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(54) **BYTECODE GENERATION FROM UML MODELS**

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(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,495,560 B2 *	7/2013	Dangeville	....	G06F 8/35 715/700
8,578,346 B2 *	11/2013	Chao	....	G06F 8/10 717/132

(Continued)

OTHER PUBLICATIONS

Usmant et al., Automatic Generation of Java Code from UML Diagrams using UJECTOR, Apr. 2009, International Journal of Software Engineering and its Applications vol. 3, No. 2 (Year: 2009).*

(Continued)

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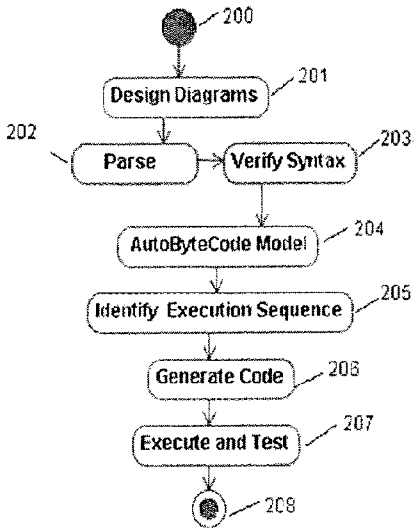
(57) **ABSTRACT**

Unified Modeling Language is a general purpose modelling language used in the field of software development to easily visualize the systems by specifying the static and dynamic aspects of the system. The conventional way of implementing design models is by writing programs in high level languages like java by a programmer. Our method automatically generates platform independent executable code in the form of bytecode without a programmer and it can be executed on any platform. The design models comprising of class and activity diagrams after parsing and syntax verification are converted to an autobytecode model. The autobytecode model is further processed to determine the execution sequence comprising of loops, sequential and conditional statements. The execution sequence, the actions and attributes associated with the nodes in the execution sequence are analyzed to automatically generate complete bytecode directly from the autobytecode model created from design models.

11 Claims, 6 Drawing Sheets



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USPC 717/104
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,311,434	B1 *	4/2016	Berg	G06F 30/367
2003/0182292	A1 *	9/2003	Leong	G06F 9/4493
2004/0060037	A1 *	3/2004	Damm	G06F 3/04883 717/104
2007/0094542	A1 *	4/2007	Bartucca	G06F 11/3672 714/38.1
2011/0179007	A1 *	7/2011	Shi	G06F 16/958 707/706
2014/0269422	A1 *	9/2014	Filsfils	H04L 41/12 370/254

OTHER PUBLICATIONS

Usman, Muhammad et al: “Automatic Generation of Java Code from UML Diagrams using UJECTOR” International Journal of Software Engineering and Its Applications vol. 3, No. 2, Apr. 2009.

Jim, Sabrina L. “From UML diagrams to behavioural source code”, Sep. 7, 2006.

International Search Report and Written Opinion dated Apr. 12, 2016 for related PCT App. No. PCT/IN2015/000389.

* cited by examiner

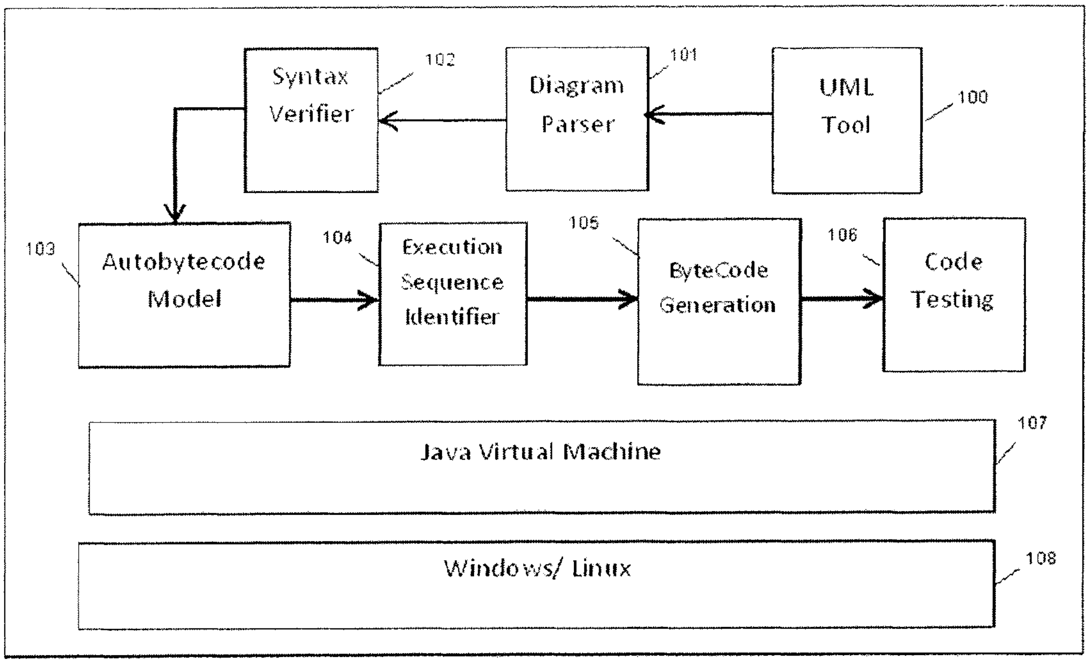

Fig. 1

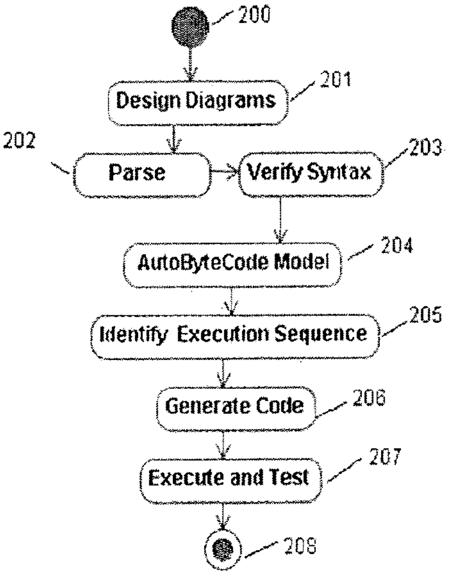

Fig. 2

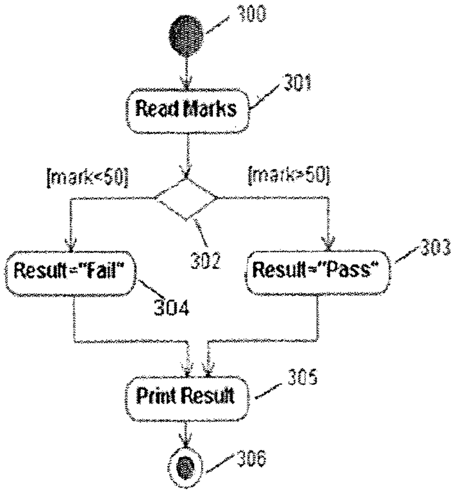

Fig. 3

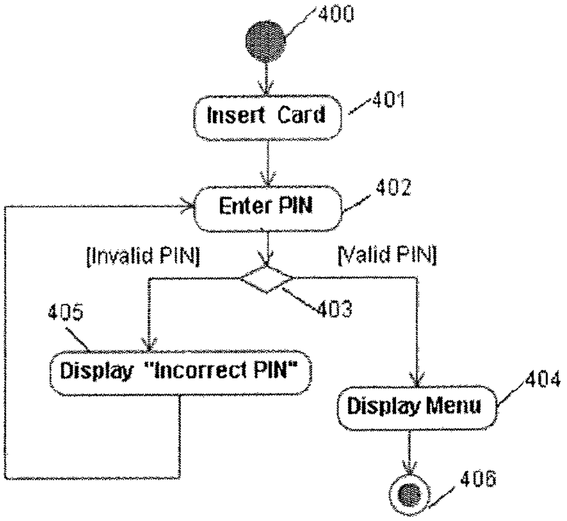
400
Insert Card
401
Enter PIN
402
[Invalid PIN]
[Valid PIN]
403
405
Display "Incorrect PIN"
Display Menu
404
406

