CPA-DF: A Tool for Configurable Interval Analysis to Boost Program Verification

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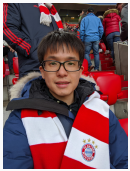

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SoSy-Lab Software Systems

CPA

Highlights of CPA-DF

- Use cases:
  - as a standalone verifier for C programs
  - as a **performance booster** in a portfolio-based verifier
- Contributions:
  - discovery of a new aspect of an existing component in CPAchecker [1]
  - large-scale evaluation
  - open-source data-flow analysis tool

Motivation

Cooperative

Invariant Injection [1]

k-induction

data-flow analysis
based on intervals

Motivation

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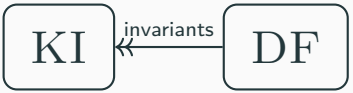
Invariant Injection [1]



k-induction

data-flow analysis based on intervals

vs.

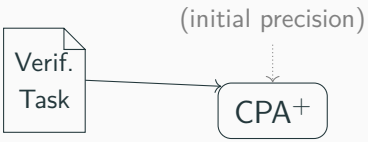
Non-cooperative

Parallel Execution

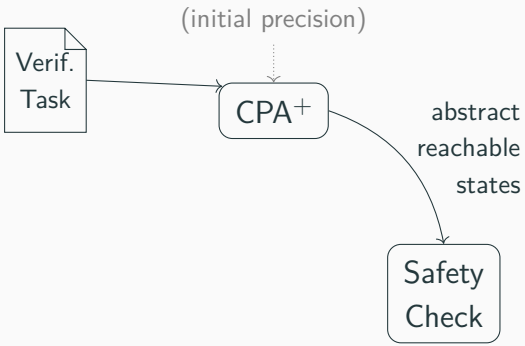
Configurable Progam Analysis using Interval Expressions

- Interval CPA $\mathbb{I}$
  - Abstract domain: *var* $\mapsto$ *interval expression*
    - E.g. $[l_1, u_1] \cup [l_2, u_2]$
  - Precision
    - Important variables: merge allowed only if expressions match on them
    - Widening [4]: whether to further relax an abstraction
- CPA$^+$ [2]: a reachability algorithm exploring abstract states

Interval Analysis with Precision Refinement



Interval Analysis with Precision Refinement



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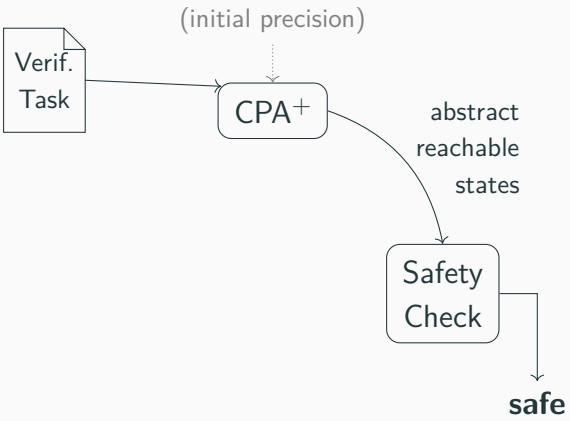

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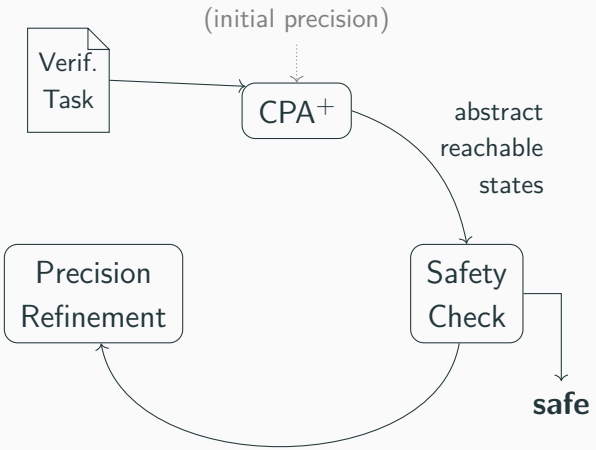
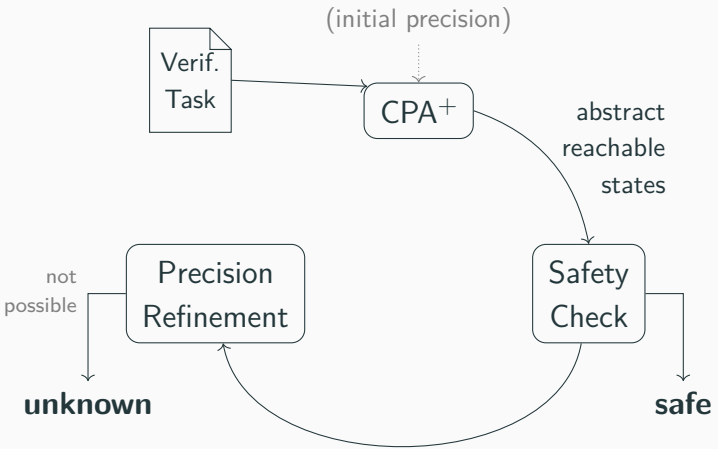
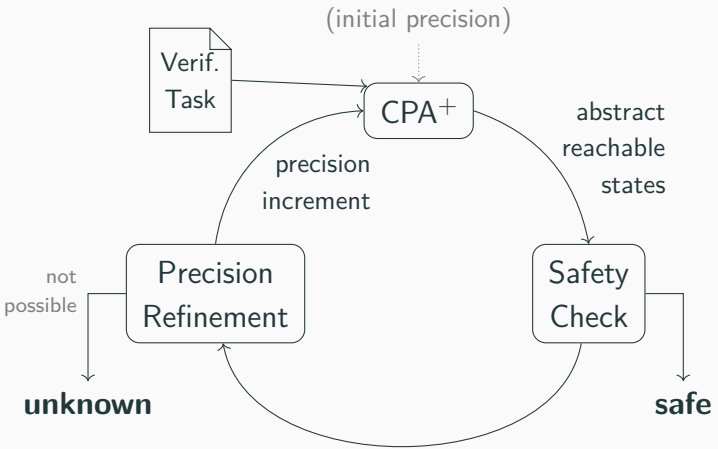


