Modular Model Checking (Frameworks)

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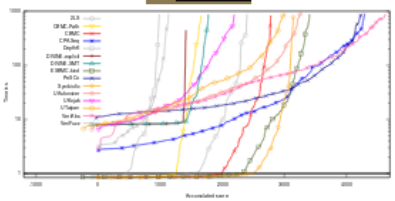
Insights from Software Model Checking

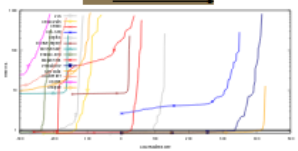
- Verifiers have different strengths
- There are plenty of tools
- $\Rightarrow$ Cooperative Verification Approaches

Different Strengths

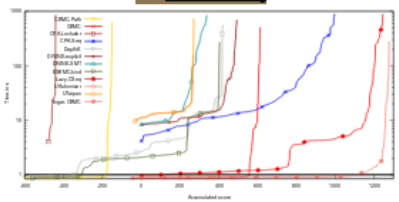
ReachSafety
1. VeriAbs
2. CPA-Seq
3. PeSCo



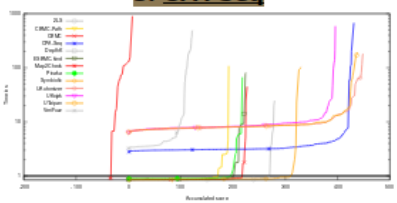
MemSafety
1. Symbiotic
2. PredatorHP
3. CPA-Seq



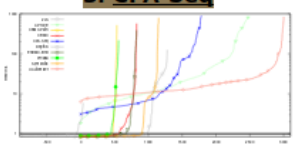
ConcurrencySafety
1. Yogar-CBMC
2. Lazy-CSeq
3. CPA-Seq



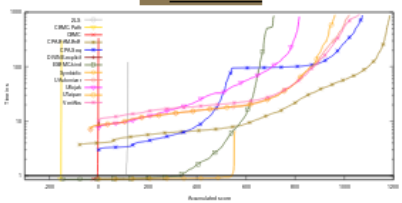
NoOverflows
1. UAutomizer
2. UTaipan
3. CPA-Seq



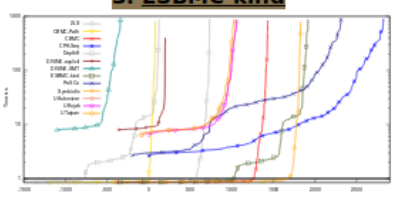
Termination
1. UAutomizer
2. AProVE
3. CPA-Seq



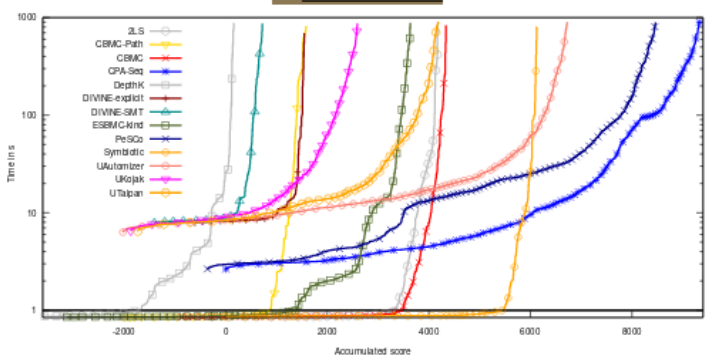
SoftwareSystems
1. CPA-BAM-BnB
2. CPA-Seq
3. VeriAbs