Fig. 4

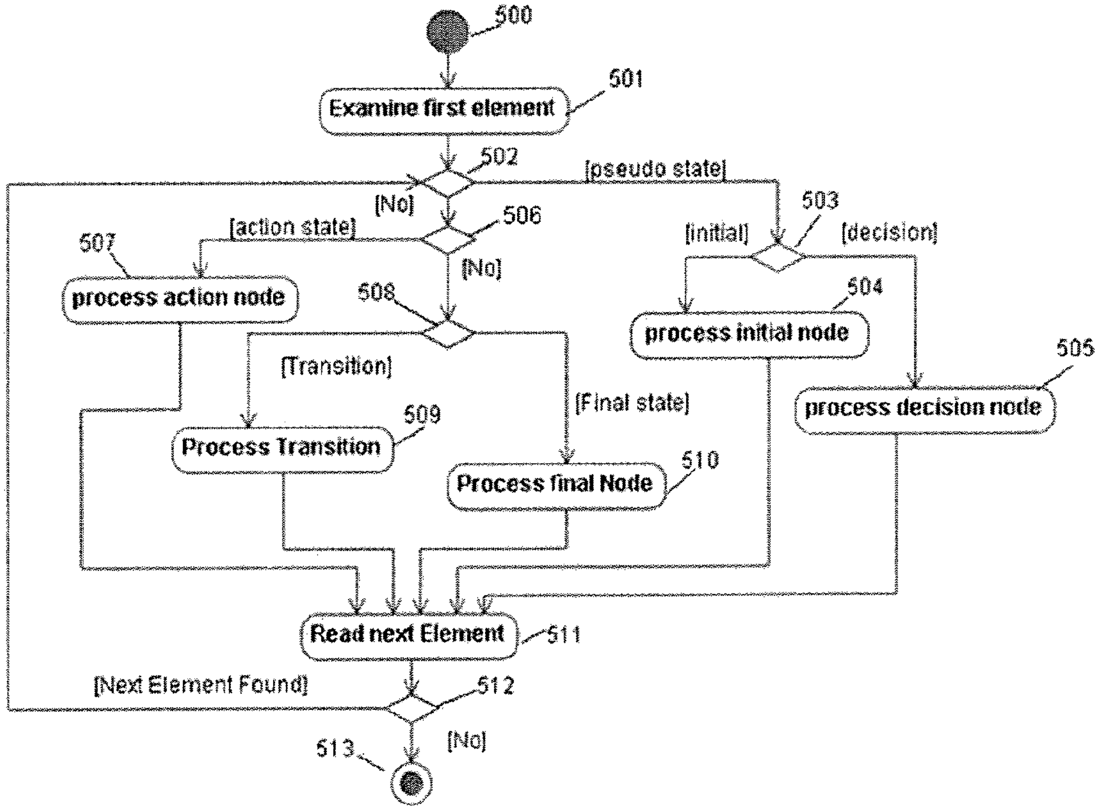
500
Examine first element
501
502
[pseudo state]
[No]
506
[action state]
503
[initial]
[decision]
507
process action node
[No]
508
504
process initial node
505
[Transition]
process decision node
[Final state]
509
Process Transition
Process final Node
510
Read next Element
511
[Next Element Found]
512
513
[No]

Fig. 5

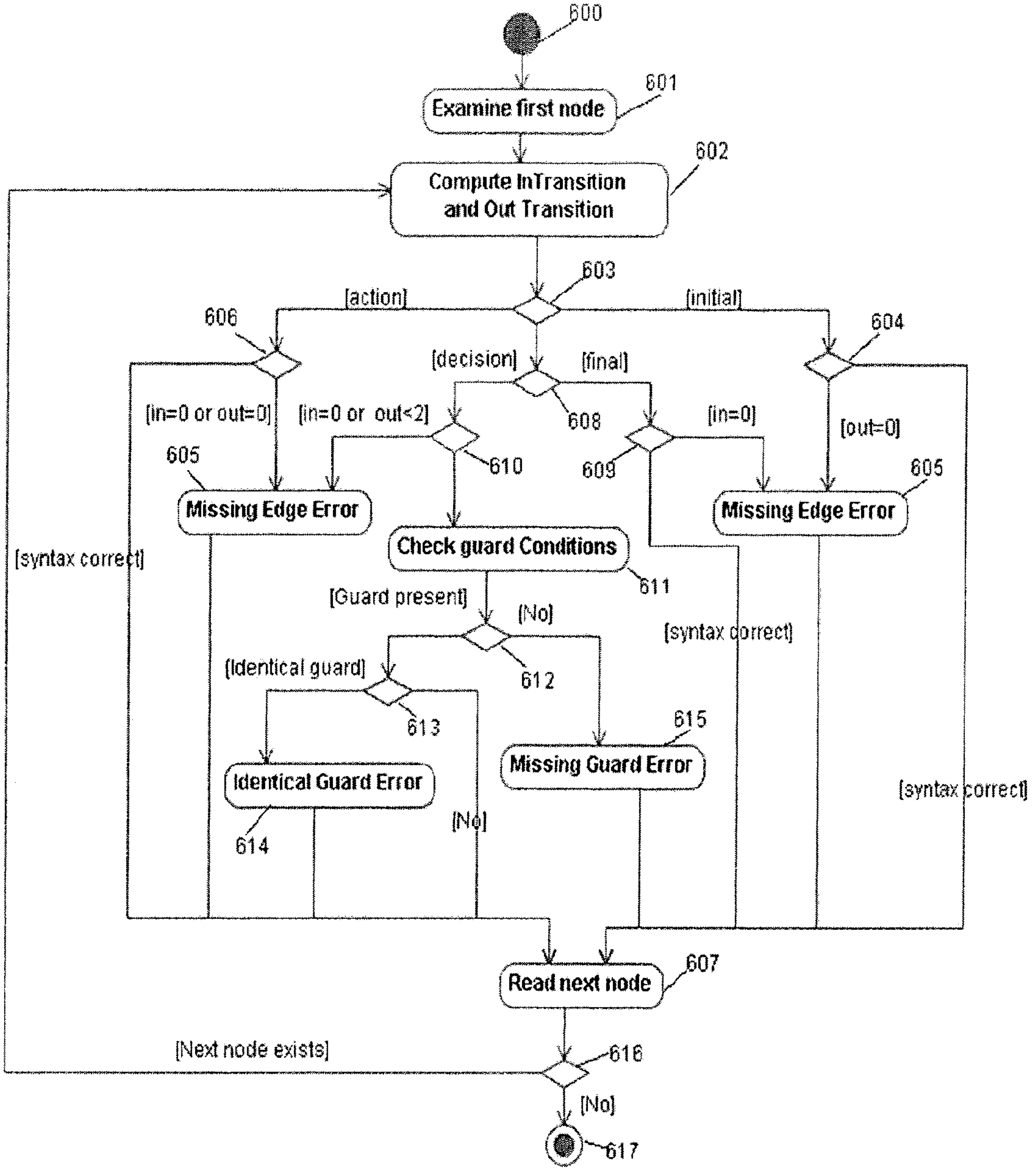
600
Examine first node
601
Compute InTransition and Out Transition
602
603
[action]
[initial]
606
604
[decision]
[final]
[in=0 or out=0]
[in=0 or out<2]
608
[in=0]
[out=0]
605
610
609
605
Missing Edge Error
Missing Edge Error
Check guard Conditions
[syntax correct]
611
[Guard present]
[No]
[syntax correct]
[Identical guard]
612
613
615
Missing Guard Error
Identical Guard Error
[syntax correct]
[No]
614
Read next node
607
[Next node exists]
616
[No]
617