Interval Analysis with Precision Refinement



Interval Analysis with Precision Refinement



Evaluation

We conducted experiments to answer the following research questions:

- **RQ1:** How is KI || DF compared to KI⟲DF in CPAchecker?
- **RQ2:** Can CPA-DF complement other verifiers in a parallel portfolio?

Benchmark Tasks and Tools

- 6386 ReachSafety tasks from SV-COMP '23 benchmark set
  - all safe, i.e. without known property violation
- Top contenders from SV-COMP '23
  - CPAchecker [3]: DF, KI, KI || DF, KI ⇢ DF
  - Esbmc [5]
  - Symbiotic [6]

Experimental Setup

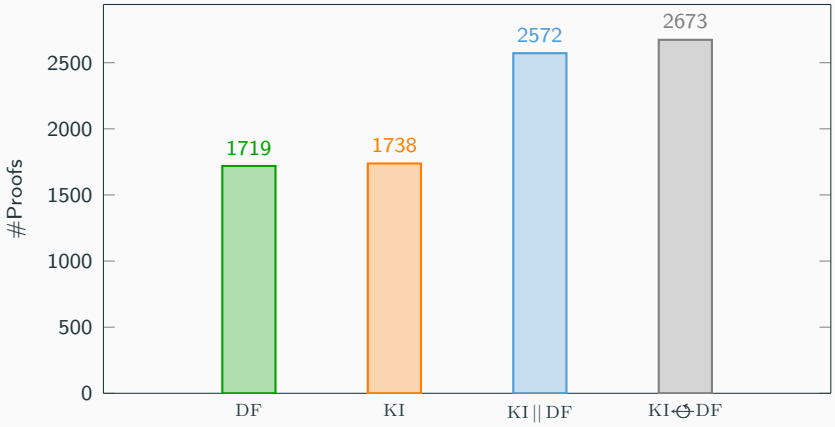
- OS: Ubuntu 22.04 (64 bit)
- Machine: 3.4 GHz CPU (8 cores) and 33 GB of RAM
- Each task is limited to
  - 4 CPU cores
  - 15 min of CPU time
  - 15 GB of RAM

  (reliable resource management by BenchExec[1])

[1] `https://github.com/sosy-lab/benchexec`

RQ1: How is KI || DF compared to KI⟲DF in CPAchecker?

Parallel Portfolio vs. Invariant Injection

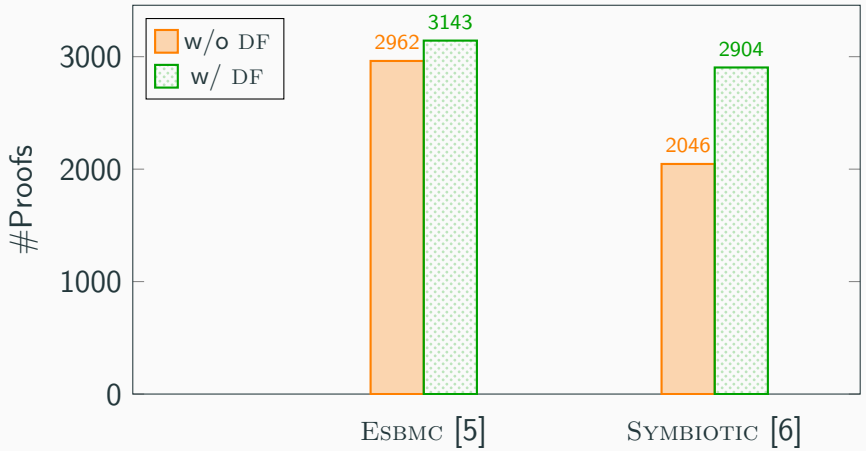


Overall Statistics of KI || DF vs. KI⇜DF

Algorithm	DF	KI	KI || DF	KI⇜DF
Correct proofs	1719	1738	2572	2673
Wrong proofs	0	0	0	**15**
Unknowns	6537	6277	5472	5356

RQ2: Can CPA-DF complement other verifiers in a parallel portfolio?

Boosting Program Verification with CPA-DF



Conclusion

- CPA-DF: a data-flow analysis tool based on interval expressions
- In our evaluation,
  - running CPA-DF in parallel to KI achieved a comparable performance as running them cooperatively, and
  - CPA-DF complemented the other well-established verifiers well and boosted the overall performance.

For more info., visit:

www.sosy-lab.org/research/cpa-df/

References i

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