Domain-Independent Multi-threaded Software Model Checking

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Software Verification

C Program

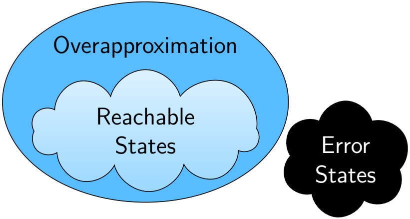
```
int main() {
    int a = foo();
    int b = bar(a);

    assert(a == b);
}
```

Verification Tool

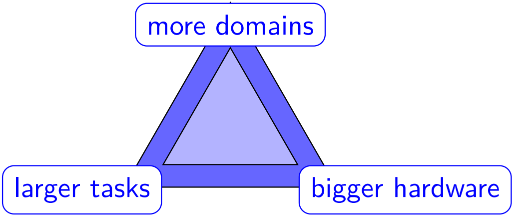
TRUE
i.e., specification is satisfied

FALSE
i.e., bug found

General method:
Create an overapproximation of the program states / compute program invariants



Basic Challenges with Software Verification



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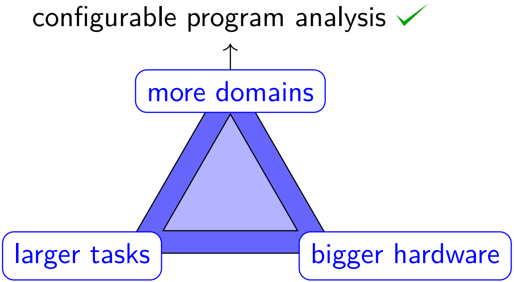

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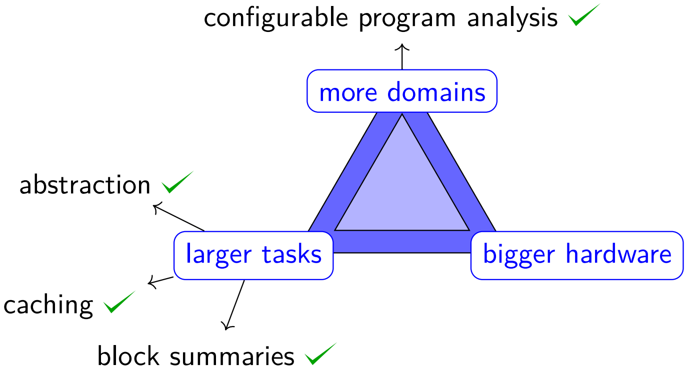

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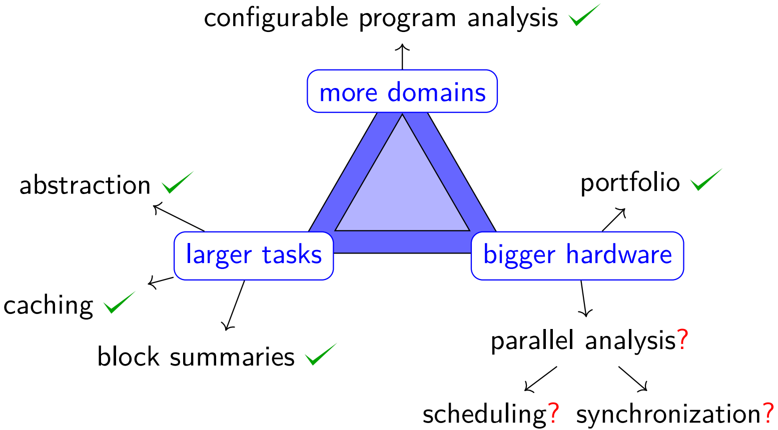

Configurable Program Analysis (CPA)

[Beyer/Henzinger/Théoduloz, 2007]

- CPA algorithm computes a fixed-point based on two sets of abstract states
  - *reached*: already analyzed abstract states
  - *waitlist*: frontier states to be analyzed

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  - *merge*: combination of two abstract states
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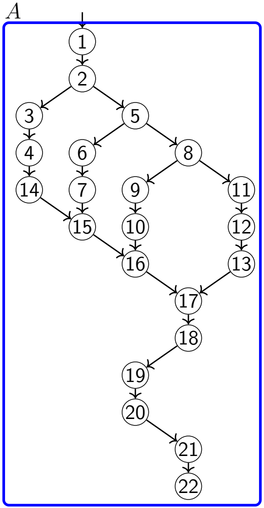
X Operators strictly sequential (per analysis!)

