Verification Artifacts in Cooperative Verification

Survey and Unifying Component Framework

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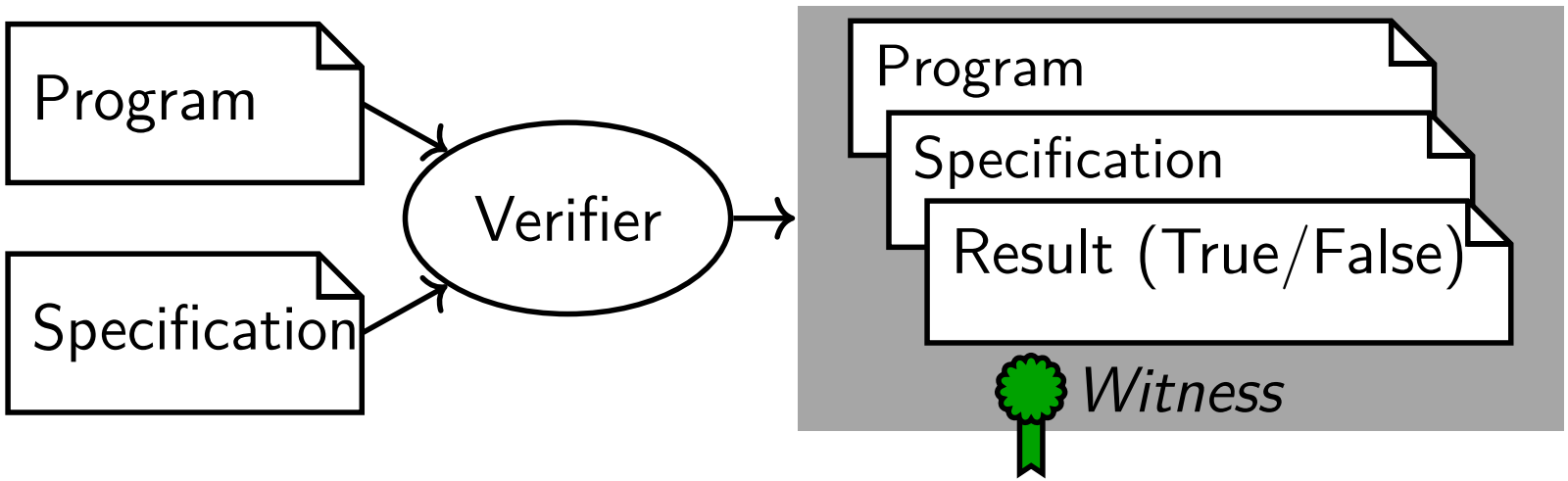
Automatic Software Verification



Competitions in Software Verification and Testing

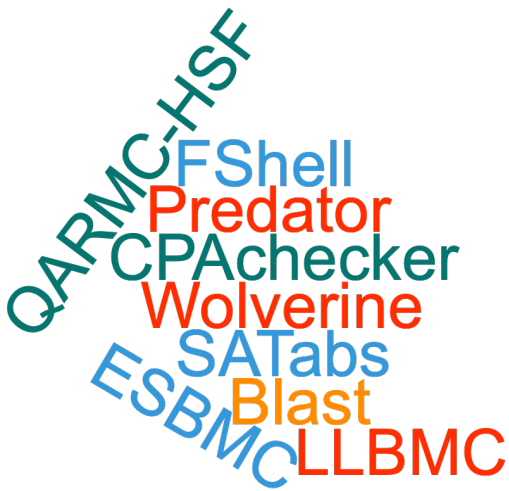
Many verification tools exist, and there are tool competitions:

- RERS: off-site, tools, free-style [16]
- SV-COMP: off-site, automatic tools, controlled [1]
- Test-Comp: off-site, automatic tools, controlled [3]
- VerifyThis: on-site, interactive, teams [17]

