Bounded Software Model Checking with CBMC

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Outline

Session I: 18^{th} November 2011

- Motivating examples
- Finding Security Vulnerabilities with CBMC
- Introduction to the Assignment
- Some homework tasks

Session II: 2^{nd} December 2011

- Discuss homework
- CBMC Background
- Q&A Session on CBMC and the assignment

Session I: 18^{th} November 2011

Session I

CBMC: Coordinates

The **C B**ounded **M**odel **C**hecker

- `http://www.cprover.org/`
- Originally by Clarke, Kroening and Lerda [CKL04]
- Currently maintained by Daniel Kroening at Oxford
- One of the key tools in PINCETTE
  `http://www.pincette-project.eu/`
- Supports very large subset of C and some C++
  `http://www.cprover.org/cbmc/language_features.html`

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- There is also SatAbs, a checker based on predicate abstraction [CKSY05]

CBMC: Getting the Tool

Installation instructions

- Windows, Linux and MacOS packages are available at `http://www.cprover.org/cbmc/`
- For Windows you need Visual Studio or the free Visual C++ 2010 Express; we recommend using Linux or MacOS
- There is Eclipse support (`http://www.cprover.org/eclipse-plugin/`). I had some trouble installing it – do not waste too much time here.
- **All assignment tasks can be accomplished by using the command-line CBMC!**

Motivating examples

Tool Demo!

The demo is based on `course_01.c`, which is available on Toledo.

Finding Security Vulnerabilities with CBMC

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Bear in mind: CBMC performs a *bounded* analysis!

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- *Finding security vulnerabilities with CBMC*
- Work in groups of 2 or 3 people, 30h per student
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- You will **get a C program** with several vulnerabilities; you have to systematically **apply CBMC** to identify these vulnerabilities and to fix or even exploit them
- **Goals:** Understand bounded model checking; understand the vulnerabilities

Introduction to the Assignment

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- 350 LOC; a doubly-linked list of address entries; textual interface for managing entries
- Intended to be used by other programs that implement the user interface
- Intended to run on an embedded device: OS takes care of persistently storing the program state
- Requirements: dependability and security

Introduction to the Assignment

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- **Task 4:** Verify the address book.

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- **Task 4:** Verify the address book.
- **Task 5:** Discuss how you would write a program that is to be verified with CBMC (given the limitations of bounded model checking and CBMC that you have explored).

Introduction to the Assignment

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- **Task 8:** If you find any format string vulnerabilities, exploit them.

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Good luck!

Getting started

Where to start

- Do the **homework** task.
- CBMC website has tutorials and documentation
- CBMC manual:
  `http://www.cprover.org/cbmc/doc/manual.pdf`
- Read the assignment text!
- Write little toy examples to isolate problems.

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If you get stuck

- There will be a *Q&A Session* on the **2nd of December**.
- Use the course forums on *Toledo* for further questions. For technical questions always add **small** example code that illustrates the problem.

Homework

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- **2:** Implement a function `sorted(int *array, int length)` which tests to ensure that an array is sorted. Use CBMC to verify that `assert (sorted (array, length))` holds.

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- **2:** Implement a function `sorted(int *array, int length)` which tests to ensure that an array is sorted. Use CBMC to verify that `assert (sorted (array, length))` holds.
- **3:** Repeat for Quicksort.

Homework

Verify Bubblesort

```
void bubblesort (int *array, int length)
 {
  int i, j;

  for (i = 0; i < length - 1; ++i)
   { for (j = 0; j < length - i - 1; ++j)
      { if (array[j] > array[j + 1])
         { int tmp = array[j];

           array[j] = array[j + 1];
           array[j + 1] = tmp; }
      } }
 }
```

Homework

Verify Bubblesort

```
#include "bubble.c"

int sorted (int *array, int length)
 { /* ... check */ }

#define SIZE ...

int main (int argc, char **argv)
 { int array[SIZE];

   /* ... array initialisation */

   bubblesort (array, SIZE);
   assert (sorted (array, SIZE));

   return (0); }
```

Thank you!

Thank you! Questions?

Session II: 2nd December 2011

Session II

Homework

Questions and Problems?