FalsificationOverall
1. CPA-Seq
2. PeSCo
3. ESBMC-kind



Overall
1. CPA-Seq
2. PeSCo
3. UAutomizer



https://sv-comp.sosy-lab.org/2019/results

Different Techniques

Participant	CEGAR	Predicate Abstraction	Symbolic Execution	Bounded Model Checking	k-Induction	Property-Directed Reach.	Explicit-Value Analysis	Numeric. Interval Analysis	Shape Analysis	Separation Logic	Bit-Precise Analysis	ARG-Based Analysis	Lazy Abstraction	Interpolation	Automata-Based Analysis	Concurrency Support	Ranking Functions	Evolutionary Algorithms
2LS				✓	✓			✓			✓						✓	
AProVE			✓				✓	✓		✓	✓						✓	
CBMC				✓							✓					✓		
CBMC-Path				✓							✓					✓		
CPA-BAM-BnB	✓	✓					✓				✓	✓	✓	✓				
CPA-Lockator	✓	✓					✓				✓	✓	✓	✓		✓		
CPA-Seq	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓		✓	✓	
DepthK				✓	✓						✓					✓		
DIVINE-explicit							✓				✓					✓		
DIVINE-SMT							✓				✓					✓		
ESBMC-kind				✓	✓						✓					✓		
JayHorn	✓	✓				✓		✓					✓	✓				
JBMC				✓							✓					✓		
JPF				✓			✓	✓			✓					✓		
Lazy-CSeq				✓							✓					✓		
Map2Check				✓							✓							
PeSCo	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓		✓	✓	
Pinaka			✓	✓							✓							
PredatorHP									✓									
Skink	✓						✓							✓	✓			
Smack	✓			✓		✓					✓		✓			✓		
SPF			✓						✓							✓		
Symbiotic			✓					✓			✓							
UAutomizer	✓	✓									✓		✓	✓	✓		✓	
UKojak	✓	✓									✓		✓	✓				
UTaipan	✓	✓									✓		✓	✓	✓			

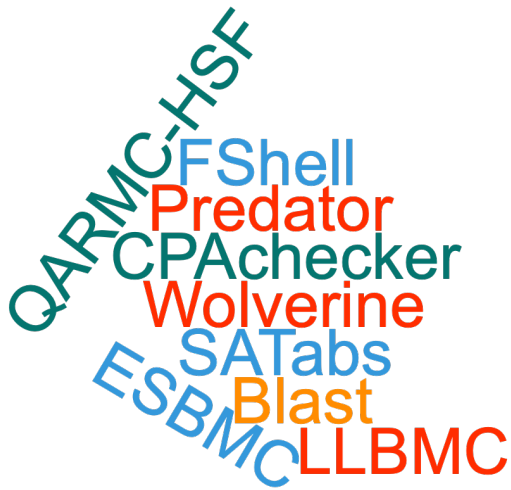
Competition Report [1]

https://doi.org/10.1007/978-3-030-17502-3_9

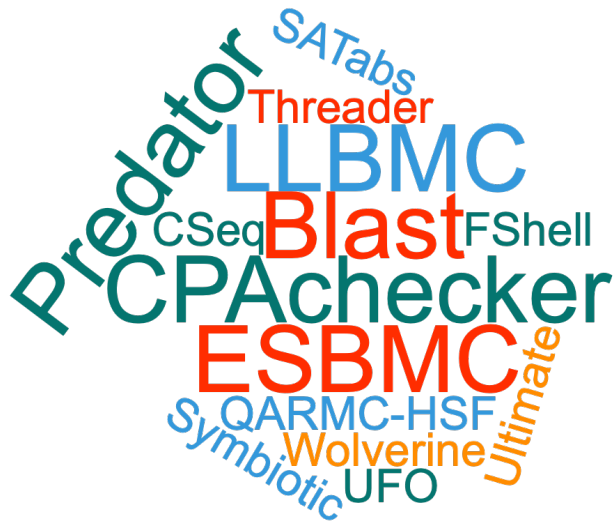
Plenty of Verifiers

- Lots of engines available

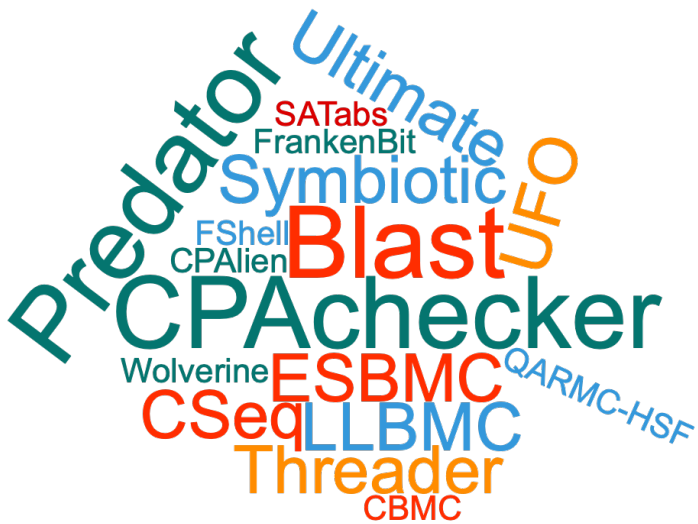
SV-COMP (Automatic Tools 2012)



SV-COMP (Automatic Tools 2013, cumulative)