Fig. 6

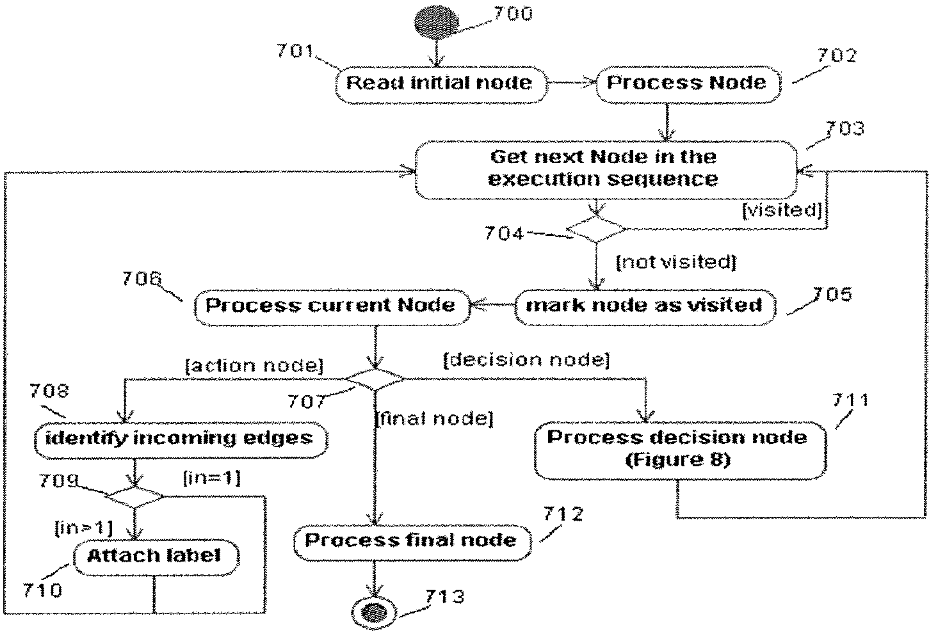
700
701
Read initial node
Process Node
702
703
Get next Node in the execution sequence
[visited]
704
[not visited]
706
Process current Node
mark node as visited
705
[action node]
[decision node]
708
707
[final node]
711
identify incoming edges
Process decision node (Figure 8)
709
[in=1]
[in>1]
Attach label
712
Process final node
710
713

Fig. 7

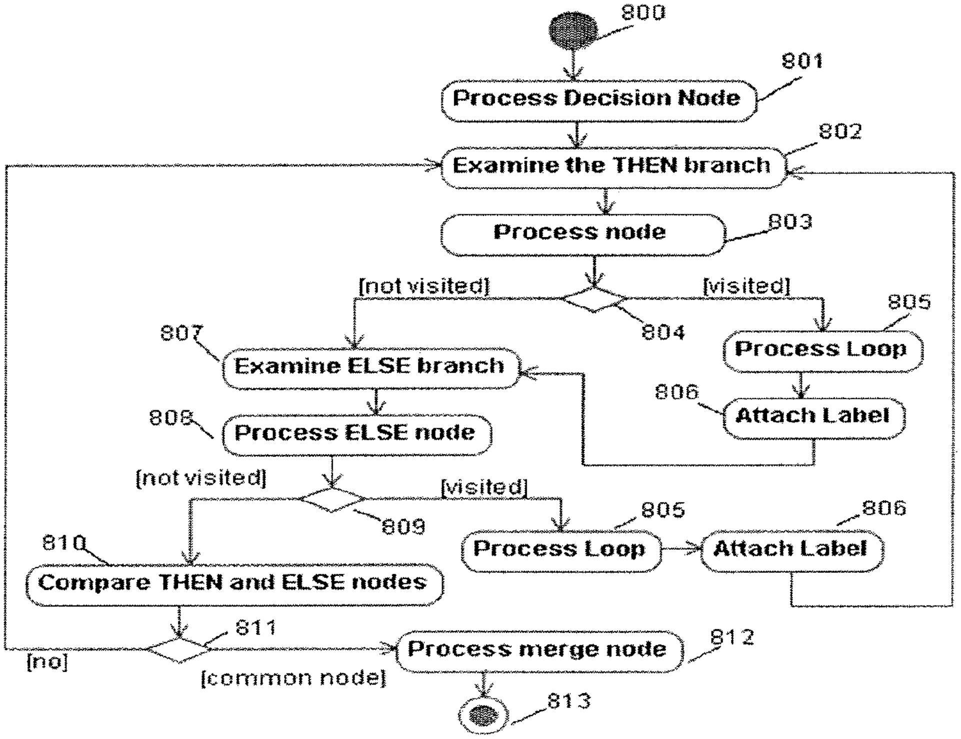
800
801
Process Decision Node
802
Examine the THEN branch
Process node
803
[not visited]
[visited]
805
804
807
Process Loop
Examine ELSE branch
806
Attach Label
808
Process ELSE node
[not visited]
[visited]
805
806
809
810
Process Loop
Attach Label
Compare THEN and ELSE nodes
811
812
[no]
Process merge node
[common node]
813

Fig. 8

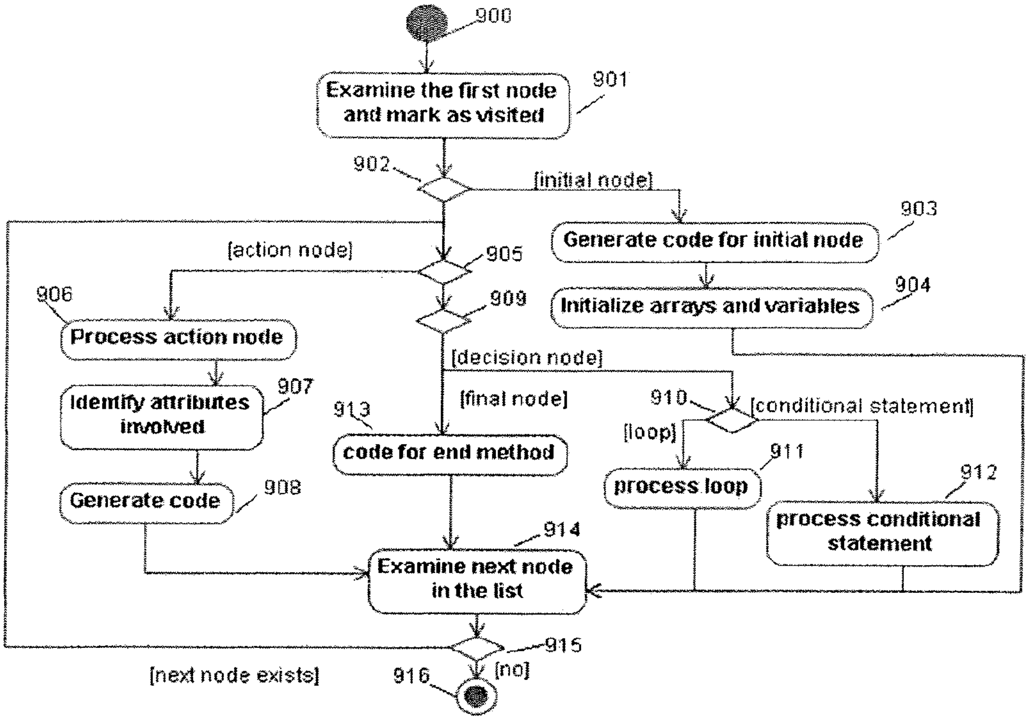
900
Examine the first node and mark as visited
901
902
[initial node]
903
Generate code for initial node
904
Initialize arrays and variables
[action node]
905
909
906
Process action node
Identify attributes involved
907
Generate code
908
[decision node]
[final node]
913
code for end method
910
[conditional statement]
[loop]
process loop
911
912
process conditional statement
914
Examine next node in the list
915
[next node exists]
916
[no]