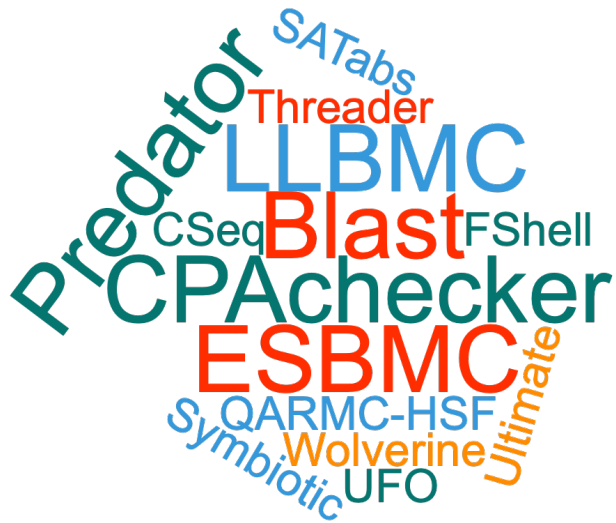
(alphabetic order)

SV-COMP (Automatic Tools 2012)

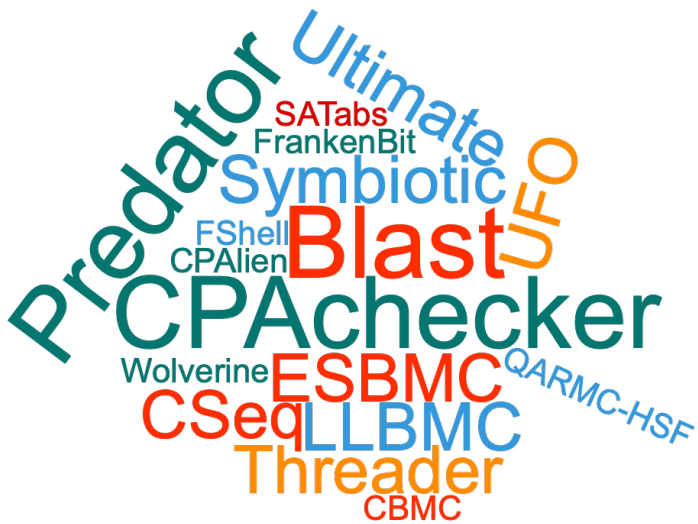
There is an increasing number of verification tools:



SV-COMP (Automatic Tools 2013, cumulative)

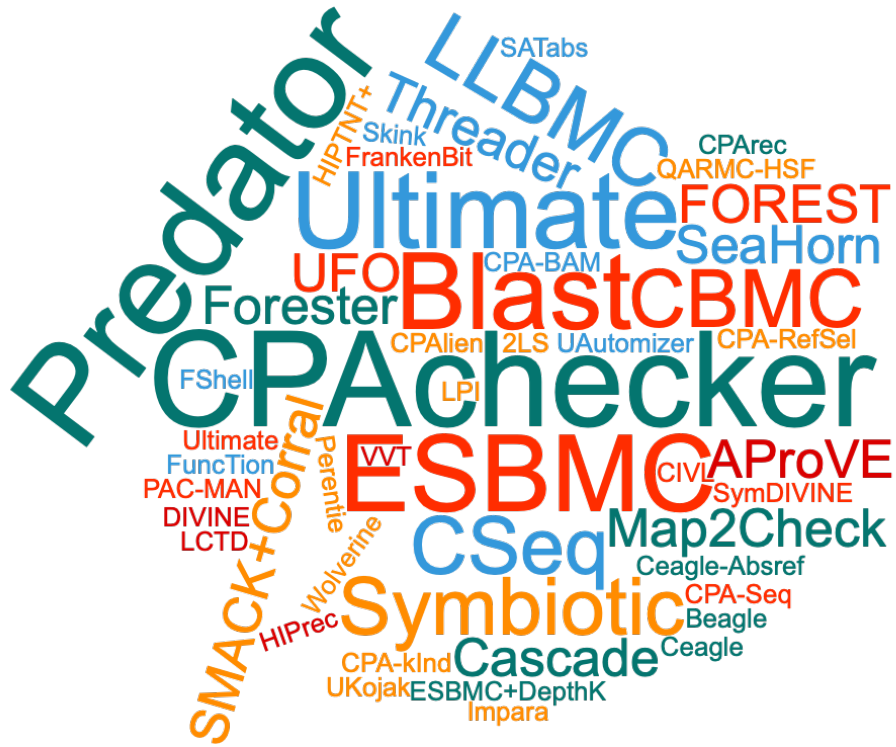


SV-COMP (Automatic Tools 2014, cumulative)

