Zeroing in on Metamorphic Computer Viruses

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To Mom and Dad

Zeroing in on Metamorphic Computer Viruses

Moinuddin Mohammed

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1 Introduction

1.1 Motivation

The security of computers is an important concern for any organization that uses computers, which in today's world leaves out very few organizations, if any. A compromise in security of its computer systems can cause severe losses in terms of sensitive information, money, time, and reputation of the organization. The most common and damaging security attacks are done using programs called computer viruses and worms. These are computer programs that can rapidly spread from one machine to another. They spread by exploiting some weakness in the existing programs on a computer, or weakness in the security policy of an organization, or by simply fooling the user into executing the programs. Damages caused by viruses and worms are estimated to be in the billions of dollars. For example, CodeRed II worm is estimated to have caused damages in excess of $2.6 billion [21].

The number of virus and worm attacks is increasing at an alarming rate. The number of known viruses was about 70,000 in 2002, which is 700% more than the number of known viruses in 1997 [6, 16]. This increase can be attributed to the increasing use of the Internet. As the number of machines on the Internet increases, so does the number of target hosts that can be exploited. The most common exploit is to transmit a virus by email. In addition, hackers also exploit the Internet to connect to remote, compromised machines to initiate other attacks. They also use compromised machines to give commands to viruses on other compromised machines. Using compromise machines help a hacker in hiding his/her identity.

Though viruses and worms are very complex computer programs, it is not very difficult to write a virus. Recipes for writing such programs are abundantly available on the Internet. There is no need to write these programs from scratch. The simplest method is to modify an existing virus to generate a new one. One does not need to be a programmer to write a virus, either. There are many virus generation tools available on the Internet [20]. Using these tools, creating a new virus is as easy as selecting its lethality from a menu of options and clicking "Ok."

Current AV technologies use virus signature, a sequence of bytes extracted from a sample of a virus, to detect copies of that virus. Thus, they can detect a virus if the virus signature extracted in the laboratory of the AV Company is found in a program on users' desktops.

It has been observed before that detecting whether a given program is a virus is an *undecidable* problem [3, 23]. A problem is undecidable if a computer (or a network of computers) cannot solve it no matter how fast the computer(s) may be. AV technologies are thus limited by this theoretical result. While they can detect a specific virus that is known *a priori* to the technology, they cannot always detect whether an arbitrary program is a virus.

Virus writers exploit this inherent limitation of AV technologies. If a virus is written such that two instances of the virus do not have the same signature, then the virus can evade detection. This is precisely what metamorphic viruses do. A metamorphic virus can modify its own program as it spreads from one host to another [7, 10-13]. The child virus, the one on the newly infected host, may not have the same sequence of bytes as the parent virus. Hence, the same signature cannot be used for detecting such viruses.

The experiments conducted by Christodorescu et al. [1] suggest that commercial anti-virus software systems fail to detect morphed virus variants, the virus variants obtained by changing the program text without changing the virus behavior. If an anti-virus system were to detect metamorphic viruses using signature-scanning approach, it would need to maintain signatures for all possible variants of the metamorphic viruses. This approach is infeasible as the number of signatures to be maintained is too high, if not infinite. More sound methods need to be developed for detecting metamorphic viruses.

1.2 Research objectives

The aim of our research is to develop methods that will help in detecting morphed variants of a virus created by changing the program text without changing the behavior of the virus.

1.3 Research contributions

In this thesis, we present a strategy for augmenting current AV technologies to detect metamorphic viruses. The key contribution is a sequence of transformations called *zeroing transformations* to nullify the effect of the code modifications performed by a metamorphic virus. *Zeroing transformations* are used to map any program to a *zero form*, a single-unique form for all variants of a program created using modifications applied by known metamorphic viruses. The name "zeroing transformations" is derived from its similarity with the multiplicative property of the number *zero*. Multiplication of any real number with zero always results in zero. Similarly, application of zeroing transformations on a program results in its zero form.

1.4 Impact of the research

The zero form of a virus may be used in the laboratory of an AV company to generate a zero signature. The zero signatures may be distributed to the AV scanners on users' desktops. The scanners can then convert a program to a zero form and then match the zero signatures. Since variants of a metamorphic virus will have the same zero form, this method improves the ability of AV technologies in detecting metamorphic viruses. Moreover, zero signatures reduce the overhead of maintaining a separate signature for every variant of a virus.

1.5 Organization of thesis

Chapter 2 introduces metamorphic viruses and transformations applied on metamorphic viruses. Chapter 3 discusses background. In Chapter 4 we describe our approach for dealing with the metamorphic viruses. We also give the algorithms for creating ZERO form for programs. Chapter 5 discusses related work. Chapter 6 gives the implementation details. In Chapter 7, we discuss the results. Chapter 8 gives the conclusions.

2 Morphing transformations

A computer virus is a program that infects a host program with its malicious code [3]. When executed, the infected host program further spreads the infection to other host programs. Metamorphic viruses are viruses that alter their instructions before spreading to a host. These viruses change their instructions without changing their behavior.

Figure 2-1 gives a diagrammatic representation of the working of a metamorphic virus. The varying shapes in Figure 2-1 suggest different variants of the same virus. The transformations that the virus applies to change its program code (shape) without changing its behavior are called *morphing transformations*.

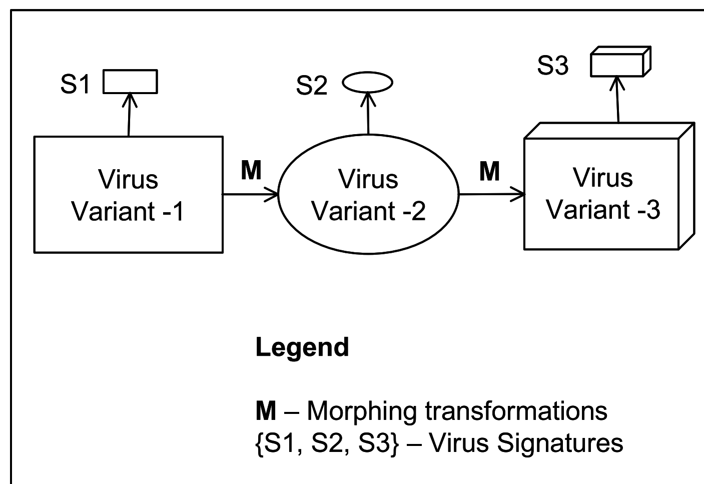


Figure 2-1: Metamorphic viruses

Definition *Variant of a virus*: A variant of a virus V is a virus V' where V, V' have the same behavior but some difference in the code.

Definition *Morphing Transformations*: Morphing transformations are the transformations that, when applied to a virus, yields a variant of that virus. These transformations change the shape of a virus, but do not change its behavior.

Definition *Morpher*: The part of virus program logic responsible for generating different variants of the virus using morphing transformations, is referred to as morpher.

Definition *Metamorphic virus*: A metamorphic virus is a virus that carries a morpher with itself to generate a variant for each infection.

2.1 Morphing transformations

Common morphing transformations used by virus writers are: dead code insertion, variable renaming, statement reordering, expressions reshaping and break & join transformations. This section discusses these transformations.

2.1.1 Dead code insertion

Dead code is the part of a program that is either not executed in the program or has no effect on results of the program. Addition/Removal of such code to/from a program doesn't change its behavior.

Figure 2-2 shows an example of dead code insertion. Adding *nops,* and *add eax, 0* to V1 creates V2, a morphed variant of V1. Similarly, addition of *nops, add exa, 0 and sub ebx, 0* to V2 creates V3. All the three variants, V1, V2 and V3, have same behavior. If AV software uses the sequence of bytes corresponding to the instructions *xor edx, edx* and *div ecx* as the virus signature, the morphed variants V2, and V3 will go undetected as *add eax, 0* is inserted after *xor edx, edx*.

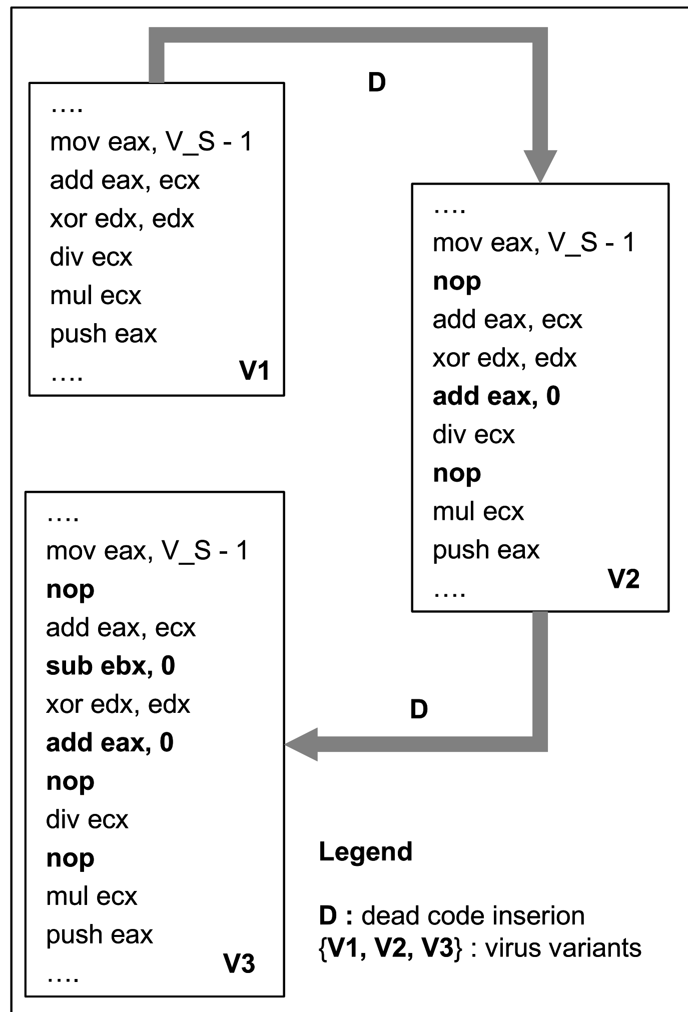


Figure 2-2: Dead code insertion

2.1.2 Variable renaming

Variable renaming transformation changes the names of a variable by changing all the instances of the variable with a new name. Variants created by variable renaming have the same behavior, as this transformation doesn’t change the program behavior.

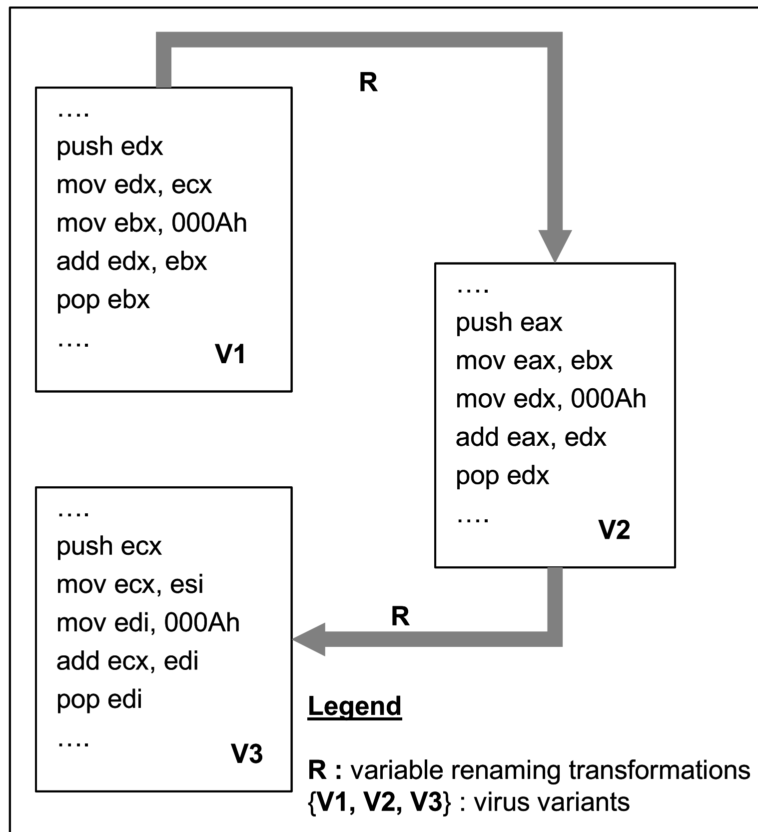


Figure 2-3: Variable renaming

Figure 2-3 shows two examples of variable renaming transformations. The example code segment shown in Figure 2-3 is in IA-32 assembly language. Renaming variables corresponds to renaming registers in assembly language. Instructions in variants V1, V2 and V3 differ in their usage of registers. The register *edx* is renamed to *eax* from

V1 to its morphed variant V2. If the signature for V1 has *edx* in its byte sequence, its morphed variants V2 and V3 will not be detected using that signature.