Fig. 9

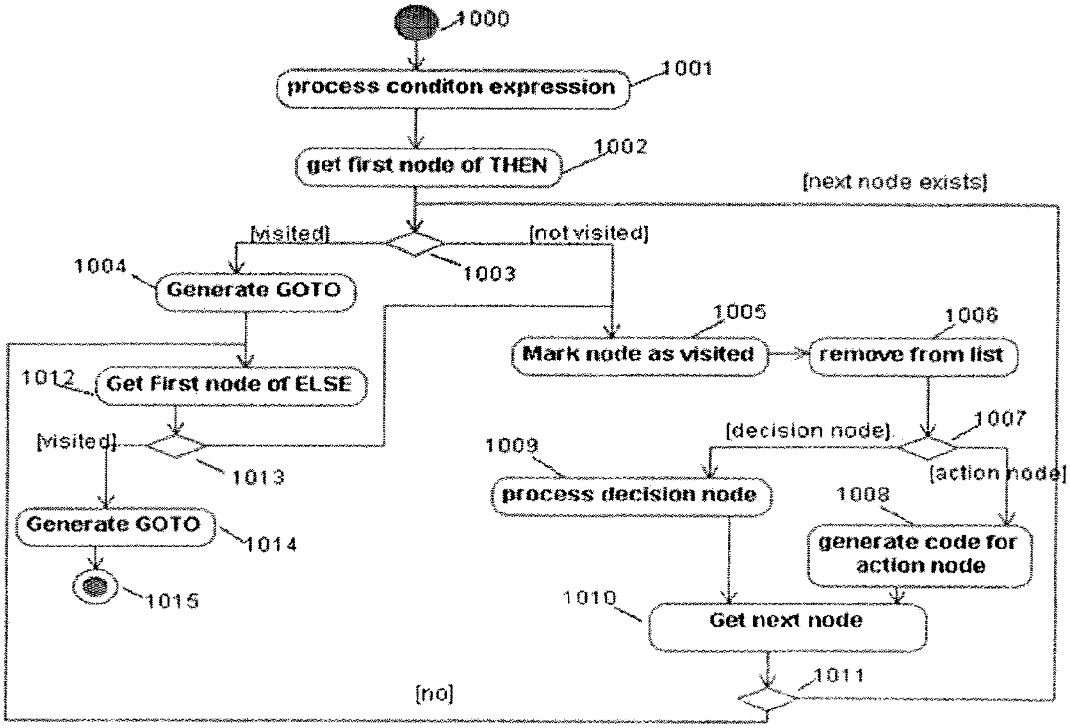
1000
process conditon expression
1001
get first node of THEN
1002
[next node exists]
[visited]
[not visited]
1003
1004
Generate GOTO
1005
Mark node as visited
1006
remove from list
1012
Get First node of ELSE
[visited]
1013
1007
[decision node]
[action node]
1009
process decision node
1008
generate code for action node
Generate GOTO
1014
1015
1010
Get next node
1011
[no]

Fig. 10

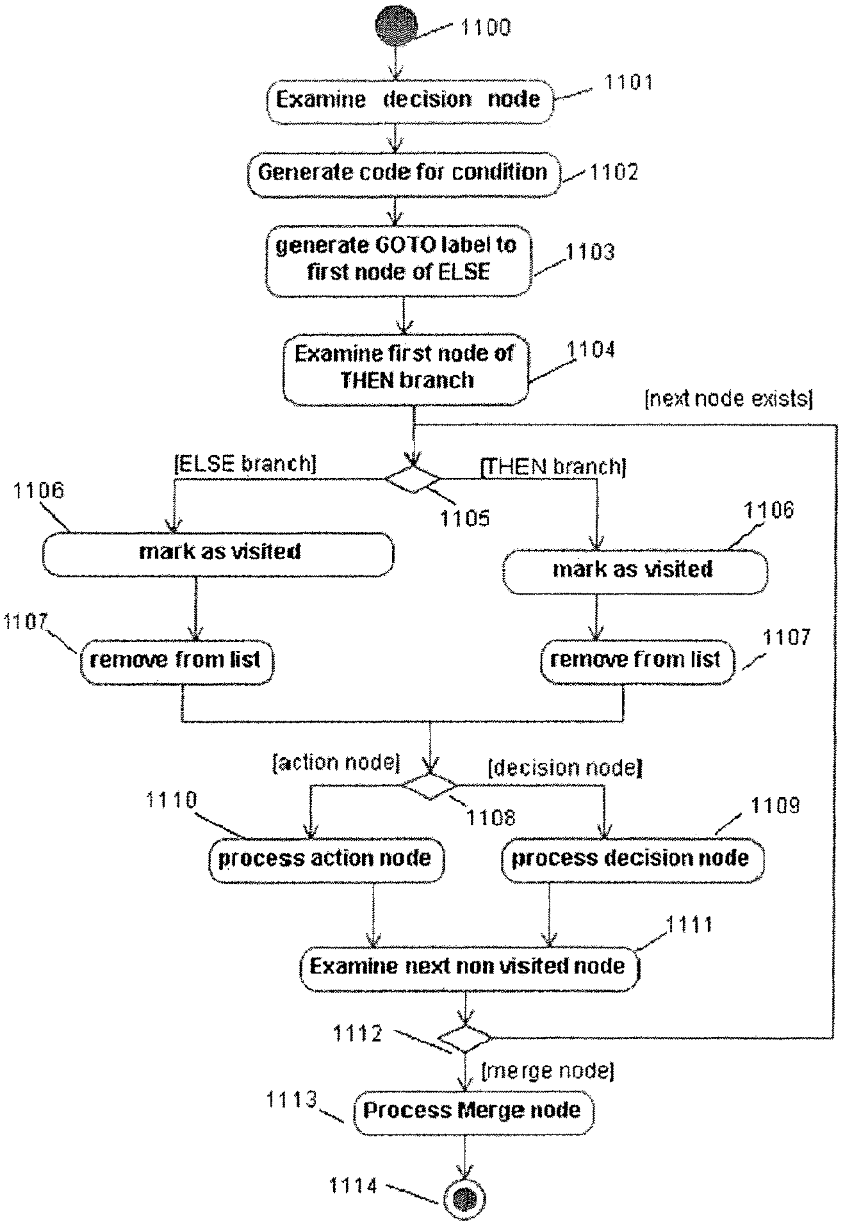
1100
Examine decision node
1101
Generate code for condition
1102
generate GOTO label to first node of ELSE
1103
Examine first node of THEN branch
1104
[next node exists]
[ELSE branch]
[THEN branch]
1105
1106
mark as visited
1106
mark as visited
1107
remove from list
1107
remove from list
[action node]
[decision node]
1108
1110
process action node
1109
process decision node
1111
Examine next non visited node
1112
[merge node]
1113
Process Merge node
1114

Fig. 11

BYTECODE GENERATION FROM UML MODELS

TECHNICAL FIELD

Our invention describes the processing of an autobytecode model created from Unified Modeling Language (UML) models to generate bytecode which is executable code facilitating execution of the design models.

