Program Verification
Critical Architectures Laboratory

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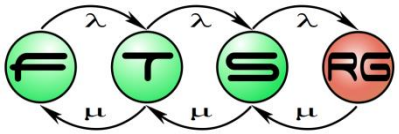
Budapesti Műszaki és Gazdaságtudományi Egyetem
Hibatűrő Rendszerek Kutatócsoport



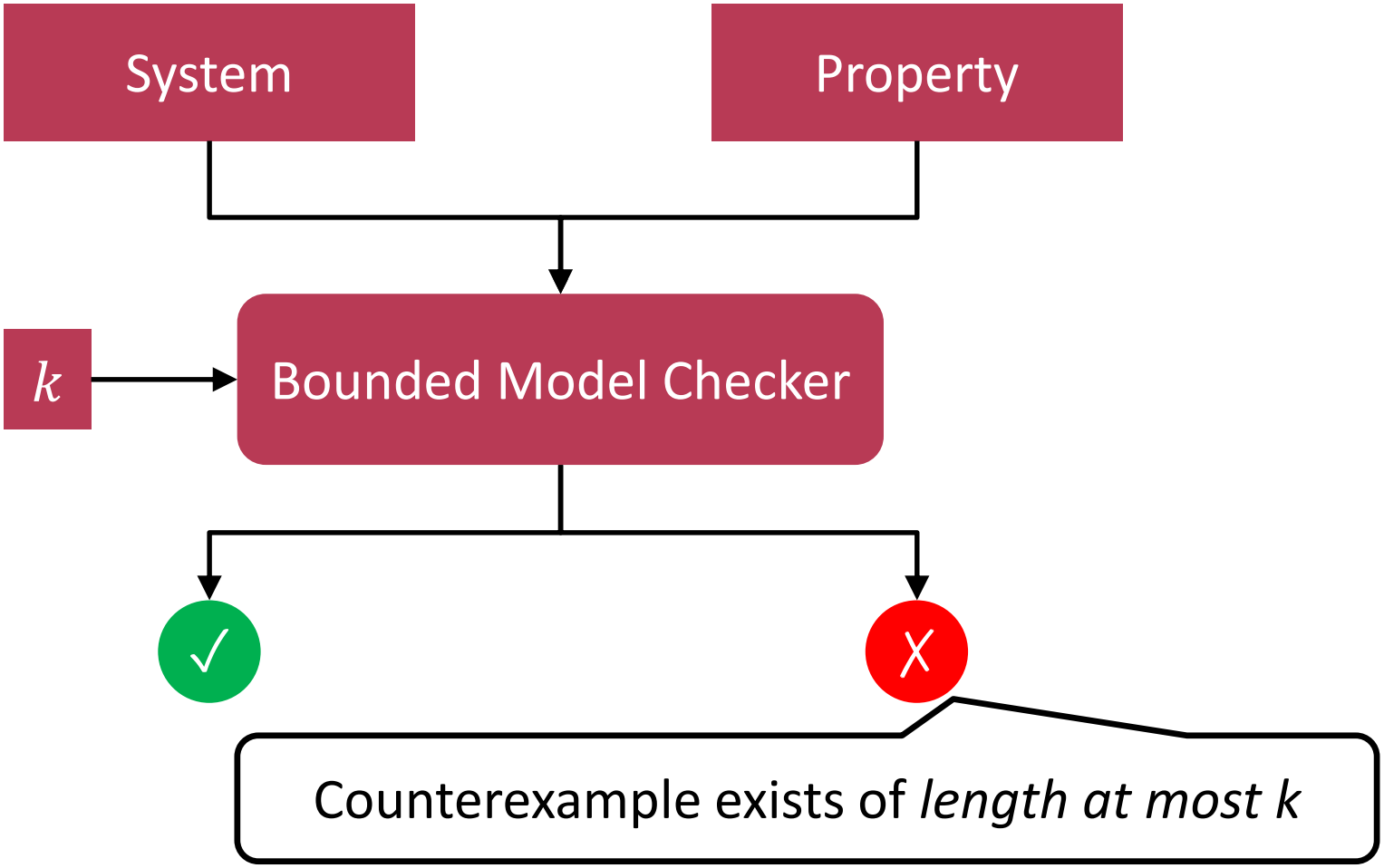
INTRODUCTION

Topic of the Lab Session:

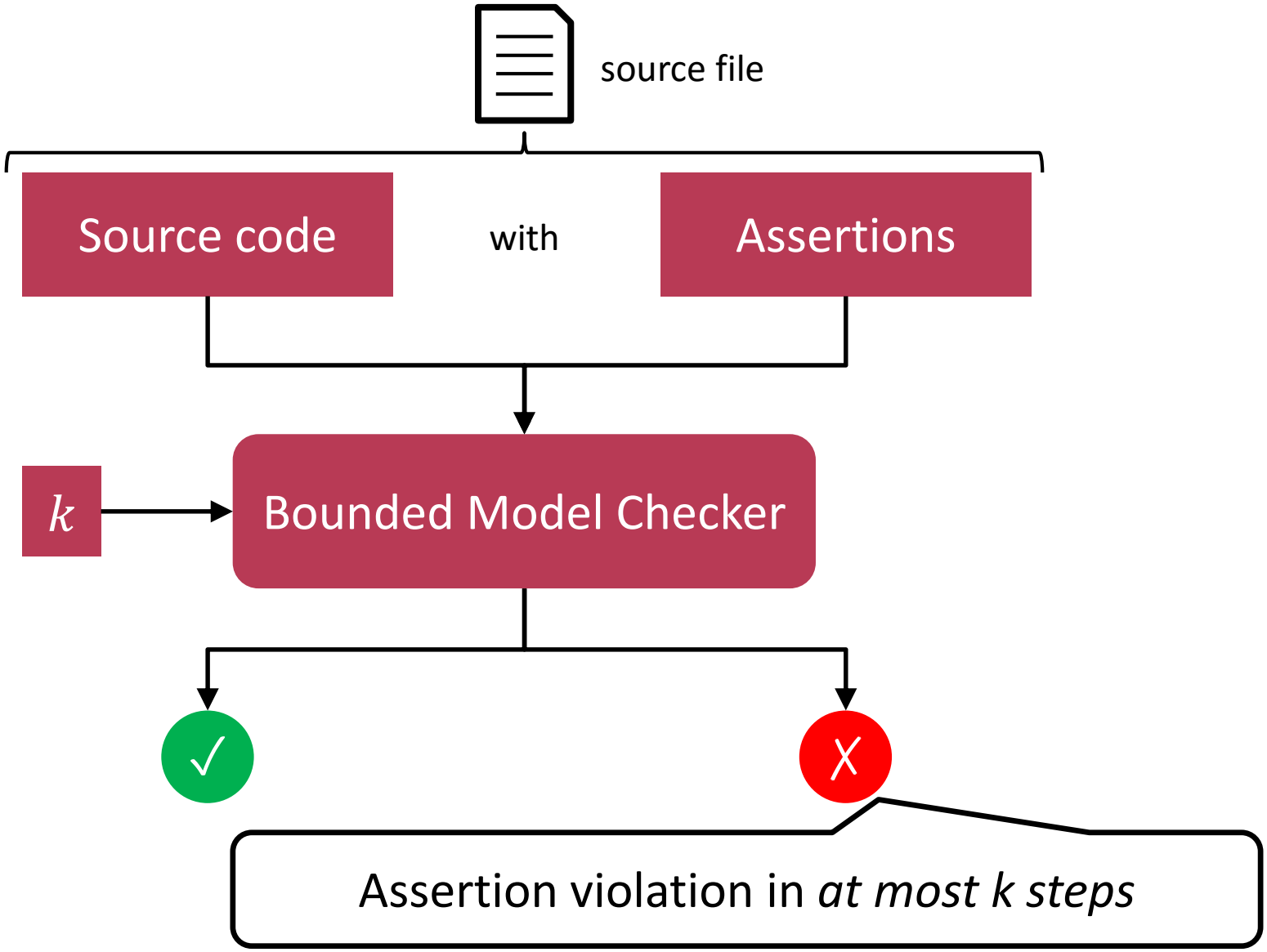
Implement a Bounded Model Checker

for a simple imperative programming language

Bounded Model Checking

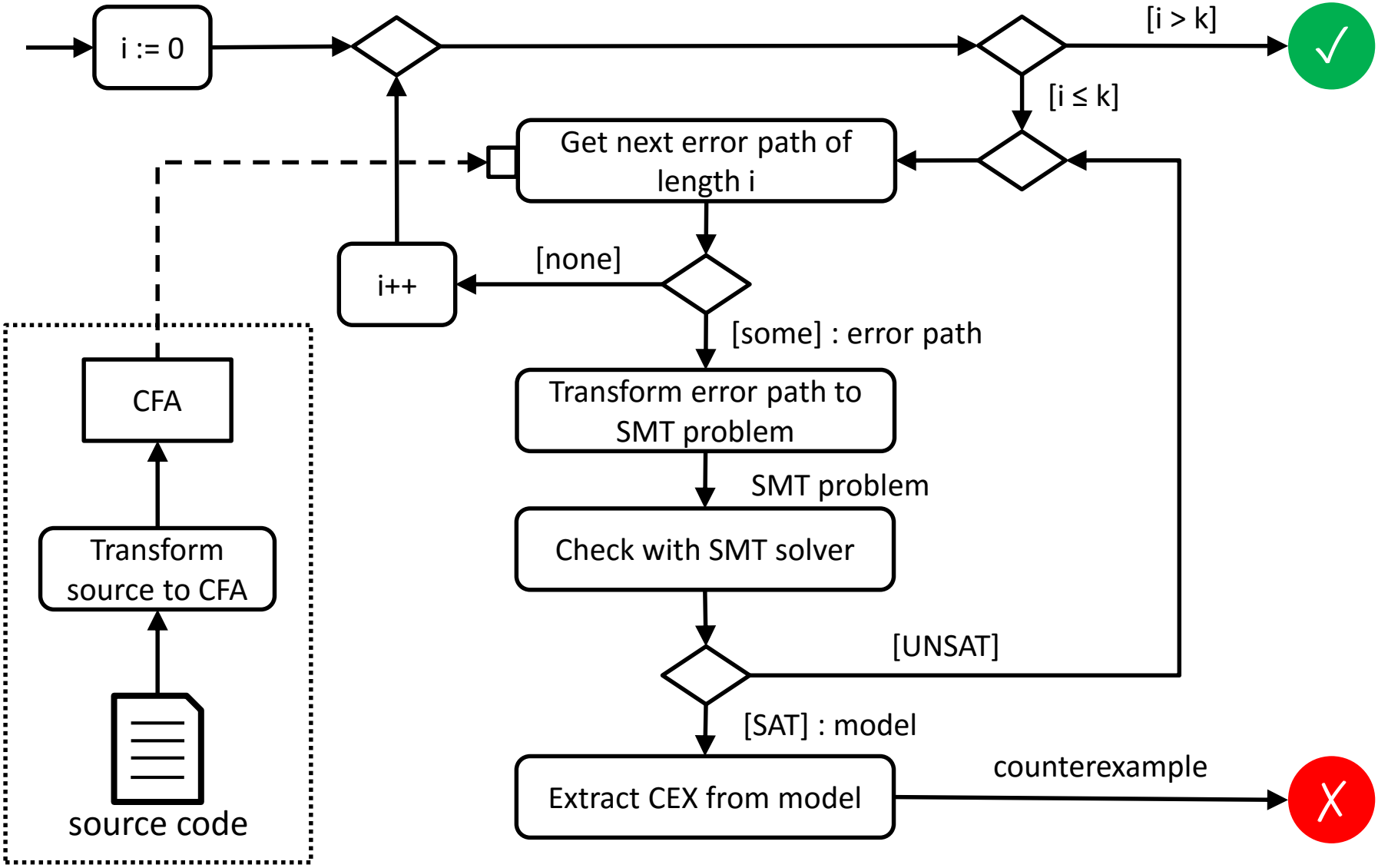


BMC for Programs