2.1.3 Break & join transformations

Break & join transformations break a program into pieces, select a random order of these pieces, and use unconditional branch statements to connect these pieces such that the statements are executed in the same sequence as in the original program.

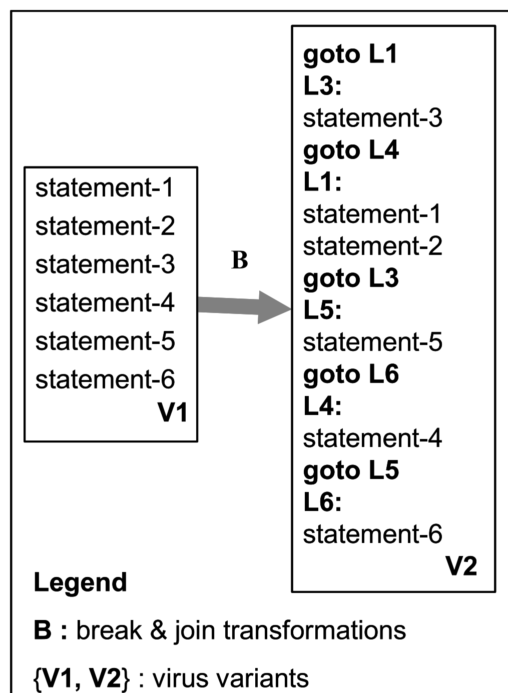


Figure 2-4: Break & join transformations

Figure 2-4 shows an example of break & join transformation. The order of statements in variant V2 is different from the order in which these statements appear in variant V1. Unconditional branch statements (GOTO statements) are used to connect these pieces so that the statements in variants V1 and V2 are executed in the same order.

2.1.4 Expression reshaping

Generating random permutations of operands in expressions with commutative and associative operators reshapes expressions in programs. This changes the structure of expressions. Expression reshaping doesn't change the behavior of the program.

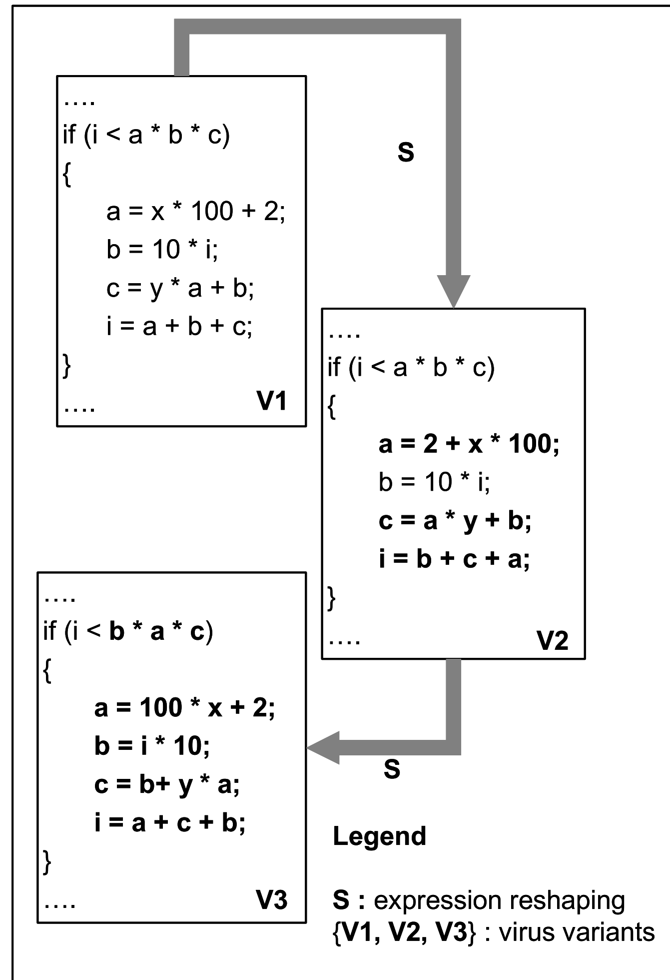


Figure 2-5: Expression reshaping

Figure 2-5 shows an example of expression reshaping transformations. The expression *x*100+2* in variant V1 is reshaped to *2+x*100* in variant V2. Behavior of the

variants V1, V2, and V3 remains the same. If the virus signature of variant V1 includes the expression *x*100+2*, variants V2 and V3 will not be detected by AV software.

2.1.5 Statement reordering

Statement reordering transformation reorders statements in a program such that the behavior of the program doesn't change. It is possible to reorder statements if and only if there are no dependences [9] between the statements being reordered. If the virus signature includes bytes corresponding to a statement from this set of reorderable statements, application of statement reordering transformation makes the original virus signature useless for morphed variants.

Figure 2-6 shows an example of statement reordering transformations. The statements *a=y*i*, *b=200*i,* and *a=x*y+i*z* can be reordered as there are no dependencies between these statements. Selection of random permutations of such reorderable statements creates the morphed variants V2 and V3.

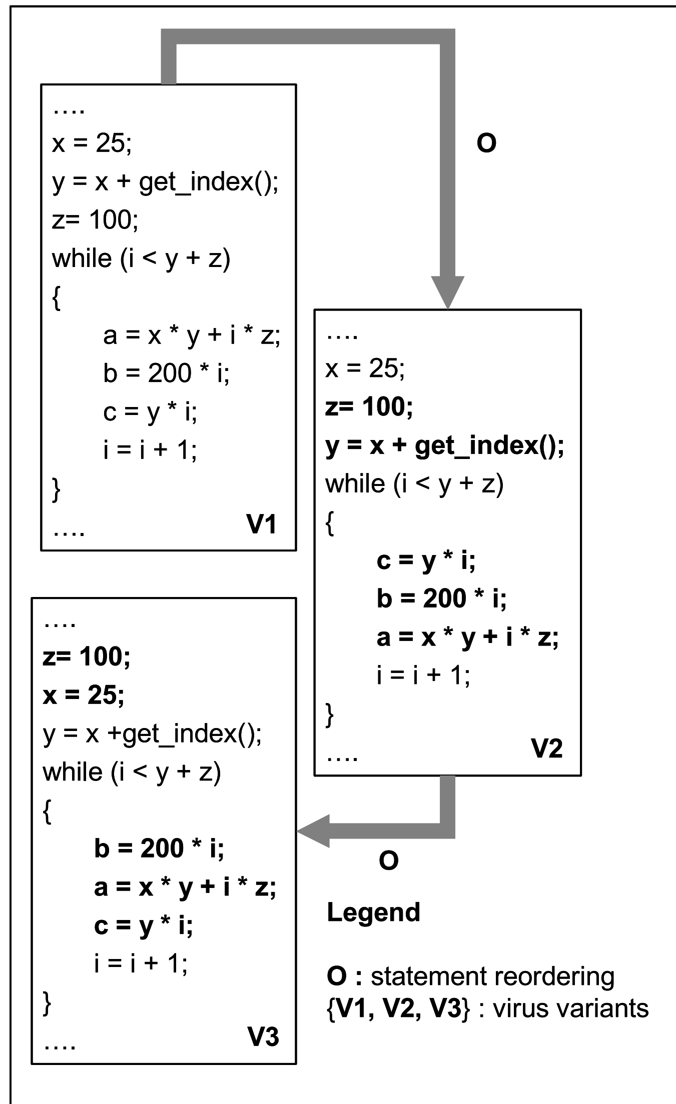


Figure 2-6: Statement reordering

3 Background

This chapter gives the definitions of the terms used and briefly discusses these concepts.

3.1 Control flow graph (CFG)

A control flow graph [2] is a directed graph containing a set of vertices V and a set of edges, E. Each vertex (also classed a node) in the control flow graph represents a sequence of instructions that are executed sequentially (also called *basic block*). Control flow graph edges represent the control flow in the program. A control flow graph has two special nodes called start and end. There is a path from start node to every node in V and a path from every node to the end node. Figure 3-2 shows the control flow graph for the program segment shown in Figure 3-1.

3.2 Dominator

A node *n1* in the control flow graph is said to dominate the node *n2* iff all the paths in the control flow graph from the start node to node *n2* include node *n1* [8]. Figure 3-3 shows the dominator relationships for the blocks of the control flow graph shown in Figure 3-2. In the tree shown in Figure 3-3, the ancestors of a node dominate that node and the parent node of a node immediately dominates that node.

```
min = A [0];
for ( i = 0; i < n; i++)
{
        if (min > A [i])
        {
                min = A [i];
        }
}
```

Figure 3-1: Sample program segment

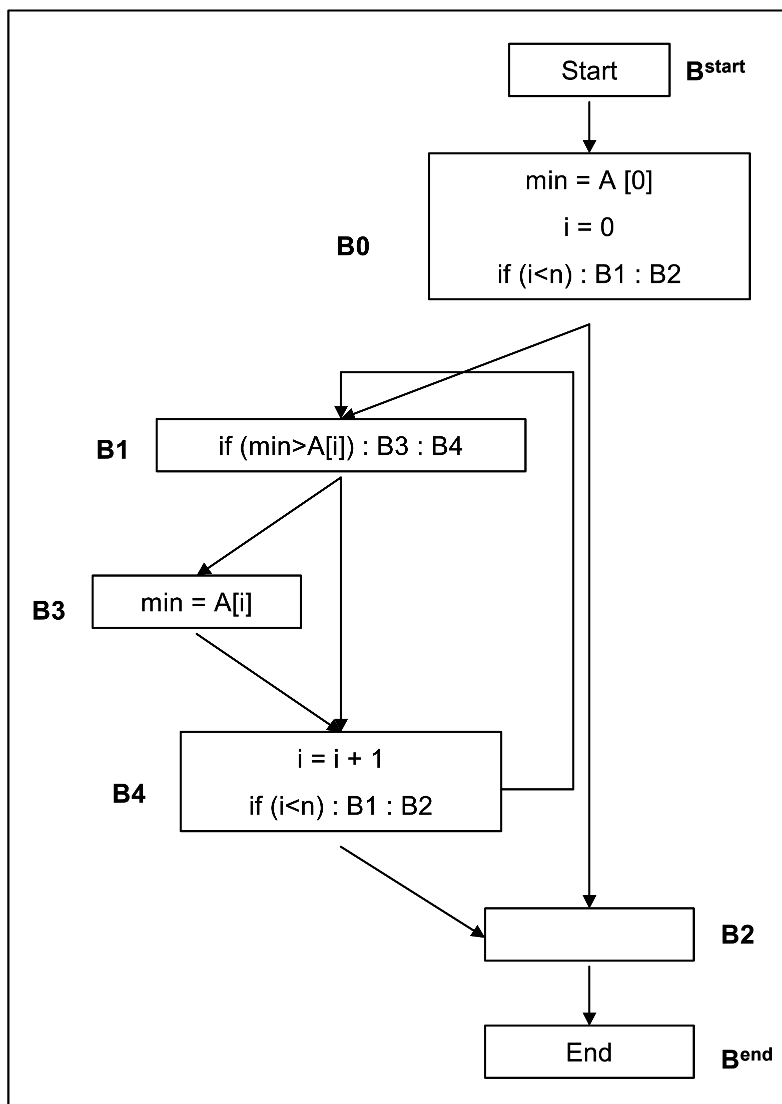


Figure 3-2: Control flow graph for the program segment in Figure 3-1

3.3 Post-Dominator

A node *n1* in the control flow graph is said to post-dominate the node *n2* if and only if all the paths in the control flow graph from node *n2* to the end node include node *n1* [8].

