustration and not limitation, in one embodiment, the analysis or scrutiny of the application code **50** may take place during the loading of the application program code such as by the operating system reading the application code from the hard disk or other storage device or source and copying it into memory and preparing to begin execution of the application program code. In another embodiment, in a JAVA virtual machine, the analysis or scrutiny may take place during the class loading procedure of the java.lang.ClassLoader loadClass method (e.g., "java.lang.ClassLoader.loadClass( )").

[0167] Alternatively, the analysis or scrutiny of the application code **50** may take place even after the application program code loading procedure, such as after the operating system has loaded the application code into memory, or optionally even after execution of the application program code has started or commenced, such as for example after the JAVA virtual machine has loaded the application code into the virtual machine via the "java.lang.ClassLoader.loadClass( )" method and optionally commenced execution.

[0168] As a consequence, of the above described analysis or scrutiny, initialization routines (for example <clinit> class initialisation methods and <init> object initialization methods) are initially looked for, and when found or identified a modifying code is inserted, so as to give rise to a modified initialization routine. This modified routine is adapted and written to initialize the class **50**A on one of the machines, for example JVM#**1**, and tell, notify, or otherwise communicate to all the other machines M**2**, . . . , Mn that such a class **50**A exists and optionally its initialized state. There are several different alternative modes wherein this modification and loading can be carried out.

[0169] Thus, in one mode, the DRT **71/1** on the loading machine, in this example Java Virtual Machine M**1** (JVM#**1**), asks the DRT's **71/2** . . . **71/***n* of all the other machines M1, . . . , Mn if the similar equivalent first class **50**A is initialized (i.e. has already been initialized) on any other machine. If the answer to this question is yes (that is, a similar equivalent class **50**A has already been initialized on another machine), then the execution of the initialization procedure is aborted, paused, terminated, turned off or otherwise disabled for the class **50**A on machine JVM#**1**. If the answer is no (that is, a similar equivalent class **50**A has not already been initialised on another machine), then the initialization operation is continued (or resumed, or started, or commenced and the class **50**A is initialized and optionally the consequential changes (such as for example initialized code and data-structures in memory) brought about during that initialization procedure are transferred to each similar equivalent local class on each one of the other machines as indicated by arrows **83** in FIG. **8**.

[0170] A similar procedure happens on each occasion that an object, say **50**X, **50**Y or **50**Z is to be loaded and initialized. Where the DRT **71/1** of the loading machine, in this example Java Machine M**1** (JVM#**1**), does not discern, as a result of interrogation of the other machines M**2** . . . Mn that, a similar equivalent object to the particular object to be initialized on machine M**1**, say object **50**Y, has already been initialised by another machine, then the DRT **71/1** on machine M**1** may execute the object initialization routine corresponding to object **50**Y, and optionally each of the other machines M**2** . . . Mn may load a similar equivalent local object (which may conveniently be termed a peer object) and associated consequential changes (such as for example initialized data, initialized code, and/or initialized system or resources structures) brought about by the execution of the initialization operation on machine M1. However, if the DRT **71/1** of machine M**1** determines that a similar equivalent object to the object **50**Y in question has already been initialization on another machine of the plurality of machines (say for example machine M**2**), then the execution by machine M**1** of the initialization function, procedure, or routine corresponding to object **50**Y is not started or commenced, or is otherwise aborted, terminated, turned off or otherwise disabled, and object **50**Y on machine M**1** is loaded, and preferably but optionally the consequential changes (such as for example initialized data, initialized code, and/or other initialized system or resource structures) brought about by the execution of the initialization routine by machine M**2**, is loaded on machine M**1** corresponding to object **50**Y. Again there are various ways of bringing about the desired result.

[0171] Preferably, execution of the initialization routine is allocated to one machine, such as the first machine M**1** to load (and optionally seek to initialize) the object or class. The execution of the initialization routine corresponding to the determination that a particular class or object (and any similar equivalent local classes or objects on each of the machines M**1** . . . Mn) is not already initialized, is to execute only once with respect to all machines M**1** . . . Mn, and preferably by only one machine, on behalf of all machines M**1** . . . Mn. Corresponding to, and preferably following, the execution of the initialization routine by one machine (say machine M**1**), all other machines may then each load a similar equivalent local object (or class) and optionally load the consequential changes (such as for example initialized data, initialized code, and/or other initialized system or resource structures) brought about by the execution of the initialization operation by machine M**1**.

[0172] As seen in FIG. **15** a modification to the general arrangement of FIG. **8** is provided in that machines M**1**, M**2** . . . Mn are as before and run the same application code **50** (or codes) on all machines M**1**, M**2** . . . Mn simultaneously or concurrently. However, the previous arrangement is modified by the provision of a server machine X which is conveniently able to supply housekeeping functions, for example, and especially the initialisation of structures, assets, and resources. Such a server machine X can be a low value commodity computer such as a PC since its computational load is low. As indicated by broken lines in FIG. **15**, two server machines X and X+1 can be provided for redundancy purposes to increase the overall reliability of the system. Where two such server machines X and X+1 are provided, they are preferably but optionally operated as redundant machines in a failover arrangement.

[0173] It is not necessary to provide a server machine X as its computational load can be distributed over machines M**1**, M**2** . . . Mn. Alternatively, a database operated by one machine (in a master/slave type operation) can be used for the housekeeping function(s).

[0174] FIG. **16** shows a preferred general procedure to be followed. After a loading step **161** has been commenced, the instructions to be executed are considered in sequence and all initialization routines are detected as indicated in step **162**. In the JAVA language these are the object initialisation methods (e.g. "<init>") and class initialisation methods (e.g. "<clinit>"). Other languages use different terms.

[0175] Where an initialization routine is detected in step **162**, it is modified in step **163** in order to perform consistent, coordinated, and coherent initialization operation (such as for example initialization of data structures and code structures) across and between the plurality of machines M**1**, M**2** . . . Mn, typically by inserting further instructions into the initialisation routine to, for example, determine if a similar equivalent object or class (or other asset) on machines M**1** . . . Mn corresponding to the object or class (or asset) to which this initialisation routine corresponds, has already been initialised, and if so, aborting, pausing, terminating, turning off, or otherwise disabling the execution of this initialization routine (and/or initialization operation(s)), or if not then starting, continuing, or resuming the executing the initialization routine (and/or initialization operation(s)), and optionally instructing the other machines M1 . . . Mn to load a similar equivalent object or class and consequential changes brought about by the execution of the initialization routine. Alternatively, the modifying instructions may be inserted prior to the routine, such as for example prior to the instruction(s) or operation(s) which commence initialization of the corresponding class or object. Once the modification step **163** has been completed the loading procedure continues by loading the modified application code in place of the unmodified application code, as indicated in step **164**. Altogether, the initialization routine is to be executed only once, and preferably by only one machine, on behalf of all machines M1 . . . Mn corresponding to the determination by all machines M1 . . . Mn that the particular object or class (i.e. the similar equivalent local object or class on each machine M1 . . . Mn corresponding to the particular object or class to which this initialization routine relates) has not been initialized.

[0176] FIG. **17** illustrates a particular form of modification. After commencing the routine in step **171**, the structures, assets or resources (in JAVA termed classes or objects) to be initialised are, in step **172**, allocated a name or tag (for example a global name or tag) which can be used to identify corresponding similar equivalent local objects on each of the machines M1, . . . , Mn. This is most conveniently done via a table (or similar data or record structure) maintained by server machine X of FIG. **15**. This table may also include an initialization status of the similar equivalent classes or object to be initialised. It will be understood that this table or other data structure may store only the initialization status, or it may store other status or information as well.

[0177] As indicated in FIG. **17**, if steps **173** and **174** determine by means of the communication between machines M1 . . . Mn by DRT **71** that the similar equivalent local objects on each other machine corresponding to the global name or tag is not already initialised (i.e., not initialized on a machine other than the machine carrying out the loading and seeking to perform initialization), then this means that the object or class can be initialised, preferably but optionally in the normal fashion, by starting, commencing, continuing, or resuming the execution of, or otherwise executing, the initialization routine, as indicated in step **176**, since it is the first of the plurality of similar equivalent local objects or classes of machines M1 . . . Mn to be initialized.

[0178] In one embodiment, the initialization routine is stopped from initiating or commencing or beginning execution; however, in some implementations it is difficult or practically impossible to stop the initialization routine from initiating or beginning or commencing execution. Therefore, in an alternative embodiment, the execution of the initialization routine that has already started or commenced is aborted such that it does not complete or does not complete in its normal manner. This alternative abortion is understood to include an actual abortion, or a suspend, or postpone, or pause of the execution of a initialization routine that has started to execute (regardless of the stage of execution before completion) and therefore to make sure that the initialization routine does not get the chance to execute to completion the initialization of the object (or class or other asset)—and therefore the object (or class or other asset) remains "un-initialized" (i.e., "not initialized").

[0179] However or alternatively, if steps **173** and **174** determine that the global name corresponding to the plurality of similar equivalent local objects or classes, each on a one of the plurality of machines M1 . . . Mn, is already initialised on another machine, then this means that the object or class is considered to be initialized on behalf of, and for the purposes of, the plurality of machines M1 . . . Mn. As a consequence, the execution of the initialisation routine is aborted, terminated, turned off, or otherwise disabled, by carrying out step **175**.

[0180] FIG. **18**, illustrative of one embodiment of step **173** of FIG. **17**, shows the inquiry made by the loading machine (one of M1, M2 . . . Mn) to the server machine X of FIG. **15**, to enquire as to the initialisation status of the plurality of similar equivalent local objects (or classes) corresponding to the global name. The operation of the loading machine is temporarily interrupted as indicated by step **181**, and corresponding to step **173** of FIG. **17**, until a reply to this preceding request is received from machine X, as indicated by step **182**. In step **181** the loading machine sends an inquiry message to machine X to request the initialization status of the object (or class or other asset) to be initialized. Next, the loading machine awaits a reply from machine X corresponding to the inquiry message sent by the proposing machine at step **181**, indicated by step **182**.

