Exploiting Undefined Behaviors for Efficient Symbolic Execution

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Motivation

Symbolic execution is a popular technique used for test generation, debugging and program analysis. We have developed a technique to reduce the runtime cost of symbolic execution with binaries.

Main Idea

- During compilation we use a static analysis to systematically introduce undefined behaviors (UB) in programs
- This triggers existing aggressive compiler optimizations based on undefined behaviors that reduce the size of generated binaries

Key Benefits

- Reuse existing compiler optimizations for eliminating code that is not relevant for symbolic execution
- Based on a simple static analysis (CVA) that is applied as a pass during the compilation
- Does not require any change in the underlying symbolic execution engine to use the results from static analysis for dynamic path exploration
- Allows reduction in size of compiled binaries and prevents generation of irrelevant constraints

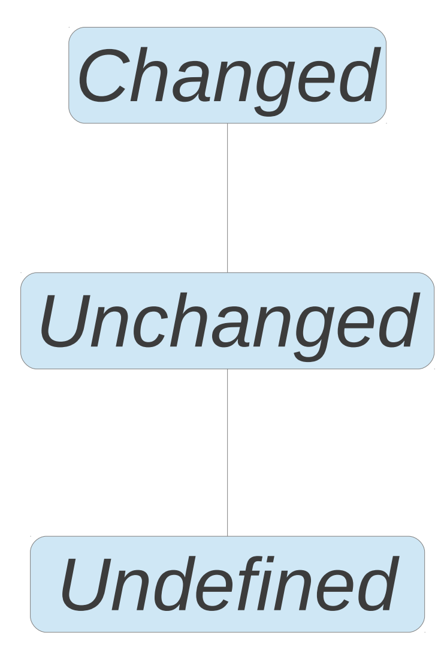
Change Value Analysis

Statically determine program variables that depend on change in the value of the output using a three point lattice on status of program variables (*Changed*, *Unchanged* and *Undefined*)

1. Initially mark all variables as *Undefined*
2. Mark all output variables as *Changed*
3. Working backwards mark all those variables that depend on *Changed* variables as *Changed*
4. Continue till fixed point is reached

In the end replace all *Undefined* and *Unchanged* variables with a nondeterministic *Undef* value