VERIFICATION WORKFLOW

BMC Workflow

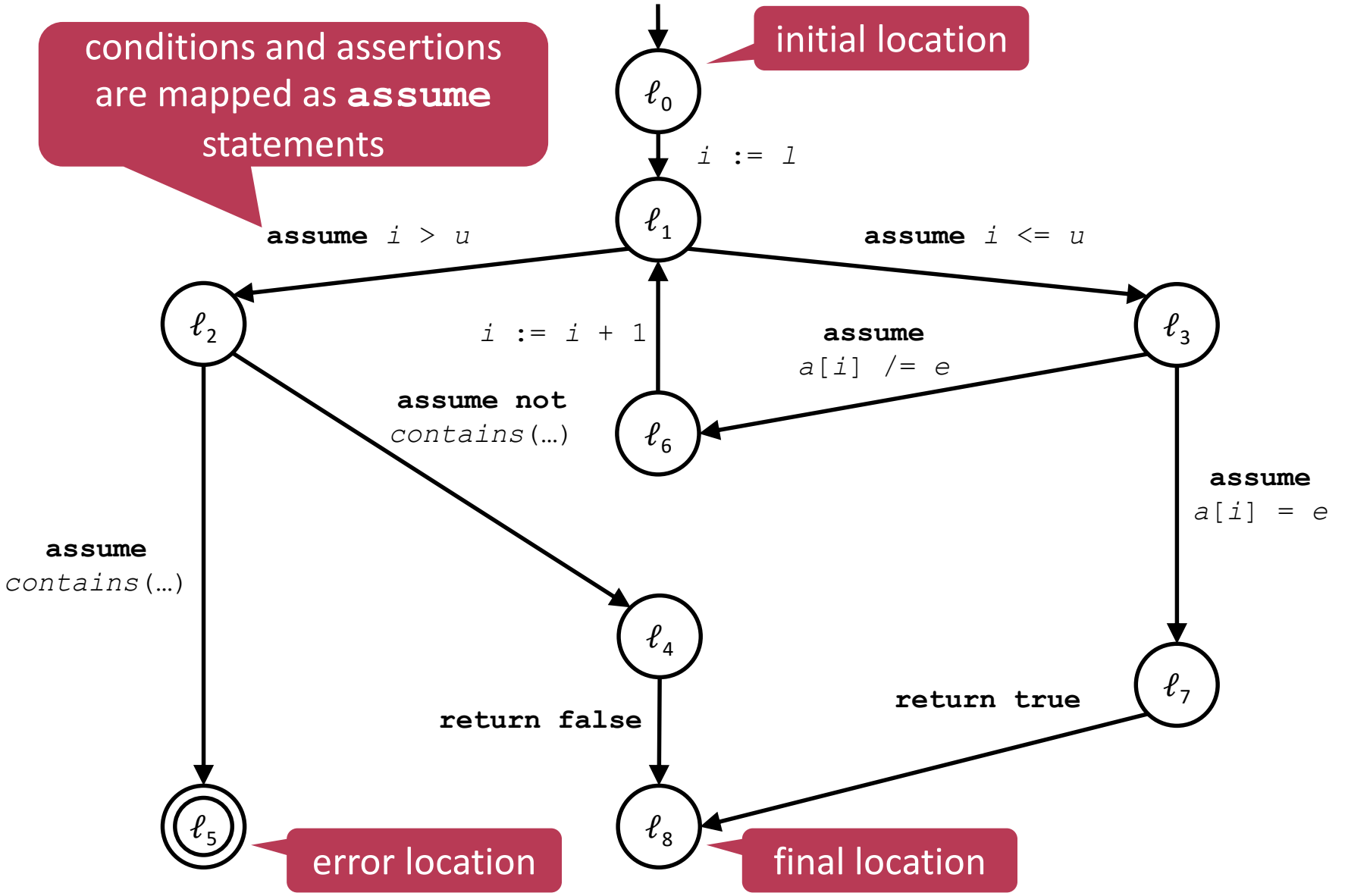


Source code with Assertions

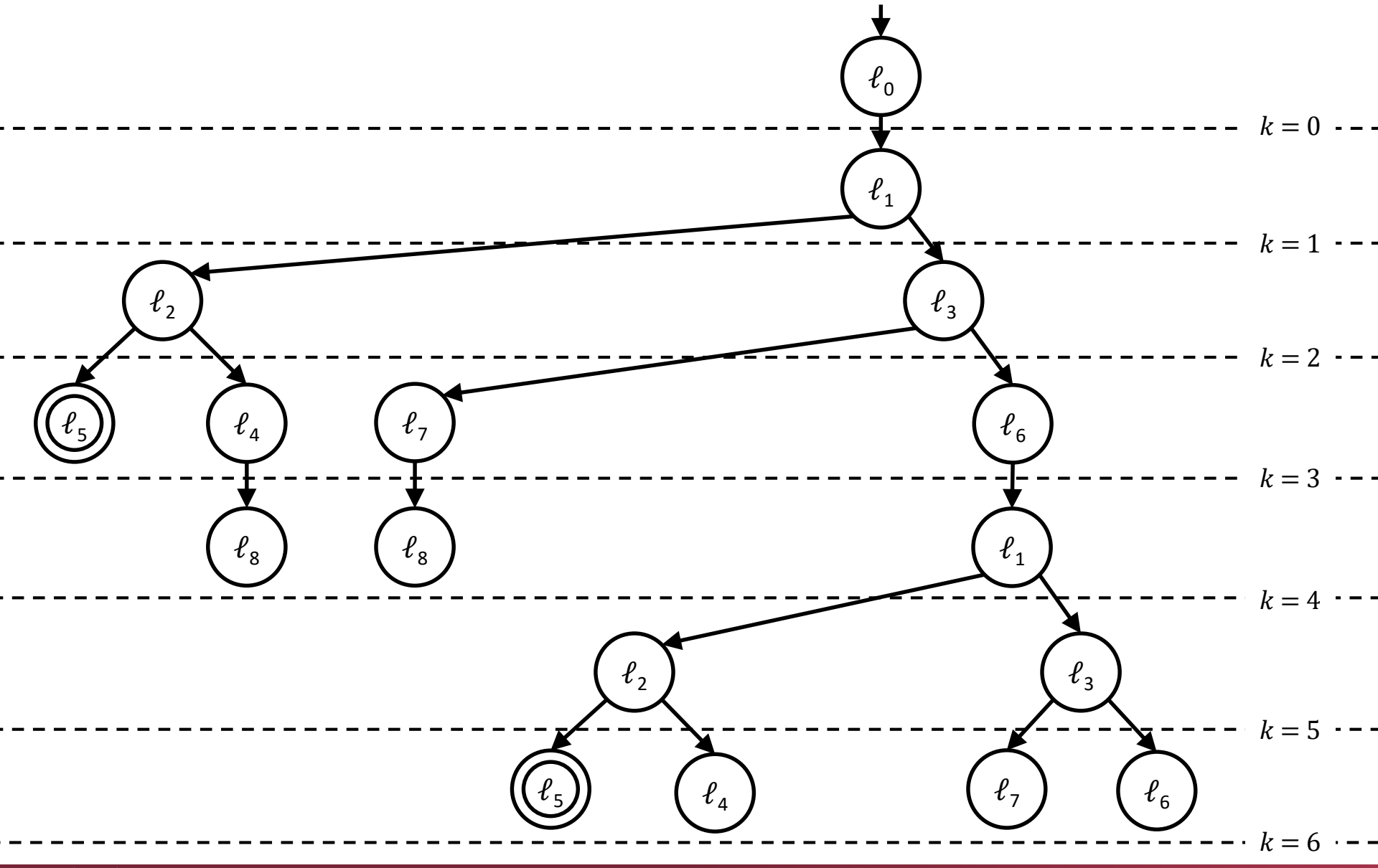
```
procedure linearSearch(
  a : array integer of integer,
  l : integer, u : integer, e : integer
) : boolean {
  var i : integer := l;

  while i <= u do {
    if a[i] = e then {
      return true;
    } else {
      i := i + 1;
    }
  }

  assert not contains(a, l, u, e);
  return false;
}
```