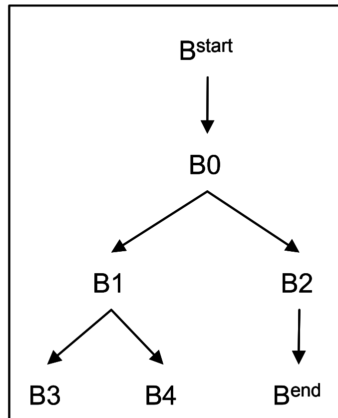


Figure 3-3: Dominator tree for Figure 3-2

Figure 3-4 shows the post-dominator relationships for the blocks of the control flow graph shown in Figure 3-2. In the tree shown in Figure 3-4, the ancestors of a node post-dominate that node, and the parent node of a node immediately post-dominates that node.

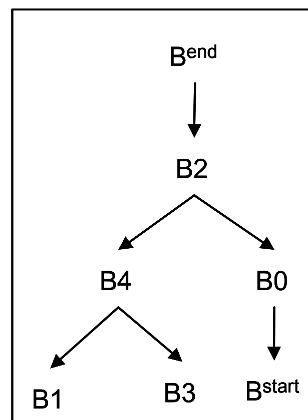


Figure 3-4: Post-Dominator tree for Figure 3-2

3.4 Program dependence graph

Program dependence graph [4] is a directed graph containing a set of vertices and a set of edges. The vertices in a program dependence graph represent the program points and the edges represent the dependencies between the program points. The edges can be of two types – control dependence edges and data dependence edges. Figure 3-6 shows the program dependence graph for the program in Figure 3-5.

A program point p1 is said to be data dependent on the program point p2 if and only if there exists a path from program point p2 to program point p1 in the control flow graph and there exists at least one variable defined at the program point p2 that is used at the program point p1 and the variable is not killed along that path.

The program point p2 is said to be control dependent on the program point p1 if and only if there exists a path in the control flow graph from p1 to p2 and p2 post-dominates all nodes on that path except p1.

```
void  main() {
        int i = 1;
        while (i<100) {
                if(i%2 == 0)
                   printf("%d is even\n", i);
                else
                   printf("%d is odd\n", i);
                i = i + 1;
        }
}
```

Figure 3-5: A sample program

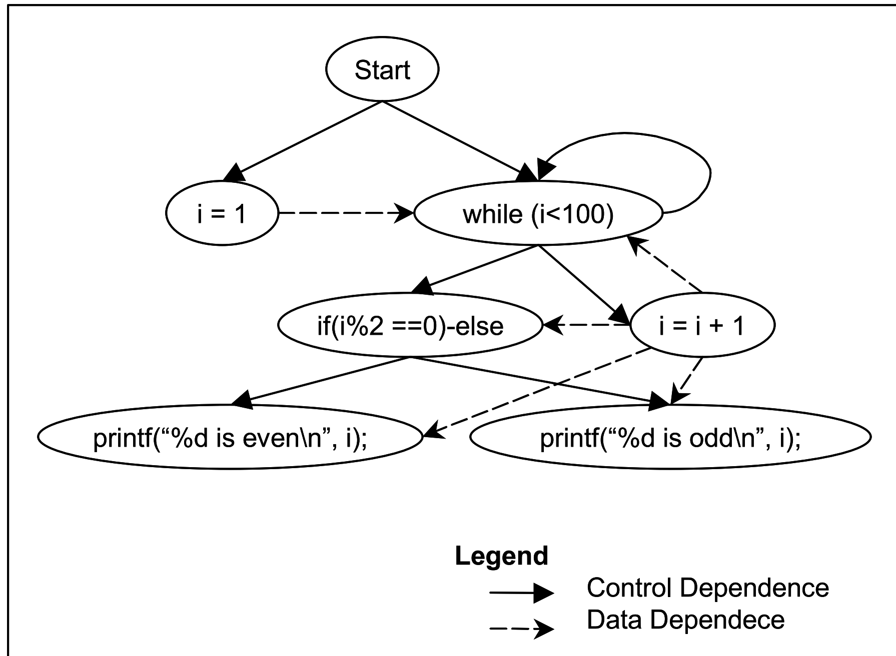


Figure 3-6: Program dependence graph for the program in Figure 3-5

3.5 Data dependence predecessors

Data dependence predecessors of a program point 'p' are program points that have a data dependence edge to p.

3.6 Data dependence successors

Data dependence successors of a program point 'p' are program points that have a data dependence edge from p.

4 Zeroing transformations

We now propose *zeroing transformations*, a set of transformations to nullify the effect of morphing transformations. Zeroing transformations, when applied to a virus, result in its zero form. Application of these transformations on the set of morphed variants of a virus related by morphing transformations result in the same zero form. Figure 4-1 illustrates the idea of applying zeroing transformations to create zero forms of the viruses. V1, V2, and V3 in Figure 4-1 are transformed to $V_\oplus$. AV companies can use this method and store the virus signature extracted from $V_\oplus$ instead of maintaining separate virus signatures for V1, V2 and V3. To use these zero signatures for virus detection, the AV software will need to apply zeroing transformations on the programs to be checked for the existence of virus behavior to get their zero forms. Zero forms of the programs can then be searched for zero signatures of the viruses.

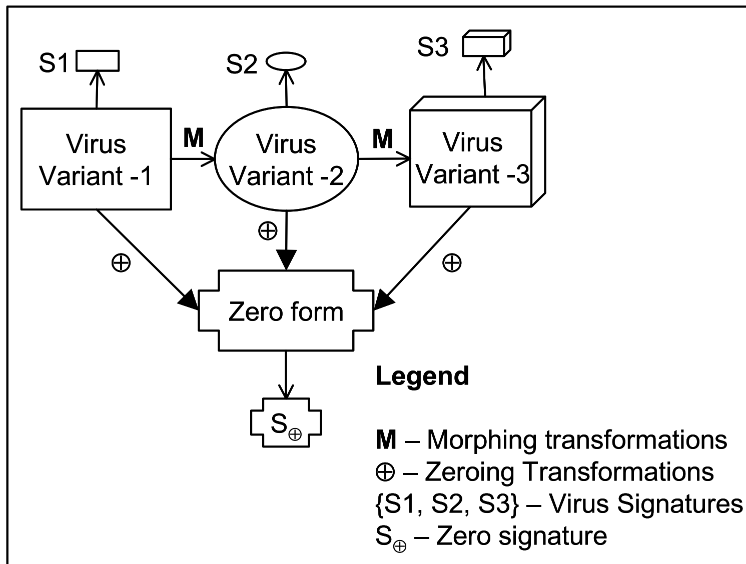


Figure 4-1: Detection approach

Figure 4-2 shows the procedure for creating the zero form of a program. A series of transformations are applied to the input program. These transformations include dead-code elimination [8], constant propagation and removal of redundant computations [8], elimination of spurious unconditional branch statements, reshaping expressions to zero form, fixing an order for the statements that can be reordered and renaming variables to a zero form. This thesis contributes a method for fixing an order for the statements in the program.

For fixing the statement order, we need to find the reorderable statements in the program and impose an ordering on them. To find the reorderable statements, we use a tree representation called program tree. We also create a graph showing the dependence relation between the nodes in the program tree.

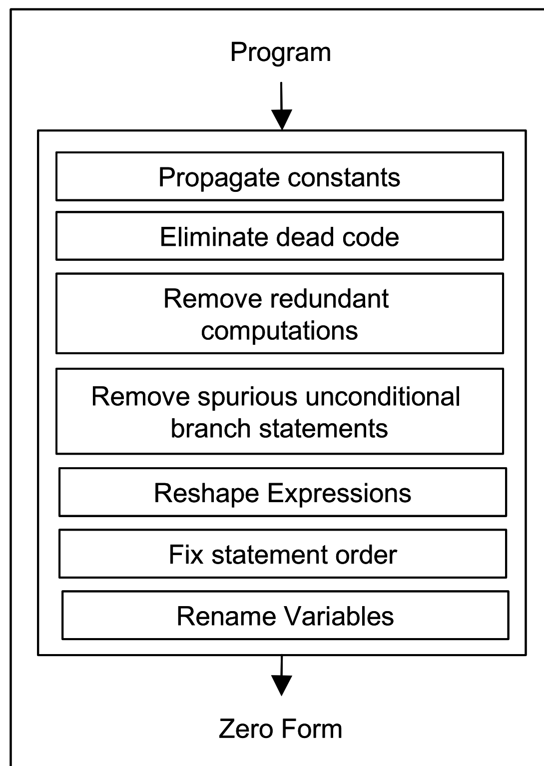


Figure 4-2: Zeroing transformations

4.1 Program Tree (PT) representation

For each procedure/function in a program we create a program tree (PT). The PT representation of the function in Figure 4-3 is shown in Figure 4-4. We use the control dependence sub-graph (CDG) for constructing the PT. Construction of PT for structured programs is straightforward. The nodes in the program tree are the statements of the program. We create an edge in the program tree from a node n_1 to node n_2 if there exists an edge from n_1 to n_2 in the corresponding control dependence subgraph. In order to make the program tree more readable, we show the corresponding program statements for control predicates in the program tree. For example, in Figure 4-4, the control predicate *(A>B)* is shown as *If (A>B)*.

```
A=0
B=3
IF (A>B) then
                    C = A + 1
                    D = A + B + 200
                    E = C + D + 10
FI
F = A + C
G = A + B
```

Figure 4-3: A sample program segment

The node *If (A>B)* in Figure 4-4 has an edge to the nodes *C=A+1*, *D=A+B+200*, *E=C+D+10* because of the control dependence relationship between the node *If (A>B)* and the nodes *C=A+1, D=A+B+200, E=C+D+10*. Some nodes have self-loops in their control dependence sub-graph. An example of a self-loop in the control dependence subgraph is shown in the Figure 4-5. We do not place any edges in the program tree for the control dependence edges involving self-loops in the control dependence subgraph.

We construct a program tree for each procedure of the program. For handling unstructured programs we use a different approach.

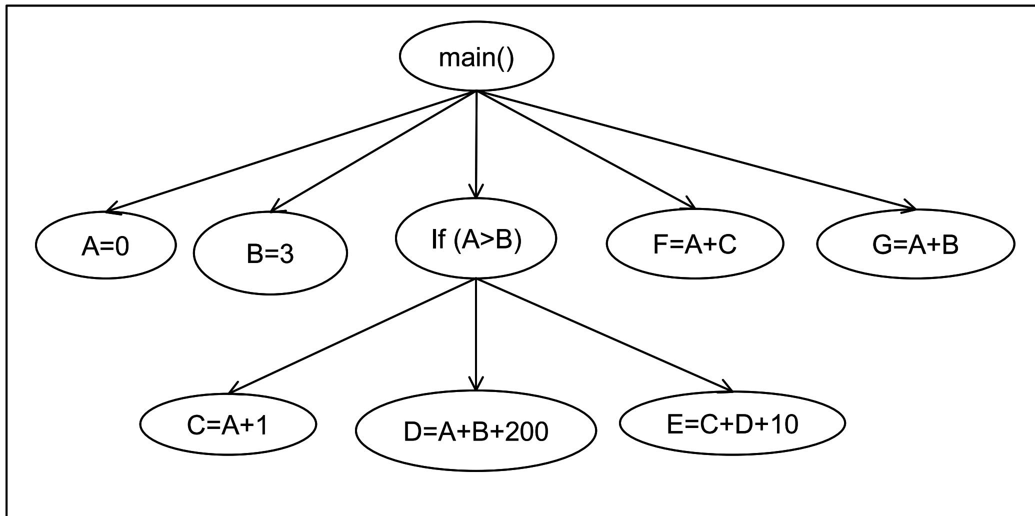


Figure 4-4: Program tree for the program segment in Figure 4-3

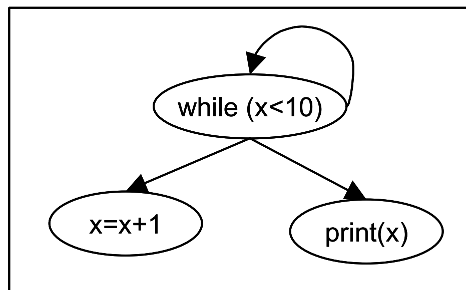


Figure 4-5: A self-loop in the control dependence subgraph

4.1.1 Handling unstructured programs

While constructing the program tree from the control dependence subgraph, we may encounter cycles in the control dependence subgraph involving more than one node. Moreover, a node can be control dependent on multiple nodes. These cases arise for some unstructured programs. For example, consider the program segment in Figure 4-6. The

control dependence subgraph for this program segment, shown in Figure 4-7, has a node that is control dependent on multiple nodes. Figure 4-9 gives an example of a cycle in the control dependence subgraph. Any node in a tree cannot have multiple parents and it cannot be involved in a cycle.

```
main()
{
    read (x)
    if (x>5)
        goto L1
    read (x)
    x = x – 1
    if (x>10)
        goto L1
    goto L2
    L1:
    read(x)
    L2:
    write(x)
}
```

Figure 4-6: A sample unstructured program segment.

