JBMC: A Bounded Model Checking Tool for Verifying Java Bytecode

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Computer Aided Verification 2018

Why?

Java and JVM languages:

- Most widely used
- Established software development culture

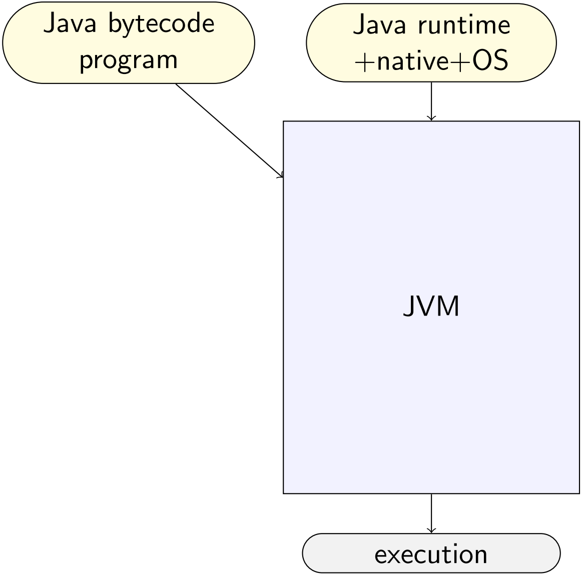
Only few model checking tools available:

- Symbolic JPF (Anand et al, TACAS'07)
- JayHorn (Kahsai et al, CAV'16)

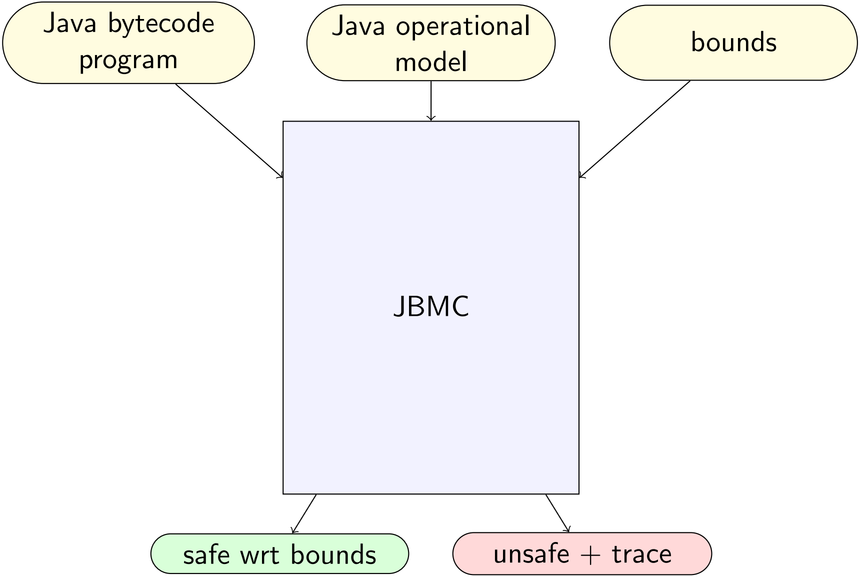
Many applications of BMC:

- Bug finding
- Program synthesis
- Test generation
- . . .

JVM vs JBMC

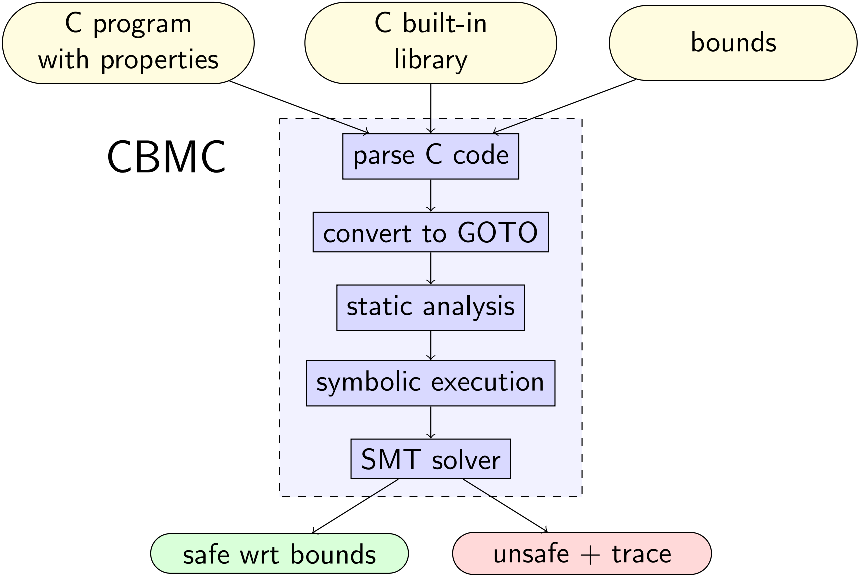

Java bytecode program
Java runtime +native+OS
JVM
execution

JVM vs JBMC


Java bytecode program
Java operational model
bounds
JBMC
safe wrt bounds
unsafe + trace

CBMC

Clarke, Kroening & Lerda, TACAS'04



CBMC

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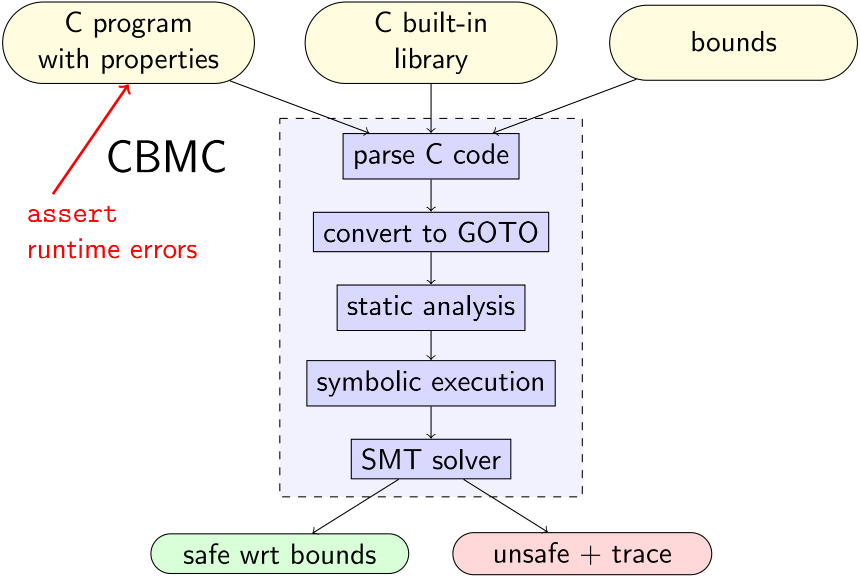