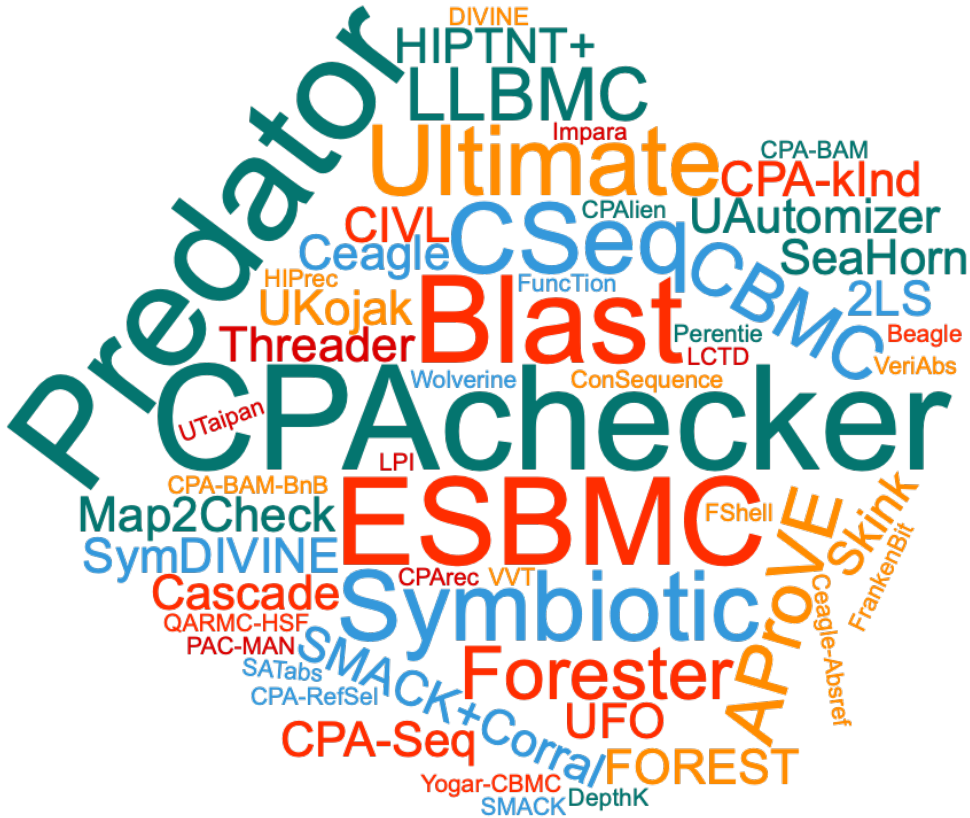


SV-COMP (Automatic Tools 2015, cumulative)

SV-COMP (Automatic Tools 2016, cumulative)

