Using SPIN to Model Check Concurrent Algorithms, using a translation from C to Promela

Ke Jiang

Bengt Jonsson

Uppsala University

UPPSALA UNIVERSITET

Informationsteknologi

1. Introduction

1.1 Background

- To achieve performance, complex concurrent algorithms have been developed, but are hard to get correct, e.g. concurrent queue algorithms
- Model checking
- SPIN model checker and Promela

1.2 Motivation

- Use SPIN to automatically analyze concurrent algorithms written in (a significant subset of) C
- Automatically abstract Promela models from input C codes

1.3 Related works

Modex and our previous paper [Bengt Jonsson, MCC 08]

UPPSALA UNIVERSITET

Informationsteknologi

2. A motivating example

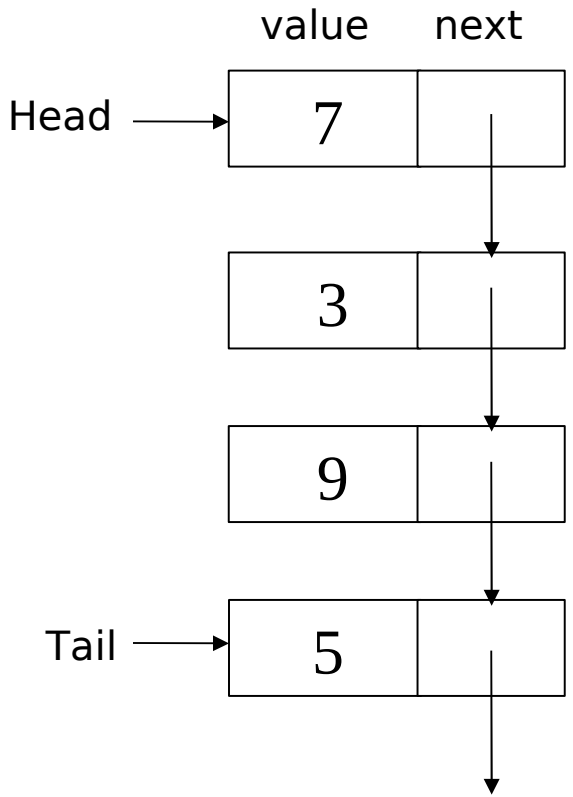
- Concurrent queue algorithms
- Translation from peudocode of Michael and Scott's blocking queue algorithm (also in our previous work)
- Such algorithms will likely cause bottlenecks in concurrent programs

```
struct node_t {
  int value;
  struct node_t *next;
};

struct queue_t {
  struct node_t *Head;
  struct node_t *Tail;
  int H_lock;
  int T_lock;
};
```

```
void enqueue(struct queue_t *Q, int val) {
  struct node_t *node =
     malloc(sizeof(struct node_t));
  node->value = val;
  node->next = 0;
  lock(&Q->T_lock);
     Q->Tail->next = node;
     Q->Tail = node;
  unlock(&Q->T_lock);
}
```

- *node_t* and *queue_t* are used to create linked lists
- The two locks in *queue_t* allow concurrent access
- Other algorithms might use **CAS** instead of locks



3. Promela

Promela is a modeling language designed for state space exploration of finite-state models

- ✓ Promela has C-like syntax
- ✓ Processes
- ✓ Basic data types
- ✓ Control flows
- ✓ Communications
- ✘ No dynamically allocated data structures
- ✘ No functions and function calls

