DSSE Dependable Systems & Software Engineering

UNIVERSITY OF Southampton
School of Electronics and Computer Science

SMT-based Bounded Model Checking for Multi-threaded Software in Embedded Systems

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Embedded systems are ubiquitous but their verification becomes more difficult.

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- functionality demanded increased significantly
  - *peer reviewing* and *testing*
- multi-core processors with scalable shared memory
  - but most verification tools focus on *message passing*

```
void *threadA(void *arg) {
  lock(&mutex);
  x++;
  if (x == 1) lock(&lock);
  unlock(&mutex); (CS1)
  lock(&mutex);   (CS3)
  x--;
  if (x == 0) unlock(&lock);
  unlock(&mutex);
}
```

Deadlock

```
void *threadB(void *arg) {
  lock(&mutex);
  y++;
    y == 1) lock(&lock); (CS2)
    ock(&mutex);
    k(&mutex);
  y- ;
  if (y == 0) unlock(&lock);
  unlock(&mutex);
}
```

Scalability and Precision in Bounded Model Checking for ANSI-C

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- state space explosion problem
  - exploit proof of unsatisfiability
  - integrate POR with symbolic algorithms
    $\rightarrow$ *visible instruction and read-write analysis*
- precision of arithmetic and bit-level operations
  - use decision procedures of QF formulae with a more accurate model of the ANSI-C semantics (SMT)
    $\rightarrow$ *combine different background theories and solvers*

Can an algorithmic method reason accurately about multi-threaded software in embedded systems by controlling the verification complexity?

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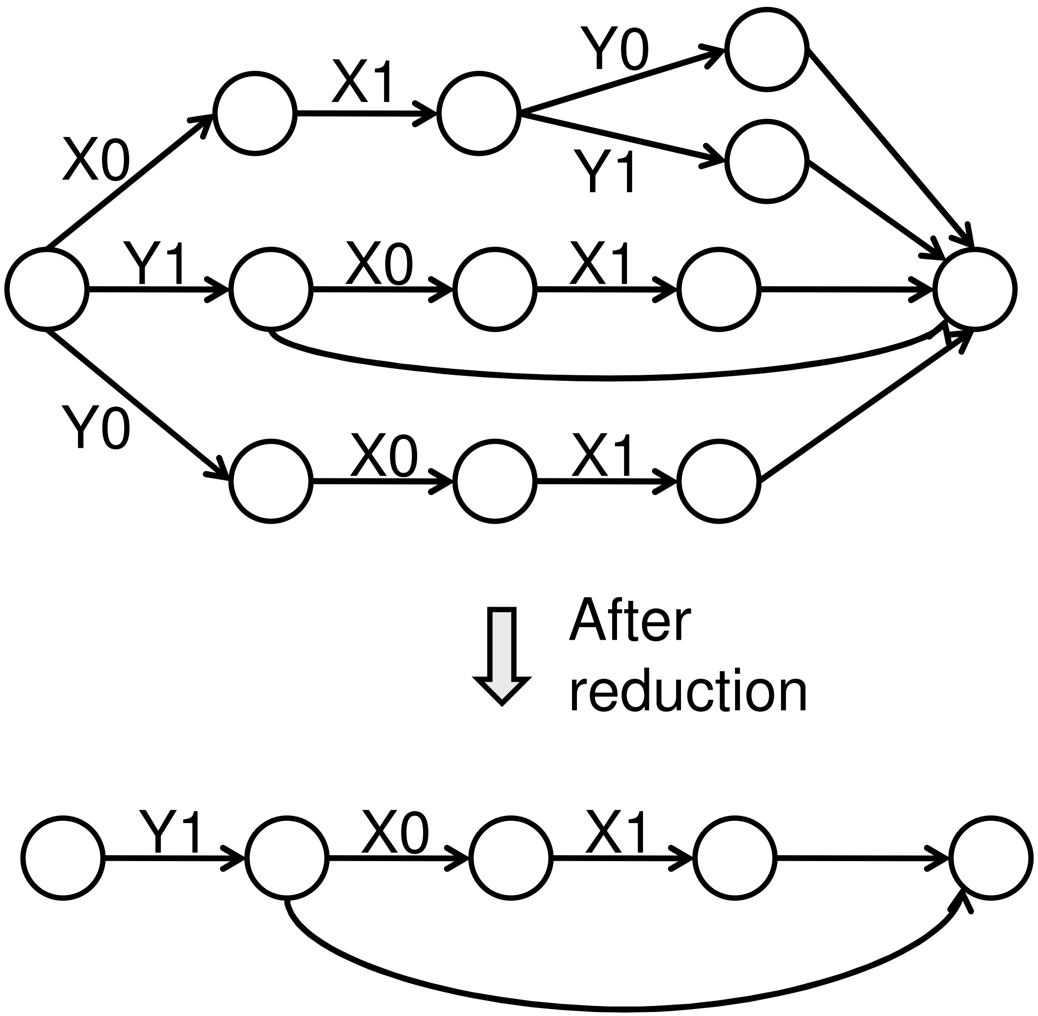
Lazy exploration of interleavings




```
#define N 10
int a [N] , i , j =1, x=2;
void *Tx(void *arg) {
  if (x>2) {
    a[i] = *((int *)arg);     //X0
    assert(i>=0 && i<N);  //X1
  }
}
void *Ty(void *arg) {
  if (x>3)
    a[j]=*((int *)arg);      //Y0
  else
    x=3;                          //Y1
}
int main(void) {
  int arg1=10, arg2=20;
  i=nondet_uint();
  //create Tx with arg1
  //create Ty with arg2
}
```