Three Point Lattice

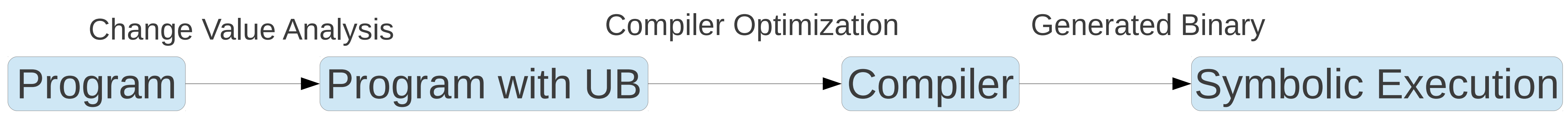


Changed Reachable code that affects the output

Unchanged Reachable code that does not affect output

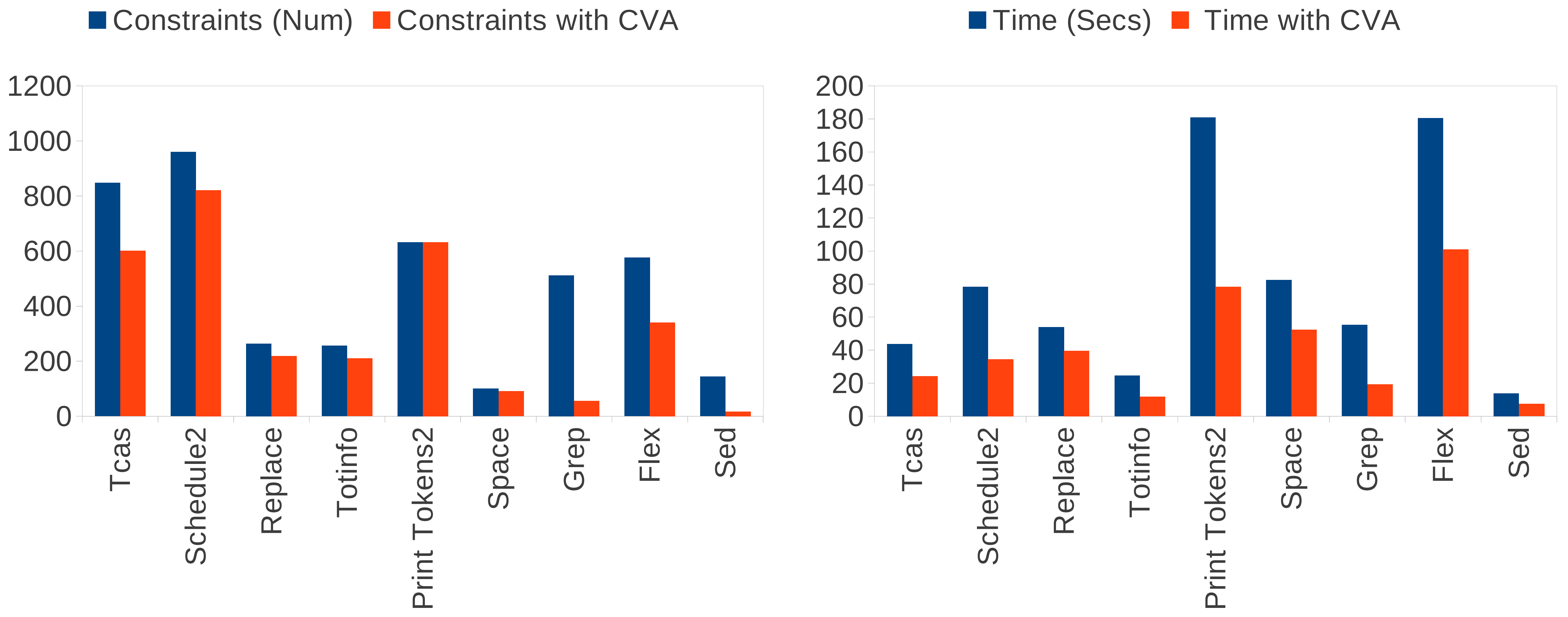
Undefined Unreachable Code

Overview of the Method



Experiments

Benchmarks from Software-artifact Infrastructure Repository (SIR)



Implemented as a compiler pass in LLVM Generated binaries are symbolically executed using Pathgrind

14% reduction in size of binaries
30% reduction in number of constraints generated
48% reduction in time taken for symbolic execution

An Example

Program before CVA

```
int foo (int x, int y, int z)
{
   int a;
   a = z;
   if (x – y > 0)
      a = x;
   else
      a = y;
   if (z > a)
      printf(“z is max”);
   return a;
}
```

Program after CVA

```
int foo (int x, int y, int z)
{
   int a;
   a = z;
   if (x – y > 0)
      a = x;
   else
      a = y;
   if (z > a)
      printf(“z is max”);
   return a;
}
```

Changed: {a,x,y}

Unchanged: {z}

Undefined: {}

Program with UB

```
int foo (int x, int y, int *)
{
   int a;
   a = *;
   if (x – y > 0)
      a = x;
   else
      a = y;
   if (* > a)
      printf(“z is max”);
   return a;
}
```

Replace 'z' with '*' which represents a nondeterministic value (e.g. *Undef* in LLVM)

Undef value triggers optimizations based on undefined behaviors which eliminates 3 lines from the program

Program after Compiler Optimizations

```
int foo (int x, int y, int z)
{
   int a;
   if (x – y > 0)
      a = x;
   else
      a = y;
   return a;
}
```

Still possible to generate the same test cases using dynamic symbolic execution as the constraints on input that affect the output are preserved

Source Code

Change Value Analysis (GPL 3) http://github.com/codelion/pa.llvm/tree/master/CVA
Pathgrind (GPL 3) http://github.com/codelion/pathgrind