BACKGROUND ART

Object oriented models have been accepted today as the de-facto standard for modelling of software systems in industry. To generate computer software for any application, the analyst performs a requirement analysis about the user needs and models the requirements to appropriate design diagrams. A standard language like UML is commonly used for modelling the requirements. UML provides a graphical representation of the system.

UML provides different diagrams for modelling the various aspects of the system. Class diagrams are used to model the static aspects. Class diagrams provide information about the classes that are present, the information about the attributes and methods of each class and how they are related.

Dynamic or behavioural aspects are modelled using activity diagrams, sequence diagrams and statechart diagrams. Activity diagram provides a high level description of the control flow in a program. An activity diagram is a collection of nodes and edges. Nodes represent computation and edges represent flow of control. The node type determines the type of computation. The sequential flow, concurrent flow as well as loops and conditional constructs can be represented by the activity diagram. The steps in the implementation of methods in class diagrams can be represented using activity diagram. There is a one to one mapping between a method in the class diagram and an activity diagram. To ensure software quality, a syntax verification process is performed on the components of the diagram. The syntax verifier verifies the components of the diagram against their syntactic specification to ensure syntactic correctness thereby ensuring software quality.

The syntactically correct diagrams are converted to an autobytecode model and the autobytecode model is analyzed to detect the control flow in the diagram thereby identifying the execution sequence. The bytecode generation is based on a mapping from the autobytecode model to executable bytecode based on the execution sequence. Automating the process of bytecode generation helps to maintain consistency between the models and code generated.

DISCLOSURE OF INVENTION

We have invented a method to generate executable bytecode from an autobytecode model. In conventional methods, a human being or programmer has to write a computer program based on the design model and this program is converted into bytecode using a compiler like java compiler. The conventional way of writing computer program in a high level programming language like Java is not needed in our invention, as we generate executable in the form of bytecode automatically from the design model. Our method consists of a computer program and a system that consists of a processor, data storage (volatile and non-volatile memory), input device and output device. The computer system should have a UML tool and a Java Virtual Machine (JVM) and it should have either Windows or Linux as the operating system. Our claim includes a method that allows for automatic generation of efficient and accurate executable bytecode from an autobytecode model comprising of the specifications of the class and activity diagrams.

The method according to the embodiment of disclosure generates executable bytecode from the autobytecode model without writing a computer program.

The method according to the embodiment of disclosure automates the process of bytecode generation which helps to bypass the role of programmer as well the process of code generation.

The method according to the embodiment of disclosure performs syntax check on the components of the diagram.

The method according to the embodiment of disclosure identifies the sequential flow of execution.

The method according to the embodiment of disclosure identifies loops and conditional construct such as if-then-else.

The method according to the embodiment of disclosure maintains consistency between the models and code generated.

The method according to the embodiment of disclosure executes the design models directly on any platform.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows the development frame work for converting an autobytecode model generated from syntactically correct UML class and activity diagrams to bytecode according to the embodiments of the invention.

FIG. **2** shows an activity diagram for converting autobytecode model to bytecode and executing the bytecode to generate the required result.

FIG. **3** shows an example activity diagram illustrating an if-then-else conditional construct.

FIG. **4** shows an example activity diagram illustrating a loop.

FIG. **5** shows an activity diagram for parsing the activity diagram to identify the components of the diagram.

FIG. **6** shows an activity diagram for performing syntax check on the components of the diagram according to the embodiments of the invention.

FIG. **7** shows an activity diagram for identifying the execution sequence according to the embodiments of the invention.

FIG. **8** shows an activity diagram for processing the decision node to identify loops and conditional constructs according to the embodiments of the invention.

FIG. **9** shows an activity diagram for performing bytecode generation by examining the control flow and nodes involved according to the embodiments of the invention.

FIG. **10** shows an activity diagram describing the steps to generate executable bytecode for a loop structure according to the embodiments of the invention.

FIG. **11** shows an activity diagram describing the steps to generate executable bytecode for a conditional construct according to the embodiments of the invention.

BEST MODE OF IMPLEMENTATION

FIG. **1** shows the development framework for generating executable bytecode from UML models. The system includes UML tool, UML diagram parser, syntax verifier, autobytecode model, execution sequence identifier, bytecode generation unit and bytecode testing unit.

The analyst collects the requirements from the user and the system designer translates the requirements to class diagram and activity diagrams using a UML tool in **100**. Any UML tool can be used to create the models and any application can be designed using UML diagrams.

The diagram parser in **101** parses the models and produces a specification of the diagram. The specification includes all the required information about class diagrams such as attributes and methods of the class. The specification also includes information about the nodes and transitions in the activity diagram.

The system further includes a syntax verifier module. The syntax verifier in **102** validates each component of the diagram against their syntactic specification and reports errors if any. An autobytecode model comprising of class and activity diagram specification is generated in **103**. The execution sequence identifier module in **104** traverses the diagram and identifies sequential flow, loops and conditional constructs.

The bytecode generation module in **105** generates executable bytecode using the information provided by autobytecode model. The function of the code test unit in **106** is to test the generated executable bytecode against the requirements provided by the user. The java virtual machine in **107** executes the bytecode to produce result. The operating system in **108** can be either Windows or Linux.

FIG. **2** represents a high level activity diagram for converting the autobytecode model to executable bytecode according to the embodiments of the invention. The class and activity diagrams are processed in various stages. Step **200** corresponds to the initial node which indicates the beginning of control flow. In step **201**, the class diagrams depicting the static structure and activity diagrams depicting the dynamic behaviour are designed using a UML tool in accordance with the requirement specification.

In step **202**, the design diagrams are parsed to obtain a specification of the diagram. The parser identifies the various syntactic elements that constitute the diagram. The attributes and their data types, methods, its parameters and return type are identified. The different components of the activity diagram such as initial node, final node, action states, decision nodes, edges and guard conditions are extracted. The information pertaining to the components of the diagram are stored in the corresponding data structures to generate the autobytecode model.

The specification obtained in step **202** is used by the syntax verifier in step **203** to verify syntactic correctness. Each component of the diagram should conform to its syntactic specification. The syntax verifier operates on the specification of the diagram by analyzing each component and reports the errors found in a separate data structure called the error table.

After system design, parsing and syntax verification, the syntactically correct specification of the models are converted to an autobytecode model in step **204**. The execution sequence is determined in step **205** from the autobytecode model. The execution sequence may be sequential involving a set of action nodes or it may be a loop or conditional statement involving a decision node and a set of action nodes. A decision node usually represents a Boolean expression. The control flow divides into two or more branches at the decision node. A conditional statement is an if-then-else statement and it starts with a decision node where the control forks into two or more branches. Each branch has action nodes specifying the activities performed in the branch. All the branches finally merge at an action node. The conditional statement consists of the decision node and the action nodes along the branches and the action node where all the branches converge.

FIG. **3** depicts the activity diagram for a conditional statement. The activity diagram reads the marks of a student, compares the marks with **50**, computes the result as either pass or fail based on the comparison and prints the result. The initial node is represented in step **300**. The action node in step **301** reads the marks of a student. The decision node in step **302** validates the marks. If the mark is greater than 50, control flows to step **303**, else control flows to step **304**. In step **303**, the result of the student is entered as "Pass" since his mark is greater than 50. In step **304**, the student result is entered as "Fail" since the marks scored by him are less than 50. After processing of marks in either step **303** or **304**, control flows to an action node **305** where both the Then and Else branches merge. In step **305** the action node prints the result as either Pass or Fail and control flows to the final node in step **306**.