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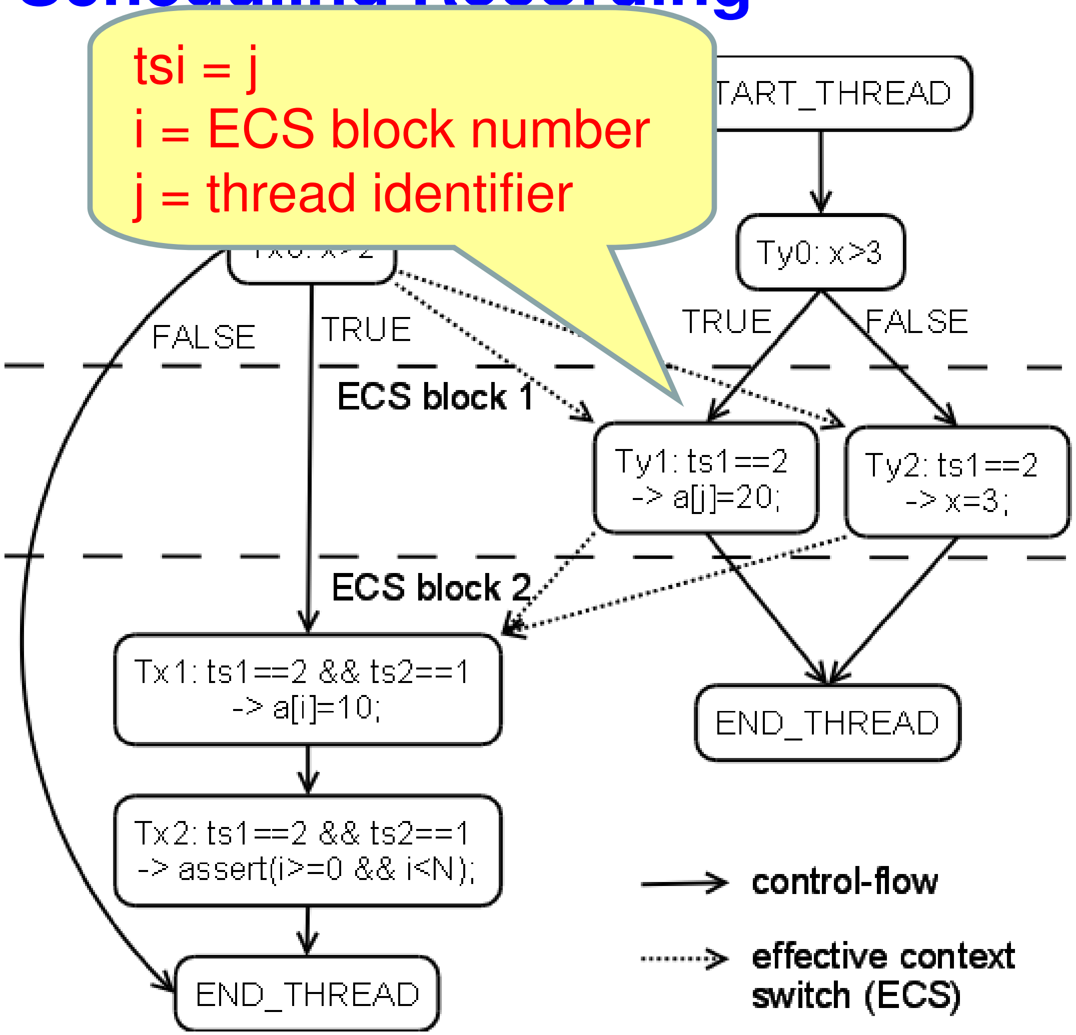
Scheduling Recording

