The CProver Suite of Verification Tools

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Rough Time Line

9:00 → 9:30 Introduction

9:30 → 10:00 CBMC work-along demonstration

10:00 → 10:30 Break

10:30 → 11:00 CBMC exercises

11:00 → 11:15 Concurrency and incremental BMC

11:15 → 11:30 Exercises

11:30 → 12:00 2LS

12:00 → 12:30 Exercises

It's Not Just Us...

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diffblue

What Do You Want From This Tutorial?

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Goals:

1. What is available? What are solved problems? What are open problems?
2. Use tools for benchmarks, experiments, software development and teaching.
3. Interface and Integrate with CPROVER.

Overview

Part I

- Verification
- CPROVER by Example
- Interfaces
- Exercises

Part II

- Concurrency
- Incremental BMC
- Program Analysis beyond BMC

The Verification Question

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Does (every run of) program P satisfy specification S?

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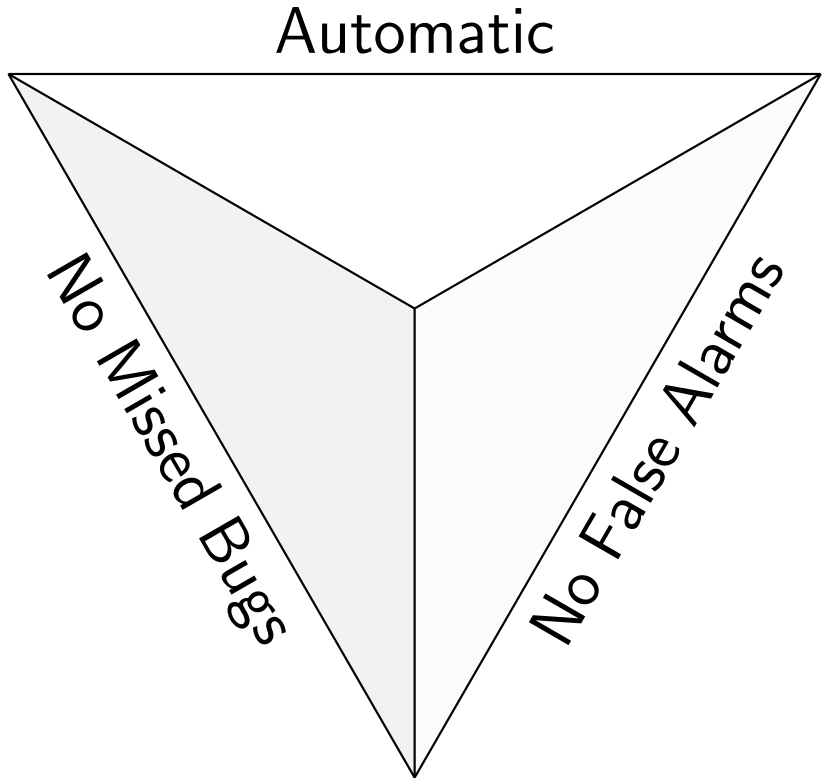
Program

- Sequential Software
- Concurrent Software
- Firmware
- Hardware
- Combinations

Specification

- Assertions
- Undefined behaviour
- Information flow
- Resources
- Termination / complexity