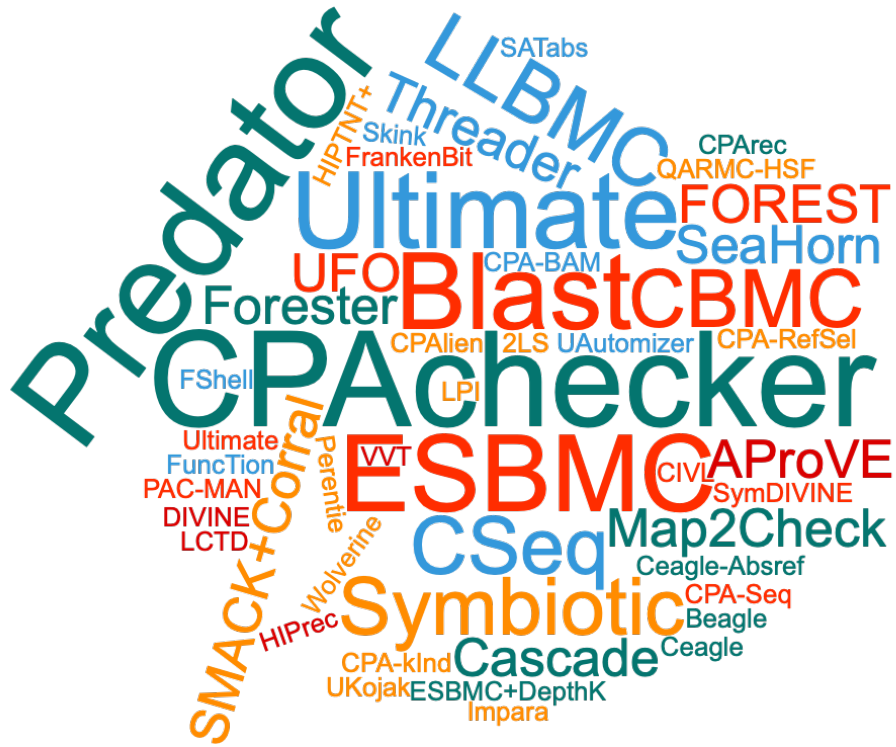


SV-COMP (Automatic Tools 2014, cumulative)

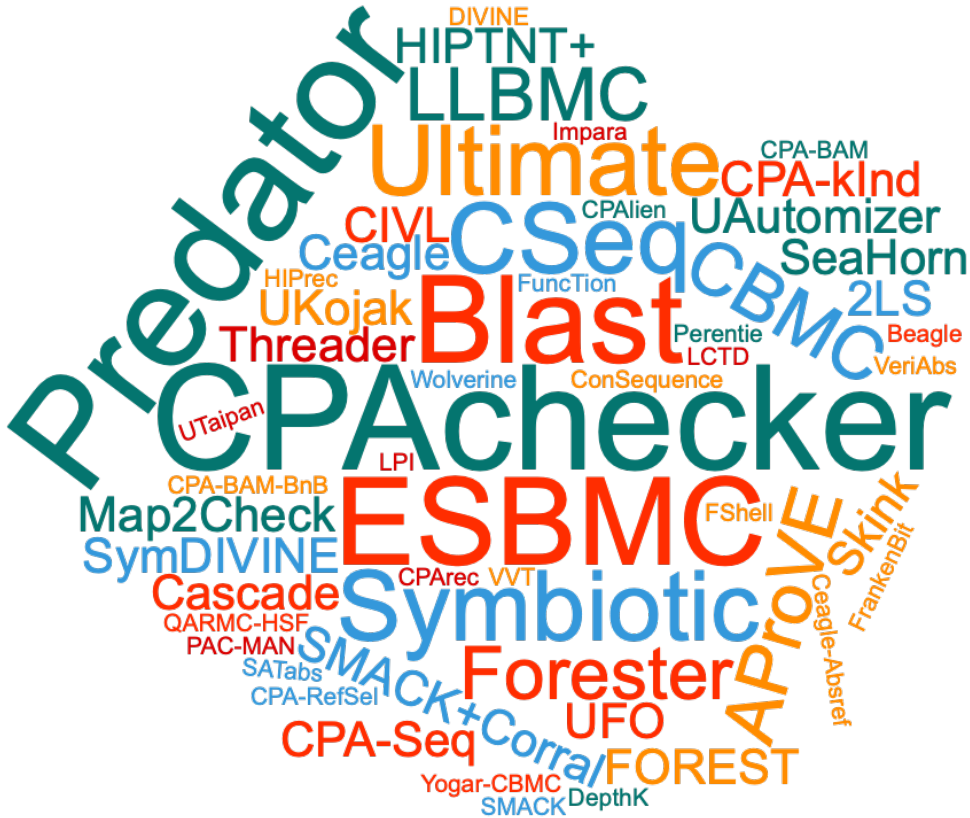


SV-COMP (Automatic Tools 2015, cumulative)