C program with properties

C built-in library

bounds

CBMC

assert

runtime errors

parse C code

convert to GOTO

static analysis

symbolic execution

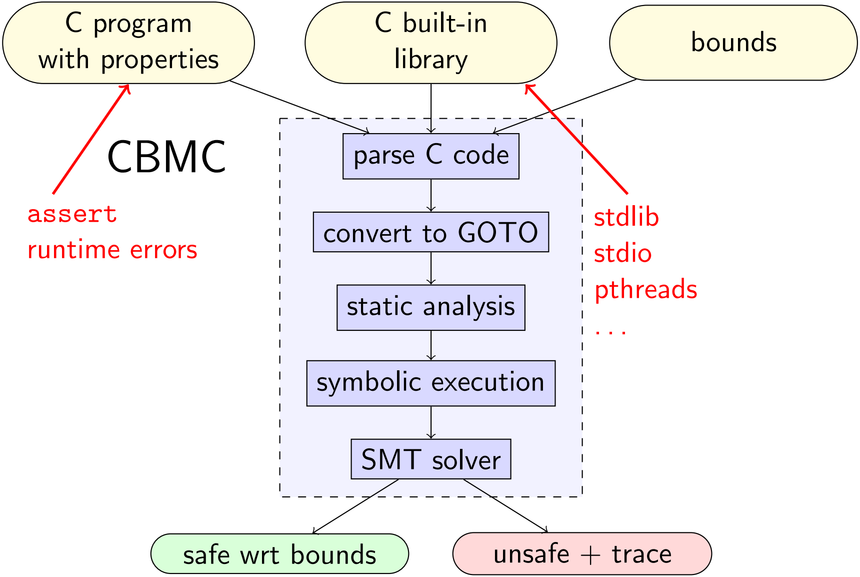
SMT solver

safe wrt bounds

unsafe + trace

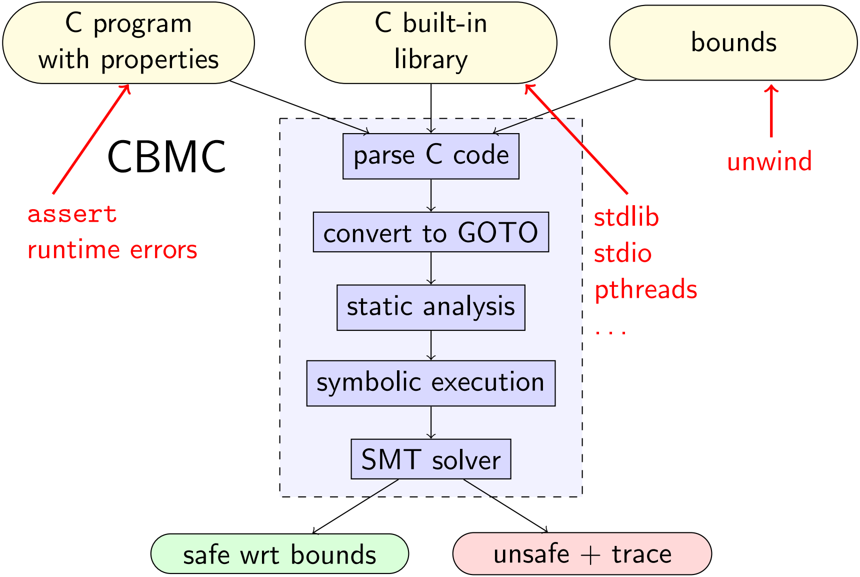
CBMC

Clarke, Kroening & Lerda, TACAS'04



CBMC