Martin's Pyramid Model of Verification



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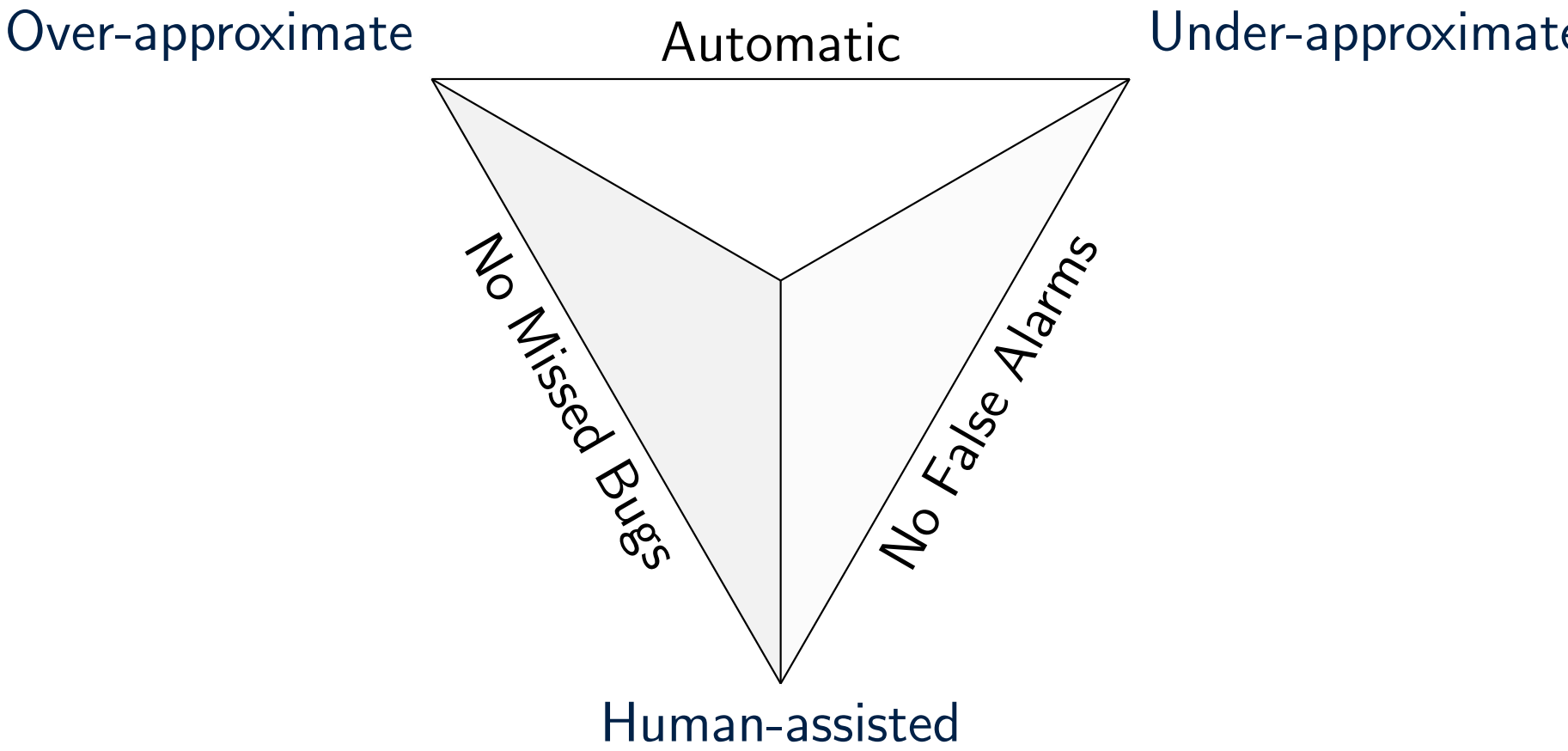

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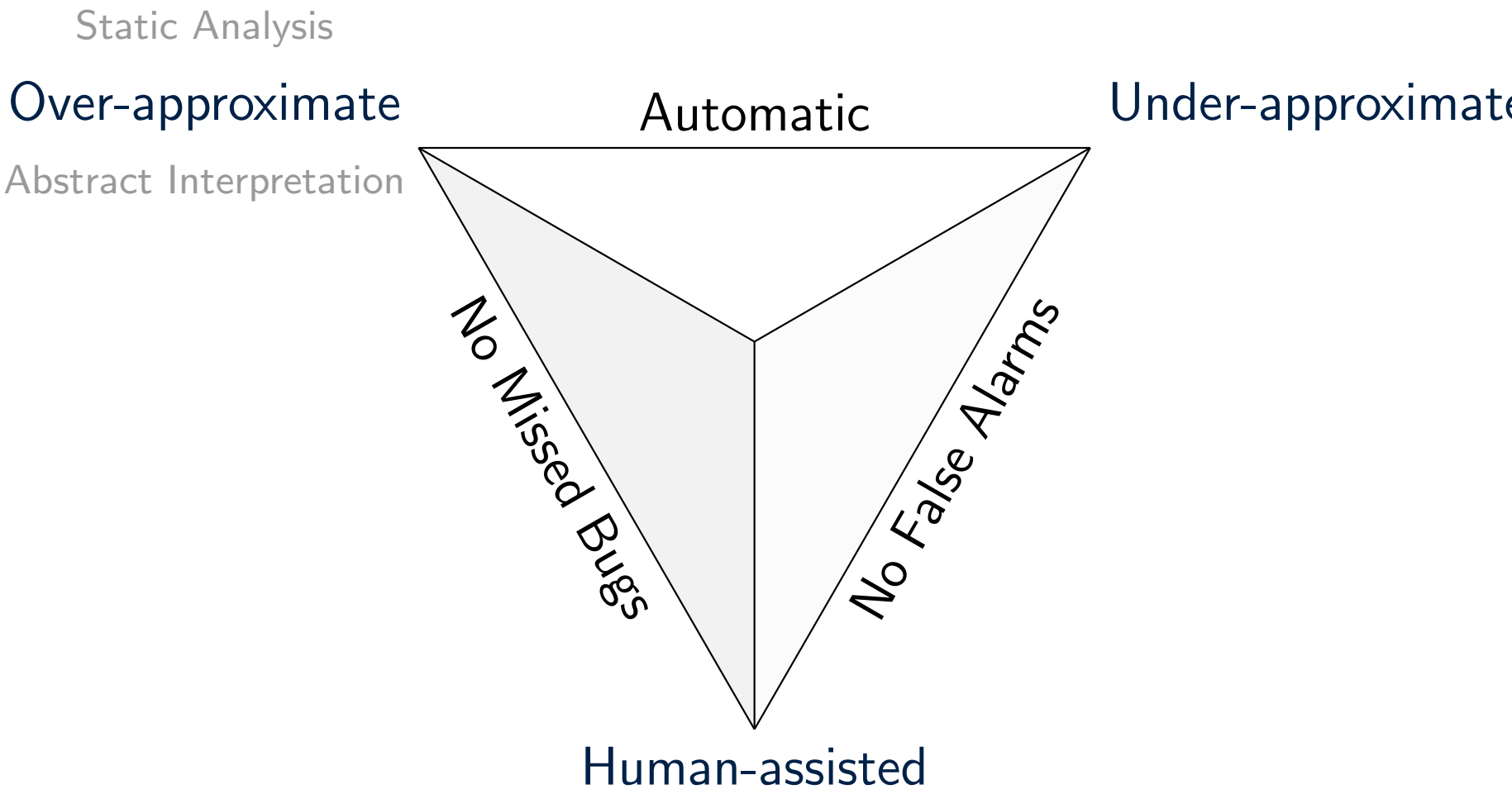