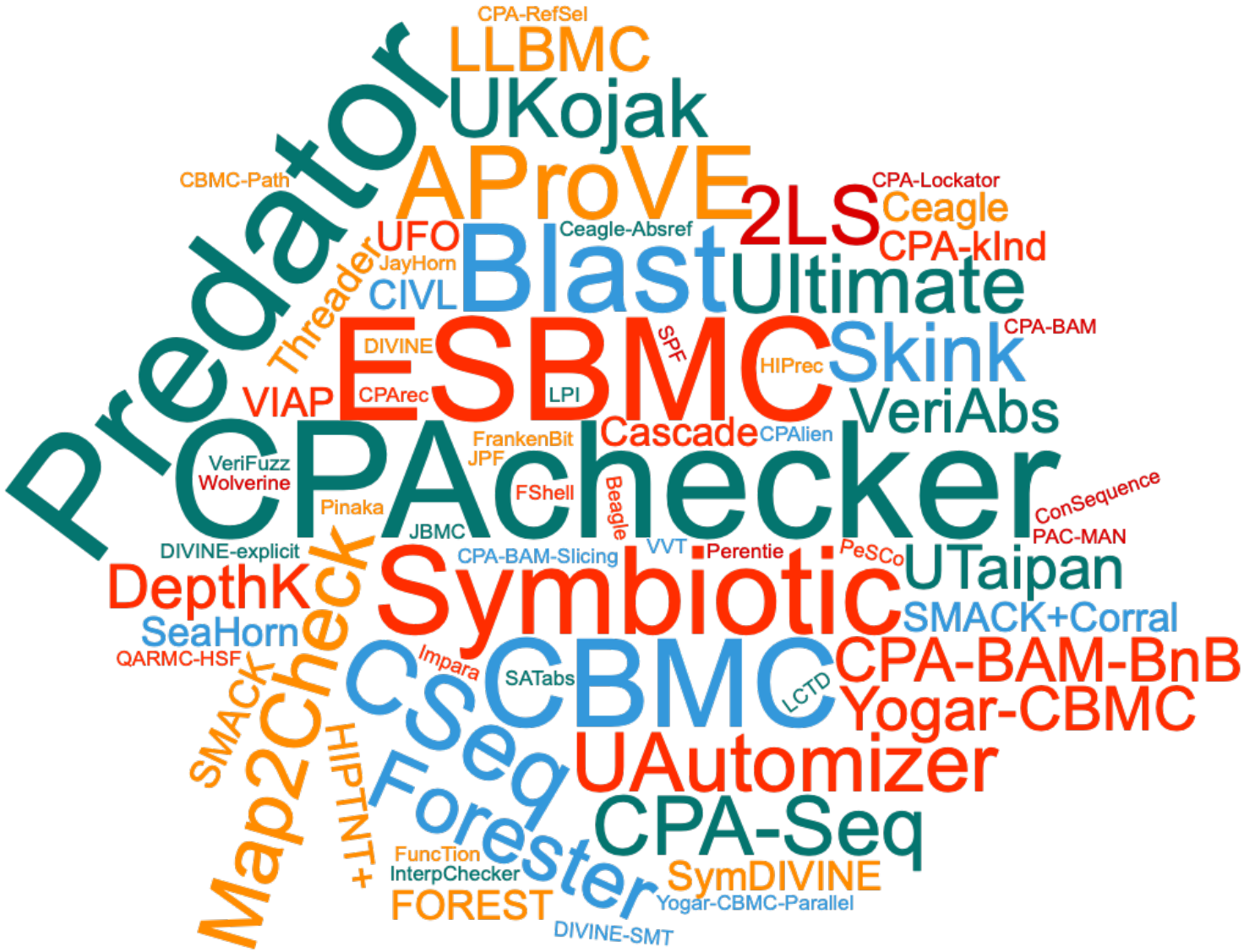


SV-COMP (Automatic Tools 2017, cumulative)



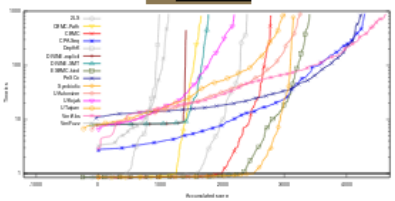
SV-COMP (Automatic Tools 2018, cumulative)

SV-COMP (Automatic Tools 2019, cumulative)

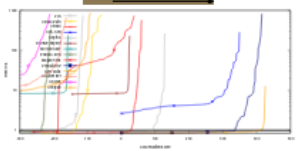


SV-COMP (Automatic Tools)

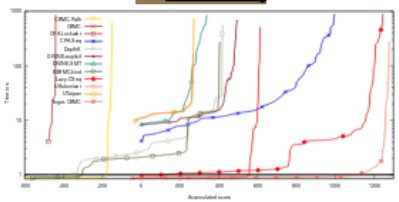
ReachSafety
1. VeriAbs
2. CPA-Seq
3. PeSCo



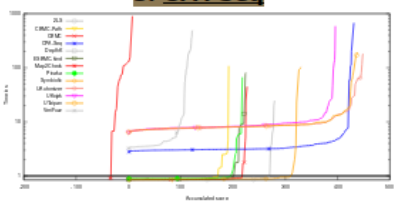
MemSafety
1. Symbiotic
2. PredatorHP
3. CPA-Seq



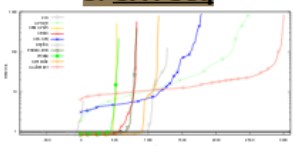
ConcurrencySafety
1. Yogar-CBMC
2. Lazy-CSeq
3. CPA-Seq