Clarke, Kroening & Lerda, TACAS'04



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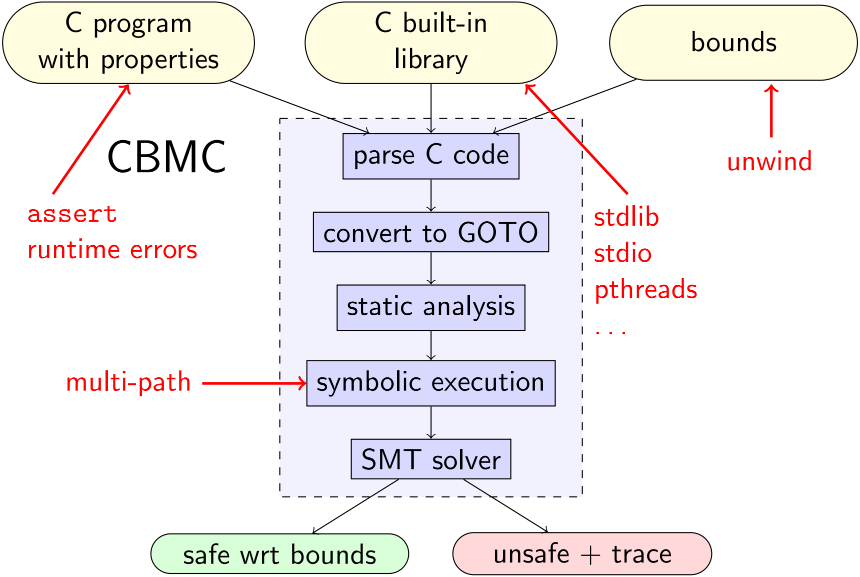
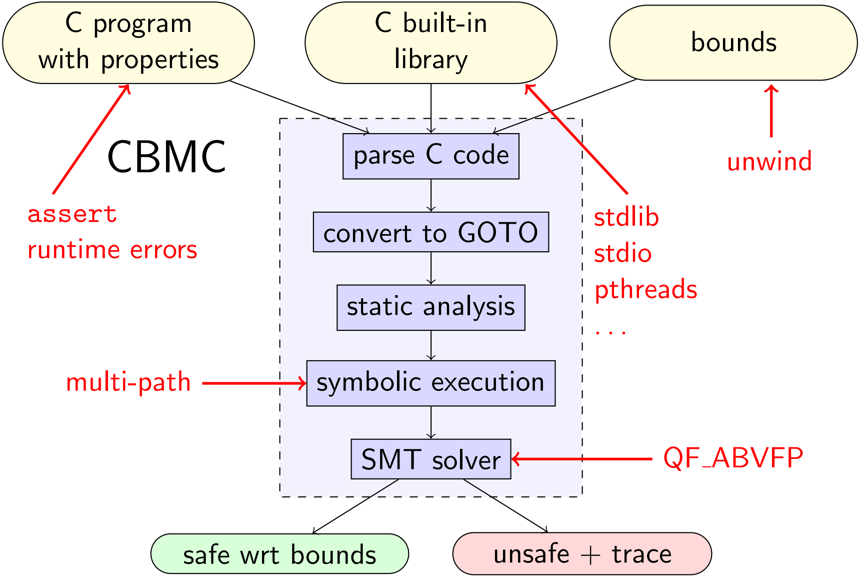
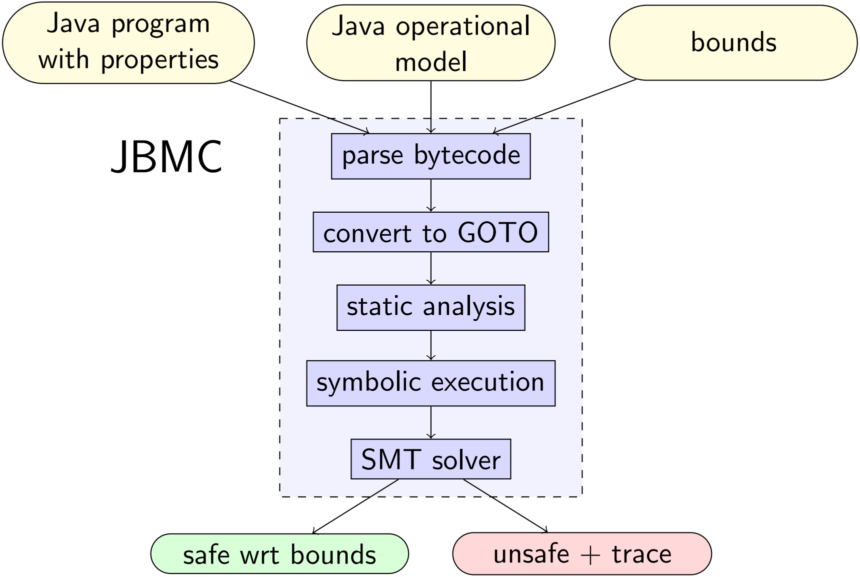


CBMC

Clarke, Kroening & Lerda, TACAS'04



JBMC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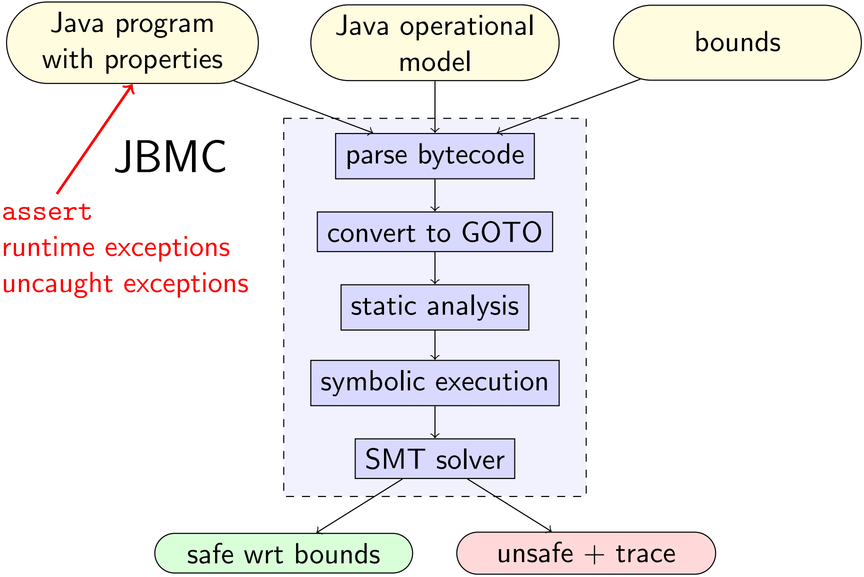
JBMC