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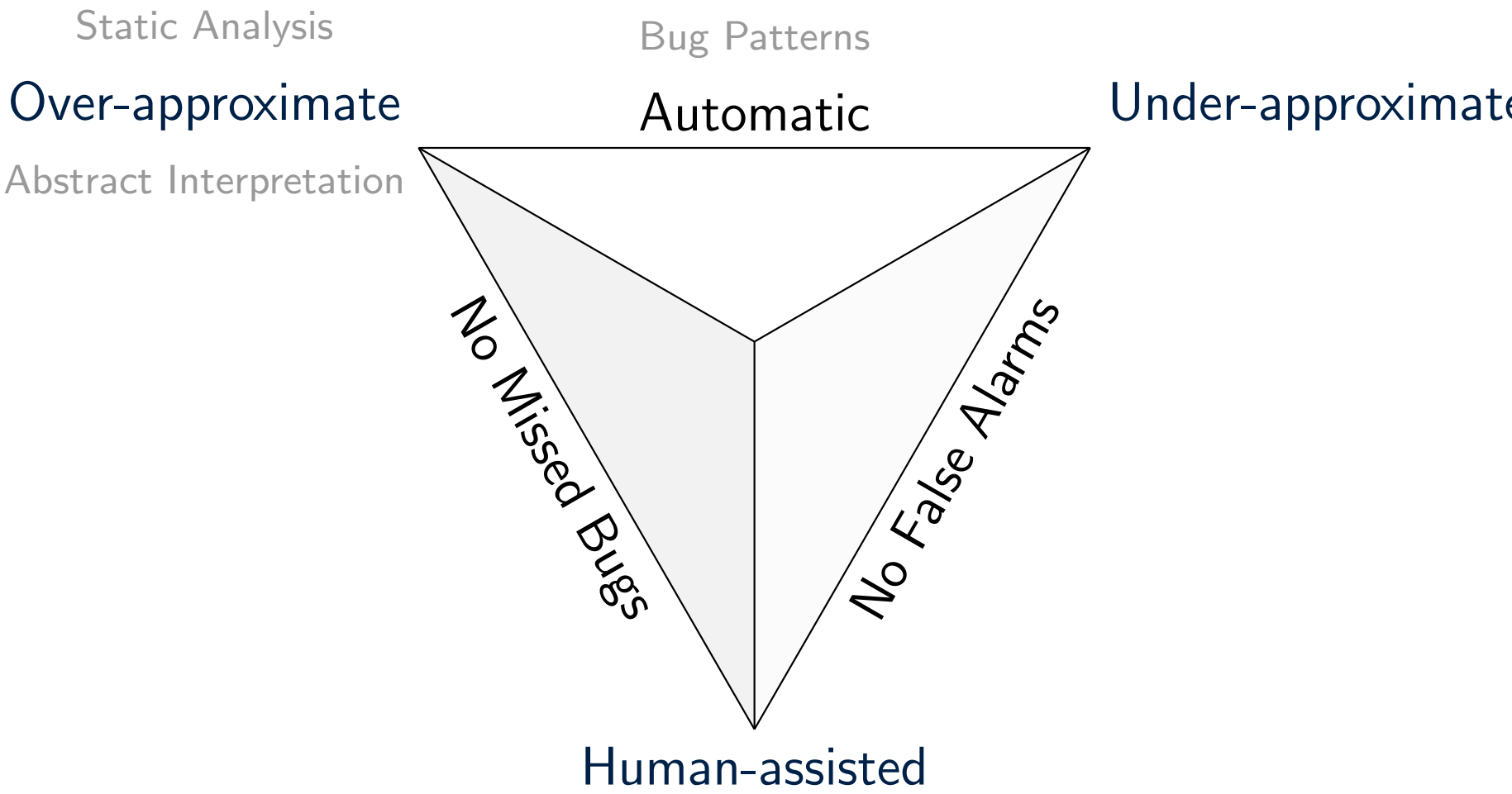