Schematic Example of an Analysis



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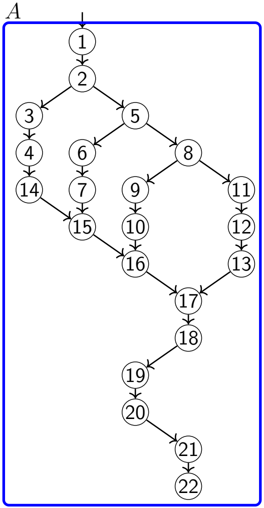
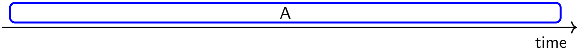


plain analysis



Block Summarization

- Block-abstraction memoization (BAM) defined as CPA [Wonisch/Wehrheim, 2012]
- Split large verification task into smaller problems and solve them separately
- Use CPA algorithm for a domain-specific analysis
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\+ Nearly independent analyses for blocks

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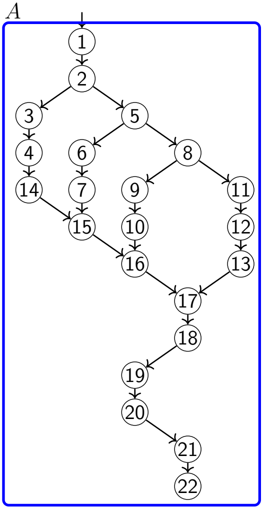

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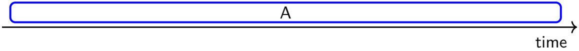

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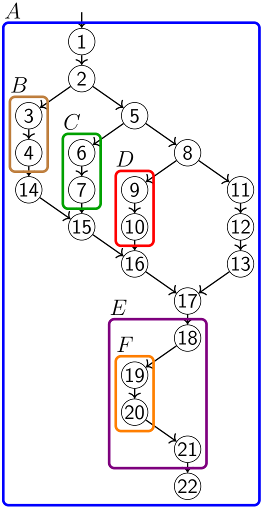

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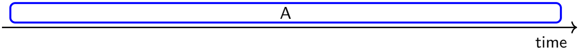

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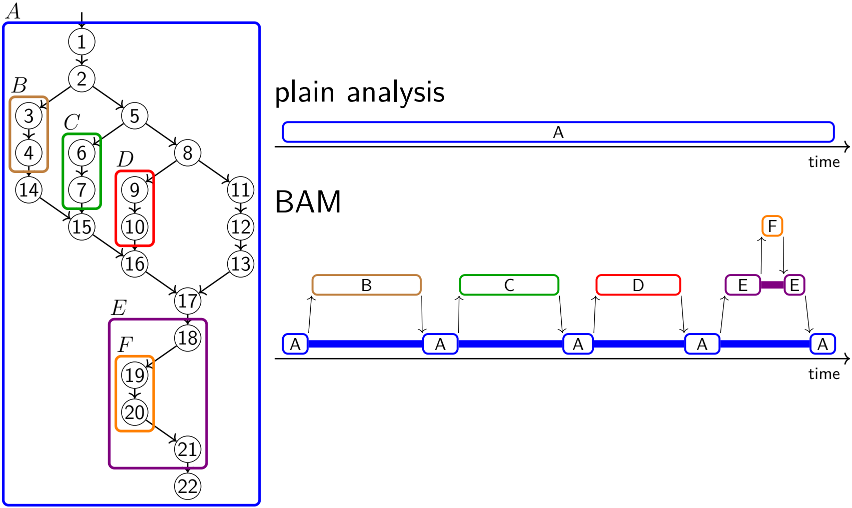