Java program with properties

Java operational model

bounds

JBMC

assert

runtime exceptions

uncaught exceptions

parse bytecode

convert to GOTO

static analysis

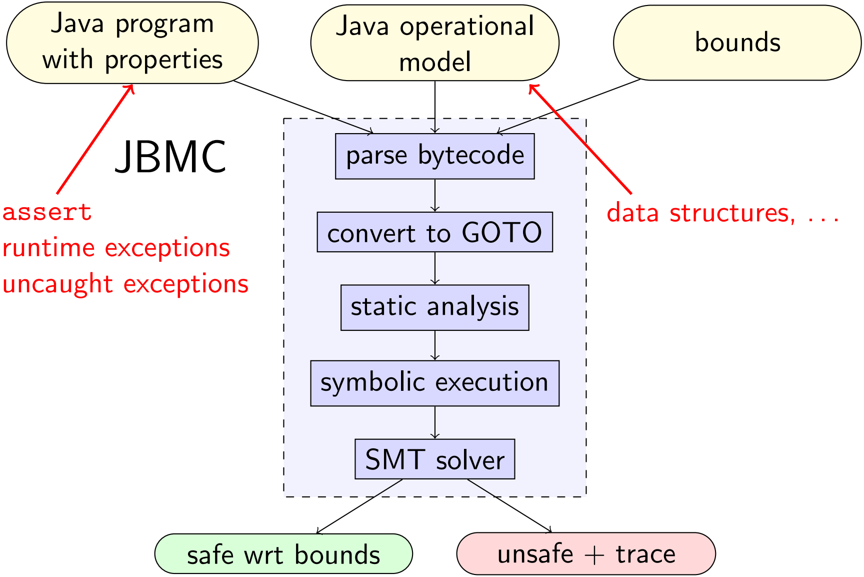
symbolic execution

SMT solver

safe wrt bounds

unsafe + trace

JBMC



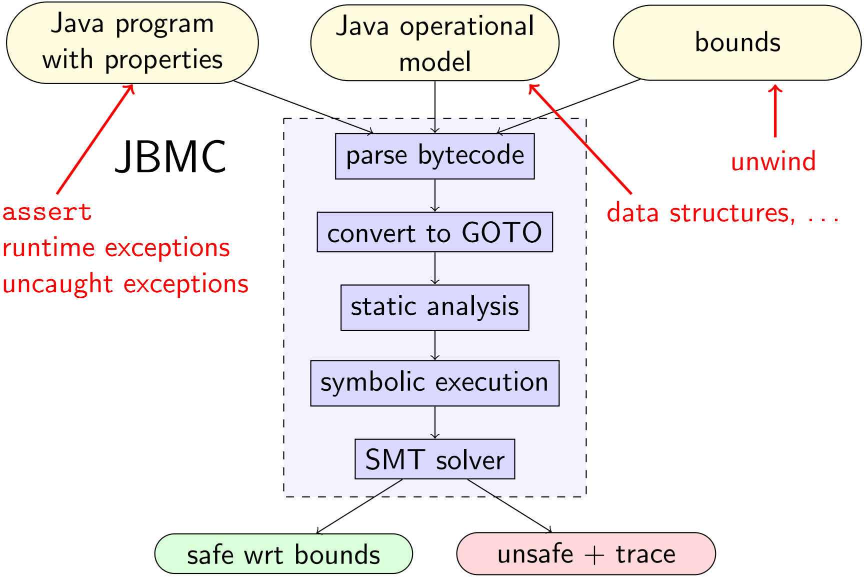
`assert`

runtime exceptions

uncaught exceptions

data structures, . . .

JBMC


Java program with properties
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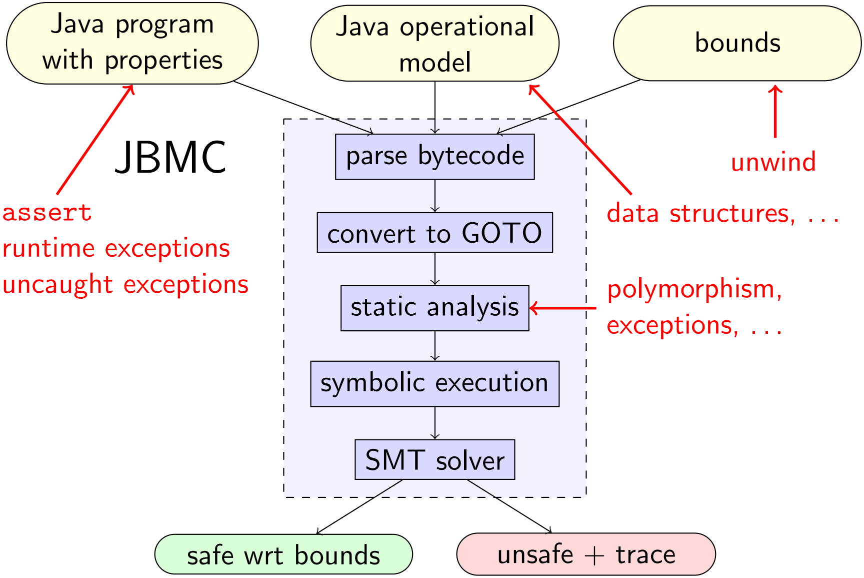
data structures, . . .
unwind
safe wrt bounds
unsafe + trace

JBMC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runtime exceptions
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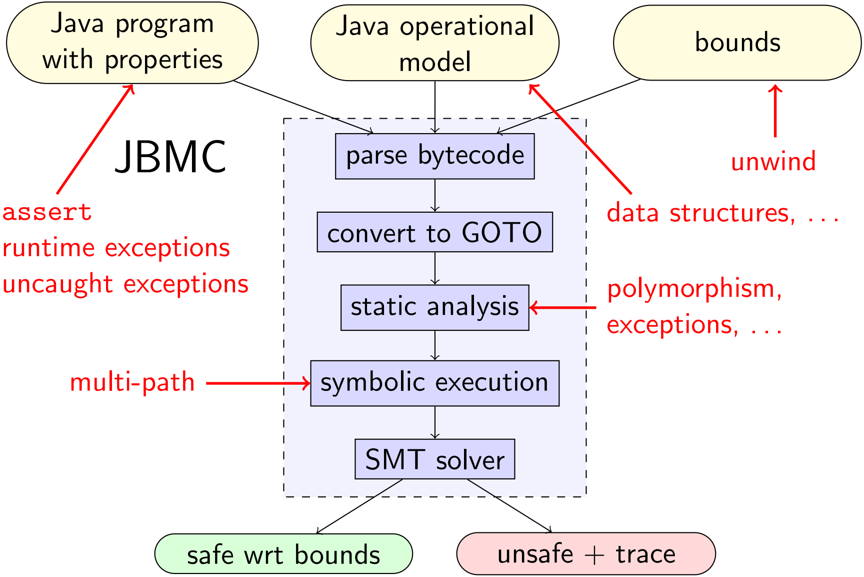
unwind
data structures, . . .
polymorphism,
exceptions, . . .