A loop consists of a decision node and a set of action nodes representing the body of the loop. One of the branches of the loop terminates at a previously visited node. Loops and conditional constructs are identified on encountering a decision node.

FIG. **4** depicts the activity diagram for validating PIN in an ATM system. The ATM system contains a simple loop. Control flow begins from the initial node **400**. The ATM card is inserted in step **401** and the PIN is entered in step **402**, The decision node in step **403** validates PIN. There are two outcomes: valid PIN or invalid PIN. If the PIN is valid control flows to step **404** which displays the menu for proceeding with the transaction and finally to the final node in step **406**. In case of invalid PIN control flows to step **405** which displays the message "Incorrect PIN" and to the previously visited action node **402** which prompts the user to re-enter the PIN. This path forms a loop. The loop involves the action node **402**, the decision node **403** and the action node **405**.

Corning back to FIG. **2**, step **206** generates executable bytecode from the autobytecode model. Bytecode generation procedure starts from the initial node and terminates at the final node. Control flow analysis is performed on the autobytecode model for executable code generation. The execution sequence obtained in step **205** determines the order in which the nodes are processed and bytecode instructions are generated. The action nodes and decision nodes are processed and mapped to the corresponding bytecode instructions during executable bytecode generation. Step **207** corresponds to the execution and testing of executable bytecode generated. The execution process consists of compiling the bytecode generated and executing. Testing is performed to ensure accuracy of bytecode generated thereby ensuring software quality. Step **208** corresponds to the final node where all computations terminate.

FIG. **5** represents the diagram for parsing the UML activity diagram. The activity diagram is a collection of initial node, final node, action nodes, decision nodes, branches, guard conditions and transitions. The aim of parsing is to extract each component of the diagram and store in the corresponding data structures in memory. Syntax checking is performed on the diagram components. Control flow begins from the initial node in step **500**. In step **501**, the first element is examined. The decision nodes in steps **502**, **506** and **508** analyzes the type of the element. The element can be a pseudo state, action state, final state or a transition. Step **502** examines the current element and checks whether it corresponds to a pseudo state. If the current element is a pseudo state control flows to step **503**, else control flows to step **506**. A pseudo state can represent either a decision node or an initial node. In step **503**, if the current element is a decision node, control flows to step **505** where the decision node is processed. If the current element is an initial node, control flows to step **504**. The name, id and type of node is obtained in step **505** and stored in memory for use in later stages of executable code generation. The information about the branches from the decision node and guard conditions on the branches are also stored in memory. In step **504**, the initial node is processed and stored in memory.

The decision node in step **506** checks whether the current element is an action state. If it is an action state, control flows to step **507**, else control flows to step **508**. In step **507**, the action node details such as node name and id are obtained and stored in a separate data structure in memory for use during the later stages of executable code generation.

Step **508** corresponds to identifying the current element, if it is a transition control flows to else if it is a final node control flows to **510**. In step **509**, the specifications of the transitions such as source, target, guard conditions, transition id are obtained and stored in a separate data structure in memory. The information pertaining to the transitions are used to identify the execution sequence as well as during executable code generation. In step **510**, the id of the final node is obtained and stored in a separate data structure. Step **511** corresponds to reading the next element. After performing the processing of steps **504**, **505**, **507**, **509**, **510** control flows to step **511**. Step **512** is a decision node that checks whether next element exists. If there are unprocessed elements, control flows to the decision node in **502**, else control flow terminates in step **513**. Steps **502** to **512** forms a loop that reads elements, identifies the type of element, processes them and stores information of the nodes in separate data structures in memory. After processing of the diagram, components of the diagram and information pertaining to each component are available in separate data structures stored in memory.

FIG. **6** depicts the activity diagram for syntax verification process. During design phase, errors can occur. A situation in which there are no incoming edges to any node except initial node or no outgoing edge from any node except final node leads to missing edge error. Missing edges result in a break in control flow. Identical or missing guard conditions associated with the branches and guard conditions can also lead to error during executable bytecode generation.

Control flow begins from node **600**. In step **601**, the first element which is usually the initial node is examined. For each node, compute the number of transitions with current node as the source (outgoing transitions) and the number of transitions with current node as the target (incoming transitions). Step **602** performs this computation. The data structure storing information about transitions computed in step **509** is accessed for performing the computation. Steps **602** to **616** are executed in a loop until all the nodes are examined. The decision node in step **603** determines the node type. If the current node is an action node step **606** is executed, if it is an initial node, step **604** is executed else control flows to the decision node in step **608**.

In step **604**, the syntax of initial node is verified. The syntactic specification is that an initial node should have an outgoing edge. If this condition is violated, missing edge error is reported in step **605**. If the syntax is correct, control flows to step **607**. In step **606**, the syntax of the action node is checked. An action node occurs in between an initial node and final node, hence it should have incoming and outgoing edges. In situations where the branches of decision node merge or in situations where the action node is the target of a loop statement, an action node can have more than one incoming edge. Action node is used to specify computations, so it must have an outgoing edge. The decision node in step **606** checks whether the number of incoming transitions is equal to zero or the number of outgoing transitions is equal to zero. If the Boolean expression evaluates to true, the error missing edge is reported in step **605**, else control flows to step **607**. After storing error in a separate data structure in memory in step **605**, control flows to step **607** to read the next node.

Step **608** checks whether the current node is a final node or a decision node. If the decision check in step **608** determines that the current node is a decision node, control flows to step **610** else control flows to step **609**. A final node is the last node in the diagram. The final node depicts the end of control flow. Hence it has only incoming edges and no outgoing edge. The decision node in step **609** checks whether there are incoming edges to the final node. If the number of incoming edges is zero, missing edge error is reported in step **605**, else control flows to step **607**.

Steps **610** to **615** correspond to the syntax checking of the decision node. Step **610** analyzes the count of incoming and outgoing transitions. A decision node evaluates a Boolean expression and control forks into two or more branches depending on the result of evaluation. So a decision node should have at least one incoming edge and at least two outgoing edges. A violation of these conditions leads to the missing edge error in step **605**. Step **611** analyzes the guard conditions on the branches leaving decision node. To be syntactically correct, all the edges leaving the decision node should be labeled with mutually exclusive guard conditions. Step **612** checks whether guard conditions are present. If guard conditions are not present, missing guard error is reported and stored in the error table in step **615**. If guard conditions are present, step **613** compares the guard conditions. Guard conditions determine which among the alternate paths are to be followed after evaluating the Boolean expression in the decision node. If the guard conditions are found identical in step **613**, the error identical guard condition is stored to error table in step **614**. If the guard conditions are mutually exclusive, control flows to step **607**. The errors identified in steps **605**, **614** and **615** are stored in a separate data structure named error table in memory. The error table contains information about the error type and the node in which the error occurs.

After performing the syntax check on the current node, the next node is read in step **607**. The decision node in step **616** checks whether next node exists. If such a node exists, control branches to step **602**, else the syntax checking process terminates at the final node in step **617**. After performing the syntax check, an autobytecode model is created and is used to determine the execution sequence.

FIG. **7** represents the activity diagram for identification of execution sequence. Activity diagrams represent sequential control flow, loops and conditional statements. To identify the execution sequence, the autobytecode model is analyzed. Separate data structures are maintained for sequential flow, loop and conditional constructs.