assert statements mark a requirement at the given point of control flow

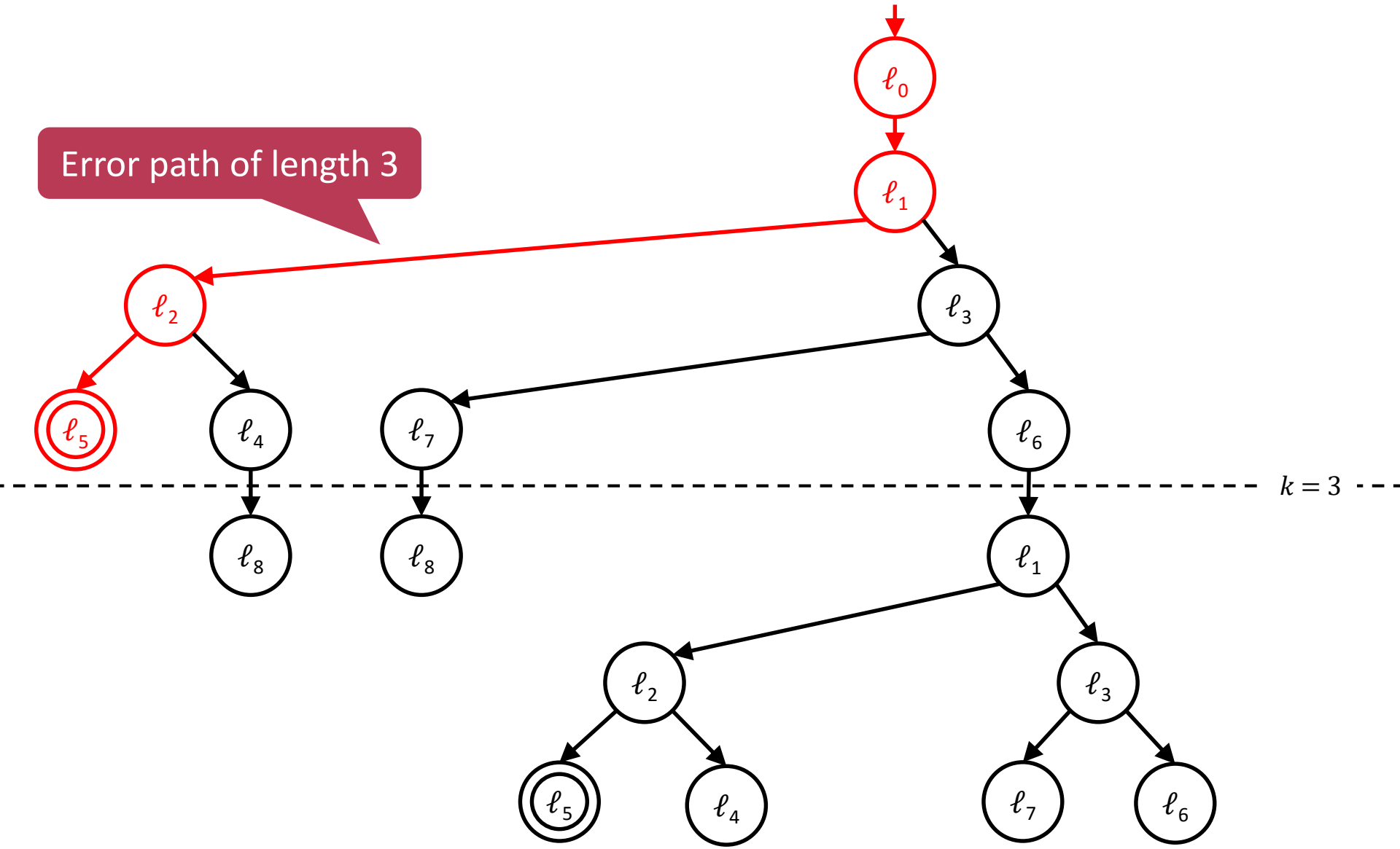
Control Flow Automata (CFA)