Homework

Some issues you may have encountered:

- Array handling: copying bytes from one array (or `malloc`ed chunk) to another
- Multiple dereferences in one statement: `x->y->z = 5`
- Loop bounds and unwinding assertions
- Recursion
- Combinatorial blow-up: CBMC terminates with “out of memory”

Bounded Software Model Checking (as in CBMC)

CBMC is based on a technique described in by Biere et al. as "symbolic model checking without BDDs" [BCCZ99]:

- Transform the program into a *control flow graph*
- Follow paths through the CFG to an assertion, and build a formula that corresponds to the path
- Formulae are instances of SAT or SMT: pass them to a solver and obtain a satisfying assignment
- ...repeat for all paths and assertions
- Satisfying assignments can be reused as input to the program

Bounded Software Model Checking (as in CBMC)

```
if ( (0 <= t) && (t <= 79) )
switch ( t / 20 )
{ case 0:
    TEMP2 = ( (B AND C) OR (~B AND D) );
    TEMP3 = ( K_1 );
    break;
  case 1:
    TEMP2 = ( (B XOR C XOR D) );
    TEMP3 = ( K_2 );
    break;
  case 2:
    TEMP2 = ( (B AND C) OR (B AND D) OR (C AND D) );
    TEMP3 = ( K_3 );
    break;
  case 3:
    TEMP2 = ( B XOR C XOR D );
    TEMP3 = ( K_4 );
    break;
  default:
    assert(0); }
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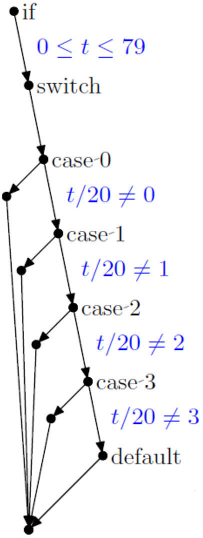

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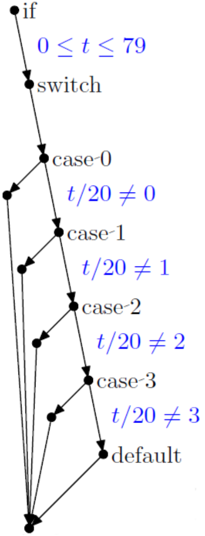
CFG



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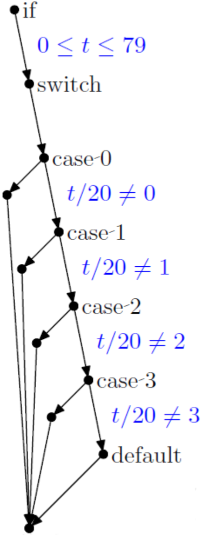
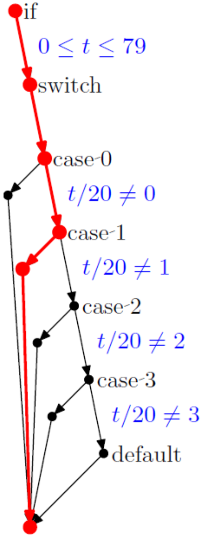


A Path



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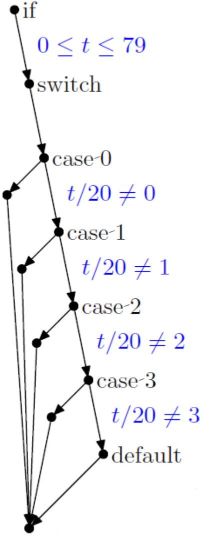

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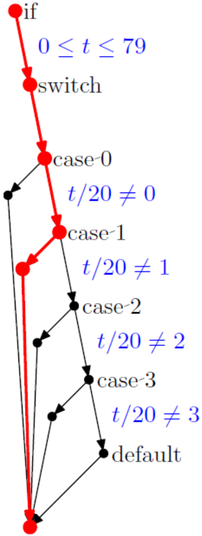

Formula

$$
\begin{aligned}
& 0 \leq \mathtt{t} \leq 79 \\
\wedge\ & \mathtt{t/20} \neq 0 \\
\wedge\ & \mathtt{t/20} = 1 \\
\wedge\ & \mathtt{TEMP2} = \mathtt{B} \oplus \mathtt{C} \oplus \mathtt{D} \\
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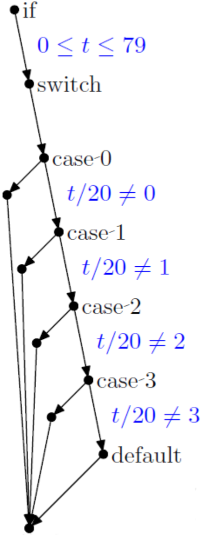