[0181] FIG. **19** shows the activity carried out by machine X of FIG. **15** in response to such an initialization enquiry of step **181** of FIG. **18**. The initialization status is determined in steps **192** and **193**, which determines if a similar equivalent object (or class or other asset) corresponding to the initialization status request of global name, as received at step **191**, is initialized on another machine (i.e. a machine other than the inquiring machine **181** from which the initialization status request of step **191** originates), where a table of initialisation states is consulted corresponding to the record for the global name and, if the initialisation status record indicates that a similar equivalent local object (or class) on another machine (such as on a one of the machines M1 . . . Mn) and corresponding to global name is already initialised, the response to that effect is sent to the inquiring machine by carrying out step **194**. Alternatively, if the initialisation status record indicates that a similar equivalent local object (or class) on another machine (such as on a one of the plurality of machines M1 . . . Mn) and corresponding to global name is uninitialized, a corresponding reply is sent to the inquiring machine by carrying out steps **195** and **196**. The singular term object or class as used here (or the equivalent term of asset, or resource used in step **192**) are to be understood to be inclusive of all similar equivalent objects (or classes, or assets, or resources) corresponding to the same global name on each one of the plurality of machines M1. Mn. The waiting inquiring machine of step **182** is then able to respond and/or operate accordingly, such as for example by (i) aborting (or pausing, or postponing) execution of the initialization routine when the reply from machine X of step **182** indicated that a similar equivalent local object on another machine (such as a one of the plurality of machines M1 . . . Mn) corresponding to the global name of the object proposed to be initialized of step **172** is already initialized elsewhere (i.e. is initialized on a machine other than the machine proposing to carry out the initialization); or (ii) by continuing (or resuming, or starting, or commencing) execution of the initialization routine when the reply from machine X of step **182** indicated that a similar equivalent local object on the plurality of machines M1 . . . Mn corresponding to the global name of the object proposing to be initialized of step

172 is not initialized elsewhere (i.e. not initialized on a machine other than the machine proposing to carry out the initialization).

[0182] Reference is made to the accompanying Annexures in which: Annexures A**1**-A**10** illustrate actual code in relation to fields, Annexure B**1** is a typical code fragment from an unmodified <clinit> instruction, Annexure B**2** is an equivalent in respect of a modified <clinit> instruction, Annexure B**3** is a typical code fragment from an unmodified <init> instruction, Annexure B**4** is an equivalent in respect of a modified <init> instruction, In addition, Annexure B**5** is an alternative to the code of Annexure B**2**, and Annexure B**6** is an alternative to the code of Annexure B**4**.

[0183] Furthermore, Annexure B**7** is the source-code of InitClient which carries out one embodiment of the steps of FIGS. **17** and **18**, which queries an "initialization server" (for example a machine X) for the initialization status of the specified class or object with respect to the plurality of similar equivalent classes or objects on the plurality of machines M**1** . . . Mn. Annexure B**8** is the source-code of InitServer which carries out one embodiment of the steps of FIG. **19**, which receives an initialization status query sent by InitClient and in response returns the corresponding initialization status of the specified class or object. Similarly, Annexure B**9** is the source-code of the example application used in the before/after examples of Annexure B**1**-B**6** (Repeated as Tables X through XV). And, Annexure B**10** is the source-code of InitLoader which carries out one embodiment of the steps of FIGS. **16**, **20**, and **21**, which modifies the example application program code of Annexure B**9** in accordance with one mode of this invention.

[0184] Annexures B**1** and B**2** (also reproduced in part in Tables X and XI below) are exemplary code listings that set forth the conventional or unmodified computer program software code (such as may be used in a single machine or computer environment) of an initialization routine of application program **50** and a post-modification excerpt of the same initialization routine such as may be used in embodiments of the present invention having multiple machines. The modified code that is added to the initialization routine is highlighted in bold text.

[0185] It is noted that the disassembled compiled code in the annexure and portion repeated in the table is taken from the source-code of the file "example java" which is included in the Annexure B**4** (Table XIII). In the procedure of Annexure B**1** and Table X, the procedure name "Method <clinit>" of Step **001** is the name of the displayed disassembled output of the clinit method of the compiled application code "example java". The method name "<clinit> " is the name of a class' initialization method in accordance with the JAVA platform specification, and selected for this example to indicate a typical mode of operation of a JAVA initialization method. Overall the method is responsible for initializing the class 'example' so that it may be used, and the steps the "example.java" code performs are described in turn.

[0186] First (Step **002**) the JAVA virtual machine instruction "new #**2** <Class example>" causes the JAVA virtual machine to instantiate a new class instance of the example class indicated by the CONSTANT_Classref_info constant_pool item stored in the 2^{nd} index of the classfile structure of the application program containing this example <clinit> method and results in a reference to an newly created object of type 'example' being placed (pushed) on the stack of the current method frame of the currently executing thread.

[0187] Next (Step **003**), the Java Virtual Machine instruction "dup" causes the Java Virtual Machine to duplicate the topmost item of the stack and push the duplicated item onto the topmost position of the stack of the current method frame and results in the reference to the new created 'example' object at the top of the stack being duplicated and pushed onto the stack.

[0188] Next (Step **004**), the JAVA virtual machine instruction "invokespecial #**3** <Method example( )>" causes the JAVA virtual machine to pop the topmost item off the stack of the current method frame and invoke the instance initialization method "<init>" on the popped object and results in the "<init>" constructor of the newly created 'example' object being invoked.

[0189] The Java Virtual Machine instruction "putstatic #**3** <Field example currentExample>" (Step **005**) causes the Java Virtual Machine to pop the topmost value off the stack of the current method frame and store the value in the static field indicated by the CONSTANT_Fieldref_info constant-pool item stored in the 3^{rd} index of the classfile structure of the application program containing this example <clinit> method and results in the reference to the newly created and initialized 'example' object on the top of the stack of the current method frame being stored in the static reference field named "currentExample" of class 'example'.

[0190] Finally, the Java Virtual Machine instruction "return" (Step **006**) causes the Java Virtual Machine to cease executing this <clinit> method by returning control to the previous method frame and results in termination of execution of this <clinit> method.

[0191] As a result of these steps operating on a single machine of the conventional configurations in FIG. **1** and FIG. **2**, the JAVA virtual machine can keep track of the initialization status of a class in a consistent, coherent and coordinated manner, and in executing the <clinit> method containing the initialization operations is able to ensure that unwanted behaviour (for example execution of the <init> method of class 'example.java' more than once) such as may be caused by inconsistent and/or incoherent initialization operation, does not occur. Were these steps to be carried out on the plurality of machines of the configurations of FIG. **5** and FIG. **8** with the memory update and propagation replication means of FIGS. **9**, **10**, **11**, **12**, and **13**, and concurrently executing the application program code **50** on each one of the plurality of machines M**1** . . . Mn, the initialization operations of each concurrently executing application program occurrence on each one of the machines would be performed without coordination between any other of the occurrences on any other of the machine(s). Given the goal of consistent, coordinated and coherent initialization operation across a plurality of a machines, this prior art arrangement would fail to perform such consistent coordinated initialization operation across the plurality of machines, as each machine performs initialization only locally and without any attempt to coordinate their local initialization operation with any other similar initialization operation on any one or more other machines. Such an arrangement would therefore be susceptible to unwanted or other anomalous behaviour due to uncoordinated, inconsistent and/or incoherent initialization states, and associated initialization operation. Therefore it is the goal of the present invention to overcome this limitation of the prior art arrangement.

[0192] In the exemplary code in Table XIV (Annexure B**5**), the code has been modified so that it solves the problem of consistent, coordinated initialization operation for a plurality of machines M**1** . . . Mn, that was not solved in the code example from Table X (Annexure B**1**). In this modified <clinit> method code, an "Idc #**2** <String "example">" instruction is inserted before the "new #**5**" instruction in order to be the first instruction of the <clinit> method. This causes the JAVA virtual machine to load the item in the constant_pool at index **2** of the current classfile and store this item on the top of the stack of the current method frame, and results in the reference to a String object of value "example" being pushed onto the stack.

[0193] Furthermore, the JAVA virtual machine instruction "invokestatic #**3** <Method Boolean is AlreadyLoaded(java.lang.String)>" is inserted after the "**0** Idc #**2**" instruction so that the JAVA virtual machine pops the topmost item off the stack of the current method frame (which in accordance with the preceding "Idc #**2**" instruction is a reference to the String object with the value "example" which corresponds to the name of the class to which this <clinit> method belongs) and invokes the "isAlreadyLoaded" method, passing the popped item to the new method frame as its first argument, and returning a boolean value onto the stack upon return from this "invokestatic" instruction. This change is significant because it modifies the <clinit> method to execute the "isAlreadyLoaded" method and associated operations, corresponding to the start of execution of the <clinit> method, and returns a boolean argument (indicating whether the class corresponding to this <clinit> method is initialized on another machine amongst the plurality of machines M**1** . . . Mn) onto the stack of the executing method frame of the <clinit> method.

[0194] Next, two JAVA virtual machine instructions "ifeq **9**" and "return" are inserted into the code stream after the "**2** invokestatic #**3**" instruction and before the "new #**5**" instruction. The first of these two instructions, the "ifeq **9**" instruction, causes the JAVA virtual machine to pop the topmost item off the stack and performs a comparison between the popped value and zero. If the performed comparison succeeds (i.e. if and only if the popped value is equal to zero), then execution continues at the "**9** new #**5**" instruction. If however the performed comparison fails (i.e. if and only if the popped value is not equal to zero), then execution continues at the next instruction in the code stream, which is the "**8** return" instruction. This change is particularly significant because it modifies the <clinit> method to either continue execution of the <clinit> method (i.e. instructions **9-19**) if the returned value of the "isAlreadyLoaded" method was negative (i.e. "false"), or discontinue execution of the <clinit> method (i.e. the "**8** return" instruction causing a return of control to the invoker of this <clinit> method) if the returned value of the "isAlreadyLoaded" method was positive (i.e. "true").

[0195] The method void isAlreadyLoaded(java.lang.String), part of the InitClient code of Annexure B**7**, and part of the distributed runtime system (DRT) **71**, performs the communications operations between machines M**1** . . . Mn to coordinate the execution of the <clinit> method amongst the machines M**1** . . . Mn. The isAlreadyLoaded method of this example communicates with the InitServer code of Annexure B**8** executing on a machine X of FIG. **15**, by means of sending an "initialization status request" to machine X corresponding to the class being "initialized" (i.e. the class to which this <clinit> method belongs). With reference to FIG. **19** and Annexure B**8**, machine X receives the "initialization status request" corresponding to the class to which the <clinit> method belongs, and consults a table of initialization states or records to determine the initialization state for the class to which the request corresponds.