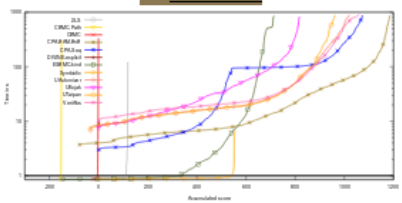
NoOverflows
1. UAutomizer
2. UTaipan
3. CPA-Seq



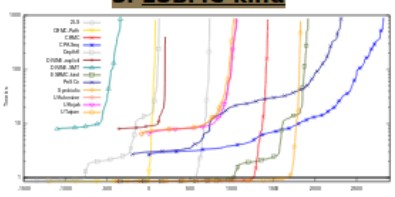
Termination
1. UAutomizer
2. AProVE
3. CPA-Seq



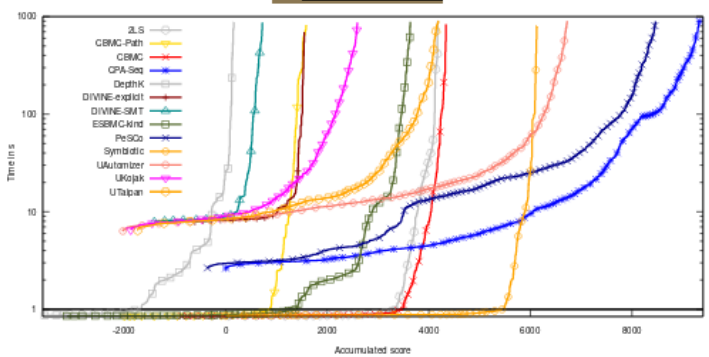
SoftwareSystems
1. CPA-BAM-BnB
2. CPA-Seq
3. VeriAbs



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

Which techniques are used?

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 [2]

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

Various Algorithms

17	Bounded Model Checking
13	CEGAR
8	Predicate Abstraction
5	k-Induction
4	Symbolic Execution
3	Automata-Based Analysis
2	Property-Directed Reachability (IC3)

Various Abstract Domains

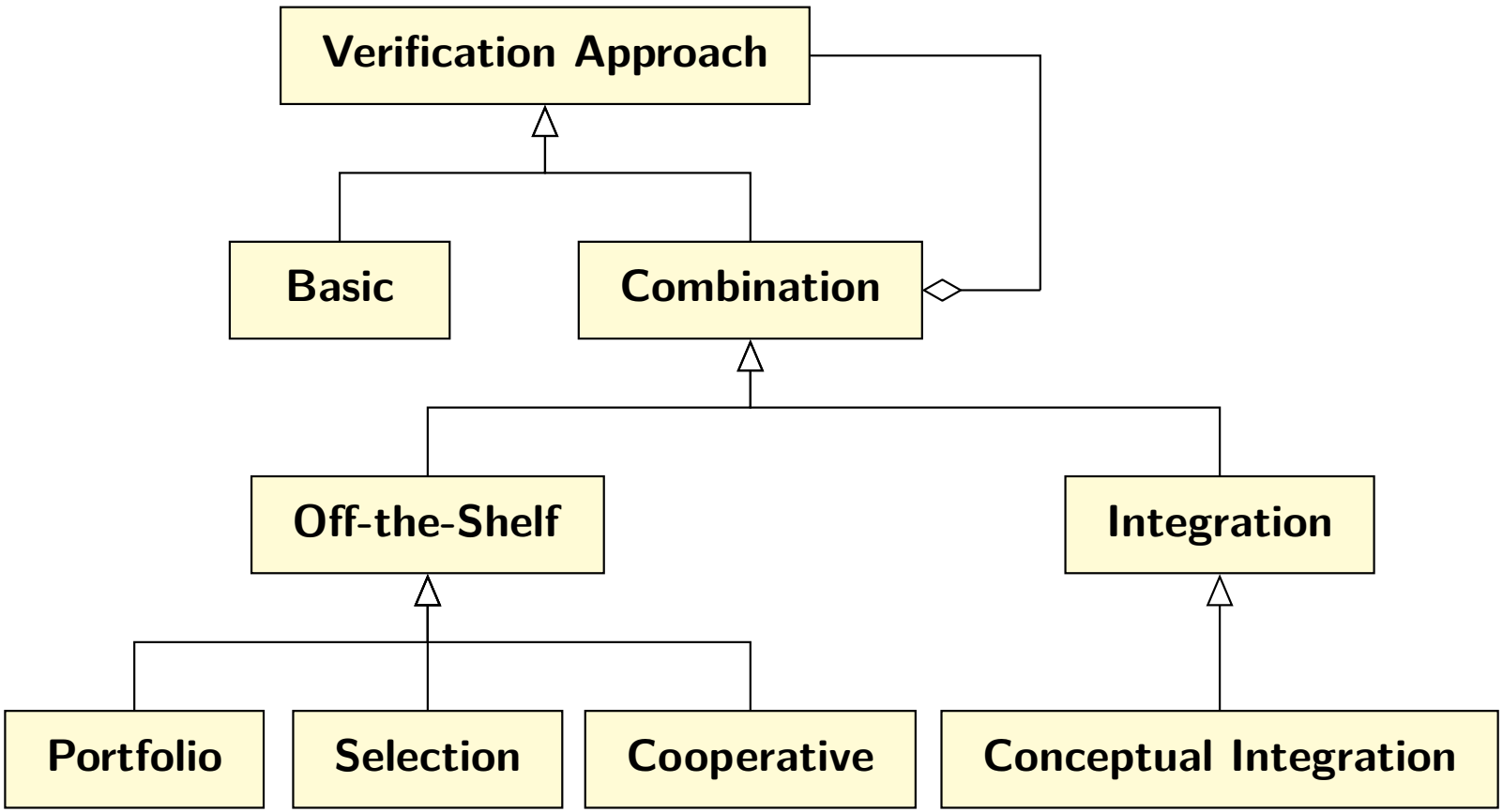
24	Bit-Precise Analysis
10	Explicit-Value Analysis
9	Numerical Interval Analysis
4	Shape Analysis
1	Separation Logic