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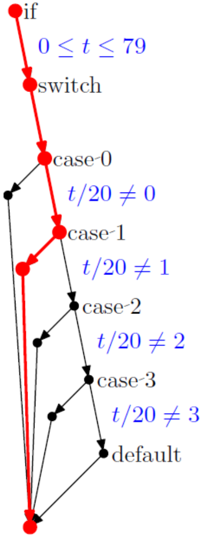

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$\wedge$ TEMP3 = K_2

Sat. Assign.

t $\mapsto$ 21; B $\mapsto$ 0;
C $\mapsto$ 0; D $\mapsto$ 0;
K_2 $\mapsto$ 10;
TEMP2 $\mapsto$ 0;
TEMP3 $\mapsto$ 10

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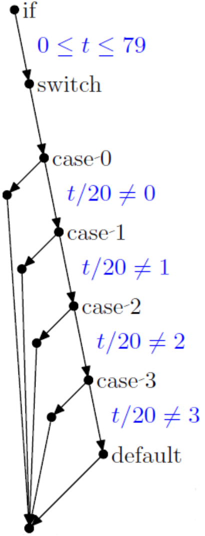

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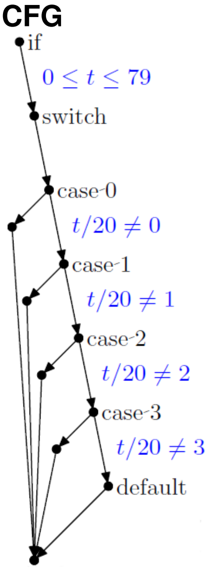

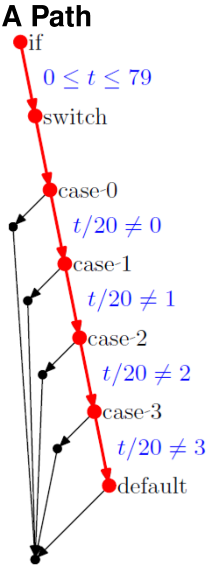

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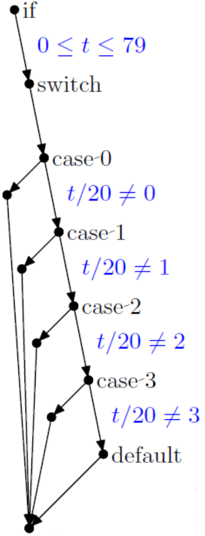

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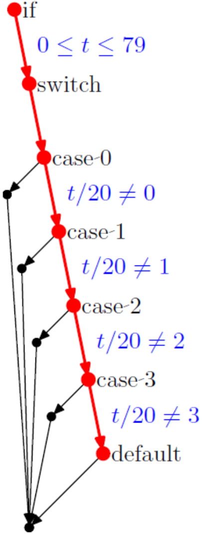

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\begin{array}{l}
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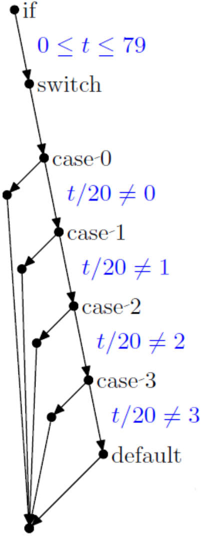

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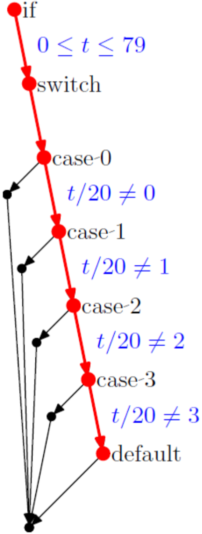

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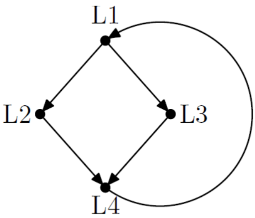
UNSAT

Bounded Software Model Checking (as in CBMC)

Let's consider the following CFG:



CBMC unwinds loops a bounded number of times.

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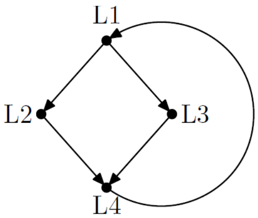

CBMC unwinds loops a bounded number of times.

How many paths do we get for *n* iterations?

Bounded Software Model Checking (as in CBMC)

Tool Demo!

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- Enabling technology: efficient decision procedures
- Advantages:
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  - Finds subtle bugs
- Great if: you only look for bugs up to specific depth or your programs are relatively “shallow”
- Good for many applications, e.g., embedded systems

Thank you!

Thank you! Questions?

This talk is largely based on material from “CBMC: Bounded Model Checking for ANSI-C” available at

`www.cprover.org/cbmc/doc/cbmc-slides.pdf`

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