SV-COMP (Automatic Tools 2016, cumulative)

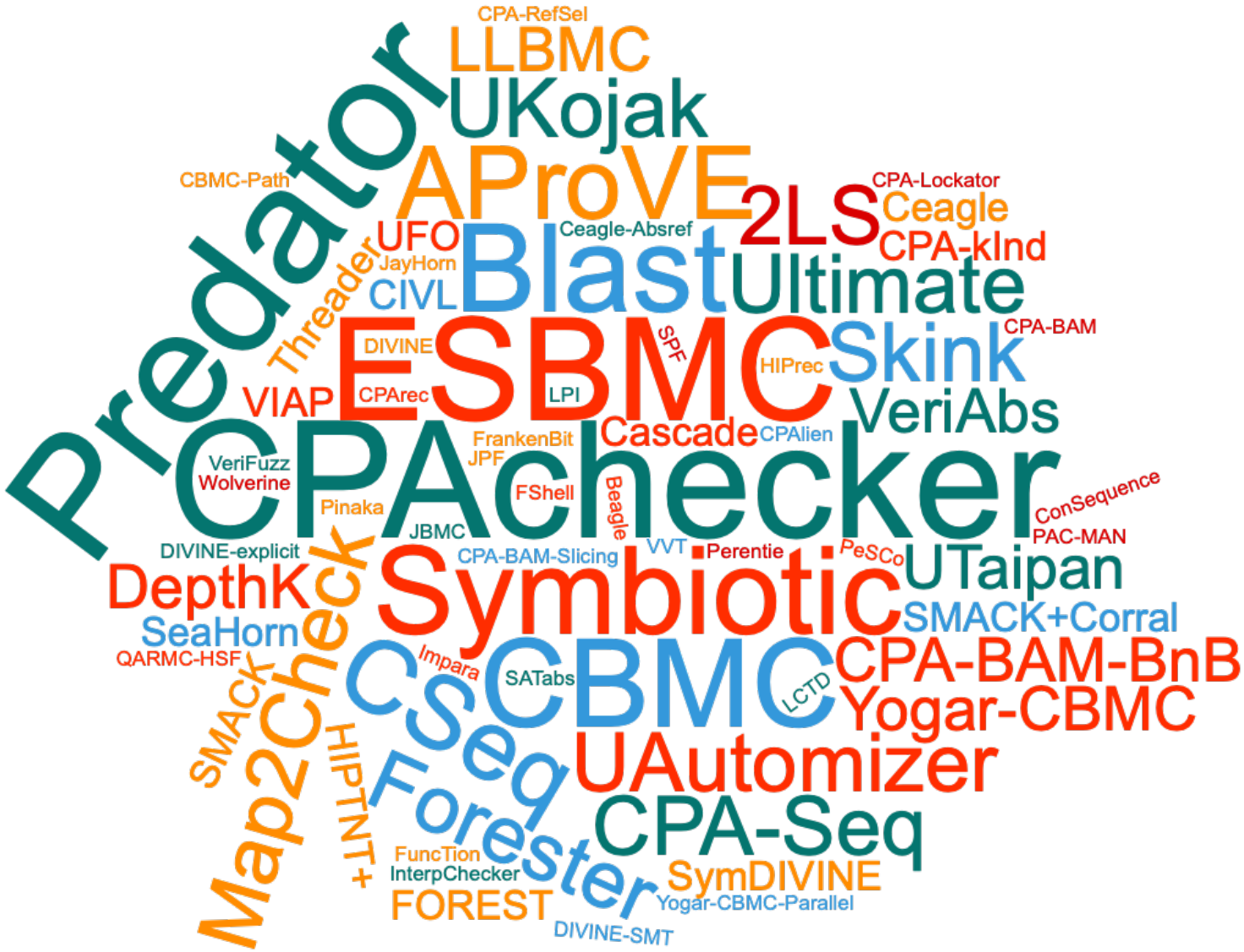


SV-COMP (Automatic Tools 2017, cumulative)



SV-COMP (Automatic Tools 2018, cumulative)

SV-COMP (Automatic Tools 2019, cumulative)



Cooperative Verification — Why?