So what is the conclusion?

- Many different kinds of programs seem to require many different good tools with different strengths.
- We do not necessarily need **more** verification tools.
- But we need **stronger** verification tools.
- And we need **combined** verification tools.
  ($\rightarrow$ this presentation)

Cooperative Verification

Approaches for Combinations



Motivation for CoVeriTeam

Problem: in software verification

- there is no silver bullet
- a lot of tools specializing in specific problem domains

Solution: cooperative verification

- employ multiple tools to solve a verification task
- which cooperate with each other through verification artifacts like witnesses

CoVeriTeam

- defines a **language** for composing verification tools
- provides an **execution engine** to execute a composition
- controls the **resources** consumed by each tool during the execution
- produces a trace of **artifacts** generated throughout the execution
- contains a **library** of (some) examples of verification composition techniques from the literature
- **open-source** implementation in Python

Running Example

Algorithm 1 Witness Validation [5, 4]

Input: Program p, Specification s
Output: Verdict

```
1: verifier := Verifier("Ultimate Automizer")
2: validator := Validator("CPAchecker")
3: result := verifier.verify(p, s)
4: if result.verdict ∈ {TRUE, FALSE} then
5:     result = validator.validate (p, s, result.witness)
6: return  (result.verdict, result.witness)
```

Cooperative Verification Language

- Artifact: means of information (and knowledge) exchange between the verification actors (tools)
- Actor: consumes, acts on, and produces artifacts
- Composition: of actors creating new actors