Processing starts with step **700**. The initial node of the activity diagram is examined in step **701**. The node is marked as visited and added to data structure for storing information about nodes in the sequential control flow in step **702**. The nodes after examination are added to a data structure and marked as visited. The visited flag serves to identify the nodes that are explored. Identification of the execution sequence starts with the initial node. A depth first search algorithm is performed on the autobytecode model to identify the nodes in the execution sequence. Step **703** identifies the next node in the execution sequence. The sequential execution consists only of action nodes and initial and final node.

The current node determined in step **703** is analyzed in step **704**. If the current node is visited, it is added to the list and no further processing of the node is performed and control flows to step **703**. Steps **703** and **704** constitute a loop to identify the next non visited node. In case of a non-visited node control flows to step **705** from step **704** which marks the node as visited. After attaching the visited label, the node is processed in step **706**. The decision node in step **707** determines the node type and control branches accordingly.

Steps **708** to **710** correspond to the processing of action node. In the case of conditional construct, the action node where the Then and Else branches merge has two incoming edges. In the case of a loop, an action node which is the target of a branch has two incoming edges. In both cases, a label is attached, with the action node. During coding, a branch to the corresponding node can be implemented using a goto statement to the label of the node. Step **708** identifies the incoming edges and the decision node in step **709** checks the number of incoming edges. If the number is greater than one, a label is attached to the node in step **710** and control flows to examining the next node in step **703**. If the count is equal to one control flows to step **703**.

If it is determined in step **707** that the current node is a decision node, control flows to step **711**. Processing of the decision node in step **711** is detailed in FIG. **8**. After processing decision node, the next node in the execution sequence is obtained in step **703**. If step **707** determines that the current node is a final node, processing of final node occurs in step **712**. The final node is added as the last node in the execution sequence in step **712** and control flow ends at the node in step **713**.

FIG. **8** depicts the activity diagram for the processing of decision node to identify loops and conditional statements. Usually decision nodes are associated with conditional constructs such as If-Then-Else or with looping statements. Step **800** represents the initial node and step **801** corresponds to processing of the decision node. The Then and Else branches of a decision node are stored in separate data structures in memory. The guard conditions on edges emanating from the decision node determines the Then and Else branches.

Step **802** examines the Then branch. The nodes in the Then branches are processed in step **803**. A label is associated with the first node of the Then branch and added to the list of nodes associated; with Then branch. The decision node in step **804** checks whether the node is an already visited node. During loop processing, one the branches will lead to an already visited node. If the current node is visited, a loop structure is encountered, and the node is added to the data structure corresponding to the loop and stored in memory for later use in step **805**. To branch to the node during bytecode generation, a loop label is associated with the node in step **806**. After processing of the node in in step **806**, the Else branch is examined in step **807**.

In the decision check of step **804**, if the current node is not visited it is added to the list of nodes corresponding to the conditional construct and the first node in Else is examined in step **807**. The node is processed and added to the list of Else nodes in step **808**. In the case of the first node of Else branch, an else label is attached in step **808**. If the current node is found to be visited in step **809**, control flows to step **805**.

If the current node is an unvisited node, control flows to step **810** which compares the Then and Else lists to identify a common action node where both the Then and Else branches merge. If a common node is encountered in step **811**, a condition label is attached to the node and the action node is added as the last node in the Then and Else lists in step **812**. If both the lists do not have a node in common, control flows from step **811** to step **802** to identify the next node in the Then branch. Identification of loops and conditional statements stops at step **813** after all the nodes in Else and Then branches have been explored.

FIG. **9** represents the activity diagram for generation of executable bytecode. The execution sequence obtained in step **205** after processing of the autobytecode model is stored in separate data structures in memory. The execution sequence and the autobytecode model is input to the bytecode generator. Step **900** corresponds to the initial node. Step **901** examines the first node in the sequential execution sequence list. Each node after examination for bytecode generation is marked as visited. The node type is checked in step **902**. If initial node is encountered, control branches to step **903** else control branches to step **905**.

In step **903**, a bytecode file is created and bytecode for the init method is written to the bytecode file. Every bytecode file contains a code segment for the init method. Step **904** examines the attributes defined in the class diagram and writes bytecode for initializing arrays and attributes. The attributes and their type are obtained from the data structure obtained as a result of parsing the class diagram.

Step **905** checks whether the current node is an action node. If yes, control branches to step **906**, else control flows to step **909**. Step **906** processes the action node. The action node is marked as visited. The action associated with the node, the attributes involved in generating the executable code, and the label associated with the action node are identified in step **907**. After obtaining the information required for generating executable bytecode, the action node is mapped to the corresponding code and written to the bytecode file in step **908**.

Step **909** checks whether the current node is a decision node or final node. In case of decision node, control branches to step **910** and to step **913** in case of final node. Step **910** processes the decision node. A decision node can be involved in a loop or a conditional statement. The conditional statement list and loop statement list obtained as a result of processing the activity diagram of FIG. **8** are used to determine whether the decision node is part of a loop or conditional statement. If the decision node is part of a loop, control branches to process loop in step **911** and to step **912** if the decision node is part of a conditional statement. Executable bytecode generation for the loop and conditional statement is based on the processing of the corresponding lists stored in memory. Bytecode generation of the loop and conditional statements are detailed in FIG. **10** and FIG. **11**. After executable bytecode generation of the loop and conditional statements, control flows to step **914** to examine the next node in the execution sequence.

A final node is the last node in the activity diagram. A bytecode file has the code for init method as well as the code for end method. On encountering a final node which denotes the end of control flow or end of processing, the executable bytecode for end method is written to the file in step **913**. Step **914** examines the next node in the current list. Control flows to step **914** after the processing of action nodes in step **904**, **908**, **911**, **912** and **913**. The decision node in step **915** checks whether next a node exists. If node exists, control flows to step **905** else control flows to the final node in step **916**.

FIG. **10** depicts the activity diagram for generating executable bytecode for the loop. A loop usually has two parts. If the loop condition is satisfied a set of statements will be executed repetitively until the condition becomes false. This branch shall be termed as the Then branch. The statements that will be executed if the condition becomes false shall be termed as the Else branch. One of the branches of the decision node will always branch to an already visited node.

Loop processing starts with the initial node in step **1000**. In step **1001**, the loop condition is analyzed to generate bytecode for the condition. Loop control variables are identified. A label is associated with the condition check inorder to effect a branch to the first statement of the loop for repeated execution. Bytecode for loop initialization is written to bytecode file. The label- and the loop condition are mapped to the corresponding bytecode. The first node of Then branch is examined in step **1002**. Step **1003** checks whether the first node is already visited. If the node is visited, a loop is identified and a goto statement to the label of the node is written to the file in step **1004**. Bytecode generation for the Then branch is complete and the nodes of the Else branch are examined for executable bytecode generation. The Else branch is examined in step **1012**.

In step **1003**, if the node is an unvisited node, control flows to step **1005**. Any node for which bytecode generation is being performed is marked as visited. Mark the node as visited in step **1005**. Remove from the list of nodes since executable bytecode is generated for the node. This function is performed in step **1006**. Inorder to generate executable bytecode, the node type has to be identified. Step **1007** performs this check. Control branches to step **1008** if the current node is an action node and to step **1009** if the node is a decision node.