[0196] If the class corresponding to the initialization status request is not initialized on another machine other than the requesting machine, then machine X will send a response indicating that the class was not already initialized, and update a record entry corresponding to the specified class to indicate the class is now initialized. Alternatively, if the class corresponding to the initialization status request is initialized on another machine other than the requesting machine, then machine X will send a response indicating that the class is already initialized. Corresponding to the determination that the class to which this initialization status request pertains is not initialized on another machine other than the requesting machine, a reply is generated and sent to the requesting machine indicating that the class is not initialized. Additionally, machine X preferably updates the entry corresponding to the class to which the initialization status request pertained to indicate the class is now initialized. Following a receipt of such a message from machine X indicating that the class is not initialized on another machine, the isAlreadyLoaded( ) method and operations terminate execution and return a 'false' value to the previous method frame, which is the executing method frame of the <clinit> method. Alternatively, following a receipt of a message from machine X indicating that the class is already initialized on another machine, the isAlreadyLoaded( ) method and operations terminate execution and return a "true" value to the previous method frame, which is the executing method frame of the <clinit> method. Following this return operation, the execution of the <clinit> method frame then resumes as indicated in the code sequence of Annexure B**5** at step **004**.

[0197] It will be appreciated that the modified code permits, in a distributed computing environment having a plurality of computers or computing machines, the coordinated operation of initialization routines or other initialization operations between and amongst machines M**1** . . . Mn so that the problems associated with the operation of the unmodified code or procedure on a plurality of machines M**1** . . . Mn (such as for example multiple initialization operation, or re-initialization operation) does not occur when applying the modified code or procedure.

[0198] Similarly, the procedure followed to modify an <init> method relating to objects so as to convert from the code fragment of Annexure B**3** (See Table XII) to the code fragment of Annexure B**6** (See Table XV) is indicated.

[0199] Annexures B**3** and B**6** (also reproduced in part in Tables XII and XV below) are exemplary code listings that set forth the conventional or unmodified computer program software code (such as may be used in a single machine or computer environment) of an initialization routine of application program **50** and a post-modification excerpt of the same initialization routine such as may be used in embodiments of the present invention having multiple machines. The modified code that is added to the initialization routine is highlighted in bold text.

[0200] It is noted that the disassembled compiled code in the annexure and portion repeated in the table is taken from the source-code of the file "example.java" which is included in the Annexure B**4**. In the procedure of Annexure B**1** and Table XI, the procedure name "Method <init>" of Step **001** is the name of the displayed disassembled output of the init method of the compiled application code "example Java". The method name "<init>" is the name of an object's initialization method (or methods, as there may be more than one) in accordance with the JAVA platform specification, and selected for this example to indicate a typical mode of operation of a JAVA initialization method. Overall the method is responsible for initializing an 'example' object so that it may be used, and the steps the "example.java" code performs are described in turn.

[0201] The Java Virtual Machine instruction "aload_**0**" (Step **002**) causes the Java Virtual Machine to load the item in the local variable array al index **0** of the current method frame and store this item on the top of the stack of the current method frame and results in the 'this' object reference stored in the local variable array at index **0** being pushed onto the stack.

[0202] Next (Step **003**), the JAVA virtual machine instruction "invokespecial #**1** <Method java.lang.Object( )>" causes the JAVA virtual machine to pop the topmost item off the stack of the current method frame and invoke the instance initialization method "<init>" on the popped object and results in the "<init>" constructor (or method) of the 'example' object's superclass being invoked.

[0203] The Java Virtual Machine instruction "aload_**0**" (Step **004**) causes the Java Virtual Machine to load the item in the local variable array at index **0** of the current method frame and store this item on the top of the stack of the current method frame and results in the 'this' object reference stored in the local variable array at index **0** being pushed onto the stack.

[0204] Next (Step **005**), the JAVA virtual machine instruction "invokestatic #**2** <Method long currentTimeMillis( )>" causes the JAVA virtual machine to invoke the "currentTimeMillis( )" method of the java.lang.System class, and results in a long value pushed onto the top of the stack corresponding to the return value from the currentTimeMillis( ) method invocation.

[0205] The Java Virtual Machine instruction "putfield #**3** <Field long timestamp>" (Step **006**) causes the Java Virtual Machine to pop the two topmost values off the stack of the current method frame and store the topmost value in the object instance field of the second popped value, indicated by the CONSTANT_Fieldref_info constant-pool item stored in the 3^{rd} index of the classfile structure of the application program containing this example <init> method, and results in the long value on the top of the stack of the current method frame being stored in the instance field named "timestamp" of the object reference below the long value on the stack.

[0206] Finally, the Java Virtual Machine instruction "return" (Step **007**) causes the Java Virtual Machine to cease executing this <init> method by returning control to the previous method frame and results in termination of execution of this <init> method.

[0207] As a result of these steps operating on a single machine of the conventional configurations in FIG. **1** and FIG. **2**, the JAVA virtual machine can keep track of the initialization status of an object in a consistent, coherent and coordinated manner, and in executing the <init> method containing the initialization operations is able to ensure that unwanted behaviour (for example execution of the <init> method of a single 'example.java' object more than once, or re-initialization of the same object) such as may be caused by inconsistent and/or incoherent initialization operation, does not occur. Were these steps to be carried out on the plurality of machines of the configurations of FIG. **5** and FIG. **8** with the memory update and propagation replication means of FIGS. **9**, **10**, **11**, **12**, and **13**, and concurrently executing the application program code **50** on each one of the plurality of machines M**1** . . . Mn, the initialization operations of each concurrently executing application program occurrence on each one of the machines would be performed without coordination between any other of the occurrences on any other of the machine(s). Given the goal of consistent, coordinated and coherent initialization operation across a plurality of a machines, this prior art arrangement would fail to perform such consistent coordinated initialization operation across the plurality of machines, as each machine performs initialization only locally and without any attempt to coordinate their local initialization operation with any other similar initialization operation on any one or more other machines. Such an arrangement would therefore be susceptible to unwanted or other anomalous behaviour due to uncoordinated, inconsistent and/or incoherent initialization states, and associated initialization operation. Therefore it is the goal of the present invention to overcome this limitation of the prior art arrangement.

[0208] In the exemplary code in Table XV (Annexure B**6**), the code has been modified so that it solves the problem of consistent, coordinated initialization operation for a plurality of machines M**1** . . . Mn, that was not solved in the code example from Table XII(Annexure B**3**). In this modified <init> method code, an "aload_**0**" instruction is inserted after the "**1** invokespecial #**1**" instruction, as the "invokespecial #**1**" instruction must execute before the object may be further used. This inserted "aload_**0**" instruction causes the JAVA virtual machine to load the item in the local variable array at index **0** of the current method frame and store this item on the top of the stack of the current method frame, and results in the object reference to the 'this' object at index **0** being pushed onto the stack.

[0209] Furthermore, the JAVA virtual machine instruction "invokestatic #**3** <Method Boolean is AlreadyLoaded(java.lang.Object)>" is inserted after the "**4** aload_**0**" instruction so that the JAVA virtual machine pops the topmost item off the stack of the current method frame (which in accordance with the preceding "aload_**0**" instruction is a reference to the object to which this <init> method belongs) and invokes the "isAlreadyLoaded" method, passing the popped item to the new method frame as its first argument, and returning a boolean value onto the stack upon return from this "invokestatic" instruction. This change is significant because it modifies the <init> method to execute the "isAlreadyLoaded" method and associated operations, corresponding to the start of execution of the <init> method, and returns a boolean argument (indicating whether the object corresponding to this <init> method is initialized on another machine amongst the plurality of machines M**1** . . . Mn) onto the stack of the executing method frame of the <init> method.

[0210] Next, two JAVA virtual machine instructions "ifeq **13**" and "return" are inserted into the code stream after the "**5** invokestatic #**2**" instruction and before the "**12** aload_**0**" instruction. The first of these two instructions, the "ifeq **13**" instruction, causes the JAVA virtual machine to pop the topmost item off the stack and performs a comparison between the popped value and zero. If the performed comparison succeeds (i.e. if and only if the popped value is equal to zero), then execution continues at the "**12** aload_**0**" instruction. If however the performed comparison fails (i.e. if and only if the popped value is not equal to zero), then execution continues at the next instruction in the code stream, which is the "**11**

return" instruction. This change is particularly significant because it modifies the <init> method to either continue execution of the <init> method (i.e. instructions **12-19**) if the returned value of the "isAlreadyLoaded" method was negative (i.e. "false"), or discontinue execution of the <init> method (i.e. the "**11** return" instruction causing a return of control to the invoker of this <init> method) if the returned value of the "isAlreadyLoaded" method was positive (i.e. "true").

[0211] The method void isAlreadyLoaded(java.lang.Object), part of the InitClient code of Annexure B**7**, and part of the distributed runtime system (DRT) **71**, performs the communications operations between machines M**1** . . . Mn to coordinate the execution of the <init> method amongst the machines M**1** . . . Mn. The isAlreadyLoaded method of this example communicates with the Initserver code of Annexure B**8** executing on a machine X of FIG. **15**, by means of sending an "initialization status request" to machine X corresponding to the object being "initialized" (i.e. the object to which this <clinit> method belongs). With reference to FIG. **19** and Annexure B**8**, machine X receives the "initialization status request" corresponding to the object to which the <clinit> method belongs, and consults a table of initialization states or records to determine the initialization state for the object to which the request corresponds.

[0212] If the object corresponding to the initialization status request is not initialized on another machine other than the requesting machine, then machine X will send a response indicating that the object was not already initialized, and update a record entry corresponding to the specified object to indicate the object is now initialized. Alternatively, if the object corresponding to the initialization status request is initialized on another machine other than the requesting machine, then machine X will send a response indicating that the object is already initialized. Corresponding to the determination that the object to which this initialization status request pertains is not initialized on another machine other than the requesting machine, a reply is generated and sent to the requesting machine indicating that the object is not initialized. Additionally, machine X preferably updates the entry corresponding to the object to which the initialization status request pertained to indicate the object is now initialized. Following a receipt of such a message from machine X indicating that the object is not initialized on another machine, the isAlreadyLoaded( ) method and operations terminate execution and return a 'false' value to the previous method frame, which is the executing method frame of the <init> method. Alternatively, following a receipt of a message from machine X indicating that the object is already initialized on another machine, the isAlreadyLoaded( ) method and operations terminate execution and return a "true" value to the previous method frame, which is the executing method frame of the <init> method. Following this return operation, the execution of the <init> method frame then resumes as indicated in the code sequence of Annexure B5 at step **006**.