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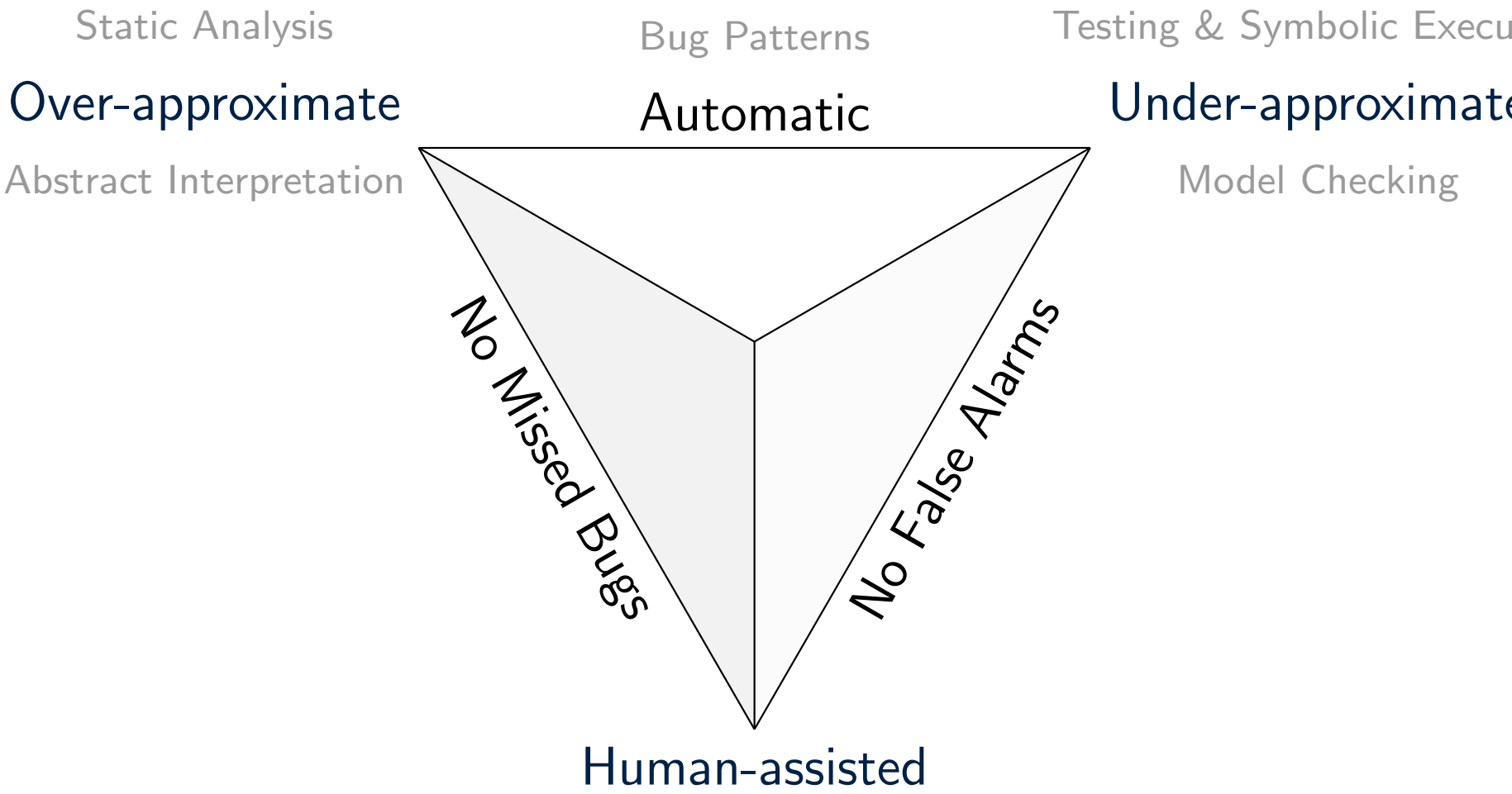