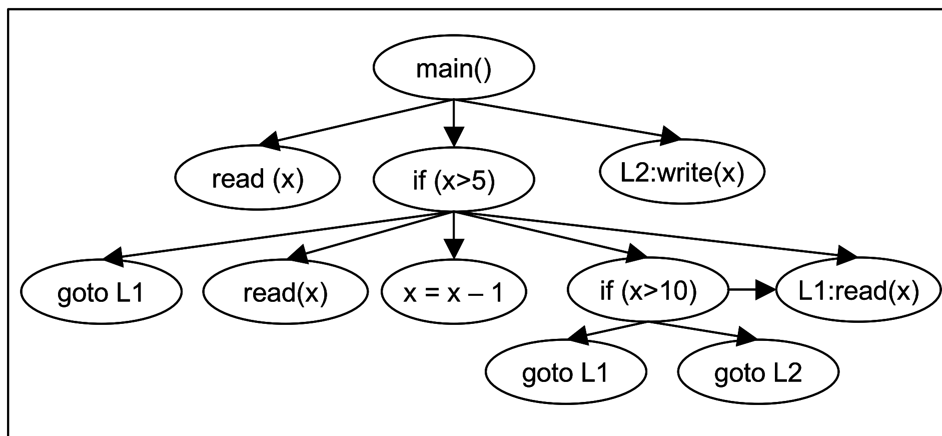


Figure 4-7: Control dependence subgraph for the program segment in Figure 4-6

If a node in the control dependence subgraph has multiple parents, we create a duplicate child node for each parent node. Figure 4-10 shows the PT for the program segment shown in Figure 4-6 obtained by following this strategy.

```
while (x<10)
        x = x+1
        if (x>5)
              break
        print (x)
```

Figure 4-8: A sample program segment

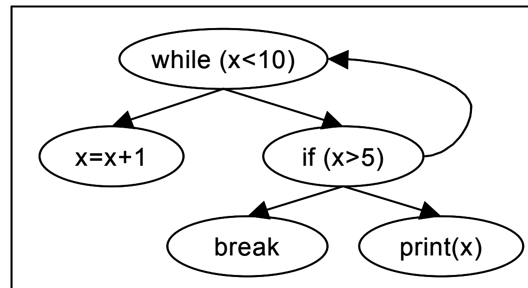


Figure 4-9: Control dependence graph for program segment in Figure 4-8

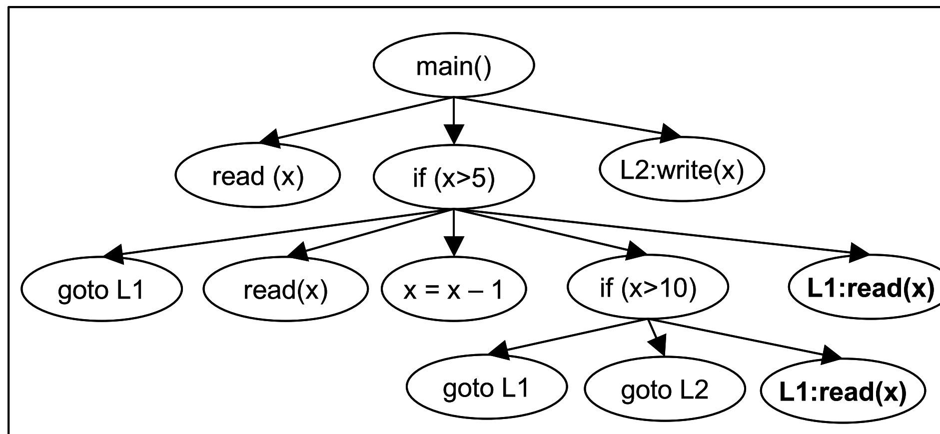


Figure 4-10: PT for program segment in Figure 4-6

To handle loops in a control dependence subgraph, we use the following method. If a node p1 has p2 as its successor in the control dependence subgraph, such that p2 is an ancestor of p1 in the program tree constructed so far, we create a special node for p2 and add it as children of p1. We do not explore this special node any further. Figure 4-11 shows the program tree obtained for Figure 4-8 using this strategy.

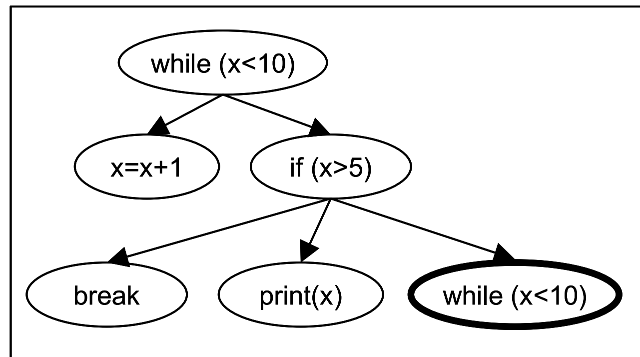


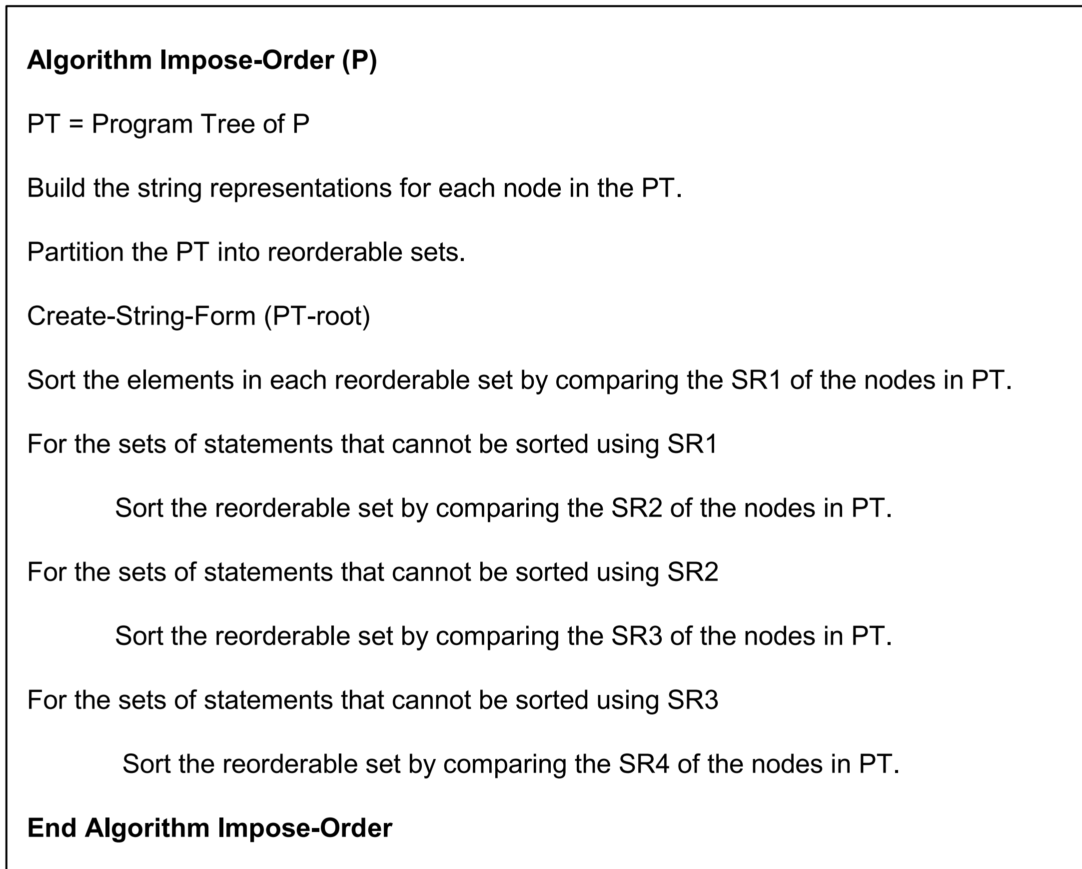
Figure 4-11: PT for the program segment in Figure 4-8

4.2 Algorithm for imposing an order on the statements

The algorithm for imposing an ordering on the nodes in a PT is shown in the Figure 4-12. This algorithm has two steps.

1) Partition PT nodes into reorderable sets.
2) Use ordering strategies to get an ordering of statements in each reorderable set.

This algorithm uses string representations of the statements (explained in Section 4.4) for imposing an ordering on the program statements.



Algorithm Impose-Order (P)

PT = Program Tree of P

Build the string representations for each node in the PT.

Partition the PT into reorderable sets.

Create-String-Form (PT-root)

Sort the elements in each reorderable set by comparing the SR1 of the nodes in PT.

For the sets of statements that cannot be sorted using SR1

    Sort the reorderable set by comparing the SR2 of the nodes in PT.

For the sets of statements that cannot be sorted using SR2

    Sort the reorderable set by comparing the SR3 of the nodes in PT.

For the sets of statements that cannot be sorted using SR3

    Sort the reorderable set by comparing the SR4 of the nodes in PT.

End Algorithm Impose-Order

Figure 4-12: Algorithm for fixing the order of statements in a program

4.3 Partitioning PT into reorderable sets

This section describes a partitioning algorithm for creating reorderable sets of PT nodes. The aim of this step is to find statements in the program that can be reordered without changing the program semantics.

Sibling PT nodes can be reordered if there are no dependencies between these nodes. Dependence relation between two nodes n1, n2 $\in$ PT, with the same parent node is defined as follows. Node n2 is said to be dependent on node n1 if and only if there exists a path from n1 to n2 in the control flow graph of P and either a node in the sub-tree of PT rooted at n2 is data dependent on a node in the sub-tree of PT rooted at n1 or there

exist two nodes n1' and n2' in the sub-trees of PT rooted at n1 and n2 respectively such that the intersecting set of variables defined in n1' and n2' in non-empty.

The sets of nodes that can be reordered are computed. Each of such set is a reorderable set. The process of creating these reorderable sets is called partitioning.

Definition *Reorderable set*: A set of nodes in PT are said to form a reorderable set if and only if they have the same parent node and they can be reordered without changing the semantics of the program represented by PT.

The children of the nodes in the PT are partitioned into one or more reorderable sets. The order of the reorderable set is fixed, but the order of the elements within the reorderable set is not fixed. Given a program (P) and its corresponding PT, the PT nodes can be partitioned into reorderable sets using the partitioning algorithm. The partitioning algorithm traverses the PT of P in the post order to find the nodes that can be reordered. The partitioning algorithm places each node in its corresponding reorderable set. It maintains data dependence information using a dependence graph. The dependence graph has an edge from node n1 to node n2 if n2 depends on n1. Figure 4-13 shows the dependence graph for the node *main ()* in the Figure 4-4. We use dependence graph depth (DG-Depth) of a node, which is initially set to '0' for all the nodes, for placing the nodes into reorderable sets. The children of a node are processed in the control flow order. For every child node C of N, the partitioning algorithm finds the node C', having the maximum DG-Depth 'm', such that either C depends on C' or C' depends on C. The child node C is placed in the reorderable set numbered m+1 and the DG-Depth of C is set to m+1. This assures that after the nodes are partitioned, the dependence order of the reorderable sets is preserved.

