Block Abstraction Memoization with Copy-On-Write Refinement

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Introduction

Basic Problem with Software Verification

Problem:

- computation of abstract state space *at once* is expensive

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- split into smaller problems and solve them separately
- use a *cache* for intermediate results

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Benefits of BAM:

- implemented as top-level CPA
- independent of sub-analysis (PA, VA, IA,... and combinations)
- modular approach: optimization and heuristics

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Basics of BAM: Structure and Components

CFA divided into *blocks*

- functions or loops as block size
- block size defines entry and exit nodes

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BAMCPA

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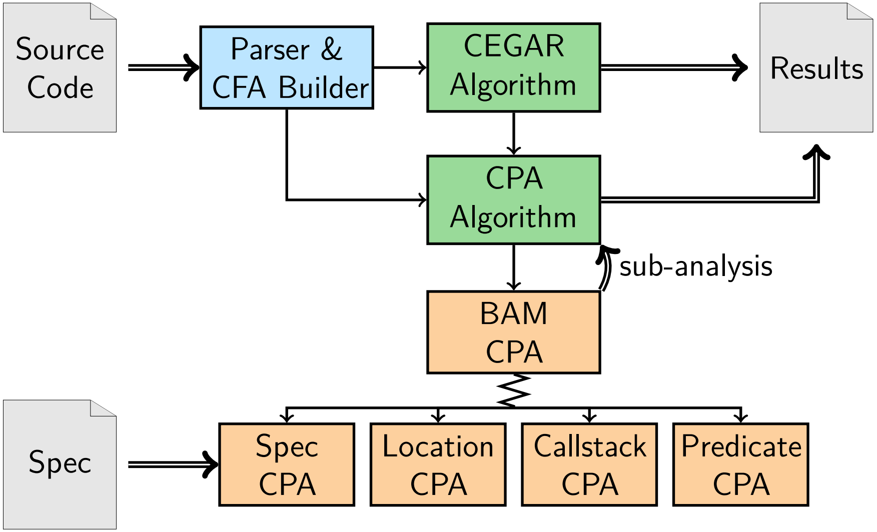
Combine with other components:

- CEGAR: specialized refinement (over several ARGs)
- Exporter: ARG & Graphml

Introduction

Overview of the CPAchecker Framework



CEGAR with Lazy Refinement

- spurious error path found $\rightarrow$ refinement procedure
  $\rightarrow$ determines a new precision and a cutpoint
  $\rightarrow$ only a "minimal" part of the ARG is remove

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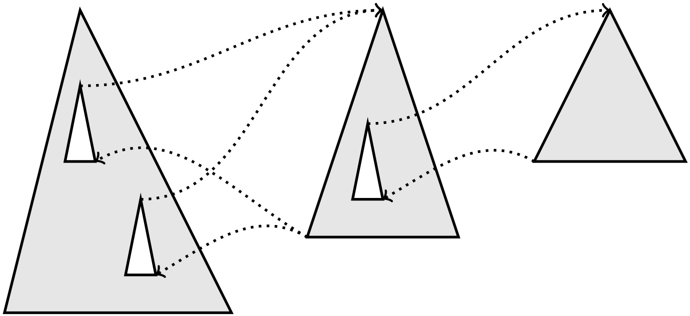
BAM Refinement

- determine precision and cutpoint over several nested ARGs
- depends only on underlying analysis
- refine the "minimal" set of ARGs
- several heuristics:
  - refine *one*, *all*, or *some* ARGs along error-path
  - merge precisions from different sources

CEGAR with Lazy Refinement

Default state space exploration in BAM with refinement, refinement applied with an *in-place* update of the ARG



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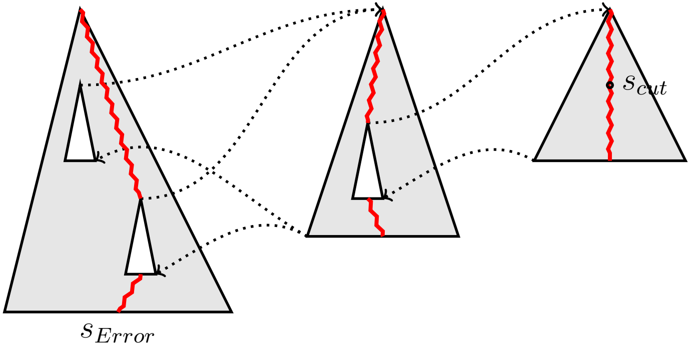