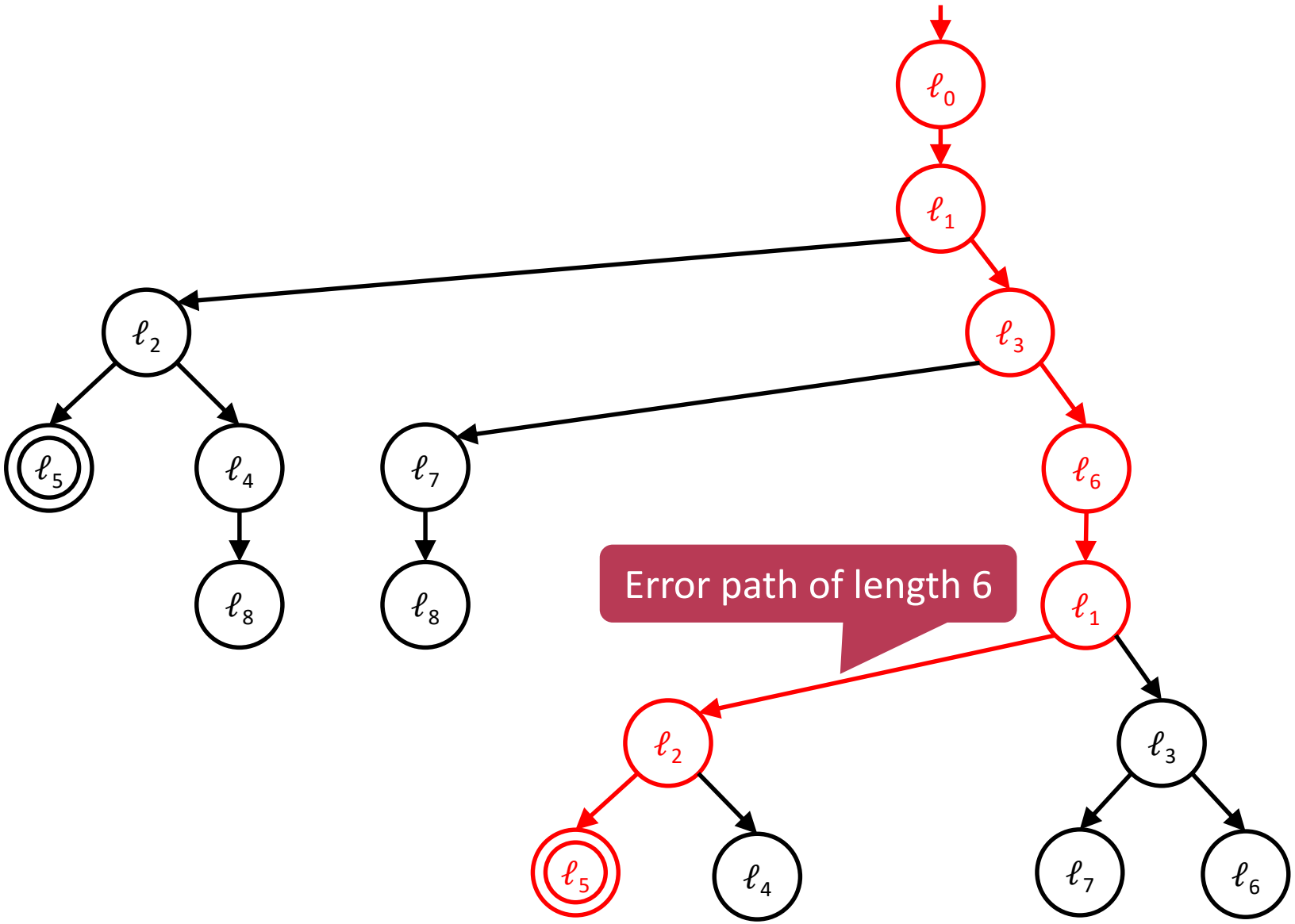
(Bounded) Unwinding of a CFA



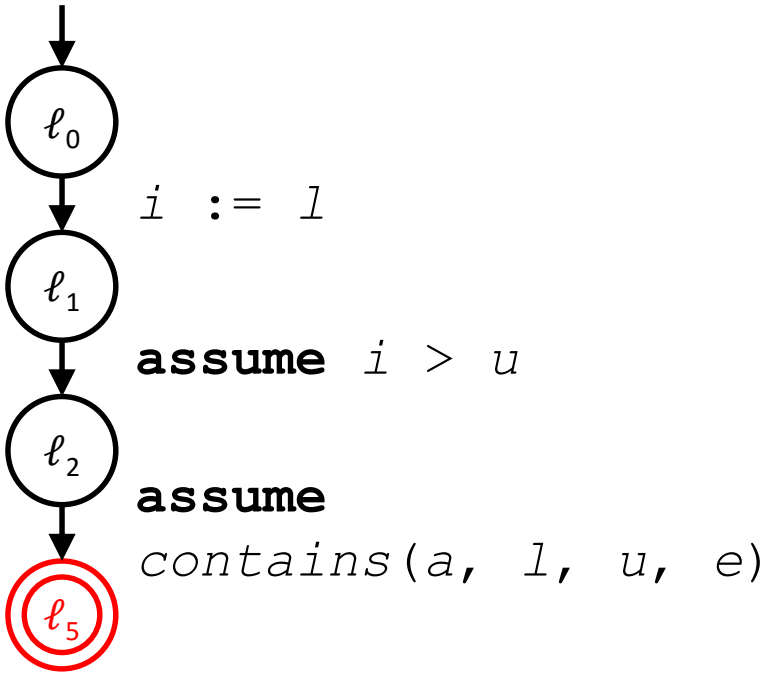
(Bounded) Unwinding of a CFA



(Bounded) Unwinding of a CFA



Error Paths



Error path

```
i := l;
assume i > u;
assume
   contains(a, l, u, e)
```

Simple program representing the error path: contains only assignments and assumptions

Checking error paths

Program path

```
i := l;
assume i > u;
assume exists (j : integer) :
   (j >= l and j < u and a[j] = e)
```

can be taken for some inputs a, l, u, e

iff

SMT problem

$$i_0 = l$$
$$i_0 > u$$
$$\exists (j : Int) : (j \geq l \wedge j < u \wedge a[j] = e)$$

is satisfiable.