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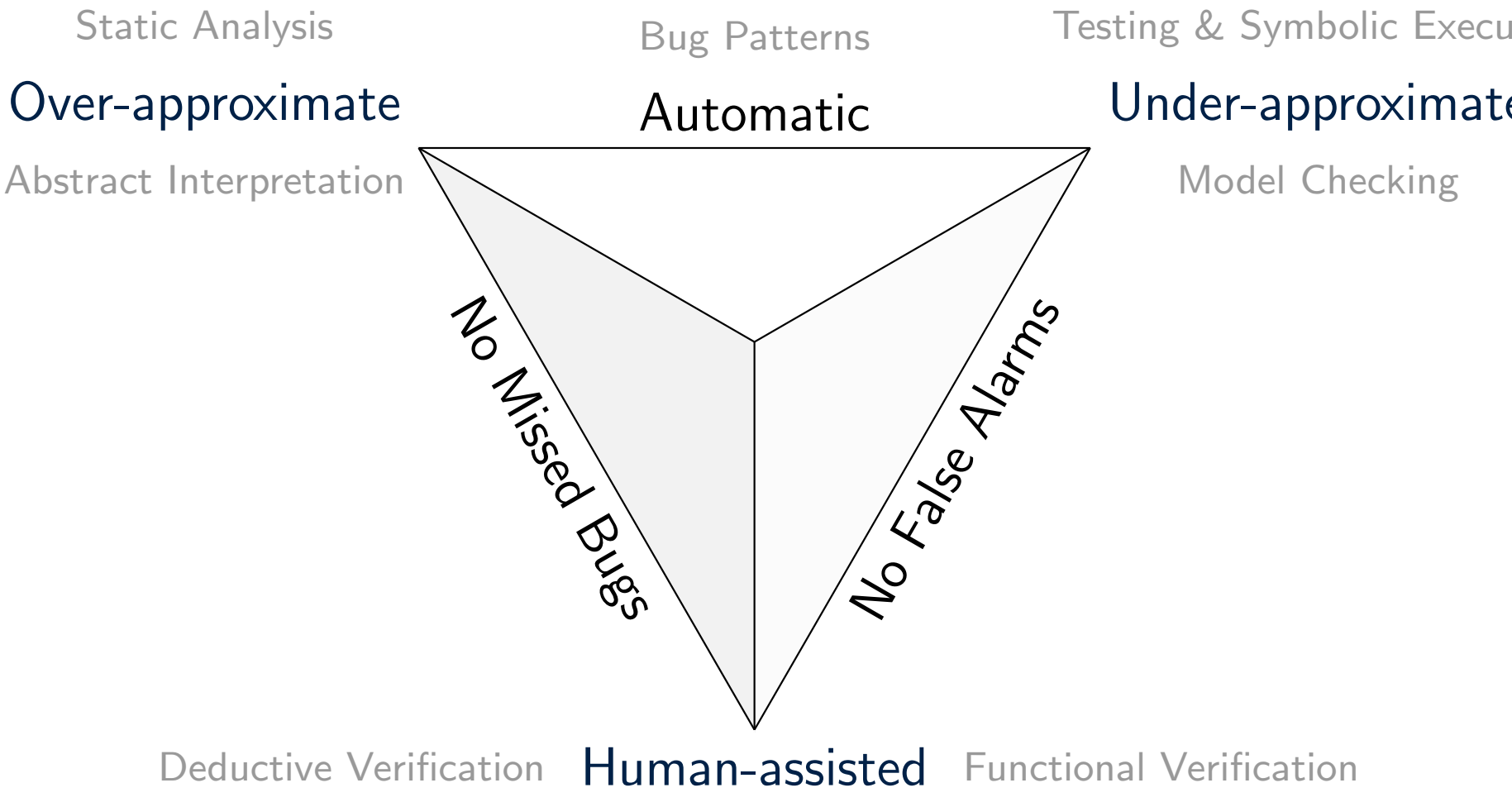