Step **1008** generates the executable bytecode for action node as detailed in steps **906** to **908**. Step **1009** processes the decision node to generate executable bytecode. After bytecode generation is performed, the next node is examined in step **1010**. If next node exists in the list (step **1011**), it is examined in step **1003**. If node does not exist, control branches to examining the Else branch. Control flows to step **1012** from steps **1011** and **1004**. Step **1012** examines the first node of Else branch. If the node is an unvisited node, control flows to step **1005**. If the check performed by step **1013** identifies the node as already visited, bytecode generation corresponds to creation of a goto statement to the label of the visited node in step **1014**. Since the node has been visited before, bytecode has been generated for the node and code generation requires only a goto statement to the label of the node. Bytecode generation for the loop is completed in step **1015**.

FIG. **1100** represents the activity diagram for the executable bytecode generation of a conditional expression. A conditional expression is an If-Then-Else construct. The decision node evaluates a conditional expression. If the condition evaluates to true, the Then branch is followed. If the condition evaluates to false, the Else branch is followed. The branches finally merge at a common node which is an action node.

Processing starts with the initial node in step **1100**. Step **1101** examines the decision node. The conditional expression is identified, the attributes involved in the expression and the labels of Then and Else branches are also identified. Step **1102** generates the executable bytecode for the conditional expression. A goto statement to the label of the first node in the list of Else nodes is also associated with the executable bytecode for conditional expression in step **1103**.

Step **1104** examines the first node of the Then branch. Steps **1105** to **1112** are executed repetitively until no more nodes are to be examined. The executable bytecode generation steps are the same for Else branch and Then branch. The nodes of the Then branch are examined first and later the nodes of the Else branch are examined. Executable bytecode generation process ends with the process of bytecode generation of the action node where the Then and Else branches merge in step **1113** and the final node in step **1114**.

Step **1105** examines whether the current node belongs to the Then branch or Else branch. Control flows to step **1106** if it belongs to either the Then branch or Else branch. In step **1106**, the node is marked as visited and removed from the list of nodes in step **1107**. The nodes for which executable bytecode is generated is labeled as visited. After bytecode generation, the list for the conditional statements shall be empty.

The type of node is checked by the decision node in step **1108**. If the node is a decision node, control flows to step **1109**. If the node is an action node, control flows to step **1110**. In step **1109**, the decision node is processed and bytecode is generated according to the steps outlined in FIGS. **10** and **11**. In step **1110**, processing of action node is, performed and bytecode generation is based on the steps **906**, **907** and **908** outlined in FIG. **9**.

After processing the node and generating executable bytecode, control flows from steps **1109** and **1110** to step **1111**. The next non visited node in the current list is examined in step **1111**. The list can be either the list associated with the Then branch or Else branch. If a node exists in the decision check of step **1112**, control branches to step **1105** else control branches to step **1113**. Steps **1105** to **1112** are executed repeatedly until the Then and Else lists are exhausted. First the nodes in the Then list is examined followed by the nodes in the Else list. After bytecode generation for the Then list is exhausted, a bytecode statement containing goto to the label of the merge node is written to the bytecode file. The processing of action node is performed in step **1113**. Executable bytecode generation process ends at the final node in step **1114**.

The disclosure provides an efficient method for automatic generation of executable bytecode from an autobytecode model and also verifying the syntactic correctness of the diagram before generating executable bytecode.

With the embodiments disclosed therein, we have verified the syntactic correctness of the activity diagrams thereby eliminating syntax errors that can occur during design stage.

With the embodiments disclosed therein, the autobytecode model generated from syntactically correct diagrams are used to determine the execution sequence that includes sequential flow of control, loops and conditional constructs.

With the embodiments disclosed therein, executable bytecode is generated based on the execution sequence and written to a file.

The method requires several stages. In the first stage, requirements are modelled using a UML tool and a diagram parser extracts the components of the diagram. Syntax verification and autobytecode model generation constitutes the second stage where each component is verified against its syntactic specification and an autobytecode model is generated from the syntactic specification. The execution sequence is determined from the autobytecode model in the third stage. The fourth stage comprises of executable bytecode generation from the execution sequence.

Activity diagrams depict the control flow behavior of the system. Any type of system can be modelled using class and activity diagrams. The disclosure can be applied to any type of activity diagram and it generates bytecode for sequential, looping and conditional constructs.

The invention may be implemented in software. The embodiment of the invention can be implemented as a computer program executing on programmable computers each comprising a processor, a data storage system, at least one input device and at least one output device. Design diagrams are given as input to the program code and output is the executable bytecode resulting in execution of the design model.

The programs for the different modules are implemented preferably in a platform independent high level object oriented programming language. Each such program is stored on a non-volatile memory. The output of the bytecode generation phase is the executable bytecode generated for the design model. The bytecode can be executed on any java virtual machine running on any platform to produce output. The syntactically correct diagrams are converted to an autobytecode model and the automatic translation of autobytecode model to executable bytecode produces accurate and efficient platform independent code that can be executed on any platform having java virtual machine running on top of it.

The invention claimed is:

1. A method of generating an executable bytecode from syntactically correct class and activity diagrams designated as autobytecode model, the method comprising the following steps:

A. automating a bytecode generation process from the autobytecode model, wherein the bytecode generation process avoids generation of Java code:

B. parsing an Unified Modified Language (UML) diagram to identify one or more components of the UML diagram;

C. verifying syntactic correctness of each component of the UML diagram;

D. identifying a sequential flow of execution in the autobytecode model;

E. identifying one or more loops and conditional constructs;

F. generating executable bytecode directly from the autobytecode model created from UML design models;

G. maintaining consistency between the UML model and the generated executable bytecode; and

H. generating platform independent bytecode executable on any computing platform,

wherein step A, further comprises:

examining an execution sequence;

identifying one or more activities represented by one or more action nodes and decision

nodes in the execution sequence; and

identifying one or more attributes involved in the one or more activities and mapping the one or more action nodes and decision nodes to equivalent executable bytecode according to the activities specified in the one or more action nodes and decision nodes without using a programmer and without writing a high level language program.

2. The method according to claim 1, wherein step B. further comprising:

utilizing a diagram parser to parse one or more class and activity diagrams to identify the one or more UML diagram components and producing a specification of the diagram.

3. The method according to claim 2, wherein step C. further comprising:

utilizing a syntax verifier to analyze each component of the UML diagram against their syntactic specification to create the autobytecode model.

4. The method according to claim 3, further comprising:

determining whether each node has a desired number of incoming and outgoing edges and does not lead to a break in control flow.

5. The method according to claim 4, further comprising:

determining whether all branches from a decision node have guard conditions and do not lead to:

i) missing guard conditions thereby causing inconsistency; and

ii) whether the guard conditions are mutually exclusive and do not lead to identical guard

conditions error thereby causing ambiguity and inconsistency.

6. The method according to claim 1, wherein step D. further comprising:

starting with an initial node, identifying a next node in the sequence and determining whether the next node is an action node that forms part of the sequential execution and, if so, adding it to a list of nodes in the sequential flow of execution.

7. The method according to claim 1, wherein step E. further comprising:

examining a decision node;

determining whether one of an outgoing edge from the decision node merges at a previously visited node and, if so, identifying a corresponding loop construct; and

determining whether there is a common node where a “Then and Else” conditional construct branch merges and, if so, determining a corresponding conditional “If-Then-Else” construct.

8. The method according to claim 1, wherein step F. is based on the execution sequence identified from the autobytecode model.

9. The method according to claim 1, wherein step G. further comprising:

automatically determining whether the UML model is syntactically correct and, if so, converting the UML model to an autobytecode model.

10. The method according to claim 9, further comprising: determining the execution sequence and automating the process of bytecode generation directly from the autobytecode model.

11. The method according to claim 1, wherein step H. further comprising:

generating a platform independent bytecode executable on a Java Virtual Machine running on either a Windows platform or a Linux platform.

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