JBMC


Java program with properties
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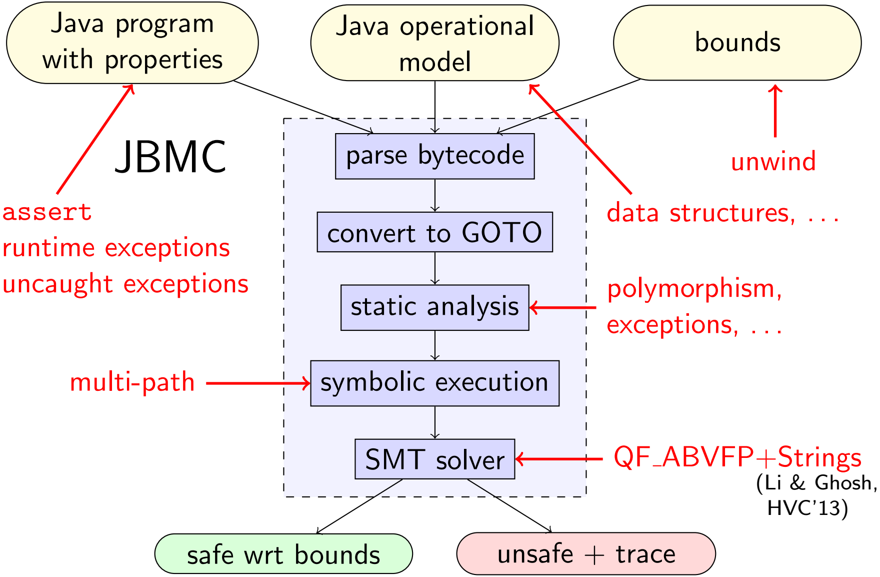
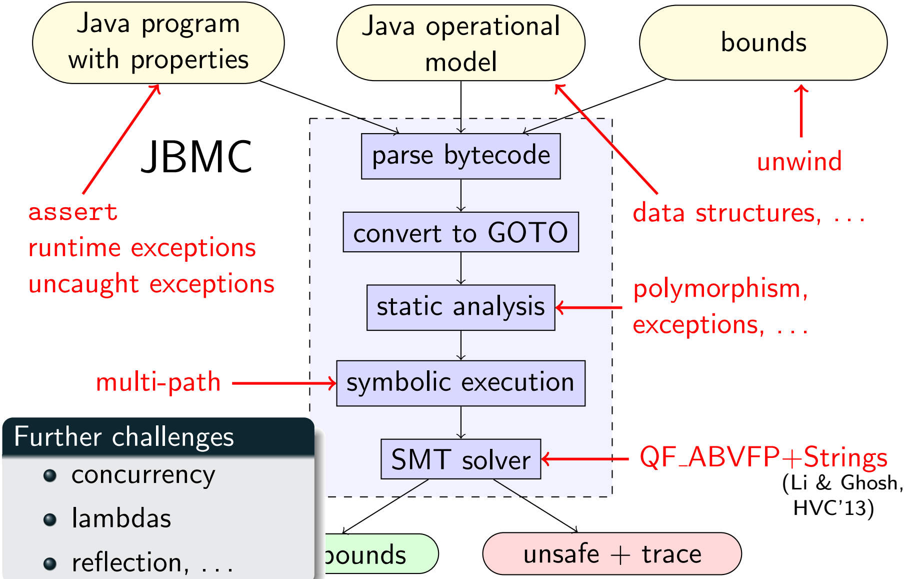
assert
runtime exceptions
uncaught exceptions
unwind
data structures, . . .
polymorphism,
exceptions, . . .
multi-path

JBMC



(Li & Ghosh, HVC'13)

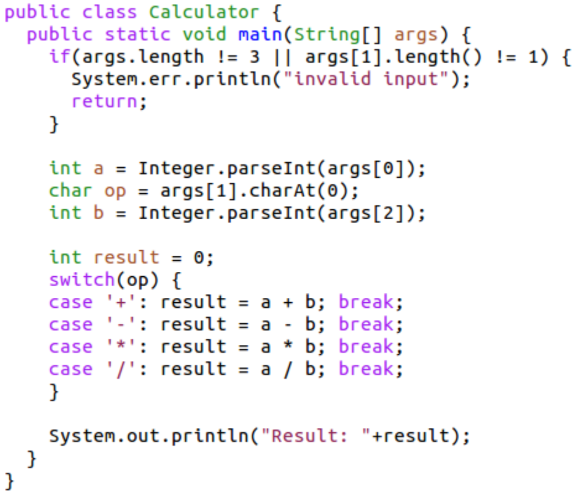
JBMC



Further challenges

- concurrency
- lambdas
- reflection, . . .