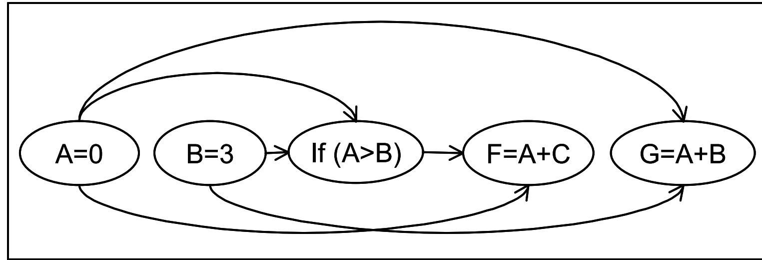


Figure 4-13: Data dependence graph for the children of "root" in Figure 4-4

Consider the Node *main ()* in Figure 4-4. It has {*A=0, B=3, If (A>B), F=A+C, G=A+B*} as its children. The dependence graph for this set of children is shown in Figure 4-13. The edge from the node *A=0* to the node *If (A>B)* corresponds to the dependence relation from node *A=0* to the node *If (A>B);* i.e., there exists a path from the node *A=0* to the node *If (A>B)* in the control flow graph of P and a value defined by the node *A=0* is used by at least one node in the sub-tree starting with the node *If (A>B)*. Similarly, the edge from the node *If (A>B)* to the node *F = A+C* corresponds to a dependence relation from *If (A>B)* to *F=A+C*.

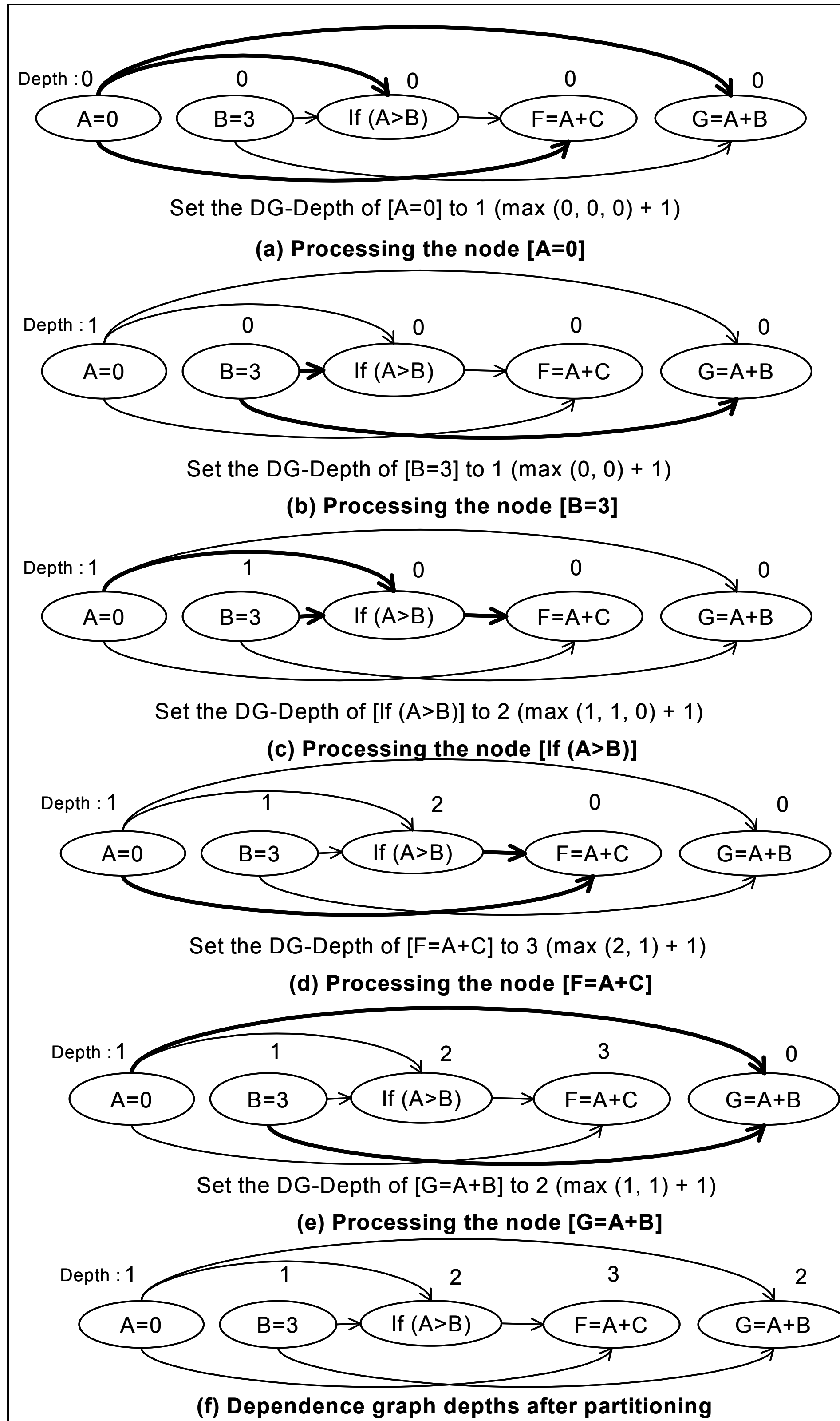


Figure 4-14: Working of partitioning algorithm

The working of the partitioning algorithm is shown in Figure 4-14. The child nodes are processed in the control flow order. At each step, we pick a node and find the reorderable set to which it belongs. Initially, all the child nodes are given a DG-Depth of '0'. Figure 4-14(a) shows the processing of the child node *A=0*. The incoming/outgoing edges of the node *A=0* are directed from/to the nodes having a DG-Depths as '0'. Hence, the node *A=0* is placed in the reorderable set numbered '1'. The DG-Depth of the node *A=0* is set to '1'. In Figure 4-14(d), the algorithm processes the child node *F=A+C*. The DG-Depths of the nodes that have a dependence relation with *F=A+C* are {2, 1}. The maximum value in this set is 2. Hence *F=A+C* is placed in the reorderable set numbered 3. The DG-Depth of the node *F=A+C* is set to '3'.

After partitioning, the reorderable sets will be as follows.

- Reorderable set–1: {*A=0, B=3*};
- Reorderable set–2: {*If (A>B), G=A+B*};
- Reorderable set–3: {*E=A+C*}.

Figure 4-14(f) shows the partitioned dependence graph.

The partitioning algorithm described above gives the same reorderable sets independent of statement reordering expression reshaping and variable renaming transformations. The next step in getting the ZERO form for a program is to impose an order on the nodes in the reorderable sets. Since we get the same reorderable sets even in the presence of statement reordering, expression reshaping, and variable renaming, the same order will be imposed for all the metamorphic variants of a virus. In the next section, we describe the ordering strategies that we have used for creating the ZERO form.

4.4 Ordering strategies

The ordering strategies we have used for getting the ZERO form require a string representation of the statements in the program. In this section, we describe the procedure for constructing string from the program statements. The basic idea behind using string representation for program statements is to impose an ordering on the statements in the same reorderable sets by comparing their string representations. Since morphing transformations can rename variables, we cannot use variable names in the string representation of the statements. In order to get the string representation of a statement, for each of the variables in the statement, we use the PT depths of the reaching definitions [9] of that variable as a string to represent that variable. This is based on the observation that the PT depths of the statements remain the same even if the metamorphic transformation for statement reordering is applied.

Another problem that needs to be addressed when constructing the string representation of statements is expression reshaping. We give a reshaping strategy for constructing string representation for expressions with commutative operators. Figure 4-15 illustrates the method for getting a string form for an expression. The Abstract Syntax Tree representation of the expression given in Figure 4-15(a) has to be restructured so that the expression reshaping transformation doesn't affect the string representation of the expression. For achieving this, we construct a tree (which can have more than two children) from AST of the expression. This tree representation constructed from the AST in Figure 4-15(a) is shown in Figure 4-15(b). Using this restructured tree for constructing the string form ensures that the expression reshaping done to the commutative and associative operators is zeroed out.

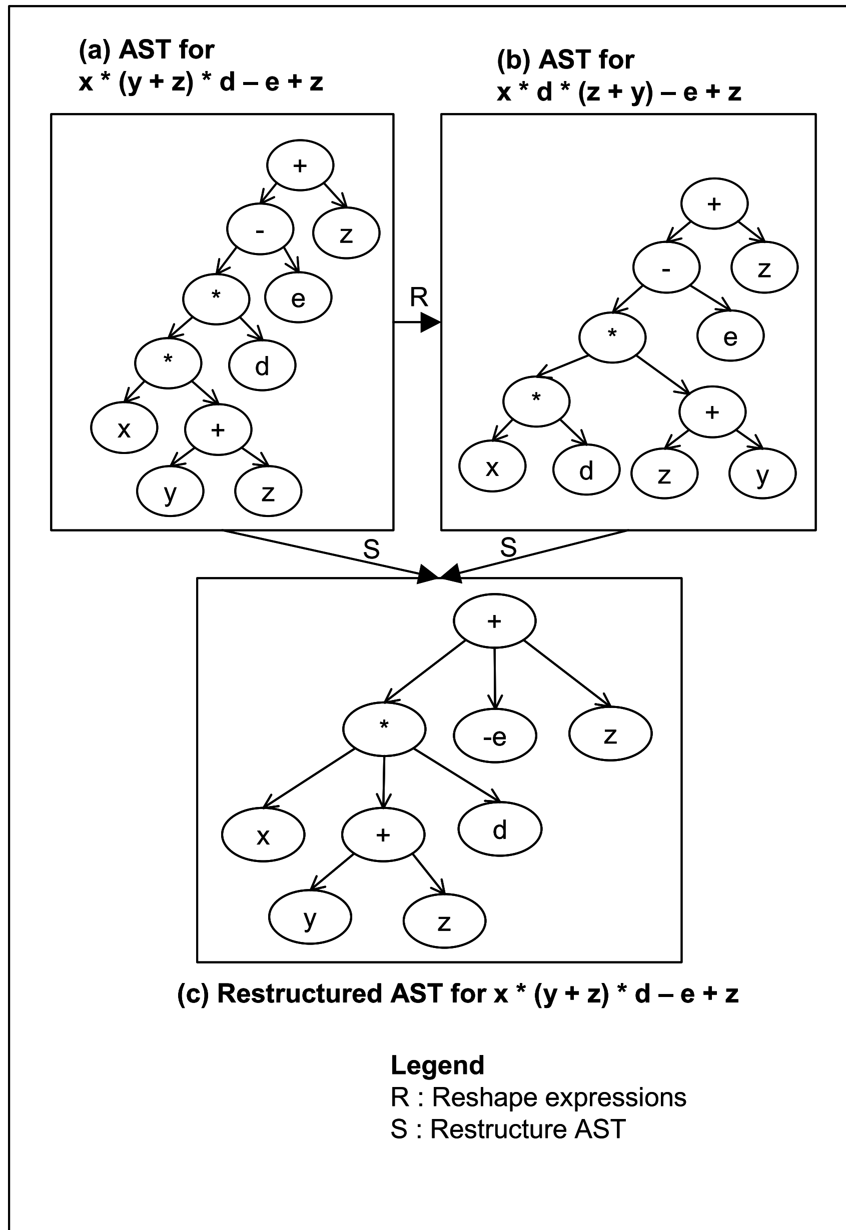


Figure 4-15: Restructuring AST to handle expression reshaping

Once we get the restructured ASTs, we create a string representation for the expression represented by the AST. We use the algorithm shown in Figure 4-16 for creating string representations of expressions. Figure 4-18 shows an example of string representations for two expressions. This figure uses the string "I" to represent the variables in the program.

```
Algorithm Create-Expression-String-Form (expression)
If (expression is leaf)
        If (expression represents a variable)
                String-Representation of expression = "I".
        Else
                String-Representation of expression = constant value in expression
        End If
Else
        S = String representation of the operator in expression
        For each child C of PT-Node
                Create-Expression-String-Form (C)
        End For
        If (PT-Node represents a commutative operator)
                L = Sorted list of string representations of the children of PT-Node
        Else
                L = List of string representations of the children of PT-Node.
        End If
        S' = String formed by appending strings in L.
        String-Represetation of expression = String formed by appending S and S'
End If
End Create-Expression-String-Form
```