[0213] It will be appreciated that the modified code permits, in a distributed computing environment having a plurality of computers or computing machines, the coordinated operation of initialization routines or other initialization operations so that the problems associated with the operation of the unmodified code or procedure on a plurality of machines M**1**. Mn (such as for example multiple initialization, or re-initialization operation) does not occur when applying the modified code or procedure.

[0214] Annexure B**1** is a before-modification excerpt of the disassembled compiled form of the <clinit> method of the example.java application of Annexure B**9**. Annexure B**2** is an after-modification form of Annexure B**1**, modified by InitLoader.java of Annexure B**10** in accordance with the steps of FIG. **20**. Annexure B**3** is a before-modification excerpt of the disassembled compiled form of the <init> method of the example.java application of Annexure B**9**. Annexure B**4** is an after-modification form of Annexure B**3**, modified by InitLoader.java of Annexure B**10** in accordance with the steps of FIG. **21**. Annexure B**5** is an alternative after-modification form of Annexure B**1**, modified by InitLoader.java of Annexure B**10** in accordance with the steps of FIG. **20**. And Annexure B**6** is an alternative after-modification form of Annexure B**3**, modified by InitLoader.java of Annexure B**10** in accordance with the steps of FIG. **21**. The modifications are highlighted in bold.

TABLE X

Annexure B1

```
B1
Method <clinit>
   0 new #2 <Class example>
   3 dup
   4 invokespecial #3 <Method example( )>
   7 putstatic #4 <Field example currentExample>
  10 return
```

TABLE XI

Annexure B2

```
B2
Method <clinit>
   0 invokestatic #3 <Method boolean isAlreadyLoaded( )>
   3 ifeq 7
   6 return
   7 new #5 <Class example>
  10 dup
  11 invokespecial #6 <Method example( )>
  14 putstatic #7 <Field example example>
  17 return
```

TABLE XII

Annexure B3

```
B3
Method <init>
   0 aload_0
   1 invokespecial #1 <Method java.lang.Object( )>
   4 aload_0
   5 invokestatic #2 <Method long currentTimeMillis( )>
   8 putfield #3 <Field long timestamp>
  11 return
```

TABLE XIII

Annexure B4

```
B4
Method <init>
   0 aload_0
   1 invokespecial #1 <Method java.lang.Object( )>
   4 invokestatic #2 <Method boolean isAlreadyLoaded( )>
   7 ifeq 11
```

TABLE XIII-continued

Annexure B4
10 return
11 aload_0
12 invokestatic #4 <Method long currentTimeMillis( )>
15 putfield #5 <Field long timestamp>
18 return

TABLE XIV

Annexure B5
B5
Method <clinit>
0 ldc #2 <String "example">
2 invokestatic #3 <Method boolean isAlreadyLoaded(java.lang.String)>
5 ifeq 9
8 return
9 new #5 <Class example>
12 dup
13 invokespecial #6 <Method example( )>
16 putstatic #7 <Field example currentExample>
19 return

TABLE XV

Annexure B6
B6
Method <init>
0 aload_0
1 invokespecial #1 <Method java.lang.Object( )>
4 aload_0
5 invokestatic #2
<Method boolean isAlreadyLoaded(java.lang.Object)>
8 ifeq 12
11 return
12 aload_0
13 invokestatic #4 <Method long currentTimeMillis( )>
16 putfield #5 <Field long timestamp>
19 return

[0215] Turning now to FIGS. **20** and **21**, the procedure followed to modify class initialisation routines (i.e., the "<clinit>" method) and object initialization routines (i.e. the "<init>" method) is presented. The procedure followed to modify a <clinit> method relating to classes so as to convert from the code fragment of Annexure B**1** (See Table X) to the code fragment of Annexure B**5** (See Table XIV) is indicated. Similarly, the procedure followed to modify an object initialization <init> method relating to objects so as to convert from the code fragment of Annexure B**3** (See Table XII) to the code fragment of Annexure B**6** (See Table XV) is indicated.

[0216] The initial loading of the application code **50** (an illustrative example in source-code form of which is displayed in Annexure B**9**, and a corresponding partially disassembled form of which is displayed in Annexure B**1** (See also Table X) and Annexure B**3** (See also Table XII)) onto the JAVA virtual machine **72** is commenced at step **201**, and the code is analysed or scrutinized in order to detect one or more class initialization instructions, code-blocks or methods (i.e. "<clinit>" methods) by carrying out step **202**, and/or one or more object initialization instructions, code-blocks, or methods (i.e. "<init>" methods) by carrying out step **212**. Once so detected, an <clinit> method is modified by carrying out step **203**, and an <init > method is modified by carrying out step **213**. One example illustration for a modified class initialisation routine is indicated in Annexure B**2** (See also Table XI), and a further illustration of which is indicated in Annexure B**5** (See also Table XIV). One example illustration for a modified object initialisation routine is indicated in Annexure B**4** (See also Table XIII), and a further illustration of which is indicated in Annexure B**6** (See also Table XV). As indicated by step **204** and **214**, after the modification is completed the loading procedure is then continued such that the modified application code is loaded into or onto each of the machines instead of the unmodified application code.

[0217] Annexure B**1** (See also Table X) and Annexure B**2** (See also Table XI) are the before (or pre-modification or unmodified code) and after (or post-modification or modified code) excerpt of a class initialisation routine (i.e. a "<clinit>" method) respectively. Additionally, a further example of an alternative modified <clinit> method is illustrated in Annexure B**5** (See also Table XIV). The modified code that is added to the method is highlighted in bold. In the unmodified partially disassembled code sample of Annexure B**1**, the "new #**2**" and "invokespecial #**3**" instructions of the <clinit> method creates a new object (of the type 'example'), and the following instruction "putstatic #**4**" writes the reference of this newly created object to the memory location (field) called "currentExample". Thus, without management of coordinated class initialisation in a distributed environment of a plurality of machines M**1**, . . . , Mn, and each with a memory updating and propagation means of FIGS. **9**, **10**, **11**, **12**, and **13**, whereby the application program code **50** is to operate as a single coordinated, consistent, and coherent instance across the plurality of machines M**1** . . . Mn, each computer or computing machine would re-initialise (and optionally alternatively re-write or over-write) the "currentExample" memory location (field) with multiple and different objects corresponding to the multiple executions of the <clinit> method, leading to potentially incoherent or inconsistent memory between and amongst the occurrences of the application program code **50** on each of the machines M**1**, . . . , Mn. Clearly this is not what the programmer or user of a single application program code **50** instance expects to happen.

[0218] So, taking advantage of the DRT, the application code **50** is modified as it is loaded into the machine by changing the class initialisation routine (i.e., the <clinit> method). The changes made (highlighted in bold) are the initial instructions that the modified <clinit> method executes. These added instructions determine the initialization status of this particular class by checking if a similar equivalent local class on another machine corresponding to this particular class, has already been initialized and optionally loaded, by calling a routine or procedure to determine the initialization status of the plurality of similar equivalent classes, such as the "is already loaded" (e.g., "isAlreadyLoaded( )") procedure or method. The "isAlreadyLoaded( )" method of InitClient of Annexure B**7** of DRT **71** performing the steps of **172**-**176** of FIG. **17** determines the initialization status of the similar equivalent local classes each on a one of the machines M**1**, . . . , Mn corresponding to the particular class being loaded, the result of which is either a true result or a false result corresponding to whether or not another one (or more) of the machines M**1**. Mn have already initialized, and optionally loaded, a similar equivalent class.

[0219] The initialisation determination procedure or method "isAlreadyLoaded( )" of InitClient of Annexure B**7**

of the DRT **71** can optionally take an argument which represents a unique identifier for this class (See Annexure B**5** and Table XIV). For example, the name of the class that is being considered for initialisation, a reference to the class or class-object representing this class being considered for initialization, or a unique number or identifier representing this class across all machines (that is, a unique identifier corresponding to the plurality of similar equivalent local classes each on a one of the plurality of machines M**1** . . . Mn), to be used in the determination of the initialisation status of the plurality of similar equivalent local classes on each of the machines M**1** . . . Mn. This way, the DRT can support the initialization of multiple classes at the same time without becoming confused as to which of the multiple classes are already loaded and which are not, by using the unique identifier of each class.

[0220] The DRT **71** can determine the initialization status of the class in a number of possible ways. Preferably, the requesting machine can ask each other requested machine in turn (such as by using a computer communications network to exchange query and response messages between the requesting machine and the requested machine(s)) if the requested machine's similar equivalent local class corresponding to the unique identifier is initialized, and if any requested machine replies true indicating that the similar equivalent local class has already been initialized, then return a true result at return from the isAlreadyLoaded( ) method indicating that the local class should not be initialized, otherwise return a false result at return from the isAlreadyLoaded( ) method indicating that the local class should be initialized. Of course different logic schemes for true or false results may alternatively be implemented with the same effect. Alternatively, the DRT on the local machine can consult a shared record table (perhaps on a separate machine (eg machine X), or a coherent shared record table on each local machine and updated to remain substantially identical, or in a database) to determine if one of the plurality of similar equivalent classes on other machines has been initialised.

[0221] If the isAlreadyLoaded( ) method of the DRT **71** returns false, then this means that this class (of the plurality of similar equivalent local classes on the plurality of machines M**1** . . . Mn) has not been initialized before on any other machine in the distributed computing environment of the plurality of machines M**1** . . . Mn, and hence, the execution of the class initialisation method is to take place or proceed as this is considered the first and original initialization of a class of the plurality of similar equivalent classes on each machine. As a result, when a shared record table of initialisation states exists, the DRT must update the initialisation status record corresponding to this class in the shared record table to true or other value indicating that this class is initialized, such that subsequent consultations of the shared record table of initialisation states (such as performed by all subsequent invocations of isAlreadyLoaded method) by all machines, and optionally including the current machine, will now return a true value indicating that this class is already initialized. Thus, if isAlreadyLoaded( ) returns false, the modified class initialisation routine resumes or continues (or otherwise optionally begins or starts) execution.