Parallel Block-Abstraction Memoization

Our contribution: Parallel BAM [Proc. ASE 2018]

- Continue with CPA algorithm (non-empty waitlist!) while asynchronously computing block abstractions
- Lazy application of computed block abstractions
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✓ Small synchronization overhead (depends on block size)

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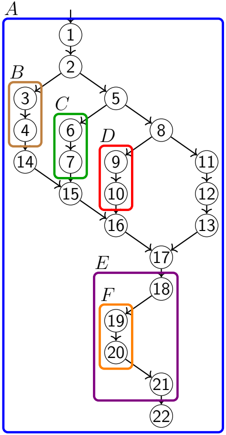

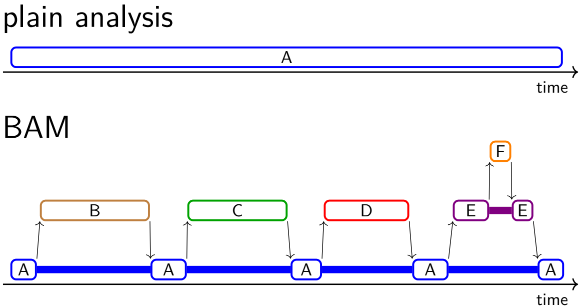

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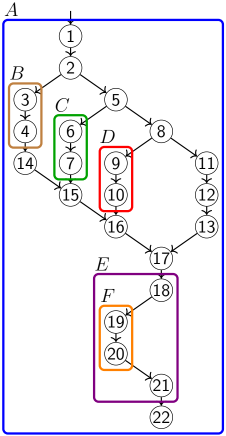

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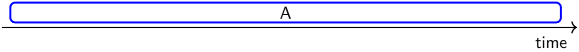
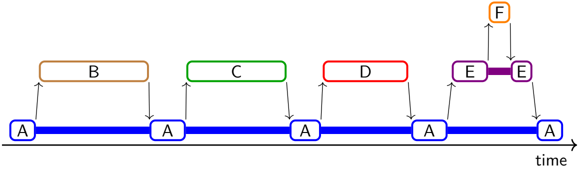
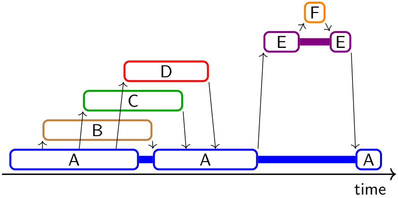


BAM



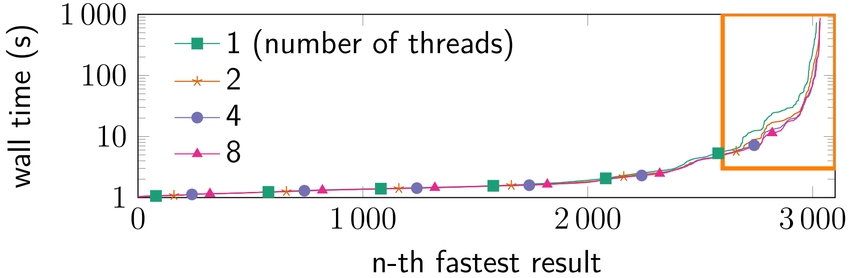
parallel BAM



Evaluation

- Configuration
  - CPAchecker `r28809`
  - Explicit Value Domain
- Environment
  - Intel Xeon E3-1230 v5 CPU with 4 physical cores
  - 5400 tasks from SV-COMP benchmark set
- Limitations
  - 15 GB RAM
  - 15 minutes

Evaluation



wall time (s)
1 000
100
10
1
1 (number of threads)
2
4
8
0
1 000
2 000
3 000
n-th fastest result