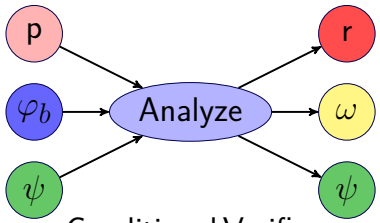
- Lots of engines available:
  Different strengths
- Exchange of results:
  Conditions, witnesses, test suites
- Great potential to increase expressive power by combining strengths

$\Rightarrow$ Step back — Think big!

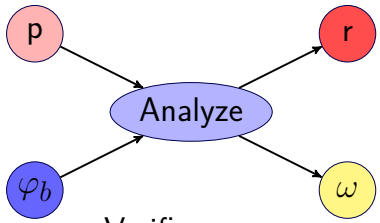
Cooperative Verification — Think big!

- Introduce a new level!
- Current tools are "low level" components (engines)
- Construct combinations
- Clear Interfaces
  via, e.g., Conditions, Witnesses, Test Suites

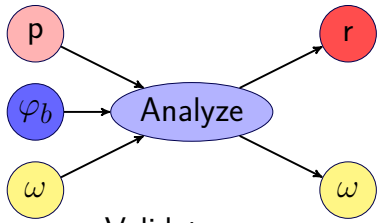
Graphical Visualization of the Coop Framework



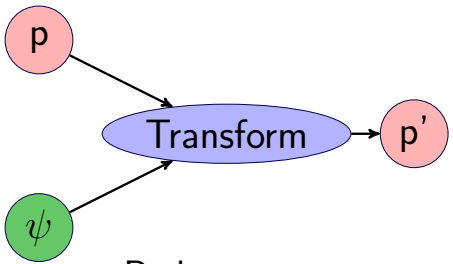
Conditional Verifier



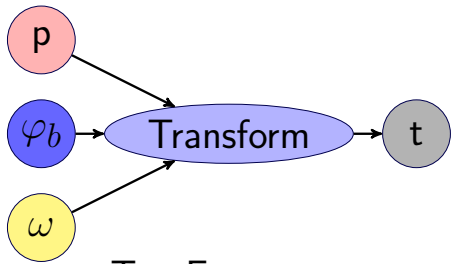
Verifier



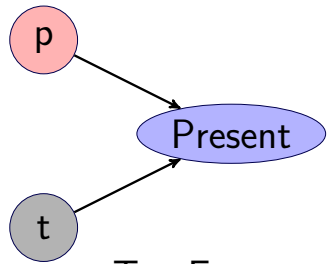
Validator



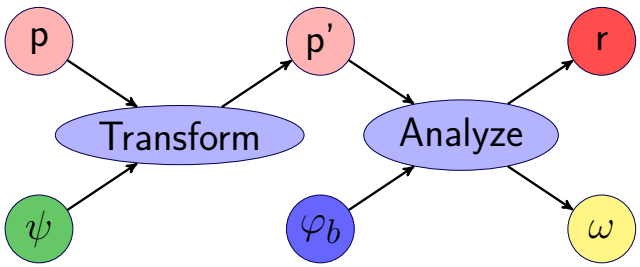
Reducer



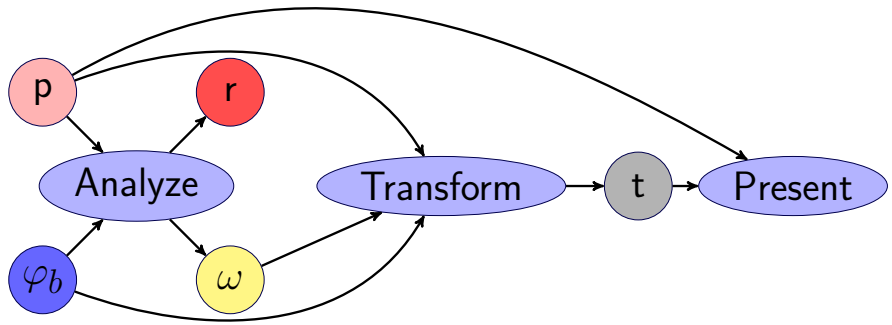
Test Extractor



Test Executor



Conditional Verifier constructed from Reducer and Verifier



Execution-Based Validation constructed from Verifier, Test Extractor, and Test Executor