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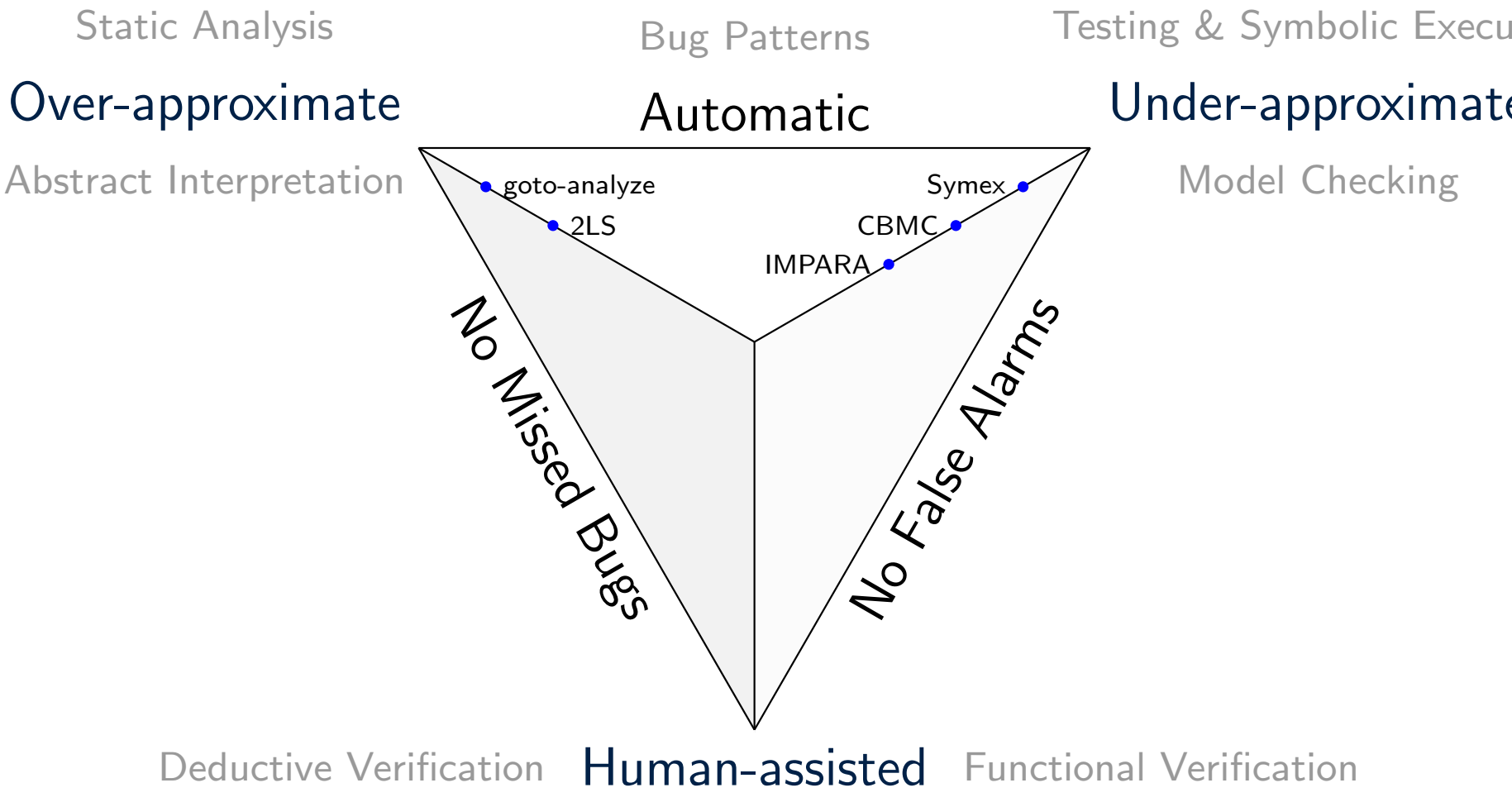