Artifacts

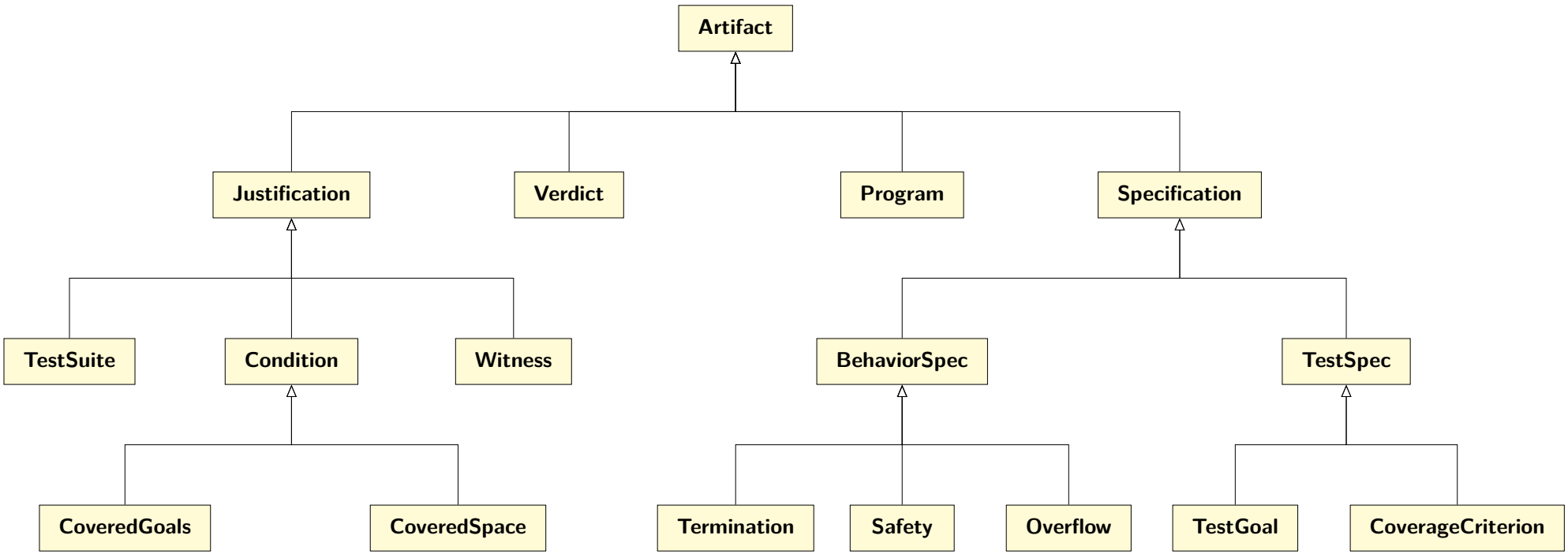


Figure: Hierachy of Artifacts (arrows indicate an is-a relation) [10]

Actors

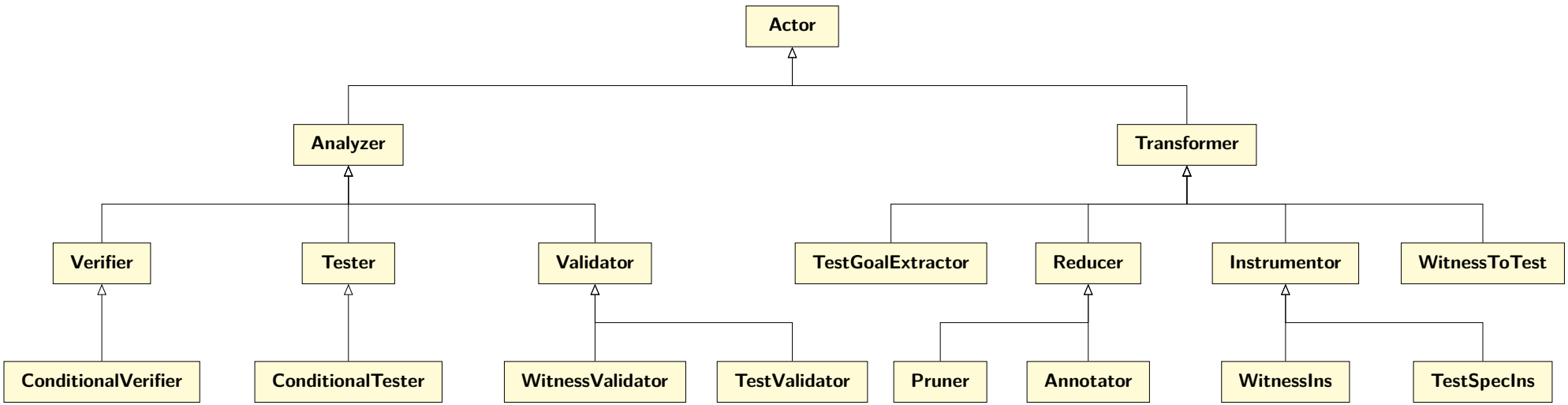


Figure: Hierachy of Actors (arrows indicate an is-a relation) [10]

Composition

- Sequential: executes actors in sequence
- Parallel: executes actors in parallel, waits for all to finish
- ITE: executes one or the other based on a condition.
- Repeat: repeats execution of an actor till a termination condition is satisfied