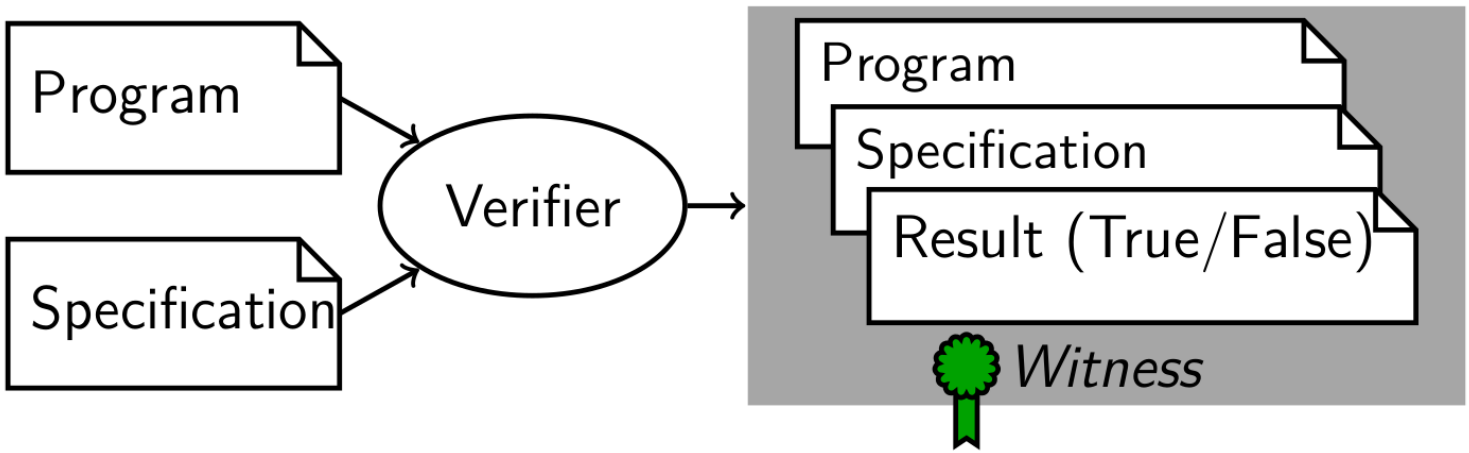
[16, Proc. ISOLA]

Cooperative Verification

Combination language and tool:
CoVeriTeam [11, Proc. TACAS 2022]
Requires interfaces!
Exchange objects!