Figure 4-16: Algorithm for creating string representation of expressions

After creating the string representations for the expressions in the statements, we apply the algorithm shown in Figure 4-17 to get the string representations for the nodes in program tree.

```
Algorithm Create-String-Form (PT-Node)
If (PT-Node is leaf)
        Create-Expression-String-Form(expression in PT-Node)
        SR1 of PT-Node = String-Representation of expression in PT-Node.
Else
        S = String representation of the expression in PT-Node
        For each child C of PT-Node
                Create-String-Form (C)
        End For
        L = Sorted list of SR1s of the children of PT-Node
        S' = String formed by appending strings in L.
        SR1 of PT-Node = String formed by appending S and S'
End If
End Create-String-Form
```

Figure 4-17: Algorithm for creating SR1

We name the string representation obtained by using this procedure as SR1. To impose an order on the statements present in the same reorderable set, we compare the SR1s of the statements in the reorderable sets. The statements in the same reorderable sets may have the same SR1. For instance, the statements $A=B+20$ and $C=20+D$ have the same SR1s. In that case, we will not be able to impose an order on the statements appearing in the reorderable sets using SR1. To minimize such cases, we modify the partitioning algorithm. Instead of partitioning the statements, we partition the dependence chains. A dependence chain is defined as follows. Two nodes n1 and n2 will be part of the same dependence chain if and only if n1 has only one dependent n2, and n2 is dependent on only one node n1. Figure 4-22 (b) shows the dependence chains formed for

the dependence graph shown in Figure 4-22 (a). The partitioning algorithm is modified to partition these dependence chains. The algorithm for partitioning the dependence chains into reorderable sets is similar to the one that partitions the PT nodes into reorderable sets. Each dependence chain is treated as a PT node. To create a dependence graph for the dependence chains, we use the following definition of dependence relation between the dependence chains. A dependence chain c1 is said to be dependent on a dependence chain c2 if and only if a PT node in c1 is dependent on a PT node in c2. The use of dependence chains instead of individual program statements improves the probability of imposing an order using the string representation of the dependence chains. This is because the string representations of two dependence chains differ if they have at least one statement with a different string representation in the dependence chains.

For the statements that cannot be ordered using SR1, we create a string from the total number of uses and definitions of the variables used and defined in the statement. We call this string representation SR2. Figure 4-19 shows an example of SR2. SR2 is used to impose an ordering on the statements that could not be ordered by SR1. If we still fail to get an ordering for the statements in the reorderable sets, we create a string from of data dependence predecessors of the statements that are to be ordered by sorting the SR1s of predecessors and appending them to get a string called SR3. Figure 4-20 shows an example of SR4. If we fail to impose an order using SR3, we create a string from the data successors of the statements to be ordered by sorting the SR1s of the successors and concatenating the sorted strings to get SR4. Figure 4-21 shows an example of SR4.

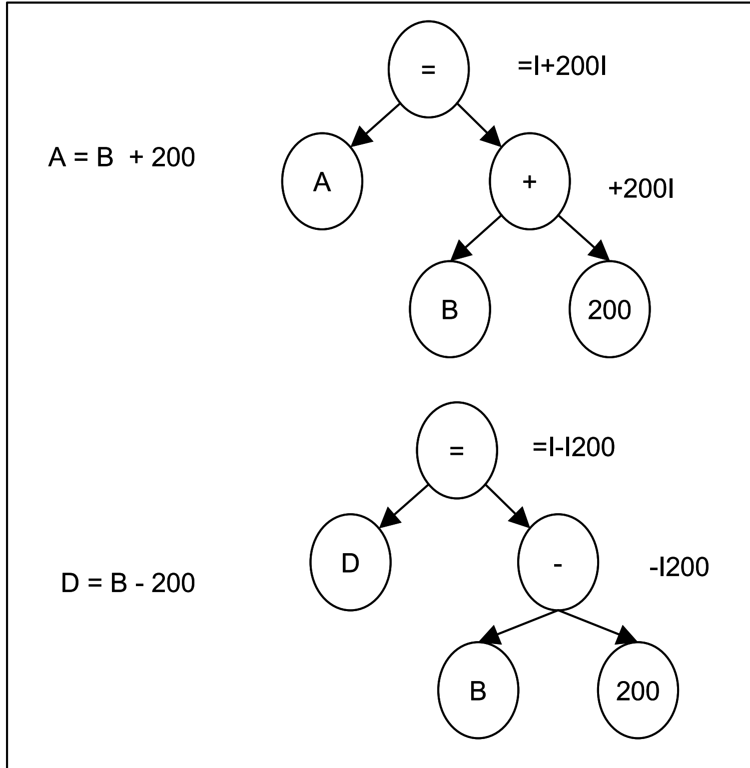


Figure 4-18: String representation of an AST - example

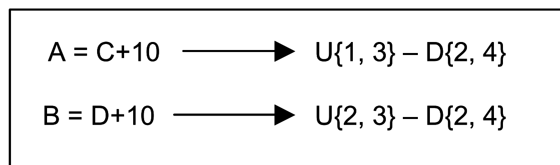


Figure 4-19: SR2 - example

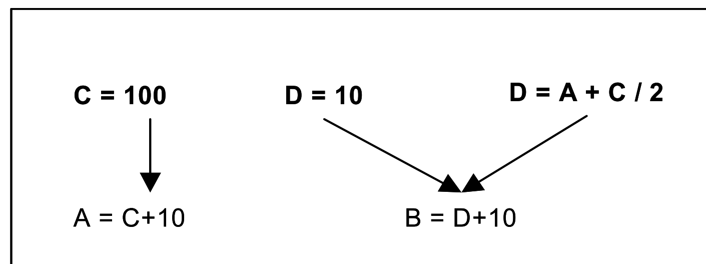


Figure 4-20: SR3 - example

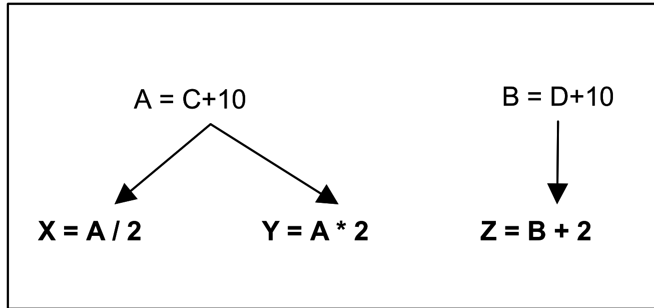


Figure 4-21: SR4 - example

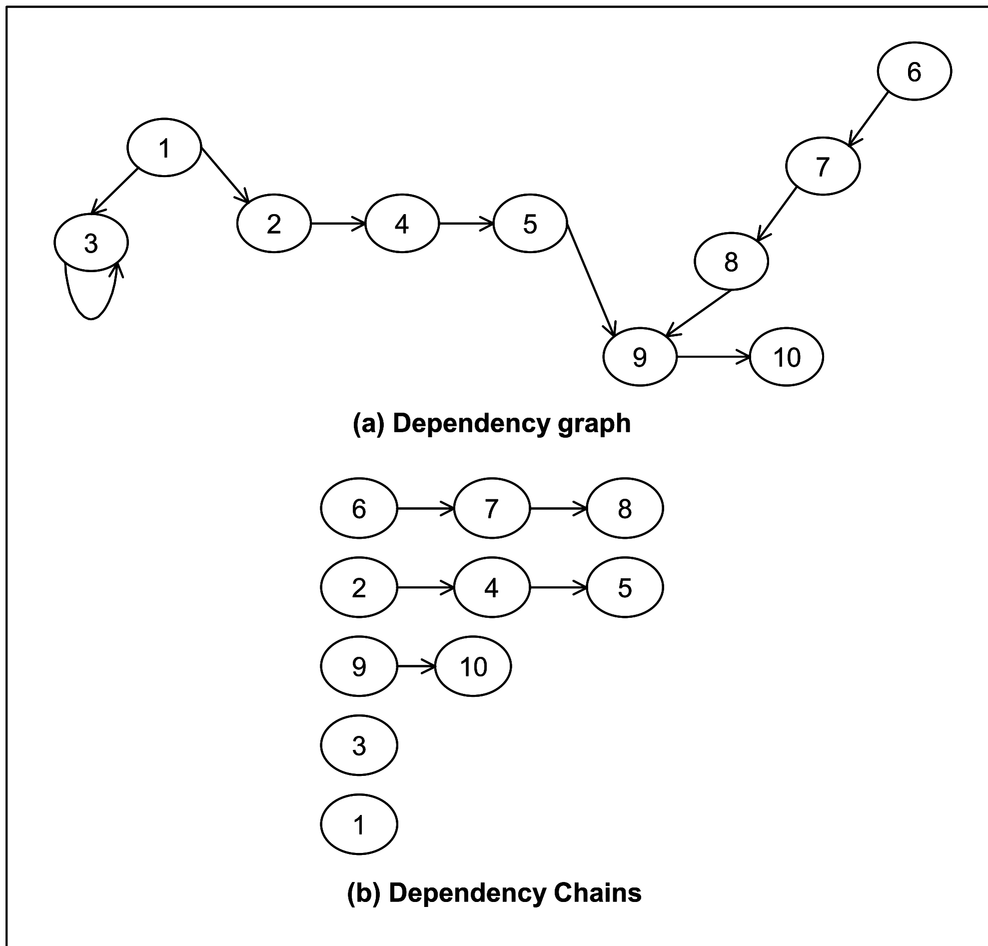


Figure 4-22: Dependence chains – example

4.5 Limitations

Virus detection in general is an undecidable problem. We cannot devise a method that can detect all possible viruses. Our method is also bounded by this theoretical limit. For instance, the dead code removal technique may not remove all possible dead code in a program as this technique sometimes cannot decide whether a particular code fragment is dead code or not.

The transformation to fix an order on the statements may not always get an ordering on all the program statements. Some instances for which an ordering is not possible are shown in Figure 4-23. But, most of the time, we observed that the statements for which an ordering cannot be imposed are either initialization statements or function calls with the same number of arguments.

Our expression reshaping approach only considers reshaping done to the commutative and associative operations. We do not take into account the reshaping done to the distributive operators.

- Initialization code
  a=0
  b=0
- Function calls with same arguments
  a(x, y)
  b(c, d)

Figure 4-23: Instances for which orderings are not possible

5 Related work

The Bloodhound technology of Symantec Inc., uses heuristics for detecting malicious code [19]. Bloodhound uses two types of heuristic scanners: static and dynamic. The static heuristic scanner maintains a signature database. The signatures are associated with program code representing different functional behaviors. The dynamic heuristic scanner uses CPU emulation to gather information about the interrupt calls the program is making. Based on this information it can identify the functional behavior of the program. Once different functional behaviors are identified using the static and dynamic heuristic scanners, they are fed to an expert system, which judges whether the program is malicious or not. Static heuristics fail to detect morphed variants of the viruses as morphed variants have different signatures. Dynamic heuristics consider only one possible execution of a program. A virus can avoid being detected by a dynamic scanner by introducing arbitrary loops.

Lo et al.'s MCF [15] uses program slicing and flow analysis for detecting computer viruses, worms, Trojan-horses, and time/logic bombs. MCF identifies telltale signs that differentiate between malicious and benign programs. MCF slices a program with respect to these telltale signs to get a smaller program segment representing the malicious behavior. This smaller program segment is manually analyzed for the existence of virus behavior.