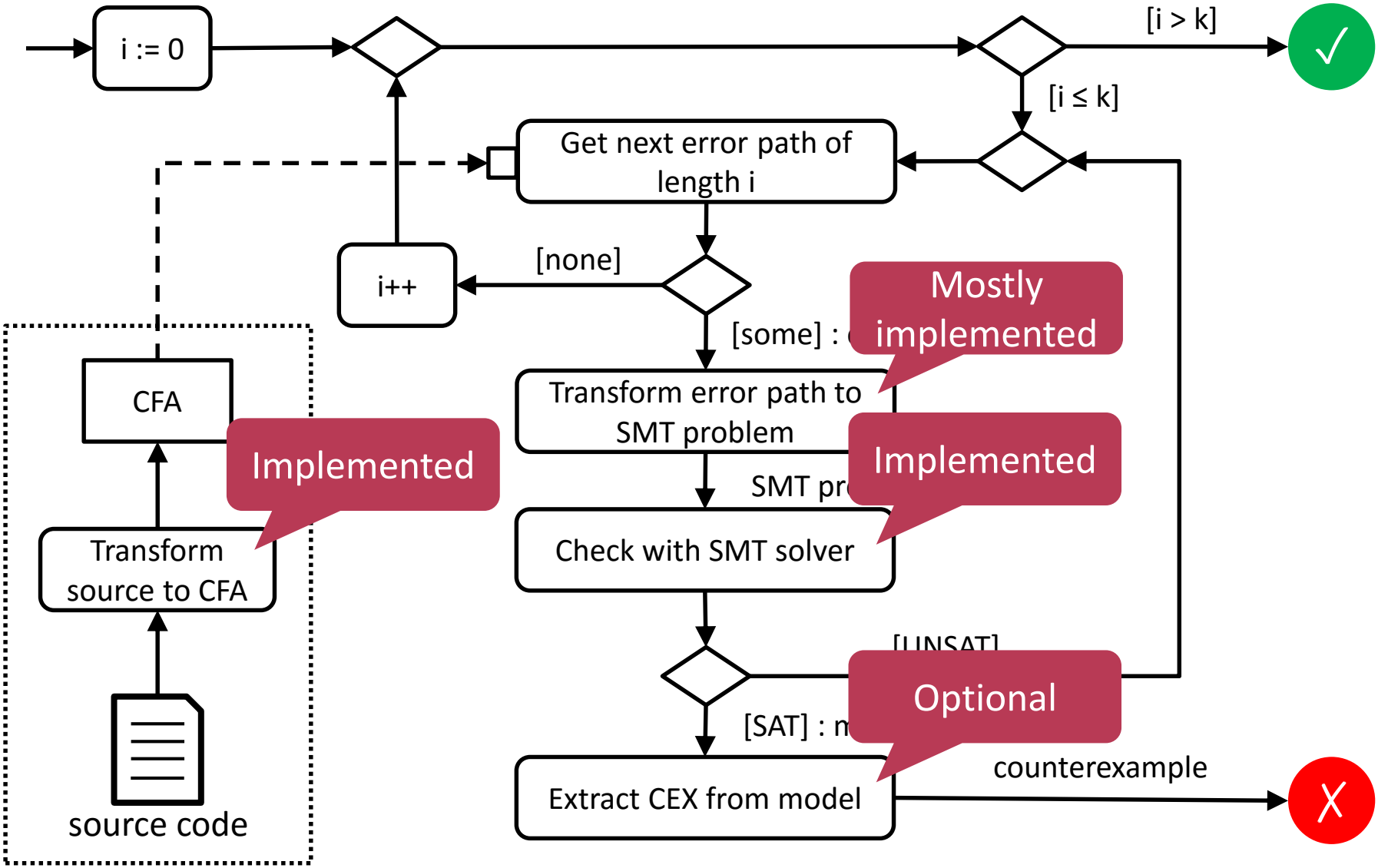
Transforming Statements to SMT

```
x := a
y := b
tmp := a
a := b
b := tmp
assume y >= a
assume x >= b
```

$$x_0 = a_0$$
$$y_0 = b_0$$
$$tmp_0 = a_0$$
$$a_1 = b_0$$
$$b_1 = tmp_0$$
$$y_0 \geq a_1$$
$$x_0 \geq b_1$$

- Introduce a fresh constant symbol for the variable in the left-hand side in each assignment
- Refer to the freshest constant symbol accordingly