JBMC in Action

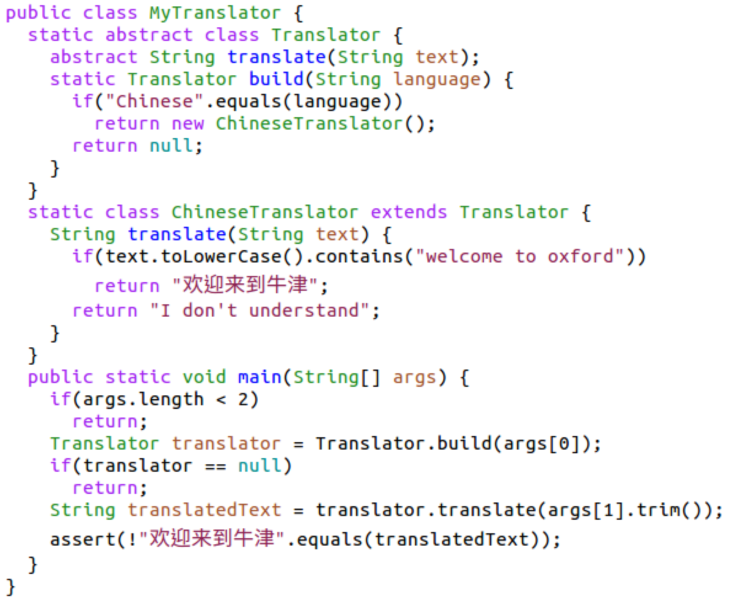


```
public class Calculator {
  public static void main(String[] args) {
    if(args.length != 3 || args[1].length() != 1) {
      System.err.println("invalid input");
      return;
    }

    int a = Integer.parseInt(args[0]);
    char op = args[1].charAt(0);
    int b = Integer.parseInt(args[2]);

    int result = 0;
    switch(op) {
    case '+': result = a + b; break;
    case '-': result = a - b; break;
    case '*': result = a * b; break;
    case '/': result = a / b; break;
    }

    System.out.println("Result: "+result);
  }
}
```

JBMC in Action

```
$ jbmc Calculator.class --classpath core-models.jar:. --trace
    --throw-runtime-exceptions

...
Runtime decision procedure: 0.980s
...
dynamic_object4={ ’-’, ’0’, ’4’ } // args[0].data
...
dynamic_object6={ ’/’ }           // args[1].data
...
dynamic_object8={ ’0’ }           // args[2].data
...
Calculator.java line 17 function Calculator.main
dynamic_object36={... .@class_identifier="java.lang.ArithmeticException" ...}
...
uncaught_exception=&dynamic_object36

Violated property:
  file Calculator.java line 3 function Calculator.main
  no uncaught exception
  uncaught_exception == null
```

JBMC in Action

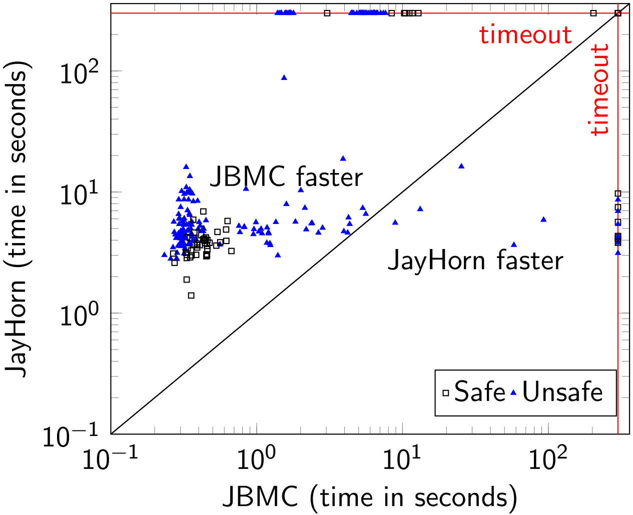


```java
public class MyTranslator {
  static abstract class Translator {
    abstract String translate(String text);
    static Translator build(String language) {
      if("Chinese".equals(language))
        return new ChineseTranslator();
      return null;
    }
  }
  static class ChineseTranslator extends Translator {
    String translate(String text) {
      if(text.toLowerCase().contains("welcome to oxford"))
        return "欢迎来到牛津";
      return "I don't understand";
    }
  }
  public static void main(String[] args) {
    if(args.length < 2)
      return;
    Translator translator = Translator.build(args[0]);
    if(translator == null)
      return;
    String translatedText = translator.translate(args[1].trim());
    assert(!"欢迎来到牛津".equals(translatedText));
  }
}
```

JBMC in Action

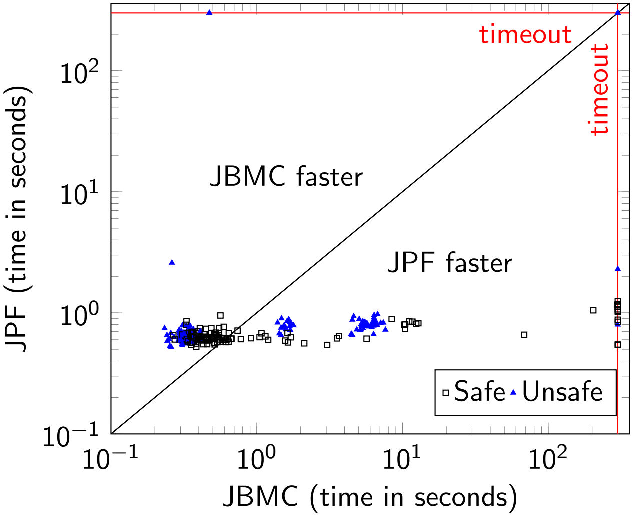
```
$ jbmc MyTranslator.class --classpath core-models.jar:. --trace
    --max-nondet-string-length 50

...
Runtime decision procedure: 0.786s
...
dynamic_object4={ ’C’, ’h’, ’i’, ’n’, ’e’, ’s’, ’e’ } // args[0].data
...
dynamic_object6={ ’\u0010’, ’\u0017’, ’w’, ’e’,
                  ’w’, ’E’, ’L’, ’C’, ’O’, ’M’, ’E’, ’ ’,
                  ’T’, ’o’, ’ ’,
                  ’o’, ’x’, ’f’, ’o’, ’r’, ’D’,
                  ’x’, ’x’, ’x’, ’x’, ’x’, ’x’, ’x’, ’x’, ’x’, ’x’, ’x’,
                  ’x’, ’ ’, ’ ’ }                     // args[1].data
...

Violated property:
  assertion at file MyTranslator.java line 31 function MyTranslator.main
```