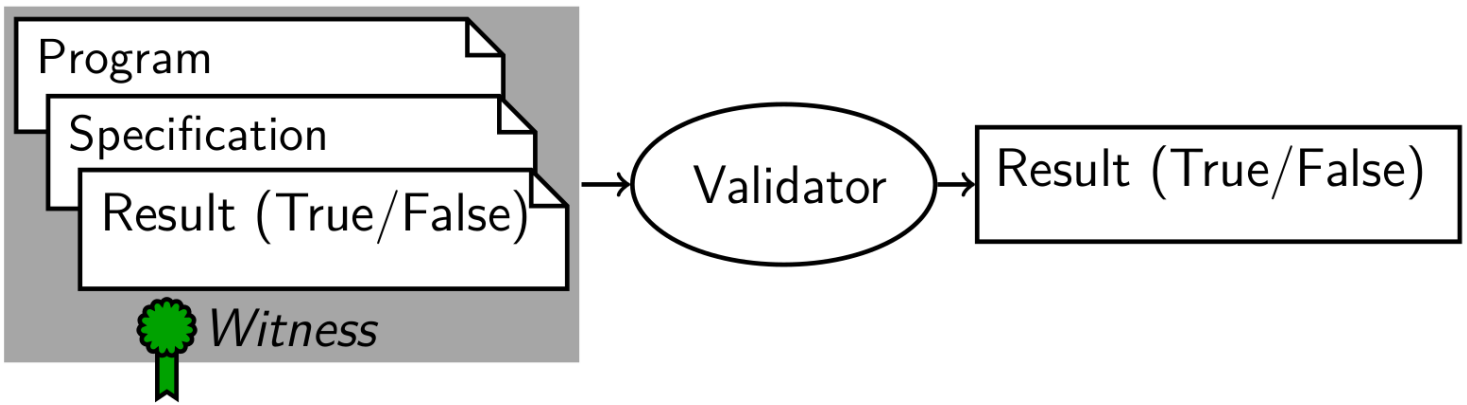
Exchange Formats for Results

Software Verification with Witnesses



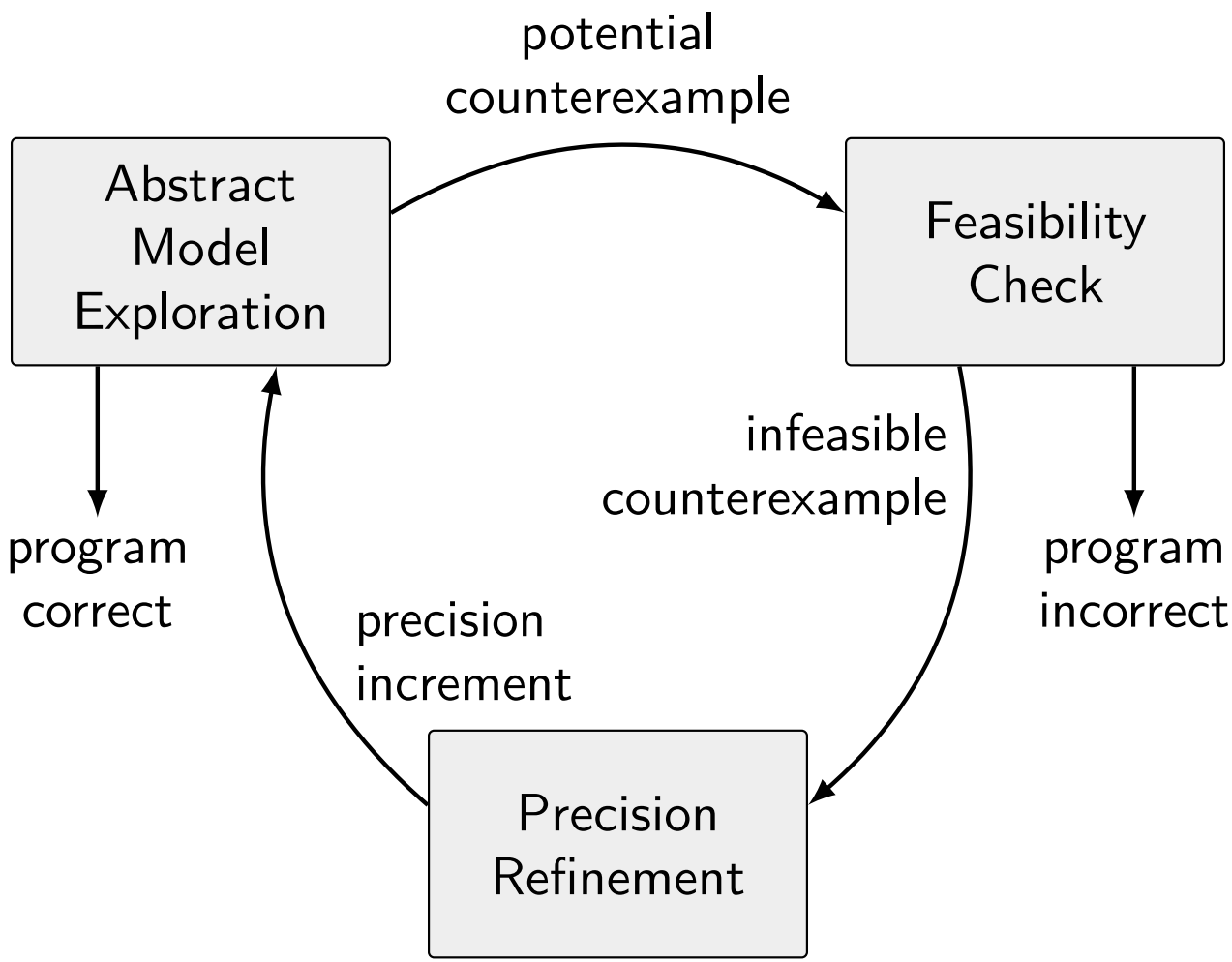
[5, Proc. FSE 2015][4, Proc. FSE 2016]