[0222] On the other hand, if the isAlreadyLoaded method of the DRT **71** returns true, then this means that this class (of the plurality of similar equivalent local classes each on one of the plurality of machines M**1** . . . Mn) has already been initialised in the distributed environment, as recorded in the shared record table on machine X of the initialisation states of classes. In such a case, the class initialisation method is not to be executed (or alternatively resumed, or continued, or started, or executed to completion), as it will potentially cause unwanted interactions or conflicts, such as re-initialization of memory, data structures or other machine resources or devices. Thus, when the DRT returns true, the inserted instructions at the start of the <clinit> method prevent execution of the initialization routine (optionally in whole or in part) by aborting the start or continued execution of the <clinit> method through the use of the return instruction, and consequently aborting the JAVA Virtual Machine's initialization operation for this class.

[0223] An equivalent procedure for the initialization routines of object (for example "<init>" methods) is illustrated in FIG. **21** where steps **212** and **213** are equivalent to steps **202** and **203** of FIG. **20**. This results in the code of Annexure B**3** being converted into the code of Annexure B**4** (See also Table XIII) or Annexure B**6** (See also Table XV).

[0224] Annexure B**3** (See also Table XII) and Annexure B**4** (See also Table XIV) are the before (or pre-modification or unmodified code) and after (or post-modification or modified code) excerpt of a object initialisation routine (i.e. a "<init>" method) respectively. Additionally, a further example of an alternative modified <init> method is illustrated in Annexure B**6** (See also Table XV). The modified code that is added to the method is highlighted in bold. In the unmodified partially disassembled code sample of Annexure B**4**, the "aload_**0**" and "invokespecial #**3**" instructions of the <init> method invokes the <init> of the java.lang.Object superclass. Next, the following instructions "aload_**0**" loads a reference to the 'this' object onto the stack to be one of the arguments to the "**8** putfield #**3**" instruction. Next, the following instruction "invokestatic #**2**" invokes the method java.lang.System.currentTimeMillis( ) and returns a long value on the stack. Next the following instruction "putfield #**3**" writes the long value placed on the stack be the preceding "invokestatic #**2**" instruction to the memory location (field) called "timestamp" corresponding to the object instance loaded on the stack by the "**4** aload_**0**" instruction. Thus, without management of coordinated object initialisation in a distributed environment of a plurality of machines M**1**, . . . , Mn, and each with a memory updating and propagation means of FIGS. **9**, **10**, **11**, **12**, and **13**, whereby the application program code **50** is to operate as a single coordinated, consistent, and coherent instance across the plurality of machines M**1** . . . Mn, each computer or computing machine would re-initialise (and optionally alternatively re-write or over-write) the "timestamp" memory location (field) with multiple and different values corresponding to the multiple executions of the <init> method, leading to potentially incoherent or inconsistent memory between and amongst the occurrences of application program code **50** on each of the machines M**1**, . . . , Mn. Clearly this is not what the programmer or user of a single application program code **50** instance expects to happen.

[0225] So, taking advantage of the DRT, the application code **50** is modified as it is loaded into the machine by changing the object initialisation routine (i.e. the <init> method). The changes made (highlighted in bold) are the initial instructions that the modified <init> method executes. These added instructions determine the initialisation status of this particular object by checking if a similar equivalent local object on another machine corresponding to this particular object, has already been initialized and optionally loaded, by calling a routine or procedure to determine the initialisation status of the object to be initialised, such as the "is already loaded" (e.g., "isAlreadyLoaded( )") procedure or method of Annexure B7. The "isAlreadyLoaded( )" method of DRT **71** performing the steps of **172-176** of FIG. **17** determines the initialization status of the similar equivalent local objects each on a one of the machines M**1**, . . . , Mn corresponding to the particular object being loaded, the result of which is either a true result or a false result corresponding to whether or not another one (or more) of the machines M**1** . . . Mn have already initialized, and optionally loaded, this object.

[0226] The initialisation determination procedure or method "isAlreadyLoaded( )" of the DRT **71** can optionally take an argument which represents a unique identifier for this object (See Annexure B**6** and Table XV). For example, the name of the object that is being considered for initialisation, a reference to the object being considered for initialization, or a unique number or identifier representing this object across all machines (that is, a unique identifier corresponding to the plurality of similar equivalent local objects each on a one of the plurality of machines M**1** . . . Mn), to be used in the determination of the initialisation status of this object in the plurality of similar equivalent local objects on each of the machines M**1** . . . Mn. This way, the DRT can support the initialization of multiple objects at the same time without becoming confused as to which of the multiple objects are already loaded and which are not, by using the unique identifier of each object.

[0227] The DRT **71** can determine the initialization status of the object in a number of possible ways. Preferably, the requesting machine can ask each other requested machine in turn (such as by using a computer communications network to exchange query and response messages between the requesting machine and the requested machine(s)) if the requested machine's similar equivalent local object corresponding to the unique identifier is initialized, and if any requested machine replies true indicating that the similar equivalent local object has already been initialized, then return a true result at return from the isAlreadyLoaded( ) method indicating that the local object should not be initialized, otherwise return a false result at return from the isAlreadyLoaded( ) method indicating that the local object should be initialized. Of course different logic schemes for true or false results may alternatively be implemented with the same effect. Alternatively, the DRT on the local machine can consult a shared record table (perhaps on a separate machine (eg machine X), or a coherent shared record table on each local machine and updated to remain substantially identical, or in a database) to determine if this particular object (or any one of the plurality of similar equivalent objects on other machines) has been initialised by one of the requested machines.

[0228] If the isAlreadyLoaded( ) method of the DRT **71** returns false, then this means that this object (of the plurality of similar equivalent local objects on the plurality of machines M**1** . . . Mn) has not been initialized before on any other machine in the distributed computing environment of the plurality of machines M**1** . . . Mn, and hence, the execution of the object initialisation method is to take place or proceed as this is considered the first and original initialization. As a result, when a shared record table of initialisation states exists, the DRT must update the initialisation status record corresponding to this object in the shared record table to true or other value indicating that this object is initialized, such that subsequent consultations of the shared record table of initialisation states (such as performed by all subsequent invocations of is AlreadyLoaded method) by all machines, and including the current machine, will now return a true value indicating that this object is already initialized. Thus, if isAlreadyLoaded( ) returns false, the modified object initialisation routine resumes or continues (or otherwise optionally begins or starts) execution.

[0229] On the other hand, if the isAlreadyLoaded method of the DRT **71** returns true, then this means that this object (of the plurality of similar equivalent local objects each on one of the plurality of machines M**1** . . . Mn) has already been initialised in the distributed environment, as recorded in the shared record table on machine X of the initialisation states of objects. In such a case, the object initialisation method is not to be executed (or alternatively resumed, or continued, or started, or executed to completion), as it will potentially cause unwanted interactions or conflicts, such as re-initialization of memory, data structures or other machine resources or devices. Thus, when the DRT returns true, the inserted instructions near the start of the <init> method prevent execution of the initialization routine (optionally in whole or in part) by aborting the start or continued execution of the <init> method through the use of the return instruction, and consequently aborting the JAVA Virtual Machine's initialization operation for this object.

[0230] A similar modification as used for <clinit> is used for <init>. The application program's<init> method (or methods, as there may be multiple) is or are detected as shown by step **212** and modified as shown by step **213** to behave coherently across the distributed environment.

[0231] The disassembled instruction sequence after modification has taken place is set out in Annexure B**4** (and an alternative similar arrangement is provided in Annexure B**6**) and the modified/inserted instructions are highlighted in bold. For the <init> modification, unlike the <clinit> modification, the modifying instructions are often required to be placed after the "invokespecial" instruction, instead of at the very beginning. The reasons for this are driven by the JAVA Virtual Machine specification. Other languages often have similar subtle design nuances.

[0232] Given the fundamental concept of testing to determine if initialization has already been carried out on a one of a plurality of similar equivalent classes or object or other asset each on a one of the machines M**1** . . . Mn, and if not carrying out the initialization, and if so, not carrying out the initialization; there are several different ways or embodiments in which this coordinated and coherent initialization concept, method, and procedure may be carried out or implemented.

[0233] In the first embodiment, a particular machine, say machine M**2**, loads the asset (such as class or object) inclusive of an initialisation routine, modifies it, and then loads each of the other machines M**1**, M**3**, . . . , Mn (either sequentially or simultaneously or according to any other order, routine or procedure) with the modified object (or class or other asset or resource) inclusive of the new modified initialization routine (s). Note that there may be one or a plurality of routines corresponding to only one object in the application code, or there may be a plurality of routines corresponding to a plurality of objects in the application code. Note that in one embodiment, the initialization routine(s) that is (are) loaded is binary executable object code. Alternatively, the initialization routine(s) that is (are) loaded is executable intermediary code.

[0234] In this arrangement, which may be termed "master/slave" each of the slave (or secondary) machines M**1**, M**3**, . . . , Mn loads the modified object (or class), and inclusive of the new modified initialisation routine(s), that was sent to it over the computer communications network or other communications link or path by the master (or primary) machine, such as machine M2, or some other machine such as a machine X of FIG. 15. In a slight variation of this "master/slave" or "primary/secondary" arrangement, the computer communications network can be replaced by a shared storage device such as a shared file system, or a shared document/file repository such as a shared database.

[0235] Note that the modification performed on each machine or computer need not and frequently will not be the same or identical. What is required is that they are modified in a similar enough way that in accordance with the inventive principles described herein, each of the plurality of machines behaves consistently and coherently relative to the other machines to accomplish the operations and objectives described herein. Furthermore, it will be appreciated in light of the description provided herein that there are a myriad of ways to implement the modifications that may for example depend on the particular hardware, architecture, operating system, application program code, or the like or different factors. It will also be appreciated that embodiments of the invention may be implemented within an operating system, outside of or without the benefit of any operating system, inside the virtual machine, in an EPROM, in software, in firmware, or in any combination of these.

[0236] In a further variation of this "master/slave" or "primary/secondary" arrangement, machine M2 loads asset (such as class or object) inclusive of an (or even one or more) initialization routine in unmodified form on machine M2, and then (for example, machine M2 or each local machine) modifies the class (or object or asset) by deleting the initialization routine in whole or part from the asset (or class or object) and loads by means of a computer communications network or other communications link or path the modified code for the asset with the now modified or deleted initialization routine on the other machines. Thus in this instance the modification is not a transformation, instrumentation, translation or compilation of the asset initialization routine but a deletion of the initialization routine on all machines except one.