Use Formulae to Represent *Sets of States*

$$\text{Program} \rightarrow \text{Formula(e)}$$

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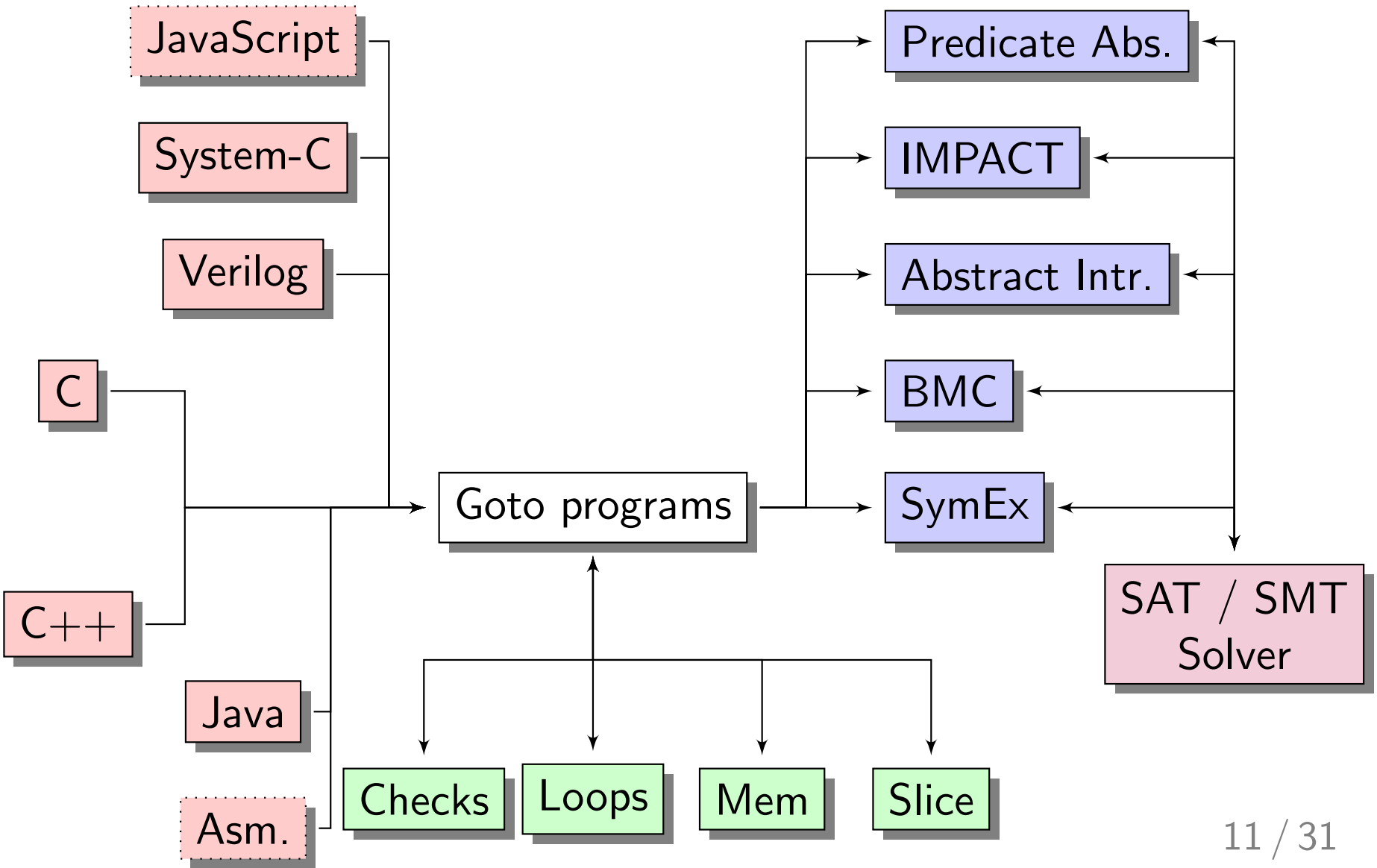
But what about the ...

- Strings
- Pointers
- Dynamic Memory
- Function Pointers
- Loops
- Recursion
- Concurrency
- Interrupts

The CPROVER Suite of Program Verification Tools

- A collection of tools built from a common code-base.
- Started in 2002/2003 with CBMC.
- Pioneered 'bit-blasting' for software verification.
- SV-COMP : 2014 Gold, 2015 Bronze
- Industrial users in automotive, EDA, aerospace.
- State-of-the-art support for floating-point, multi-core, firmware, ...

CPROVER System Architecture



Install CBMC Now!

Binary:

`http://www.cprover.org/cbmc/`

Source:

`http://github.com/diffblue/cbmc/`

Examples:

`http://www.cprover.org/tutorial/`

abs.c

```
#include <assert.h>
#include <stdlib.h>

int abs (int x) {
  int y = x;

  if (x < 0) {
    y = -x;
  }

  return y;
}
```

1. Front End

```
cbmc abs.c --function abs --show-goto-functions
```

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```
cbmc abs.c --function abs --show-goto-functions
```

Notice:

- Uses system preprocessor and headers
- Library functions are stubs
- OS/Architecture specific information

2. Instrumentation

```
cbmc abs.c --function abs --signed-overflow-check
           --show-goto-functions
```

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```
cbmc abs.c --function abs --signed-overflow-check
           --show-goto-functions
```

Notice:

- `--*-check` flags.
- Specifications are assertions.