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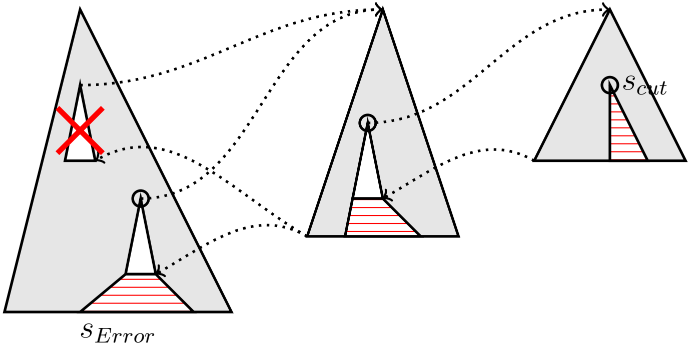

Problem: Repeated Counterexamples

What is a *repeated counterexample*?

- an error path cannot be excluded from repeated exploration
- cycles of error paths (and refinements)

  $\rightarrow$ no progress in CEGAR

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Observation

- problem mostly appears with "big" programs, e.g. with many blocks and several refinements
- small changes in programs cause large differences in runtime of BAM

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Manual analysis shows *possible reasons*

- deleting block abstractions (*holes* in the ARG)
- imprecise caching (aggressive caching) $\rightarrow$ heuristics
- imprecise reducer (Predicate Analysis) $\rightarrow$ heuristics

Problem: Repeated Counterexamples

The old Approach

And after the refinement?

- start exploration again
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  $\rightarrow$ precision for a missing block?
  $\rightarrow$ re-compute nested blocks or take from cache?
- exporting incomplete data (witnesses, ARGs, statistics)

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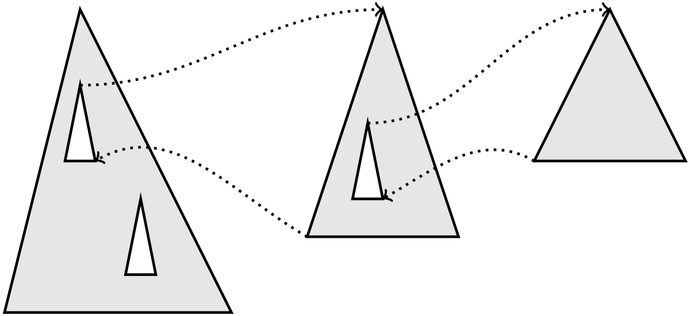
Idea: do not delete computed block abstractions

Improved Refinement Strategy

Use *Copy-on-Write* for Updates of the ARG



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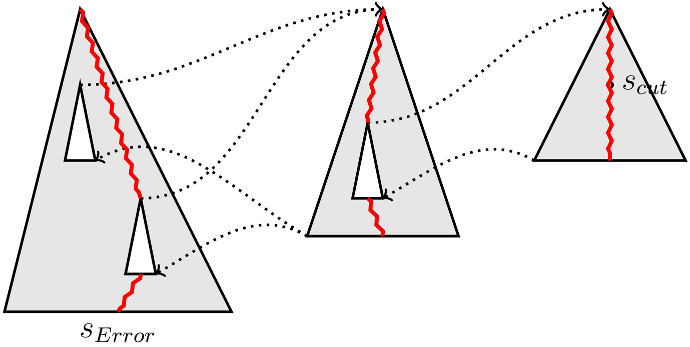

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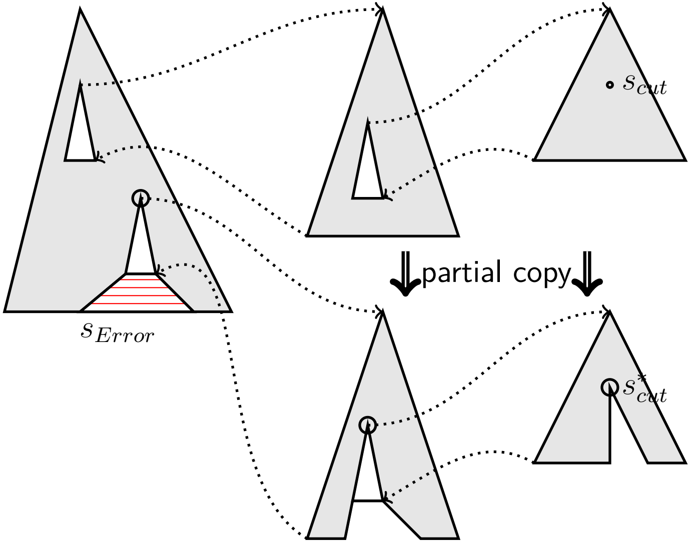

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Use *Copy-on-Write* for Updates of the ARG

Computational overhead?