[0237] The process of deleting the initialization routine in its entirety can either be performed by the "master" machine (such as machine M2 or some other machine such as machine X of FIG. 15) or alternatively by each other machine M1, M3, . . . , Mn upon receipt of the unmodified asset. An additional variation of this "master/slave" or "primary/secondary" arrangement is to use a shared storage device such as a shared file system, or a shared document/file repository such as a shared database as means of exchanging the code (including for example, the modified code) for the asset, class or object between machines M1, M2, . . . , Mn and optionally a machine X of FIG. 15.

[0238] In a still further embodiment, each machine M1, . . . , Mn receives the unmodified asset (such as class or object) inclusive of one or more initialization routines, but modifies the routines and then loads the asset (such as class or object) consisting of the now modified routines. Although one machine, such as the master or primary machine may customize or perform a different modification to the initialization routine sent to each machine, this embodiment more readily enables the modification carried out by each machine to be slightly different and to be enhanced, customized, and/or optimized based upon its particular machine architecture, hardware, processor, memory, configuration, operating system, or other factors, yet still similar, coherent and consistent with other machines with all other similar modifications and characteristics that may not need to be similar or identical.

[0239] In a further arrangement, a particular machine, say M1, loads the unmodified asset (such as class or object) inclusive of one or more initialisation routine and all other machines M2, M3, . . . , Mn perform a modification to delete the initialization routine of the asset (such as class or object) and load the modified version.

[0240] In all of the described instances or embodiments, the supply or the communication of the asset code (such as class code or object code) to the machines M1, . . . , Mn, and optionally inclusive of a machine X of FIG. 15, can be branched, distributed or communicated among and between the different machines in any combination or permutation: such as by providing direct machine to machine communication (for example, M2 supplies each of M1, M3, M4, etc. directly), or by providing or using cascaded or sequential communication (for example, M2 supplies M1 which then supplies M3 which then supplies M4, and so on), or a combination of the direct and cascaded and/or sequential.

[0241] In a still further arrangement, the initial machine, say M2, can carry out the initial loading of the application code 50, modify it in accordance with this invention, and then generate a class/object loaded and initialised table which lists all or at least all the pertinent classes and/or objects loaded and initialised by machine M2. This table is then sent or communicated (or at least its contents are sent or communicated) to all other machines (including for example in branched or cascade fashion). Then if a machine, other than M2, needs to load and therefore initialise a class listed in the table, it sends a request to M2 to provide the necessary information, optionally consisting of either the unmodified application code 50 of the class or object to be loaded, or the modified application code of the class or object to be loaded, and optionally a copy of the previously initialised (or optionally and if available, the latest or even the current) values or contents of the previously loaded and initialised class or object on machine M2. An alternative arrangement of this mode may be to send the request for necessary information not to machine M2, but some other, or even more than one of, machine M1, . . . , Mn or machine X. Thus the information provided to machine Mn is, in general, different from the initial state loaded and initialise by machine M2.

[0242] Under the above circumstances it is preferable and advantageous for each entry in the table to be accompanied by a counter which is incremented on each occasion that a class or object is loaded and initialised on one of the machines M1, . . . , Mn. Thus, when data or other content is demanded, both the class or object contents and the count of the corresponding counter, and optionally in addition the modified or unmodified application code, are transferred in response to the demand. This "on demand" mode may somewhat increase the overhead of the execution of this invention for one or more machines M1, . . . , Mn, but it also reduces the volume of traffic on the communications network which interconnects the computers and therefore provides an overall advantage.

[0243] In a still further arrangement, the machines M1 to Mn, may send some or all load requests to an additional machine X (see for example the embodiment of FIG. 15), which performs the modification to the application code 50 inclusive of an (and possibly a plurality of) initialisation routine(s) via any of the afore mentioned methods, and returns the modified application code inclusive of the now modified initialization routine(s) to each of the machines **M1** to Mn, and these machines in turn load the modified application code inclusive of the modified routines locally. In this arrangement, machines **M1** to Mn forward all load requests to machine X, which returns a modified application program code **50** inclusive of modified initialization routine(s) to each machine. The modifications performed by machine X can include any of the modifications covered under the scope of the present invention. This arrangement may of course be applied to some of the machines and other arrangements described herein before applied to other of the machines.

[0244] Persons skilled in the computing arts will be aware of various possible techniques that may be used in the modification of computer code, including but not limited to instrumentation, program transformation, translation, or compilation means.

[0245] One such technique is to make the modification(s) to the application code, without a preceding or consequential change of the language of the application code. Another such technique is to convert the original code (for example, JAVA language source-code) into an intermediate representation (or intermediate-code language, or pseudo code), such as JAVA byte code. Once this conversion takes place the modification is made to the byte code and then the conversion may be reversed. This gives the desired result of modified JAVA code.

[0246] A further possible technique is to convert the application program to machine code, either directly from source-code or via the abovementioned intermediate language or through some other intermediate means. Then the machine code is modified before being loaded and executed. A still further such technique is to convert the original code to an intermediate representation, which is thus modified and subsequently converted into machine code.

[0247] The present invention encompasses all such modification routes and also a combination of two, three or even more, of such routes.

[0248] Having now described aspects of the memory management and replication and initialization, attention is now directed to an exemplary operational scenario illustrating the manner in which application programs on two computers may simultaneously execute the same application program in a consistent, coherent manner.

[0249] In this regard, attention is directed to FIGS. **22-24**, two laptop computers **101** and **102** are illustrated. The computers **101** and **102** are not necessarily identical and indeed, one can be an IBM or IBM-clone and the other can be an APPLE computer. The computers **101** and **102** have two screens **105**, **115** two keyboards **106**, **116** but a single mouse **107**. The two machines **101**, **102** are interconnected by a means of a single coaxial cable or twisted pair cable **314**.

[0250] Two simple application programs are downloaded onto each of the machines **101**, **102**, the programs being modified as they are being loaded as described above. In this embodiment the first application is a simple calculator program and results in the image of a calculator **108** being displayed on the screen **105**. The second program is a graphics program which displays four coloured blocks **109** which are of different colours and which move about at random within a rectangular box **310**. Again, after loading, the box **310** is displayed on the screen **105**. Each application operates independently so that the blocks **109** are in random motion on the screen **105** whilst numerals within the calculator **108** can be selected (with the mouse **107**) together with a mathematical operator (such as addition or multiplication) so that the calculator **108** displays the result.

[0251] The mouse **107** can be used to "grab" the box **310** and move same to the right across the screen **105** and onto the screen **115** so as to arrive at the situation illustrated in FIG. **23**. In this arrangement, the calculator application is being conducted on machine **101** whilst the graphics application resulting in display of box **310** is being conducted on machine **102**.

[0252] However, as illustrated in FIG. **24**, it is possible by means of the mouse **107** to drag the calculator **108** to the right as seen in FIG. **23** so as to have a part of the calculator **108** displayed by each of the screens **105**, **115**. Similarly, the box **310** can be dragged by means of the mouse **107** to the left as seen in FIG. **23** so that the box **310** is partially displayed by each of the screens **105**, **115** as indicated FIG. **24**. In this configuration, part of the calculator operation is being performed on machine **101** and part on machine **102** whilst part of the graphics application is being carried out the machine **101** and the remainder is carried out on machine **102**.

Further Description

[0253] The foregoing describes only some embodiments of the present invention and modifications, obvious to those skilled in the art, can be made thereto without departing from the scope of the present invention. For example, reference to JAVA includes both the JAVA language and also JAVA platform and architecture.

[0254] In all described instances of modification, where the application code **50** is modified before, or during loading, or even after loading but before execution of the unmodified application code has commenced, it is to be understood that the modified application code is loaded in place of, and executed in place of, the unmodified application code subsequently to the modifications being performed.

[0255] Alternatively, in the instances where modification takes place after loading and after execution of the unmodified application code has commenced, it is to be understood that the unmodified application code may either be replaced with the modified application code in whole, corresponding to the modifications being performed, or alternatively, the unmodified application code may be replaced in part or incrementally as the modifications are performed incrementally on the executing unmodified application code. Regardless of which such modification routes are used, the modifications subsequent to being performed execute in place of the unmodified application code.

[0256] An advantage of using a global identifier in the invention described is as a form of 'meta-name' or 'meta-identity' for all the similar equivalent local objects (or classes, or assets or resources or the like) on each one of the plurality of machines **M1**, . . . , Mn. For example, rather than having to keep track of each unique local name or identity of each similar equivalent local object on each machine of the plurality of similar equivalent objects, one may instead define or use a global name corresponding to the plurality of similar equivalent objects on each machine (e.g., "globalname**7787**"), and with the understanding that each machine relates the global name to a specific local name or object (e.g., "globalname**7787**" corresponds to object "localobject**456**" on machine **M1**, and "globalname**7787**" corresponds to object "localobject**885**" on machine **M2**, and "globalname**7787**" corresponds to object "localobject**111**" on machine **M3**, and so forth).

[0257] Those skilled in the programming arts will be aware that when additional code or instructions is/are inserted into an existing code or instruction set to modify same, the existing code or instruction set may well require further modification (such as for example, by renumbering of sequential instructions) so that offsets, branching, attributes, mark up and the like are catered for.

[0258] Similarly, in the JAVA language memory locations include, for example, both fields and array types. The above description deals with fields and the changes required for array types are essentially the same mutatis mutandis. Also the present invention is equally applicable to similar programming languages (including procedural, declarative and object orientated) to JAVA including Micrsoft.NET platform and architecture (Visual Basic, Visual C/C^{++}, and C#) FORTRAN, C/C^{++}, COBOL, BASIC etc.

[0259] The abovementioned arrangement, in which the JAVA code which updates memory locations or field values is modified, is based on the assumption that either the runtime system (say, JAVA HOTSPOT VIRTUAL MACHINE written in C and Java) or the operating system (LINUX written in C and Assembler, for example) of each machine M**1** . . . Mn will ordinarily update memory on the local machine (say M**2**) but not on any corresponding other machines (M**1**, M**3** . . . Mn). It is possible to leave the JAVA code which updates memory locations or field values unamended and instead amend the LINUX or HOTSPOT routine which updates memory locally, so that it correspondingly updates memory on all other machines as well. In order to embrace such an arrangement the term "updating propagation routine" used herein in conjunction with maintaining the memory of all machines M**1** . . . Mn essentially the same, is to be understood to include within its scope both the JAVA putfield and putstatic instructions and related operations and the "combination" of the JAVA putfield and putstatic operations and the LINUX or HOTSPOT code fragments which perform memory updating.