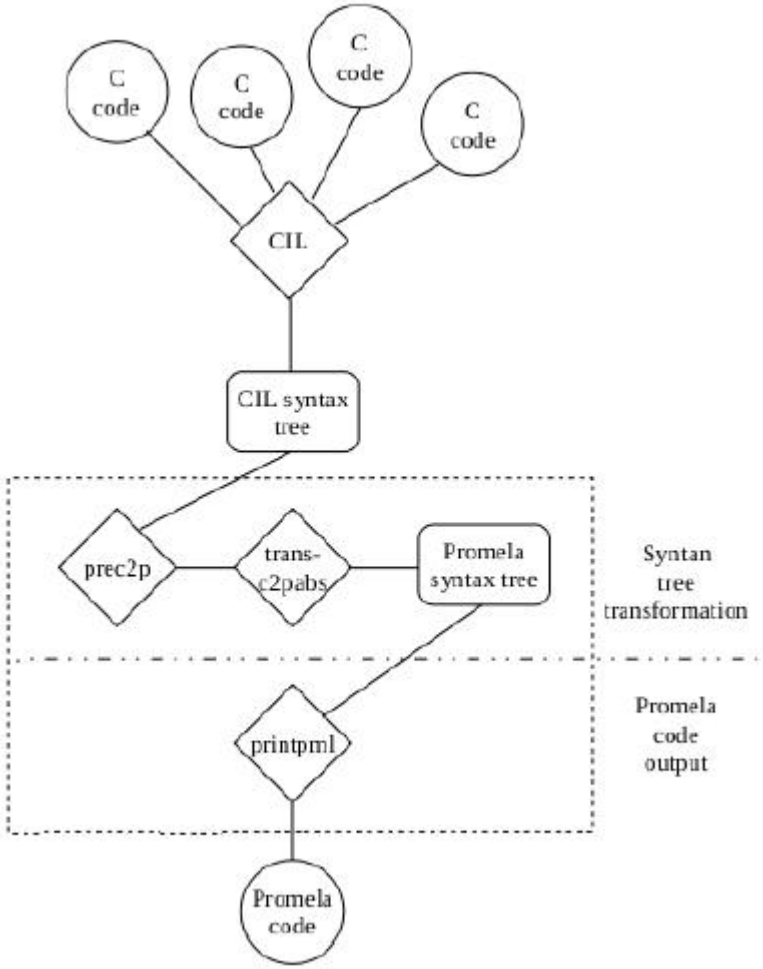
4. Implementation

CIL (C Intermediate Language): the carrier of our translator

- Handles the parsing and semantic analysis of C programs
- Compiles valid C programs into core constructs (e.g. the loops)
- Can be guided to perform user defined transformation (e.g. the translator we developed)
- Provides C syntax trees for our translator

4. Implementation

The whole translation flow



5. Syntax-directed translation

5.1 Data Structures and Statements

Translate in a straight-forward fashion:

- ✓ Simple statements and control structures
- ✓ Integers and arrays
- ✘ Pointers and structures

```
struct record{
      int min;
      int max;
};

...
      struct record r;
      for(x=0; x<5; x++)
            for(y=0; y<4; y++)
                  if(a[y]>a[y+1]) {
                        temp = a[y+1];
                        a[y+1] = a[y];
                        a[y] = temp;
                  }
      r.min = a[0];
      r.max = a[4];
...
```

```
typedef record {
  int min;
  int max;
}
...
  record r;
  x = 0;
  do
  :: (!(x < 5)) -> break
  :: else ->
     y = 0;
     do
     :: (!(y < 4)) -> break
     :: else ->
        if
        :: (a[y] > a[(y + 1)]) ->
              temp = a[(y + 1)];
              a[(y + 1)] = a[y];
              a[y] = temp
        :: else
        fi;
        y ++
     od;
     x ++
  od;
  r.min = a[0];
  r.max = a[4];
...
```

5. Syntax-directed translation

5.2 Dynamically Allocated Memory

- ✓ Dynamically allocated memory simulated by dedicated array
- ✓ Integers and structures
- ✓ One array per data type
- ✓ All memory operations must be type-respecting
- ✘ Pointer arithmetic is not supported

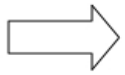
5. Syntax-directed translation

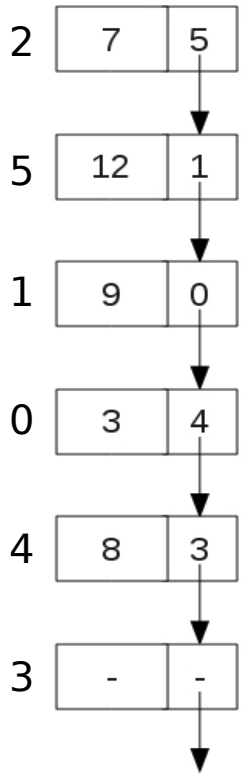
5.2 Dynamically Allocated Memory

- ✓ Dynamically allocated memory simulated by dedicated array
- ✓ Integers and structures
- ✓ One array per data type
- ✓ All memory operations must be type-respecting
- ✘ Pointer arithmetic is not supported