Szappanos [13] uses code normalization techniques to detect polymorphic viruses. Normalization techniques remove junk code & white spaces, and comments in programs before they generate virus signature. To deal with variable renaming, Szappanos suggests two methods – first, renaming variables by the order they appear in the program

and second, renaming all the variables in a program with a same name. Former approach fails if the virus reorders its statements, and the later approach abstracts a lot of information and may lead to incorrect results. As our approach fixes the order of the statements in a program, the first approach suggested by Szappanos for renaming the variable can be used in combination with our method.

Our work relates to the work done by Christodorescu et al. [1] for detecting of malicious patterns in the executables. They use abstraction patterns, patterns representing sequences of instructions. These patterns are parameterized in order to match different instructions sequences with the same instruction set but different operands. They use this mechanism for handling the variable renaming transformation. A pattern may contain instructions that can be reordered. To detect variants with renamed variables that have reorderable statements, they would need to maintain all possible permutations of the reorderable statements in the abstraction patterns. Another problem with abstraction patterns is that it becomes difficult for AV companies to distribute virus signatures, as the virus may be reconstructed using these patterns. Their approach gives fewer false positives but the cost of creating and matching the abstraction patterns is high. They detect the virus variants created by performing dead code insertion, variable renaming in the absence of statement reordering, and break & join transformations. Our method, in addition to the above morphing transformations, can detect the viruses that apply statement reordering and expression reshaping transformations.

6 Implementation & results

We have implemented a tool, C⊕, for generating the ZERO form for C programs. C⊕ uses the Program Dependence Graph (PDG), generated by the CodeSurfer [5], to perform the analysis required for imposing an order on the statements of the program. CodeSurfer provides an API in Scheme [14] to access the PDG representation of the C programs. The use-def and def-use dependence information is calculated using this PDG representation. We calculate the def-def dependencies using the CodeSurfer's defs/kill sets of the statements. Figure 6-1 shows the architecture of C⊕.

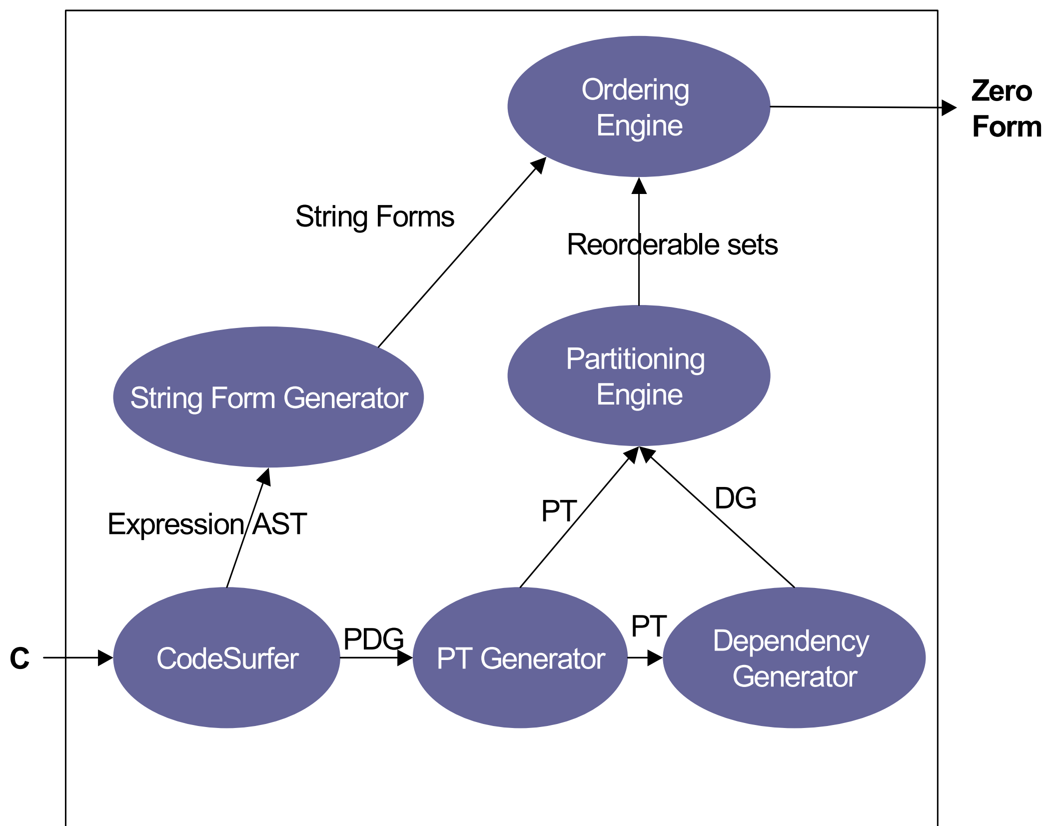


Figure 6-1: C⊕ architecture

We performed a series of experiments on different sets of C programs to find study how well our approach imposed order on the statement of the program. The C programs used in the experiments are listed in Figure 6-2. The Fractal programs [17] create fractals using C programming language. The COOK system [22] is used for writing build scripts for projects. It is a powerful and easy to use replacement for make [18]. Search/Sort programs are the programs that search for data and sort data. We calculated reorderable percentages, zeroing percentages, and sizes of reorderable sets for these test programs.

Number	Name	Description
S1 S2 S3	Fractal (6 files) COOK (5 files) Search & Sort (5 files)	Code for creating fractals COOK's project files Programs to search for data and sort data.

Figure 6-2: Test programs used in C⊕

6.1 Reorderable percentage

We calculated the percentage of program statements that can be reordered by using the morphing transformation for reordering statements. We call this reorderable percentage. To calculate this reorderable percentage before the application of zeroing transformations, we used the following formulae.

Reorderable nodes in PT={n | n∈PT, ∃n' ∈ PT and parent (n)=parent (n') & reorderable-set-number (n)=reorderable-set-number (n')} (i.e. the set of nodes that fall in the reorderable set with size greater than one before application of zeroing transformations).

Percentage of Reorderable nodes = (total number of reorderable nodes in PT * 100) / (total number of nodes in the PT).

After the application of zeroing transformations, reorderable percentage is calculated using following formulae.

Reorderable nodes in PT={n | n∈PT, ∃n' ∈ PT ∋ parent (n)=parent (n') & equivalence-class-number (n)=equivalence-class-number (n') & SR (n)=SR (n')} (i.e. the set of nodes that fall in the reorderable set with size greater than one after application of zeroing transformations).

Reorderable percentage = (total number of failure nodes) *100 / (total number of nodes in the PT).

We calculated the reorderable percentages for different string representations. With the increase in reorderable percentage for a given program, the number of possible permutations for that program increases. Figure 6-3 shows the reorderable percentages for our test programs. SR0 corresponds to the reorderable percentage before the application of zeroing transformations. The Fractal programs have higher reorderable percentages than COOK system and Search/Sort programs. This is because the Fractal programs have image processing code that has similar structure of statements that operate on X and Y coordinates.

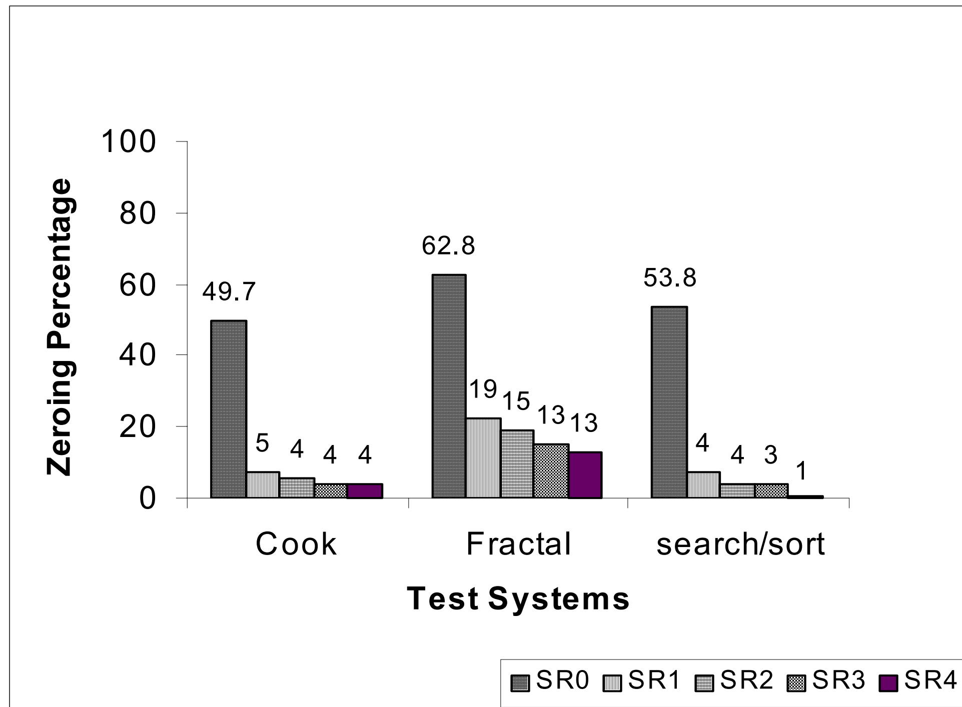


Figure 6-3: Reorderable percentages for the test programs

6.2 Reorderable set sizes

We calculated the sizes of the reorderable sets for the test programs before and after the application of zeroing transformations on those programs.

The number of reorderable sets with larger size before the appicaltion of zeroing transformations will be more than the number of reorderable sets with the same size after application of zeroing transformations. For example, zeroing transformations break reorderable set of size 25 to two reorderable sets of size 15, and 10 respectively. Ideal case for zeroing transformations is when the zeroing transformations yield reorderable sets of size '1' only.

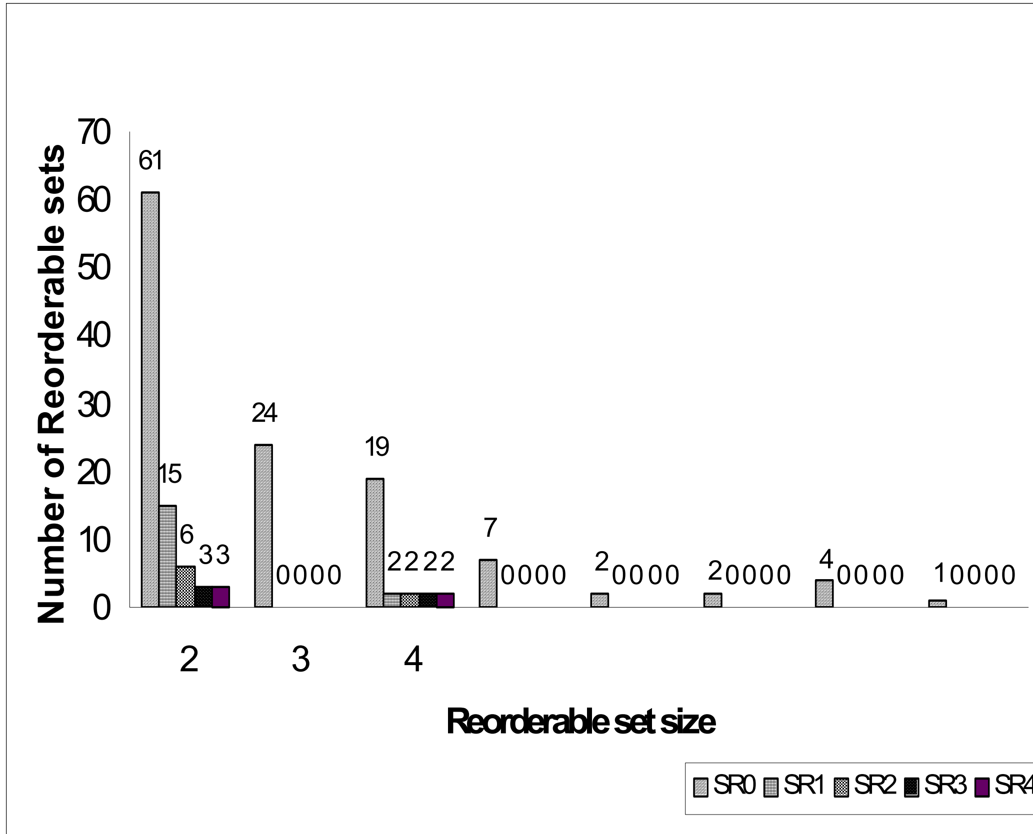


Figure 6-4 plots the sizes of reorderable sets against the number of reorderable sets with that size for the COOK system before and after application of zeroing transformations. Reorderable sets with size '1' are not shown in this figure. The aim of zeroing transformations is to reduce the number of reorderable sets with larger size and break them into reorderable sets of size '1'.