3.A. Static Single Assign

```
#include <assert.h>
#include <stdlib.h>

int abs (int x) {
  int y = x;

  if (x < 0) {
    y = -x;
  }

  return y;
}
```

```
#include <assert.h>
#include <stdlib.h>

int abs (int x1) {
  int y2 = x1;

  int guard1 = (x1 < 0);
    int y3 = -x1;
  int y4 = (guard1) ? y3 : y2

  return y4;
}
```

3.A. Static Single Assign

```
#include <assert.h>
#include <stdlib.h>

int abs (int x) {
  int y = x;

  if (x < 0) {
    y = -x;
  }

  return y;
}
```

```
#include <assert.h>
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int abs (int x1) {
  int y2 = x1;

  int guard1 = (x1 < 0);
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  int y4 = (guard1) ? y3 : y2

  return y4;
}
```

```
cbmc abs.c --function abs --signed-overflow-check
           --program-only
```

3.B. Verification Conditions

```
cbmc abs.c --function abs --signed-overflow-check
           --show-vcc
```

3.B. Verification Conditions

```
cbmc abs.c --function abs --signed-overflow-check
           --show-vcc
```

Notice:

- `--slice-formula`
- Each assertion becomes a VC.

Putting It All Together

```
cbmc abs.c --function abs --signed-overflow-check
```

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```
cbmc abs.c --function abs --signed-overflow-check
```

Notice:

- Instructions in goto-program $\rightarrow$ steps in trace.
- Reporting values and locations.

escapeFunction.c

```
#include <string.h>
#include <stdlib.h>

char * escape (const char *s) {
  char * escaped = malloc((strlen(s) + 1) * 2);
  char * output = escaped;

  *(output++) = '"';
  while (*s != '\0') {
    if ((*s == '"') || (*s == '\\')) {
      *(output++) = '\\';
    }
    *(output++) = *(s++);
  }
  *(output++) = '"';
  *(output++) = '\0';

  return escaped;
}
```

Harnesses and Unwinding

```
cbmc escapeFunction.c --function escape
--pointer-check --bounds-check --slice-formula
```

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```
cbmc escapeFunction.c --function escape
--pointer-check --bounds-check --slice-formula
```

```
cbmc escapeFunction.c --function escape
--pointer-check --bounds-check --slice-formula
                    --unwind 4
```

escapeFunctionHarness.c

```
#include "escapeFunction.c"

char nondet_char (void);

int main (void) {
  char string[16];
  int i;

  for (i = 0; i < 16; ++i) {
    string[i] = nondet_char();
    if (string[i] == '\0') { break; }
  }

  char *output = escape(string);

  return 0;
}
```

Unwinding Assertions

```
cbmc escapeFunctionHarness.c --pointer-check
  --bounds-check --slice-formula --unwind 4
        --no-unwinding-assertions
```

goto-cc

```
goto-cc simple.c -o simple.goto
```

goto-cc

```
goto-cc simple.c -o simple.goto
```

Notice:

- Compiler replacement for build system integration.
- Has both compile and link phases.
- Also `goto-cl`, `goto-cw`, ...

goto-instrument

```
goto-instrument --dump-c simple.goto
```

goto-instrument

```
goto-instrument --dump-c simple.goto
```

Notice:

- Program to program transforms
- k-induction
- loop-acceleration

Program → Result

XML

`--xml-ui`

`--xml-interface`

SV-COMP GraphML

`--graphml-cex`

(Counter-examples only)

Program → Formula

DIMACS

```
cbmc abs.c --function abs --signed-overflow-check
                          --dimacs
```

SMT-LIB

```
cbmc abs.c --function abs --signed-overflow-check
                    --smt2 --outfile -

cbmc abs.c --function abs --signed-overflow-check
                  --smt2 --outfile - --fpa
```

Internal Interfaces

Goto-Programs

`goto-programs/goto_program_template.h : instructiont`

Formulae

`util/decision_procedure.h : decision_proceduret`

`solvers/prop/prop_conv.h : prop_convt`

Challenges and The Future

We Always Need Better...

- Provers
- Pointer analysis
- Analysis Techniques

How Do We ...

- Loop Acceleration
- Summaries
- Handle libraries
- Strings

Someone Could Build...

Front-ends x86, PHP, Python, ...

Instrumentation `dump-*`

Back-ends Interpolation

Why Not Try...

- Crypto libraries
- Parts of the Linux Kernel
- Trust Zone OS
- GLibc

Try These!

1. Fix the error in `abs.c` and confirm that it is fixed.
2. Using `escapeFunctionHarness.c`:
   1. Fix the off-by-one-error in allocation and confirm it is fixed.
   2. By increasing the unwinding limit, locate and fix the other bug.
3. `loopUnwinding.c`
4. `sorting.c`
5. `searchTree.c`

`http://www.cprover.org/tutorial/`