A example of a “static” list in Promela

	value	next
0	3	4
1	9	0
2	7	5
3	-	-
4	8	3
5	12	1



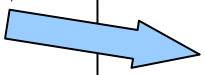


5. Syntax-directed translation

Translating Pointer operations

- Pointer assignments will be translated into integer assignments
- Assignments to the original variable by pointers will be translated to assignments corresponding positions of memory arrays

```
struct person{
  int age;
};
...
  struct person *ptr;
  struct person *temp;
...
  ptr = temp;
...
  temp->age = 24;
...
```



```
typedef person {
  int age;
}
person person_mem[9];
int person_valid[9];
...
  int ptr;
  int temp;
...
  ptr = temp;
...
  person_mem[temp].age = 24;
...
```

5. Syntax-directed translation

- Memory allocations using *malloc* are simulated
- Memory releases using *free* are analogous

```
struct person{
  int age;
};
...
  struct person *ptr;
  ptr = malloc(sizeof(struct person));
...
  free(ptr);
...
```

```
typedef person {
  int age;
}
person person_mem[9];
int person_valid[9];
...
  int ptr;
  $$$ //person_ct gets first available
                position of person_valid
  ptr = person_ct;
...
  d_step {
    person_valid[ptr] = 0;
    person_mem[ptr].age = 0
  };
...
```

5. Syntax-directed translation

5.3 Translating functions

- No function concept in Promela! Need to be emulated
- Use process to simulate functions

Function definitions: parameters and function body

Function calls: into 3 steps. Exceptions: *lock* and *unlock*

Return statements: emulate the two properties of *return*.

Recursive functions: are automatically handled. Recursion depth need to be noticed

```
int test(int a, int b){
        if(a >= b) return a;
        else return b;
}

...
        int x = 2;
        int y = 3;
        test(x, y);
...
```

```
proctype test(chan in_test; int a; int b){
        if
        :: (a >= b) ->
                in_test ! a;
                goto end
        :: else ->
                in_test ! b;
                goto end
        fi;
end :
        printf ("End of test")
}

...
        chan ret_test = [0] of { int };
        int x; int y; int tmp;
        x = 2;
        y = 3;
        run test(ret_test, x, y);
        ret_test ? tmp;
...
```

UPPSALA UNIVERSITET

Informationsteknologi

6. Experiments

- We denote test harnesses using a sequence of *E* (*enqueue*) and *D* (*dequeue*) in threads separated by I, e.g. *EE|DD.*
- Two verification modes: Exhaustive and Bitstate
- The following experiments were performed using Exhaustive mode

Test harness	States	Mem.	Time
E | D	851	5.044	~0
EE | DD	14,467	11.587	0.13
EE | DDD	29,506	19.009	0.26
EEE | DDD	138,751	74.575	1.33
EEEE | DD	128,611	69.399	1.26
EEEE | DDDD	1,101,416	583.583	11.5
EEEEE | DDDD	3,181,607	1727.196	34.4
EEEEE | DDDDD	7,894,946	4403.891	87.5

6. Experiments

- We denote test harnesses using a sequence of *E* (*enqueue*) and *D* (*dequeue*) in threads separated by I, e.g. *EE|DD.*
- Two verification modes: Exhaustive and Bitstate
- The following experiments were performed using Exhaustive mode

Test harness	States	m.	Time
E | D	851	5.044	~0
EE | DD	14,467	11.587	0.13
EE | DDD	29,506	19.009	0.26
EEE | DDD	138,751	74.575	1.33
EEEE | DD	128,611	69.399	1.26
EEEE | DDDD	1,101,416	583.583	11.5
EEEEE | DDDD	3,181,607	1727.196	34.4
EEEEE | DDDDD	7,894,946	4403.891	87.5

900

100,000

7. Conclusion

- ✓ Automatic translation from C to Promela makes model checking C programs using SPIN possible.
- ✓ Innovative solutions for “untranslatable” structures in previous works, e.g. pointers and functions.
- ✗ Still does not have the same capabilities comparing to our manual work, e.g. no impact of weak memory models, not as efficient.

UPPSALA UNIVERSITET

Informationsteknologi

8. Future works

- Add the impact of weak memory models
- Optimize the current translation
  - Better output layout
  - Support more complex C structures, e.g. multi-dimensional arrays, pointer to pointers
  - Divide necessary statements into atomic parts, e.g. x++
- Garbage collection