Witness Validation



- Validate untrusted results
- Easier than full verification

CEGAR

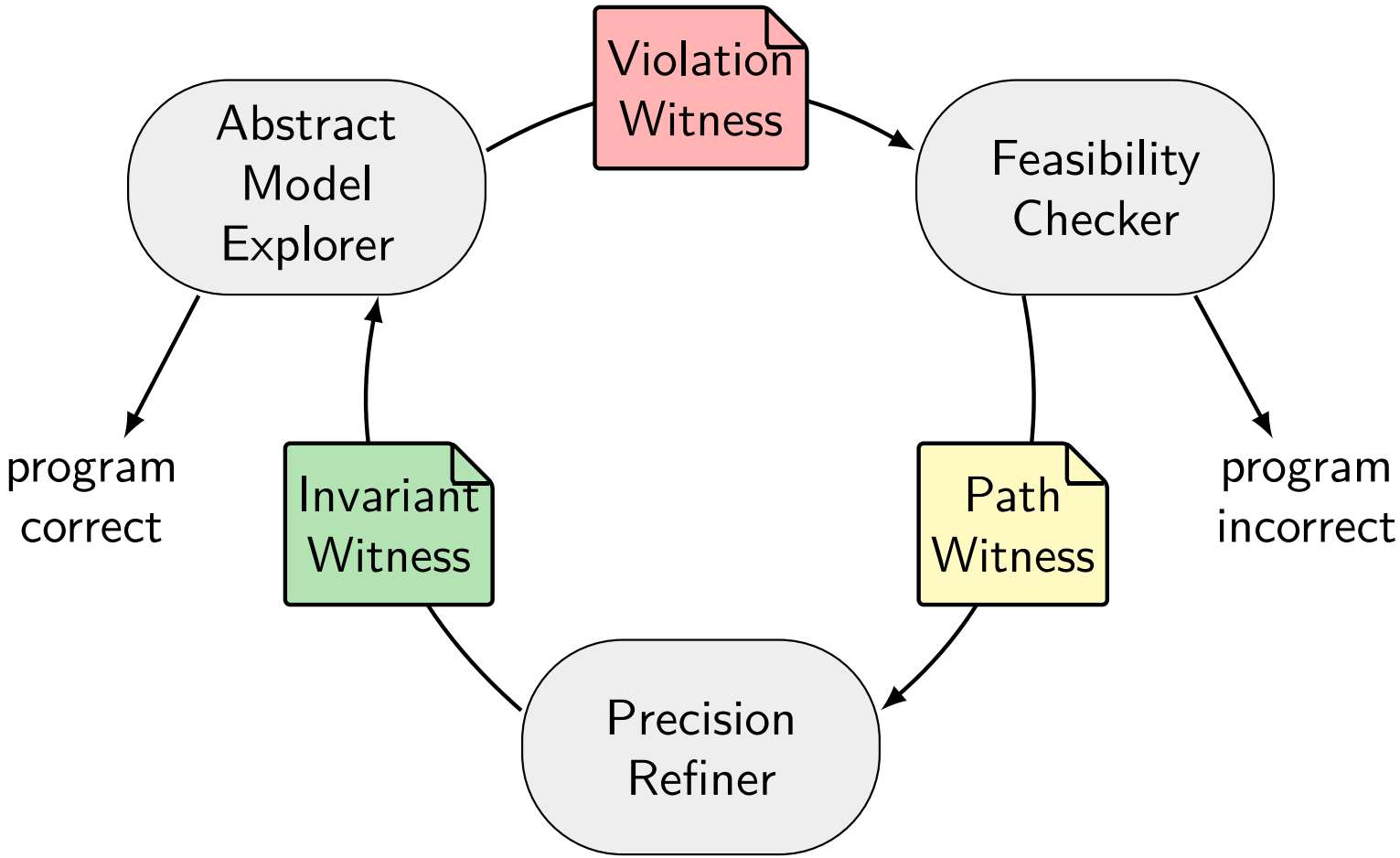

potential
counterexample
Abstract
Model
Exploration
Feasibility
Check
infeasible
counterexample
program
correct
program
incorrect
precision
increment
Precision
Refinement

Modularization of CEGAR

- CEGARdefines I/O interfaces
- But instances not exchangeable
- Aim: generalize CEGAR, allow exchange of components

$\Rightarrow$ Modular reformulation

Workflow of modular CEGAR



[8, Proc. ICSE 2022]

Software Verification Framework CPAchecker

[12, Proc. CAV]

- Included Concepts:
  - CEGAR [18]
  - Interpolation [14, 7]
  - Adjustable-block encoding [13]
  - Conditional model checking [9]
  - Verification witnesses [5, 4]
  - Various abstract domains: predicates, intervals, BDDs, octagons, explicit values
- Available analyses approaches:
  - Predicate abstraction [2, 13, 10, 15]
  - Impact algorithm [20, 17, 7]
  - Bounded model checking [19, 7]
  - k-Induction [6, 7]
  - IC3/Property-directed reachability [3]
  - Explicit-state model checking [14]
  - Interpolation-based model checking

Conclusion

- Combinations and Cooperation
- CPAchecker as framework

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