Comparison with JayHorn 0.5.1



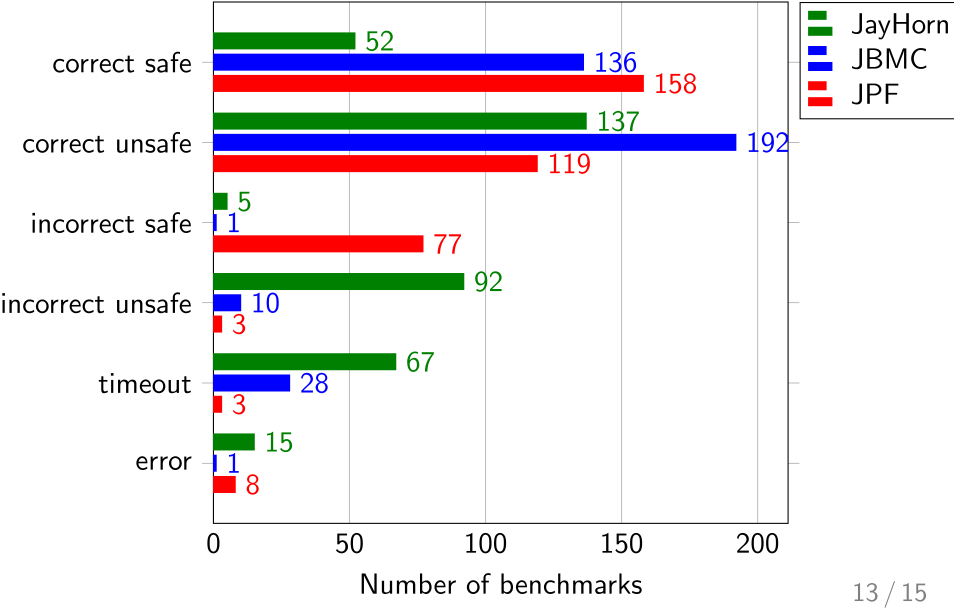
timeout 300s, 15GB

Comparison with JPF v32

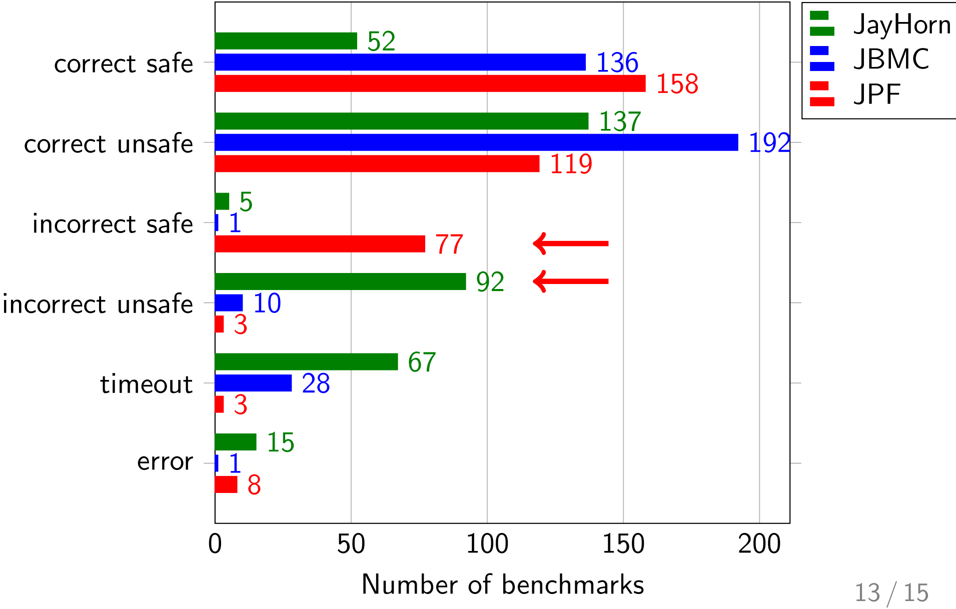


timeout 300s, 15GB

Comparison


JayHorn
JBMC
JPF
correct safe
52
136
158
correct unsafe
137
192
119
incorrect safe
5
1
77
incorrect unsafe
92
10
3
timeout
67
28
3
error
15
1
8
0
50
100
150
200
Number of benchmarks

Comparison


correct safe
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1
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timeout
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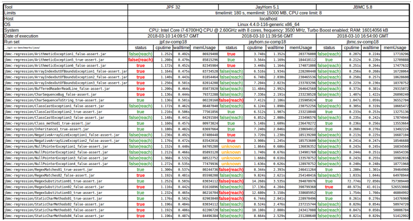
150
200
Number of benchmarks
JayHorn
JBMC
JPF

Java @ TACAS SV-COMP 2019

Objectives:

- More languages in SV-COMP
- Standard benchmark set
- Comparability
- Reproducibility
- Re-use existing benchmarking infrastructure
  3 tools already integrated: JPF, Jayhorn, JBMC



