Pinaka: Symbolic Execution meets Incremental Solving
(Competition Contribution)

Eti Chaudhary⋆ and Saurabh Joshi
Department of Computer Science and Engineering,
Indian Institute of Technology Hyderabad, India
{cs17mtech11029, sbjoshi}@iith.ac.in

Abstract. Many modern-day solvers offer functionality for incremental SAT solving, which preserves the state of the solver across invocations. This is beneficial when multiple, closely related SAT queries need to be fed to the solver. Pinaka is a symbolic execution engine which makes aggressive use of incremental SAT solving coupled with eager state infeasibility checks. It is built on top of the CProver/Symex framework. Pinaka supports both Breadth First Search and Depth First Search as state exploration strategies along with partial and full incremental modes. For SVCOMP 2019, Pinaka is configured to use partial incremental mode with Depth First Search strategy.

Keywords: Symbolic Execution · Incremental Solving · Software Bug Detection.

1 Verification Technique

Pinaka extends symbolic execution with incremental solving coupled with eager infeasibility checks. A pure symbolic execution engine builds a logical formula representing a potential execution path using symbolic values which may then be passed on to theorem-provers/solvers. An UNSAT outcome from the solver implies that the verification condition will not be violated along that path, whereas a SAT outcome provides a scenario leading to failure of an assertion during an execution along that path. The number of paths in a program blow-up exponentially as the number of branches increases. Pinaka, being a single-path symbolic execution engine, never merges two paths (i.e., diamonds). It employs eager infeasibility checks to avoid unnecessary exploration. Rather than making queries to the solver only when a path encounters an assertion, a query is made everytime a branch is encountered to check its feasibility. Infeasible branches are not explored further. These eager checks help Pinaka tremendously in reducing its search efforts. Pinaka is further powered by incremental solving offered by many state-of-the-art solvers such as MiniSAT. Incremental Solving greatly

⋆ Jury Member
benefits our technique by reducing the overhead encountered due to eager infeasibility checks. Pinaka has Depth First Search (DFS) and Breadth First Search (BFS) as its search strategies. It offers two different modes of operation: Partial Incremental (PI) Mode and Full Incremental (FI) Mode.

In PI mode, a single solver instance is maintained along a search path. In the event that a branch is encountered, only a partial path is encoded from the current point to the previous point from which a query was made along the current path. For example, in Fig. 1, a query would be made at $b_1$. If both $s_1$ and $s_2$ are feasible, $s_2$ is put in a queue and the current solver instance is used to further explore the path starting from $s_1$. When $b_2$ is encountered, only the path from $s_1$ to $b_2$ is encoded and added in the current solver instance before making a query. If both the branches at $b_2$ are infeasible, a new solver instance is created and a path from the initial state to another symbolic state (e.g., $s_2$) in the queue is encoded and the path along that symbolic state is explored further. Essentially, a new solver instance is created every-time a backtrack happens. Using BFS in PI mode is very memory consuming because for every symbolic state in the queue, a corresponding solver instance is retained. Running Pinaka with this combination is not recommended.

In FI mode, a single solver instance is retained throughout. In Fig. 1 if $b_1 \rightarrow s_1$ is a feasible branch, a new activation variable $a_{b_1,s_1}$ is created. Let $\phi_{b_1,b_2}$ be the encoding of the path from $b_1$ to $b_2$. When $b_2$ is encountered, $a_{b_1,s_1} \Rightarrow \phi_{b_1,b_2}$ is added in the solver, and $a_{b_1,s_1}$ is added as an assumption to enforce the path. Since the underlying SAT solvers integrated with Pinaka do not allow popping of a stack, upon backtrack, $\neg a_{b_1,s_1}$ is set as an assumption to disable the constraints generated by this fragment of the path.

FI mode is beneficial when the input program does not have too many paths. Otherwise, the solver becomes quite slow over time with a large memory footprint. For a large program with too many paths, the benefit of a lower memory footprint and speed of PI mode outweighs its overhead of instantiating a new solver instance on every backtrack.

Loops are handled just like branches. Consider the program fragment given in Fig. 2. Assume that along some path where $(x_1 = 1) \land (y_3 = -1)$ the loop is encountered. Branch $x_1 >= 3$ is infeasible along this path and will not be explored. Since $x_1 < 3$ is feasible, it is explored further by unrolling this iteration on-the-fly. Therefore, the path will further add $y_3 < 0$. Since it is feasible, $x_2 = x_1 + 1$ is added and feasibility of $x_2 < 3$ will be checked. After one more unrolling

```
while(x<3)
{
  if (y < 0 )
    { x=x+1; }
}
```

Fig. 1. Branching State in a Program Graph

Fig. 2. Handling loops
$x_3 < 3$ will be found infeasible, thus guaranteeing termination of the loop along this path. Note that, along a path having $y_3 = 2$, the loop will be non-terminating for that path. In this case, Pinaka may not terminate. Function calls, including recursion, are handled in a similar fashion by inlining a call on-the-fly. Therefore, even though Pinaka provides an option of `--unwind NUM` to specify an unwinding limit, it does not mandate that a loop unwinding limit is specified. If a user-given unwinding limit is not sufficient to reach an assertion violation, it declares the program as `safe`, which may be unsound. To ensure soundness, we run it without any loop unwinding limit. For `unsafe` programs, upon encountering the first assertion violation, Pinaka terminates and reports a failure. For `safe` programs, however, Pinaka terminates only if all the paths of the program are terminating.