[0260] The abovementioned embodiment in which the code of the JAVA initialisation routine is modified, is based upon the assumption that either the run time system (say, JAVA HOTSPOT VIRTUAL MACHINE written in C and JAVA) or the operating system (LINUX written in C and Assembler, for example) of each machine M**1** . . . Mn will call the JAVA initialisation routine. It is possible to leave the JAVA initialisation routine unamended and instead amend the LINUX or HOTSPOT routine which calls the JAVA initialisation routine, so that if the object or class is already loaded, then the JAVA initialisation routine is not called. In order to embrace such an arrangement the term "initialisation routine" is to be understood to include within its scope both the JAVA initialisation routine and the "combination" of the JAVA initialisation routine and the LINUX or HOTSPOT code fragments which call or initiates the JAVA initialisation routine.

[0261] The terms object and class used herein are derived from the JAVA environment and are intended to embrace similar terms derived from different environments such as dynamically linked libraries (DLL), or object code packages, or function unit or memory locations.

[0262] Various means are described relative to embodiments of the invention, including for example but not limited to lock means, distributed run time means, modifier or modifying means, propagation means, distribution update means, counter means, synchronization means, and the like. In at least one embodiment of the invention, any one or each of these various means may be implemented by computer program code statements or instructions (possibly including by a plurality of computer program code statements or instructions) that execute within computer logic circuits, processors, ASICs, microprocessors, microcontrollers, or other logic to modify the operation of such logic or circuits to accomplish the recited operation or function. In another embodiment, any one or each of these various means may be implemented in firmware and in other embodiments such may be implemented in hardware. Furthermore, in at least one embodiment of the invention, any one or each of these various means may be implemented by an combination of computer program software, firmware, and/or hardware.

[0263] Any and each of the aforedescribed methods, procedures, and/or routines may advantageously be implemented as a computer program and/or computer program product stored on any tangible media or existing in electronic, signal, or digital form. Such computer program or computer program products comprising instructions separately and/or organized as modules, programs, subroutines, or in any other way for execution in processing logic such as in a processor or microprocessor of a computer, computing machine, or information appliance; the computer program or computer program products modifying the operation of the computer on which it executes or on a computer coupled with, connected to, or otherwise in signal communications with the computer on which the computer program or computer program product is present or executing. Such computer program or computer program product modifying the operation and architectural structure of the computer, computing machine, and/or information appliance to alter the technical operation of the computer and realize the technical effects described herein.

[0264] The invention may therefore includes a computer program product comprising a set of program instructions stored in a storage medium or exiting electronically in any form and operable to permit a plurality of computers to carry out any of the methods, procedures, routines, or the like as described herein including in any of the claims.

[0265] Furthermore, the invention may include a plurality of computers interconnected via a communication network or other communications ink or path and each operable to substantially simultaneously or concurrently execute the same or a different portion of an application program code written to operate on only a single computer on a corresponding different one of computers, wherein the computers being programmed to carry out any of the methods, procedures, or routines described in the specification or set forth in any of the claims, or being loaded with a computer program product.

[0266] The term "comprising" (and its grammatical variations) as used herein is used in the inclusive sense of "having" or "including" and not in the exclusive sense of "consisting only of".

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I/We claim:

1. A method of compiling or modifying an application program written to operate on only one computer to have different portions thereof to execute substantially simultaneously on different ones of a plurality of computers interconnected via a communications link without creating a distributed shared memory arrangement; said method comprising the steps of: (i) detecting instructions which create objects a in local independent memory of a single one of said computers; and (ii) activating an initialization routine following each said detected object creation instruction, said initialization routine forwarding each created object to the remainder of said computers.

2. The method as claimed in claim **1** and carried out prior to loading the application program onto each said computer, or during loading of the application program onto each said computer, or after loading of the application program onto each said computer and before execution of the relevant portion of the application program.

3. A method of ensuring for a single computer consistent initialization of an application program written to operate on only one computer but different portions of which application program are to be executed substantially simultaneously each on a different one of a plurality of computers: said plurality of computers including said single computer and being interconnected via a communications network without forming a distributed shared memory arrangement; said method comprising the steps of:

(i) scrutinizing said application program at, or prior to, or after loading to detect each program step defining an initialization routine; and

(ii) modifying said initialization routine to generate a corresponding modified initialization routine to ensure consistent operation of all said computers.

4. The method as claimed in claim **3** wherein said initialization routine is modified to execute once only on the creation of a first object by any one of said computers and is modified to be disabled on the creation of each subsequent peer copy of said object by the remainder of said computers.

5. The method claimed in claim **3** wherein step (ii) comprises the steps of:

(iii) loading and executing said initialization routine on said single computer;

(iv) modifying said initialization routine by said single computer; and

(v) transferring said modified initialization routine to each of the remaining computers.

6. The method as claimed in claim **5** wherein said modified initialization routine is supplied by said single computer direct to each of said remaining computers.

7. The method as claimed in claim **5** wherein said modified initialization routine is supplied in cascade fashion from said single computer sequentially to each of said remaining computers.

8. The method claimed in claim **3** wherein step (ii) comprises the steps of: (vi) loading and modifying said initialization routine on said single computer; (vii) said single computer sending said initialization routine to each of the remaining computers; and (viii) each of said remaining computers modifying said initialization routine after receipt of same.

9. The method claimed in claim **8** wherein said initialization routine is supplied by said single computer directly to each of said remaining computers.

10. The method claimed in claim **8** wherein said initialization routine is supplied in cascade fashion from said single computer sequentially to each of said remaining computers.

11. The method claimed in claim **4** wherein step (ii) comprises the steps

(iii) loading and executing said initialization routine on said single computer;

(iv) modifying said initialization routine by said single computer; and

(v) transferring said modified initialization routine to each of the remaining computers.

12. The method as claimed in claim **11** wherein said modified initialization routine is supplied by said single computer direct to each of said remaining computers.

13. The method as claimed in claim **11** wherein said modified initialization routine is supplied in cascade fashion from said single computer sequentially to each of said remaining computers.

14. The method claimed in claim **11** wherein step (ii) comprises the steps of:

(vi) loading and modifying said initialization routine on said single computer;

(vii) said single computer sending said unmodified initialization routine to each of the remaining computers; and

(viii) each of said remaining computers modifying said initialization routine after receipt of same.

15. The method claimed in claim **14** wherein said unmodified initialization routine is supplied by said single computer directly to each of said remaining computers.

16. The method claimed in claim **14** wherein said unmodified initialization routine is supplied in cascade fashion from said single computer sequentially to each of said remaining computers.

17. A computer program product comprising a set of program instructions stored in a storage medium and operable to permit either a single computer or a plurality of computers, or a plurality of computers in cooperation with a single computer, to carry out the method as claimed in claim **1**.

18. A computer program product comprising a set of program instructions stored in a storage medium and operable to permit either a single computer, or a plurality of computers, or a plurality of computers in cooperation with a single computer, to carry out the method as claimed in claim **3**.

19. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being programmed to carry out the method as claimed in claim **1**.

20. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being programmed to carry out the method as claimed in claim **3**.

21. A single computer intended to operate in a multiple computer system comprising a plurality of computers interconnected by a communications network without forming a distributed shared memory arrangement, said single computer having at least one application program each written to operate on only one computer but running simultaneously on said plurality of computers wherein different portions of said at least one application program execute substantially simultaneously on different ones of said plurality of computers and for each said different portion a like plurality of substantially identical objects are created; each in a local independent memory of the corresponding computer and each having a substantially identical name; and wherein the initial contents of each of said substantially identically named objects is substantially the same.

22. The single computer as claimed in claim **21** wherein each said computer includes a distributed run time means with the distributed run time means of each said computer able to communicate with all other computers so that if a portion of said application program(s) running on one of said computers creates an object in that computer then the created object is propagated by the distributed run time means of said one computer to all the other computers.

23. The single computer as claimed in claim **22** wherein each said application program is modified before, during, or after loading by inserting an initialization routine to modify each instance at which said application program creates an object, said initialization routine propagating every object newly created by one computer to all said other computers.

24. The single computer as claimed in claim **23** wherein said inserted initialization routine modifies a preexisting initialization routine to enable the pre-existing initialization routine to execute on creation of the first of said like plurality of objects, and to disable the pre-existing initialization routine on creation of all subsequent ones of said like plurality of objects.

25. The single computer as claimed in claim **24** wherein the application program is modified in accordance with a procedure selected from the group of procedures consisting of re-compilation at loading, pre-compilation prior to loading, compilation prior to loading, just-in-time compilation, and re-compilation after loading and before execution of the relevant portion of application program.

26. The single computer as claimed in claim **25** wherein said modified application program is transferred to all said computers in accordance with a procedure selected from the group consisting of master/slave transfer, branched transfer and cascaded transfer.

27. A single computer arranged to operate within a plurality of computers interconnected via a communications link without forming a distributed shared memory arrangement, said plurality of computers substantially simultaneously operating at least one application program each written to operate on only one computer; wherein each said computer substantially simultaneously executes a different portion of said at least one application program; each said computer in operating its application program portion creates objects only in local independent memory physically located in each said computer, the contents of the local independent memory utilized by each said computer are fundamentally similar but not, at each instant, identical; and every one of said computers has a distribution update means to distribute to all other said computers objects created by said single computer.

28. The single computer as claimed in claim **27** wherein the local memory capacity allocated to each said application program is substantially identical and the total memory capacity available to each said application program is said allocated memory capacity.

29. The single computer as claimed in claim **27** wherein all said distribution update means communicate via said communications link at a data transfer rate which is substantially less than the local memory read rate.

30. The single computer as claimed in claim **27** wherein at least some of said computers are manufactured by different manufacturers and/or have different operating systems.

31. A method of running on a single computer at least one application program each written to operate on only one computer; said single computer being intended to operate in cooperation with a plurality of other computers which are interconnected by means of a communications network without forming a distributed shared memory arrangement; said method comprising the steps of:

(i) executing different portions of said at least one application program substantially simultaneously on different ones of said other computers and for each said portion creating a like plurality of substantially identical objects each in a local independent memory of the corresponding computer and each having a substantially identical name; and

(ii) creating the initial contents of each of said identically named objects substantially the same.