- old approach: removing a subtree needs $O(N)$ time
- new approach: copying a subtree needs $O(N)$ time
- only small increase in memory consumption:
  $\rightarrow$ *flat copy* of ARG states

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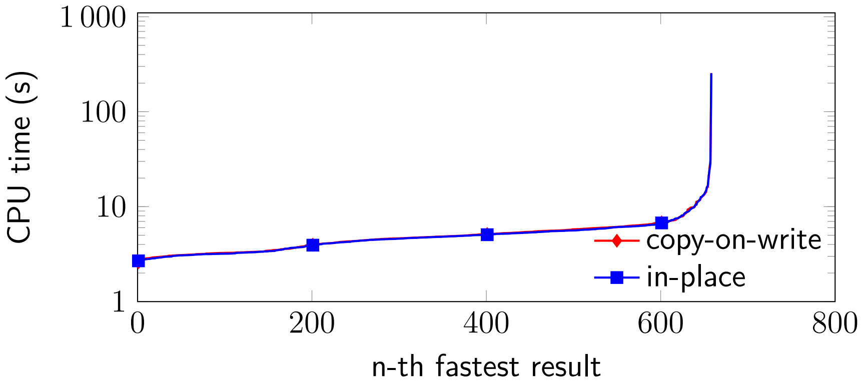
More benefits

- no need to re-computate deletes blocks
- *all* information available at end of analysis
- immutable ARGs (after finished sub-analysis)

Evaluation (<=1 refinements)

Runtime of refinement approaches of BAM with predicate analysis

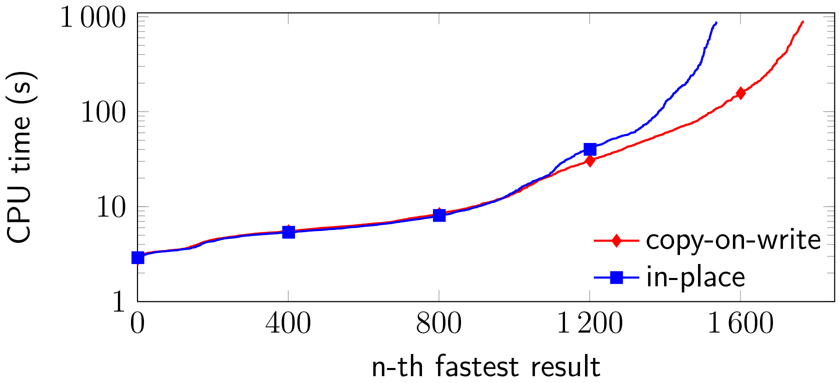
tasks with up to one refinement → no difference expected!



Evaluation (>1 refinements)

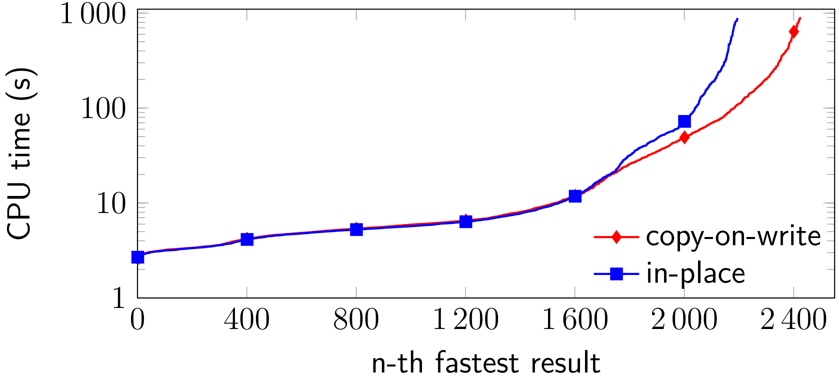
Runtime of refinement approaches of BAM with predicate analysis

tasks with more than one refinement



Evaluation (<=1 and >1 refinements combined)

Runtime of refinement approaches of BAM with predicate analysis



Conclusion

Current status:

- works for most tasks
- slower on some tasks, faster on more tasks
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Future work:

- some heuristics might no longer be beneficial
- new: choose from several cache-entries for the same key?
- merge into trunk, maybe soon :-)