2 Architecture

Pinaka 0.1 is built upon the CProver + Symex framework\(^1\). Taking a C program as input, it makes use of CProver framework APIs to convert the input C program to a GOTO program. CProver APIs further come into play for pre-processing of GOTO-programs, witness generation, transformation passes such as setting the rounding-mode for floating-point operations, handling complex data types, etc. Pinaka implements PI and FI mode and eager infeasibility checks along with BFS/DFS exploration. Apart from DFS, none of those features are present in Symex \(^{10}\). Additionally, we make use of our forked version of the Symex repository in which we fix many bugs, especially for handling recursive procedures and ternary operators. As of now Pinaka only supports some MiniSAT-like solvers (i.e., Glucose \(^4\), MapleSAT \(^7\)) and not SMT solvers. Once a program has been verified, a verification successful/failed outcome is generated along with the appropriate witness.

![Architectural Overview of Pinaka](image)

3 Strengths and Weaknesses

Modulo the soundness of the CProver/Symex framework and the back-end solver, Pinaka’s technique is sound. In addition, if CProver/Symex do not have any over-approximation in modeling the C constructs, then a bug reported by Pinaka would indeed be a bug.

\(^1\) Note the specific Symex version used on which Pinaka is built
As explained in Section 1, Pinaka can potentially be non-terminating if for some input value there is a non-terminating path. However, termination of verification process guarantees the termination of the underlying program (modulo the approximations introduced in modeling by CProver/Symex) if the program is declared safe by Pinaka. A notable strength of Pinaka lies in its speed. A majority of Pinaka’s verification outcomes were obtained under a mere limit of 10 seconds. A clear display of the same can be seen in the ReachSafety-Floats category, where Pinaka came in second with 1500 seconds CPU time [9], as compared to other tools that share a similar score but require 4 to 10 times more CPU time.

One major weakness of the current version Pinaka is a lack of techniques for loop invariants. Even with eager infeasibility checks and incremental solving, there is still a need for more loop-directed abstraction based approaches. Furthermore, support for handling multi-dimensional arrays is still lacking.

4 Tool Setup and Configuration

Pinaka 0.1 is available for download at https://github.com/sbjoshi/Pinaka. The repository contains a description of Pinaka’s working along with all the necessary configuration files required to run Pinaka SVCOMP style. All the instructions are listed in a stepwise manner in the README.md file. Although Pinaka is built on top of the CProver/Symex framework, the binary itself is sufficient and the tool does not require any additional pre-requisites. Pinaka has been tested on Ubuntu 18.04.

Pinaka 0.1 submitted for SVCOMP 2019 runs DFS in PI Mode as for SVCOMP benchmarks we found this combination the best. No loop unwinding limit was specified to retain soundness. For SVCOMP'19 [11] it uses Glucose-Syrup (Glucose-4.1) [11] as its solver back-end. Tool’s default search strategy, i.e., DFS may be overridden by providing --bfs option. Similarly, a default of FI mode may also be overridden by providing --partial-incremental option. Other additional options may be explored from the --help menu. The set of global parameters passed to the tool are: (1) --graphml-witness: to specify the witness file to be generated, (2) --propertyfile: to specify the property file, (3) --32/--64: to define the architecture to be used. Pinaka 0.1 participated in all ReachSafety subcategories except ReachSafety-Sequentialized, and also participated in NoOverflows and Termination meta-categories in SVCOMP 2019.

5 Software Project and Contributors

Pinaka is a result of very heavy code rewriting and refactoring of VerifOx [8] (developed by Saurabh Joshi) with a lot of feature additions and bug fixes. Pinaka is developed at Indian Institute of Technology, Hyderabad, India. It is available at https://github.com/sbjoshi/Pinaka under BSD License. The authors acknowledge the financial support from DST, India under SERB ECR 2017 grant.
References

1. Beyer, D.: Automatic verification of C and Java programs: Sv-comp 2019. In: Proc. TACAS, part 3. LNCS 11429, Springer (2019)
2. Cprover homepage. http://www.cprover.org, last accessed 10 Feb 2019
3. Een, N., Sörensson, N.: Minisat v2.0 (beta). Solver description, SAT race 2006 (2006)
4. Glucose’s homepage. http://www.labri.fr/perso/lsimon/glucose/, last accessed 10 Feb 2019
5. Hooker, J.N.: Solving the incremental satisfiability problem. The Journal of Logic Programming 15(1-2), 177–186 (1993)
6. King, J.C.: Symbolic execution and program testing. Communications of the ACM 19(7), 385–394 (1976)
7. Maplesat homepage. https://sites.google.com/a/gsd.uwaterloo.ca/maplesat/, last accessed 10 Feb 2019
8. Mukherjee, R., Joshi, S., Griesmayer, A., Kroening, D., Melham, T.: Equivalence checking of a floating-point unit against a high-level C model. In: FM (2016)
9. SVCOMP 2019 results. https://sv-comp.sosy-lab.org/2019/results/results-verified/, last accessed 4 Jan 2019
10. Symex repository. https://github.com/diffblue/symex/tree/9b5a72cf992d29a005441f9d9fa8802379546e1b7, last accessed 10 Feb 2019