Tool	JPF 32				JayHorn 5.1				JBMC 5.8			
Limits	timelimit: 180 s, memlimit: 15000 MB, CPU core limit: 8											
Host	localhost											
OS	Linux 4.4.0-116-generic x86_64											
System	CPU: Intel Core i7-6700HQ CPU @ 2.60GHz with 8 cores, frequency: 3500 MHz, Turbo Boost enabled; RAM: 16014056 kB											
Date of execution	2018-03-10 14:09:57 GMT				2018-03-10 11:39:56 GMT				2018-03-10 16:54:00 GMT			
Run set	jpf.sv-comp18				jayhorn.sv-comp18				jbmc.sv-comp18			
../git-sv-benchmarks/java/	status	cputime	walltime	memUsage	status	cputime	walltime	memUsage	status	cputime	walltime	memUsage
jbmc-regression/ArithmeticException1_false-assert.jar	false(reach)	1.252s	0.492s	86929408	true	3.748s	1.352s	203776000	false(reach)	0.207s	0.224s	17719296
jbmc-regression/ArithmeticException5_true-assert.jar	false(reach)	1.208s	0.479s	85815296	true	3.564s	1.169s	184410112	true	0.212s	0.226s	12709888
jbmc-regression/ArithmeticException6_false-assert.jar	true	1.172s	0.452s	82345984	true	3.448s	1.164s	174071808	false(reach)	0.251s	0.264s	17477632
jbmc-regression/ArrayIndexOutOfBoundsException1_false-assert.jar	true	1.164s	0.475s	83734528	false(reach)	6.516s	1.934s	228200448	false(reach)	0.256s	0.268s	16728064
jbmc-regression/ArrayIndexOutOfBoundsException2_false-assert.jar	true	1.140s	0.443s	81854464	false(reach)	6.748s	2.030s	230465536	false(reach)	0.250s	0.257s	18628608
jbmc-regression/ArrayIndexOutOfBoundsException3_false-assert.jar	true	1.256s	0.501s	82014208	false(reach)	7.204s	2.023s	233783296	false(reach)	0.223s	0.236s	18378752
jbmc-regression/BufferedReaderReadLine_false-assert.jar	true	1.200s	0.464s	85073920	false(reach)	11.484s	2.992s	264642560	false(reach)	0.373s	0.381s	29315072
jbmc-regression/CharSequenceBug_false-assert.jar	true	1.136s	0.444s	79372288	false(reach)	7.336s	2.191s	233238528	false(reach)	1.407s	1.422s	26890240
jbmc-regression/CharSequenceToString_true-assert.jar	true	1.136s	0.501s	80220160	false(reach)	7.412s	2.186s	235905024	true	1.047s	1.059s	36552704
jbmc-regression/ClassCastException1_false-assert.jar	false(reach)	1.172s	0.462s	86487040	false(reach)	6.124s	1.898s	230752256	false(reach)	0.305s	0.319s	18665472
jbmc-regression/ClassCastException2_true-assert.jar	true	1.216s	0.506s	77561856	true	6.512s	1.907s	233218048	true	0.233s	0.253s	13275136
jbmc-regression/ClassCastException3_false-assert.jar	false(reach)	1.148s	0.441s	84291584	false(reach)	6.852s	2.080s	233496576	false(reach)	0.235s	0.242s	17874944
jbmc-regression/Class_method1_true-assert.jar	true	1.160s	0.457s	80973824	true	5.148s	1.609s	236470272	true	0.236s	0.256s	13553664
jbmc-regression/Inheritance1_true-assert.jar	true	1.180s	0.482s	83697664	true	7.240s	2.046s	230694912	true	0.260s	0.276s	13492224
jbmc-regression/NegativeArraySizeException1_false-assert.jar	false(reach)	1.236s	0.492s	87400448	true	3.720s	1.230s	185139200	false(reach)	0.213s	0.225s	16687104
jbmc-regression/NegativeArraySizeException2_false-assert.jar	false(reach)	1.176s	0.472s	83542016	true	3.908s	1.245s	185753600	false(reach)	0.241s	0.247s	18546688
jbmc-regression/NullPointerException1_false-assert.jar	false(reach)	1.152s	0.440s	84705280	unknown	1.864s	0.686s	136036352	false(reach)	0.243s	0.245s	16834560
jbmc-regression/NullPointerException2_false-assert.jar	false(reach)	1.212s	0.466s	85893120	unknown	1.740s	0.676s	134901760	false(reach)	0.244s	0.251s	16654336
jbmc-regression/NullPointerException3_false-assert.jar	false(reach)	1.368s	0.532s	88522752	unknown	1.668s	0.616s	133578752	false(reach)	0.243s	0.255s	16982016
jbmc-regression/NullPointerException4_false-assert.jar	false(reach)	1.272s	0.535s	77479936	unknown	1.636s	0.626s	128970752	false(reach)	0.240s	0.248s	18771968
jbmc-regression/RegexMatches01_true-assert.jar	true	1.300s	0.537s	80244736	false(reach)	8.344s	2.393s	246411264	true	1.280s	1.301s	39464960
jbmc-regression/RegexMatches02_false-assert.jar	true	1.192s	0.481s	85598208	false(reach)	9.824s	2.621s	254140416	false(reach)	1.033s	1.044s	64978944
jbmc-regression/RegexSubstitution01_true-assert.jar	true	1.252s	0.503s	83034112	false(reach)	14.268s	3.535s	394878976	true	72.774s	72.850s	757309440
jbmc-regression/RegexSubstitution02_false-assert.jar	true	1.116s	0.442s	81616896	false(reach)	17.136s	4.284s	390799360	true	40.973s	41.011s	526553088
jbmc-regression/RegexSubstitution03_true-assert.jar	true	1.232s	0.465s	86216704	false(reach)	12.680s	3.158s	338685952	true	1.754s	1.766s	46804992
jbmc-regression/StaticCharMethods01_true-assert.jar	true	1.176s	0.502s	82903040	false(reach)	6.744s	2.041s	228970496	true	0.261s	0.276s	14376960
jbmc-regression/StaticCharMethods02_false-assert.jar	true	1.196s	0.484s	83034112	false(reach)	8.524s	2.476s	237215744	false(reach)	0.829s	0.854s	50974720
jbmc-regression/StaticCharMethods03_false-assert.jar	true	1.192s	0.486s	82206720	false(reach)	10.188s	2.888s	243417088	false(reach)	0.847s	0.858s	50806784
jbmc-regression/StaticCharMethods04_false-assert.jar	true	1.196s	0.487s	84496384	false(reach)	8.664s	2.529s	231280640	false(reach)	0.821s	0.829s	51412992

Timeline:

- September 2018: Contribution of benchmarks
- October 2018: Tool submission

Watch out on `sv-comp.sosy-lab.org`
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Download JBMC and contribute!

`www.cprover.org/jbmc`

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