32. The method as claimed in claim **31** comprising the further step of: (iii) if a portion of said application program running on one of said computers creates an object in that computer, then the created object is propagated to all of the other computers via said communications network.

33. The method as claimed in claim **32** including the further step of: (iv) modifying said application program before, during or after loading by inserting an initialization routine to modify each instance at which said application program creates an object, said initialization routine propagating every object created by one computer to all said other computers.

34. The method as claimed in claim **33** including the further step of: (v) modifying said application program utilizing a procedure selected from the group of procedures consisting of re-compilation at loading, pre-compilation prior to loading, compilation prior to loading, just-in-time compilation, and re-compilation after loading and before execution of the relevant portion of application program.

35. The method as claimed in claim **33** including the further step of: (vi) transferring the modified application program to all said computers utilizing a procedure selected from the group consisting of master/slave transfer, branched transfer and cascaded transfer.

36. In a multiple thread processing computer operation taking place on a single computer intended to operate in cooperation with a plurality of computers and in which individual threads of a single application program written to operate on only one computer are simultaneously being processed each on a different corresponding one of a plurality of computers interconnected via a communications link without forming a distributed shared memory arrangement; the improvement comprising: communicating objects created in local independent memory physically associated with the computer processing each thread to the local independent memory of each other said computer via said communications link.

37. The improvement as claimed in claim **36** wherein objects created in the memory associated with one said thread are communicated by the computer of said one thread to all other said computers.

38. The improvement as claimed in claim **36** wherein objects created the memory associated with one said thread are transmitted to the computer associated with another said thread and are transmitted thereby to all said other computers.

39. A computer program product comprising a set of program instructions stored in a storage medium and operable to permit either a single computer, or a plurality of computers, or a plurality of computers in cooperation with a single computer, to carry out the method as claimed in claim **36**.

40. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being programmed to carry out the method as claimed in claim **31**.

41. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being programmed to carry out the method as claimed in claim **36**.

42. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being loaded with the computer program product as claimed in claim **17**.

43. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being loaded with the computer program product as claimed in claim **39**.

44. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being loaded with the computer program product as claimed in claim **18**.

45. A computer program product comprising a set of program instructions stored in a storage medium and operable to permit either a single computer, or a plurality of computers, or a plurality of computers in cooperation with a single computer, to carry out the method as claimed in claim **31**.

46. A single computer intended to operate with a plurality of computers interconnected via a communication network without forming a distributed shared memory arrangement and operable to ensure consistent initialization of an application program written to operate on only one computer but running substantially simultaneously on all said computers, said single computer being loaded with the computer program product as claimed in claim **45**.

47. In a multiple computer system comprising a plurality of computers, a method of compiling or modifying an application program written to operate on only one computer to have different portions thereof to execute substantially simultaneously on different ones of said plurality of computers interconnected via a communications link without creating a distributed shared memory arrangement; said method comprising the steps of:

(i) detecting instructions which create objects a in local independent memory of a single one of said computers of said plurality of computers; and

(ii) activating an initialization routine following each said detected object creation instruction, said initialization routine forwarding each created object to the remainder of said plurality of computers.

48. In a multiple computer system comprising a plurality of computers interconnected via a communications network, a method of ensuring for a single computer selected from among the plurality of computers consistent initialization of an application program written to operate on only one computer but different portions of which application program are to be executed substantially simultaneously each on a different one of said plurality of computers: said plurality or computers including said single computer and being interconnected via a communications network without forming a distributed shared memory arrangement; said method comprising the steps of:

(i) scrutinizing said application program at, or prior to, or after loading to detect each program step defining an initialization routine; and

(ii) modifying said initialization routine to generate a corresponding modified initialization routine to ensure consistent operation of all said computers.

49. A multiple computer system comprising a plurality of computers interconnected by a communications network without forming a distributed shared memory arrangement, said plurality of computers each having at least one application program each written to operate on only one computer but running simultaneously on said plurality of computers wherein different portions of said at least one application program execute substantially simultaneously on different ones of said plurality of computers and for each said different portion a like plurality of substantially identical objects are created; each in a local independent memory of the corresponding one of the plurality of computers and each having a substantially identical name; and wherein the initial contents of each of said substantially identically named objects is substantially the same.

50. A multiple computer system comprising:

a plurality of single computers arranged to operate within said multiple computer system, said plurality of computers interconnected via a communications link without forming a distributed shared memory arrangement, said plurality of computers substantially simultaneously operating at least one application program each written to operate on only one computer; wherein each said computer substantially simultaneously executes a different portion of said at least one application program;

each said computer in operating its application program portion creates objects only in local independent memory physically located in each said computer, the contents of the local independent memory utilized by each said computer are fundamentally similar but not, at each instant, identical; and every one of said computers has a distribution update means to distribute to all other said computers objects created by said single computer.

51. A method of running on a multiple computer system comprising a plurality of single computers at least one application program each written to operate on only one computer; each said single computer being intended to operate in cooperation with said plurality of computers which are interconnected by means of a communications network without forming a distributed shared memory arrangement; said method comprising the steps of:

(i) executing different portions of said at least one application program substantially simultaneously on different ones of said plurality of computers and for each said portion creating a like plurality of substantially identical objects each in a local independent memory of the corresponding single computer and each having a substantially identical name; and

(ii) creating the initial contents of each of said identically named objects substantially the same.

52. In a multiple thread processing computer operation configured to operate in cooperation with a plurality of single computers and in which individual threads of a single application program written to operate on only one computer are simultaneously being processed each on a different corresponding one of said plurality of computers interconnected via a communications link without forming a distributed shared memory arrangement; the improvement comprising: communicating objects created in local independent memory physically associated with the single computer from the plurality of computers processing each thread to the local independent memory of each other said plurality of computer via said communications link different from the single computer processing the tread.

53. A single computer configured for operating with a plurality of single computers in a multiple computer system and having at least one application program written to operate on only a single computer but running substantially simultaneously on the plurality of single computers interconnected by a communications network; the single computer comprising:

a local independent memory structure defined in a local independent memory of the single computer and configured to provide execution of application program code of the application program including a plurality of code threads that are written with the intent to execute on and reference a single computer having a single processing unit or symmetric multiple processing units and the single independent local memory with a local memory capacity that is not shared with any other single computer of said plurality of single computers;

the single computer configured for and executing a different portion of said at least one application program than the other computers of the plurality of single computers, and executing its portion substantially simultaneously with the execution of different portions of the application program on the different other ones of said plurality of computers and for each portion in said single computer a plurality of objects are created in its independent local memory while a like plurality of substantially identical objects are created in the independent local memory of the other computers and each object having a substantially identical name; and

means for consistently creating or initializing all said identical objects on said single computer and on the other plurality of computers.

54. A single computer configured for use with a plurality of different networked single computers that are interconnected via a communications link, the single computer and the plurality of different computers operating substantially simultaneously to execute an application program written to operate on only a single computer, the application program having application program code including a plurality of code threads all intended to execute on and reference a single computer having a single processing unit or symmetric multiple processing units and a single independent local memory with a local memory capacity that is not shared with any other single computer of said plurality of single computers;

said single computer substantially simultaneously executes a first portion of said application program and other of said plurality of different networked single computers substantially simultaneously executes a second and other different portion with said first portion;

said single computer in operating said application program first portion utilizes an named object only by using a local replica of the named object stored in independent local memory physically located in said single computer with a local memory capacity that is not shared with or accessible by any other of the plurality of different networked single computers; the contents of the independent local memory utilized by said single computer and by each said plurality of different networked single computers is fundamentally similar but not, at each instant, identical; and

said single computer having and executing an object creation or initialization routine which creates or initializes objects consistently across the plurality of computers.

55. In a single computer, a method of ensuring consistent initialization of an application program written to operate only on one single computer but different portions of which are to be executed substantially simultaneously on the single computer and on each different one of a plurality of computers interconnected with each other and with the single computer via a communications network, the application program having application program code including a plurality of code threads all intended to execute on and reference only one computer having a single processing unit or symmetric multiple processing units and only one independent local memory with a local memory capacity that is not shared with any other computer, said method comprising:

(i) scrutinizing said application program at, or prior to, or after loading on said single computer to detect each application program step defining an initialization routine instruction creating or initializing an object utilizing said single computer or one of said plurality of other computers in the application program, wherein for each said different portion of the application program a like plurality of substantially identical objects are created in each single independent local memory of the corresponding computer including in the single independent memory of the single computer and with a local memory capacity that is not shared with or accessible by any other computer of said plurality of computers and each object having a substantially identical name; and

(ii) modifying said initialization routine to generate a corresponding modified initialization routine to ensure consistent operation of all said plurality of computers and forwarding each created object to the remainder of said plurality of computers.

56. A multiple computer system having at least one application program each written to operate on only a single computer but running substantially simultaneously on a plurality of single computers interconnected by a communications network; the system comprising:

a local independent memory structure defined for each of the plurality of single computers configured to provide execution of application program code of the application program including a plurality of code threads that are written with the intent to execute on and reference a single computer having a single processing unit or symmetric multiple processing units and a single independent local memory with a local memory capacity that is not shared with any other single computer of said plurality of single computers;

means for executing different portions of said at least one application program substantially simultaneously on different ones of said computers and for each portion a like plurality of substantially identical objects are created in each independent local memory of the corresponding single computer and each object having a substantially identical name; and

a distribution update means including a distributed run time to distribute to all other said plurality of computers objects created or initialized by said single computer.

57. A method of ensuring consistent initialization of an application program written to operate only on a single computer but different portions of which are to be executed substantially simultaneously each on a different one of a plurality of single computers interconnected via a communications network, the application program having application program code including a plurality of code threads all intended to execute on and reference a single computer having a single processing unit or symmetric multiple processing units and a single independent local memory with a local memory capacity that is not shared with any other single computer of said plurality of single computers, said method comprising the steps of:

(i) scrutinizing said application program at, or prior to, or after loading to detect each application program step defining a object creation or initialization routine instruction creating or initializing an object utilizing one of said computers in the application program, wherein for each said different portion of the application program a like plurality of substantially identical objects being created in each single independent local memory of the corresponding computer with a local memory capacity that is not shared with or accessible by any other single computer of said plurality of single computers and each object having a substantially identical name; and

(ii) modifying said object creation or initialization routine to ensure collective creation or initialization of corresponding objects in all said single computers to ensure consistent object creation and initialization in everyone of said plurality of computers.

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