CoVeriTeam- Implementation and Usage

- Demo: key points
- Usage: config, input, output, command

Implementation Details

- Just-in Time Compilation
- Actor instantiation
- Use of BenchExec:
  - Tool-Info Modules
  - Containerized Execution
  - Resource Measurement

Usage and Features

```yaml
actor_name: uautomizer
toolinfo_module: "ultimateautomizer.py"
archive:
  location: "https://zenodo.org/record/3813788/files/uautomizer.zip"
  doi: "10.5281/zenodo.3813788"
  spdx_license_identifier: "LGPL-3.0-or-later"
options: ['--full-output', '--architecture', '32bit']
resourcelimits:
  memlimit: "15 GB"
  timelimit: "15 min"
  cpuCores: "8"
format_version: '1.1'
```

Figure: YAML configuration for an atomic actor

Revisit the Running Example

Algorithm 2 Witness Validation [5, 4]

Input: Program p, Specification s
Output: Verdict

```
1: verifier := Verifier("Ultimate Automizer")
2: validator := Validator("CPAchecker")
3: result := verifier.verify(p, s)
4: if result.verdict ∈ {TRUE, FALSE} then
5:     result = validator.validate (p, s, result.witness)
6: return  (result.verdict, result.witness)
```

Usage and Features

```
1  // Create verifier and validator from yml files
2  ver = ActorFactory.create(Verifier, "config/uautomizer.yml");
3  val = ActorFactory.create(Validator, "config/cpa-val.yml");
4
5  // Use validator if verdict is true or false,
6  // otherwise use an identity mapping of inputs to outputs
7  condition = ELEMENTOF(verdict, {TRUE, FALSE});
8  second_component = ITE(condition, val, Identity(val));
9
10 // Verifier and second component to be executed in sequence
11 validating_verifier = SEQUENCE(ver, second_component);
12
13 // Print type information about the composition (for illustration)
14 print(validating_verifier);
15
16 // Prepare example inputs
17 prog = ArtifactFactory.create(CProgram, prog_path);
18 spec = ArtifactFactory.create(ReachSafety, spec_path);
19 inputs = {'program':prog, 'spec':spec};
20
21 // Execute the new component on the inputs
22 execute(validating_verifier, inputs);
```

Figure: Running Example in CoVeriTeam Language

Usage and Features

Command to execute the example:

```
bin/coveriteam examples/validated-verifier.cvt \
--input prog_path=c/Problem02_label16.c \
--input spec_path=properties/unreach-call.prp
```

Usage and Features

```
 5 <actor name="Sequence">
 6   <inputs>
 7     <input name="program" type="CProgram">.../c/Problem02_label16.c</input>
 8     <input name="spec" type="Specification">.../properties/unreach-call.prp</input>
 9   </inputs>
10   <outputs>
11     <output name="verdict" type="Verdict">false</output>
12     <output name="witness" type="Witness">.../witness.graphml</output>
13   </outputs>
14   <first>
15     <actor name="uautomizer">
16       <inputs>
17         <input name="program" type="CProgram">.../c/Problem02_label16.c</input>
18         <input name="spec" type="Specification">.../properties/unreach-call.prp</input>
19       </inputs>
20       <outputs>
21         <output name="verdict" type="Verdict">false</output>
22         <output name="witness" type="Witness">.../witness.graphml</output>
23       </outputs>
24       <measurements cputime="25.170865524" memory="659492864" walltime="7.451572395977564"/>
25     </actor>
26   </first>
27   <second>
28     <actor name="ITE">
```

Figure: Snippet of the output xml produced by CoVeriTeam

Evaluation Through Case Studies

Table: Examples of cooperative techniques in literature

Technique	Year
Counterexample Checking [18]	2012
Conditional Model Checking [7]	2012
Slicing and Symbolic Execution [19]	2013
Precision Reuse [12]	2013
Algorithm Selection [20, 14]	2014, 2017
Witness Validation [5, 4]	2015, 2016
Execution-Based Validation [6]	2018
Reducer [9]	2018
Executable Counterexamples [15]	2018
CoVeriTest [8]	2019
CondTest [11]	2019
MetaVal [13]	2020

Conclusion: CoVeriTeam

- defines a language for composing verification tools
- provides an execution engine to execute a composition
- predefined actors
- open-source implementation in Python

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