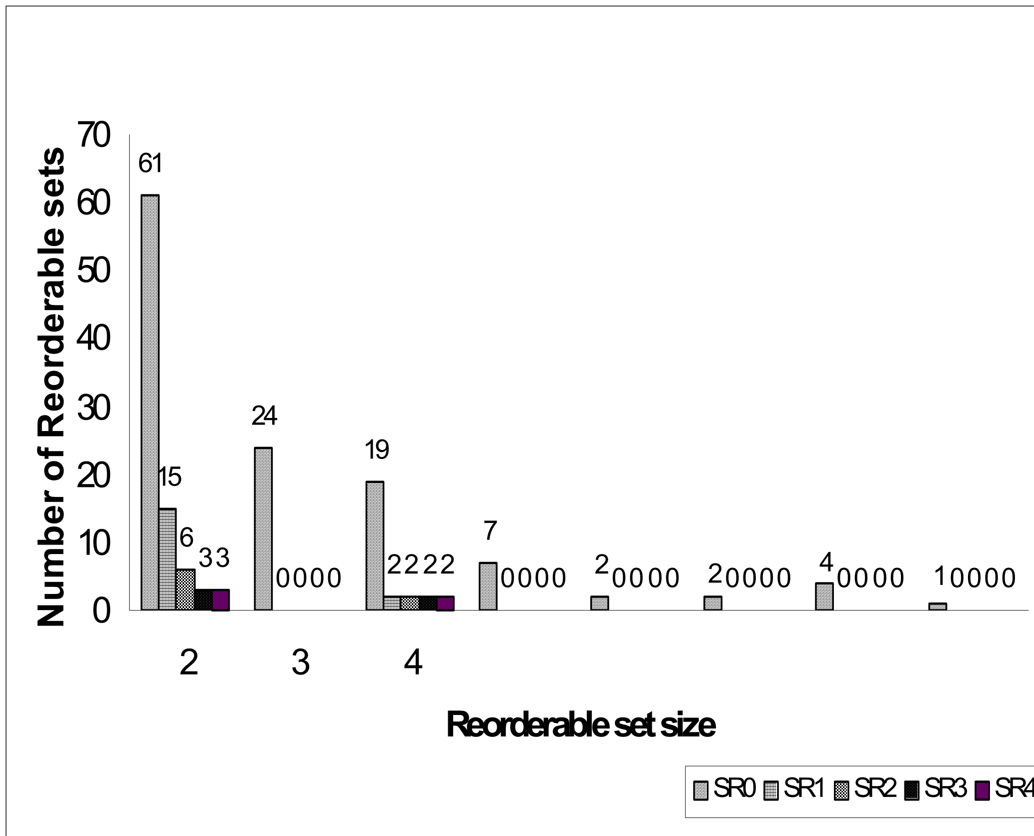


Figure 6-4: COOK - Reorderable set sizes

Figure 6-5 and Figure 6-6 show the reorderable set sizes before and after applying zeroing transformations on Fractal and SEARCH/SORT programs, respectively. The Fractal programs have reorderable sets of larger sizes when compared to other programs. This is because the Fractal programs have more dependencies between its statements when compared to other programs

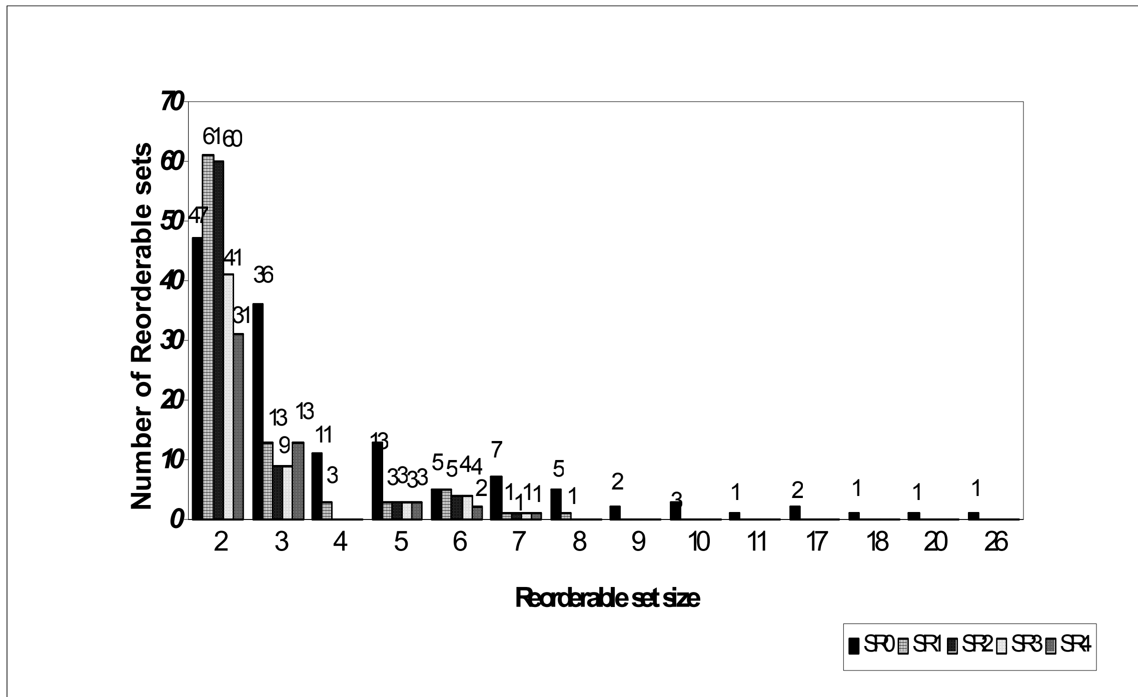


Figure 6-5: FRACTAL - Reorderable set sizes

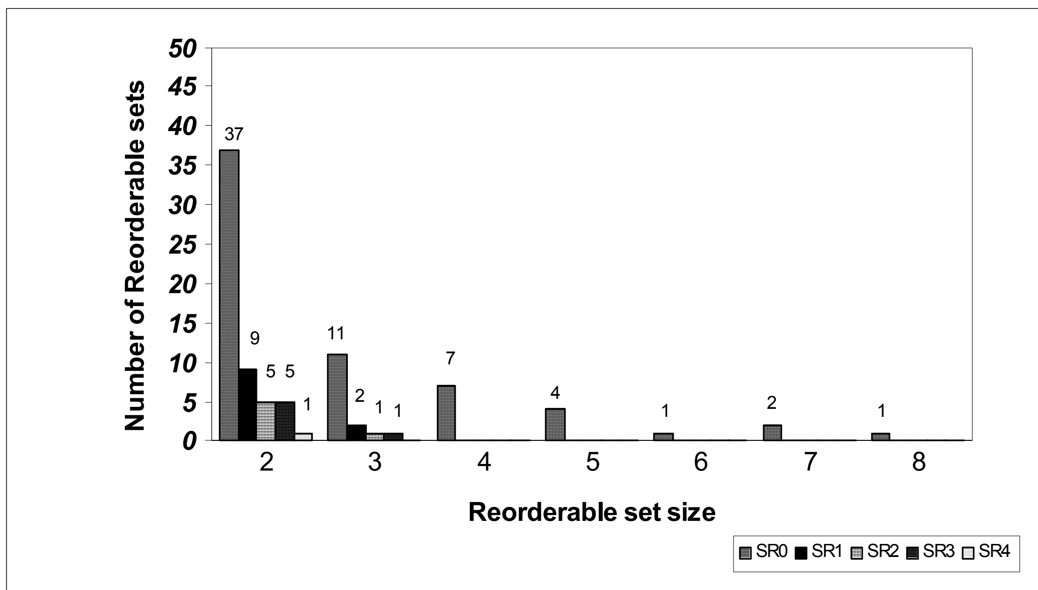


Figure 6-6: SEARCH/SORT – Reorderable set sizes

6.3 Number of possible variants

The total number of possible variants of a program that can be generated using statement-reordering transformation is calculated using the procedure given below.

P = A node in PT

$C_1, C_2, \ldots, C_n$ are children of P.

$E_1, E_2, \ldots, E_q$ are Reorderable sets obtained by partitioning $C_1, C_2, \ldots, C_n$.

$K_1, K_2, \ldots, K_q$ are sizes of reorderable sets $E_1, E_2, \ldots, E_q$.

$\rho(P)$ = Total number of permutation obtained by reordering the nodes in the sub-tree starting with P.

$$\rho(P) = \prod_{i=1}^{q} (K_i!(\prod_{j} \rho(C_j) \ni C_j \in E_i)). \quad If\ P \in Non-leaf\ PT-nodes.$$

$$\rho(P) = 1 \quad If\ P \in Leaf\ PT-nodes.$$

The total number of possible permutations for the test programs before and after applying zeroing transformations is shown in Figure 6-7.

Test System	Permutations before Zeroing	Permutations after Zeroing
COOK	383968511	2
SEARCH/SORT	78674	1
Fractal	$1.19 * 10^{43}$	196787849

Figure 6-7: Number of possible permutations for test programs

7 Conclusions and future work

We have described a method for detecting morphed variants of the viruses. Our method maps different variants of a virus obtained by morphing transformations to their respective zero forms. This method may be used to augment the current AV technologies such as traditional signature scanning approach, and other static and dynamic detection schemes. AV technologies can use our method to create zero form for a virus and extract zero signatures of that virus. These zero signatures can be distributed to the users as virus signatures.

Our method uses zeroing transformations to map different variants of a virus to zero form. The effectiveness of our method is determined by the effectiveness of zeroing transformations that map a program to zero form. As our method is a heuristic, we may not always map all the variants to a single zero form. But the application of zeroing transformations results in a significant decrease in the number of possible variants of a program. The experiments we conducted show that, on an average, 55% of the program statements were reorderable before the application of zeroing transformations which decreased to 6% after the application of zeroing transformation for fixing the statement order.

The morphing transformations we consider are dead code insertion, statement reordering, variable renaming, expression reshaping, and break & join transformations.

In future work, we would like to test our method on actual viruses. We would also like to do an investigation on other possible morphing transformations and the zeroing transformations to create zero forms in such cases.

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ABSTRACT

Metamorphic computer viruses programmatically vary their instructions to create a different form for each infection. This is done using code evolution techniques, such as introducing dead code, reordering statements, reshaping expressions, and changing variable names. Current anti-virus technologies use signature, a fixed sequence of bytes from a sample of a virus, to detect its copies on a user's machine. Use of signatures does not work very well with metamorphic viruses since two versions of a metamorphic virus may have very little in common.

This thesis presents a method to transform different variants of a metamorphic virus to the same form, called the zero form. Current technologies can be improved to detect metamorphic viruses by using the zero form of a virus, and not the original version, for extracting signature. We developed a tool for generating zero forms for C programs. For the test programs we used, we found that 55% of the statements were reorderable before applying zeroing transformations for fixing the statement order. After applying zeroing transformations for fixing the statement order, only 6% of the statements could not be ordered. The average number of possible permutations of the program statements obtained by statement reordering transformation reduced from 10^{43} to 10^{8} with the application of zeroing transformations for fixing the statement order.

Biographical sketch

Mr. Moinuddin Mohammed was born in Rajgaopalpet, India on August 01, 1980. He graduated with a Bachelor's degree in Computer Science in June 2001 from Osmania University, Hyderabad, India. He entered the Master's program in Computer Science at the University of Louisiana at Lafayette in Fall 2001. Following completion of this degree, he will be pursuing a Ph.D. in the area of compilers.