BMC Workflow: Tasks



LIST OF QUESTIONS

List of questions

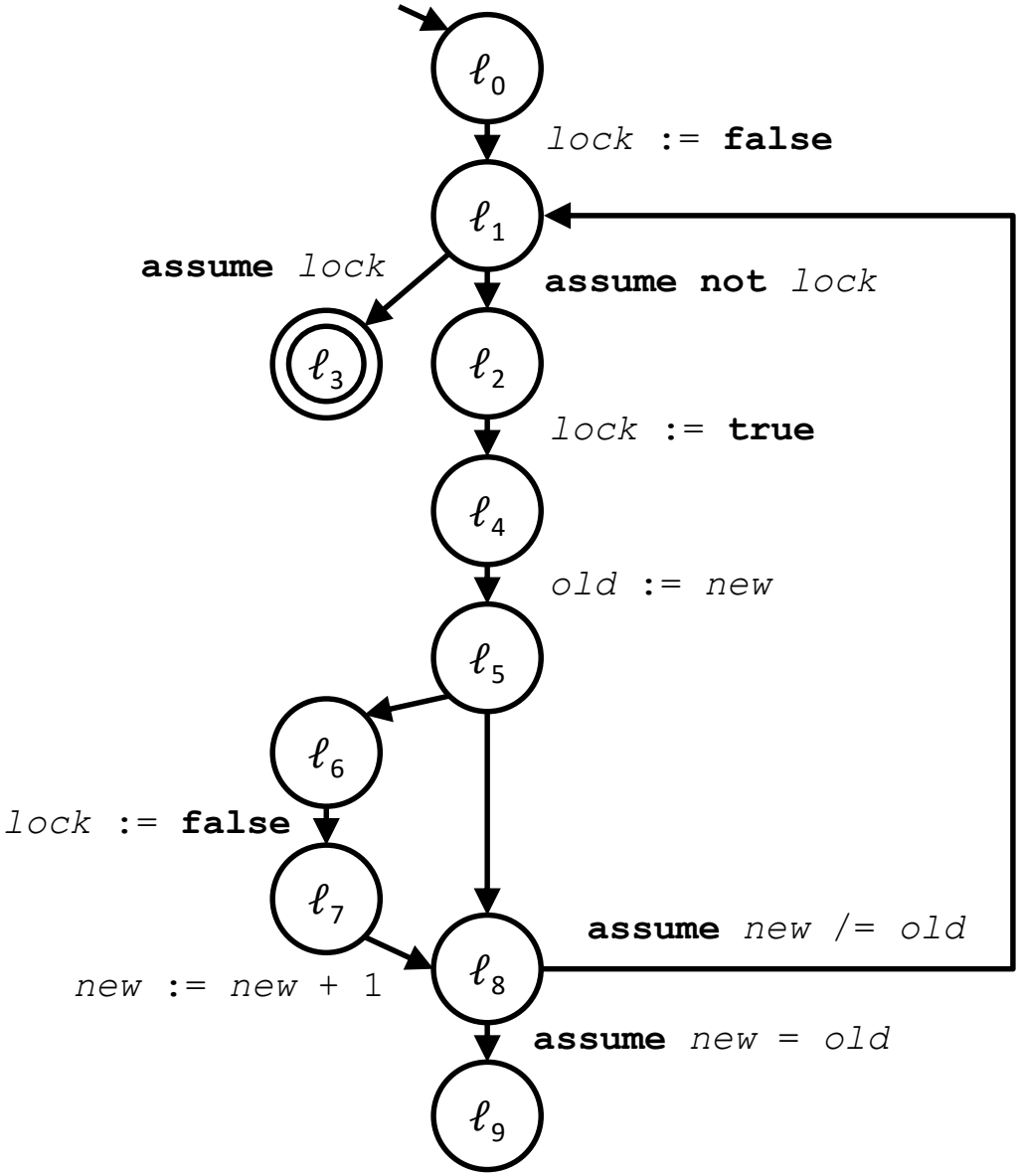
1. Transform the following program to CFA form:

```
var lock : boolean := false;
var old, new : integer;
  do {
    assert lock = false;
    lock := true;
    old := new;
    if * then {
      lock := false;
      new := new + 1;
    }
  } while new /= old;
}
```

2. Determine the program paths that represent the three shortest error paths of the program
3. Transform the paths to SMT problems
4. Give an argument for their unsatisfiability

SOLUTIONS

Solution (1)


ℓ_0
lock := false
ℓ_1
assume lock
assume not lock
ℓ_3
ℓ_2
lock := true
ℓ_4
old := new
ℓ_5
ℓ_6
lock := false
ℓ_7
assume new /= old
new := new + 1
ℓ_8
assume new = old
ℓ_9

Solution (2)(3)(4)

```
lock := false;
assume lock;
```

$\neg lock_0$
$lock_0$

```
lock := false;
assume not lock;
lock := true;
old := new;
assume new /= old;
assume lock;
```

$\neg lock_0$
$\neg lock_0$
$lock_1$
$old_0 = new_0$
$new_0 \neq old_0$
$lock_1$

```
lock := false;
assume not lock;
lock := true;
old := new;
lock := false;
new := new + 1;
assume new /= old;
assume lock;
```

$\neg lock_0$
$\neg lock_0$
$lock_1$
$old_0 = new_0$
$\neg lock_2$
$new_1 = new_0 + 1$
$new_1 \neq old_0$
$lock_2$