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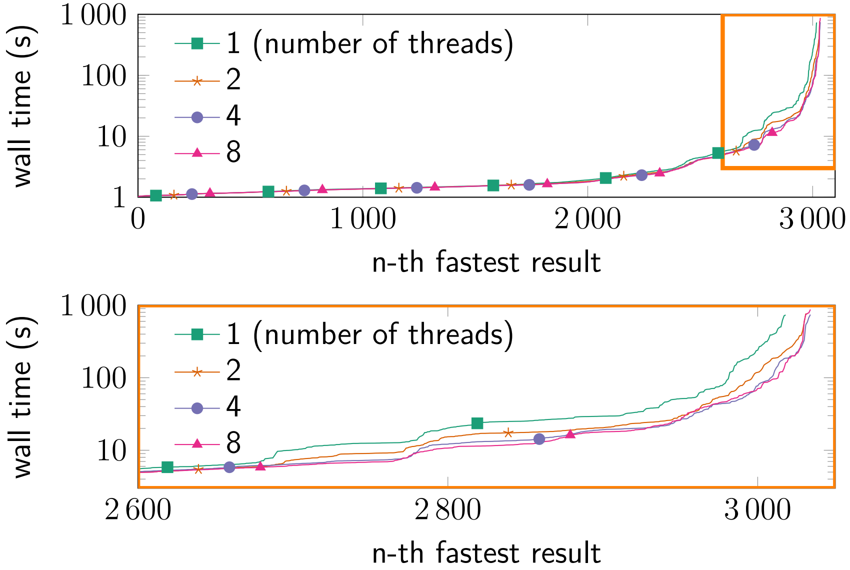

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Conclusion

- Small overhead for synchronization in parallel analysis
- Elegant integration into the framework CPAchecker
- No changes necessary to existing analyses and concepts
  - Small refactoring on implementation if necessary
  - CEGAR, proof and counterexample witnesses

Hints for developers

CPA operators are applied in parallel
(on different reached sets and waitlists)

- CPA operators should be *stateless*
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Statistics are *data*!

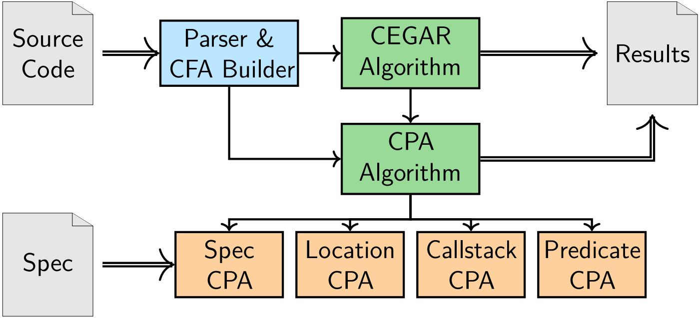
- Often shared across several components
- Allow concurrent access!

Future work

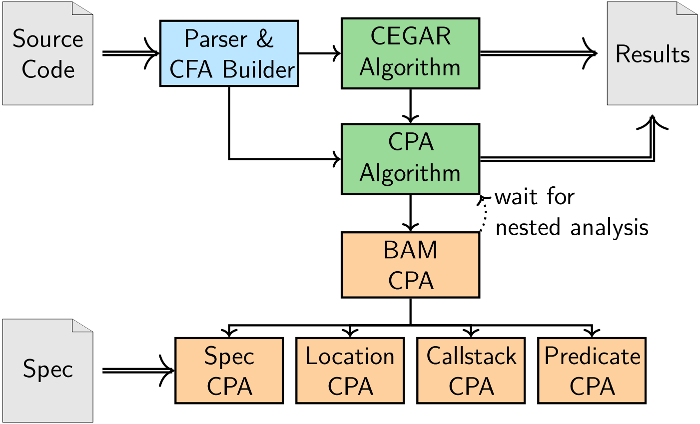
- Scheduling/iteration order:
  - Prefer parts deeper in the program
  - Depending on machine load?
- Processes instead of threads
  - Cluster instead multi-core machine
  - Easier handling of external libraries
- Support more domains
  - Mostly simple refactoring, only a few *hard* changes
  - Dependencies, e.g., on external libraries like SMT solvers

Questions? Discussion?

CPAchecker Framework



BAM in CPAchecker



Parallel BAM in CPAchecker