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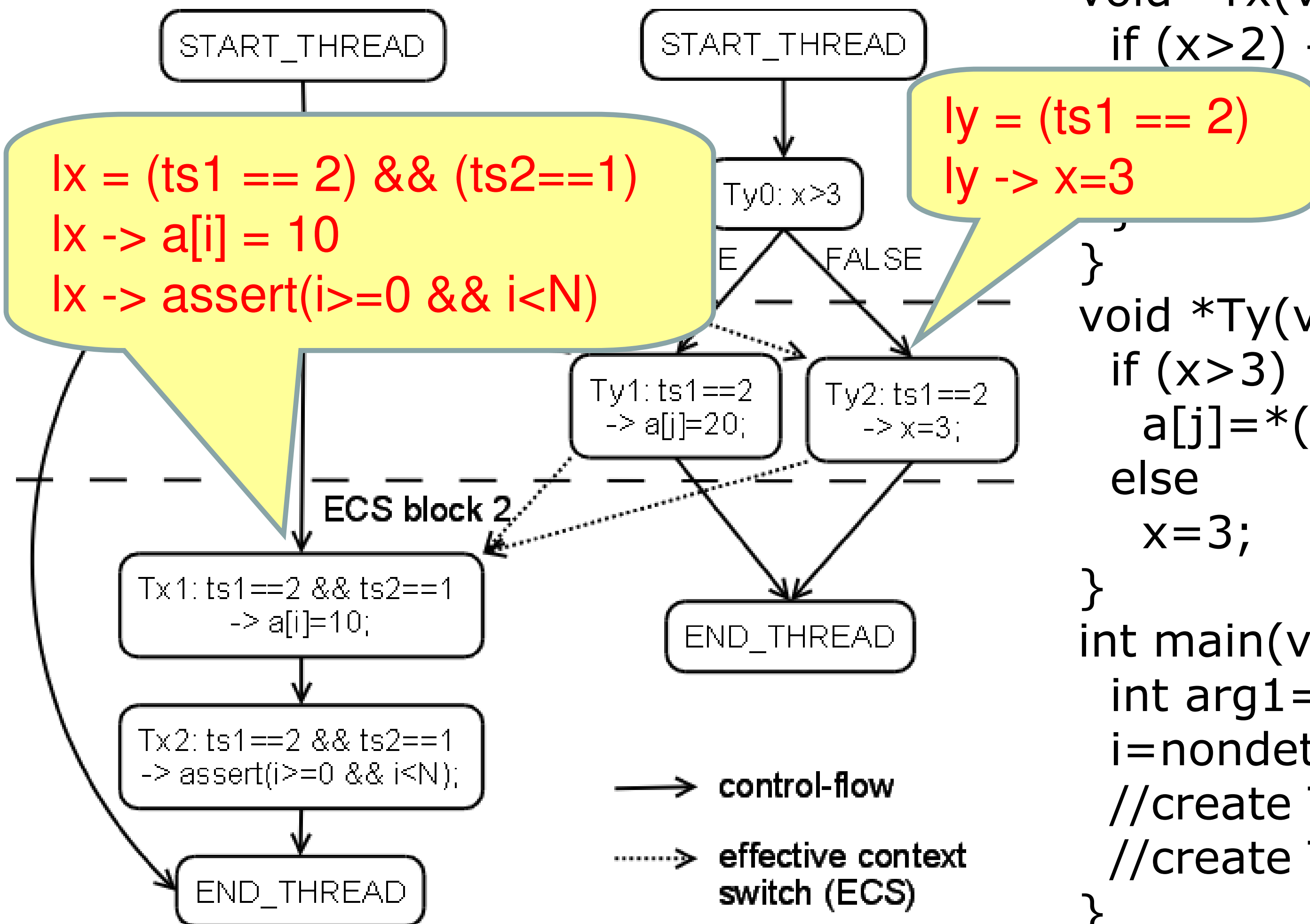
Under-approximation & Widening

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  if (x>2) {
    ...((int *)arg);        //X0
    ...>=0 && i<N);        //X1
  ...
}
void *Ty(void *arg) {
  if (x>3)
    a[j]=*((int *)arg);     //Y0
  else
    x=3;                    //Y1
}
int main(void) {
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```

Experimental Evaluation

- described and evaluated SMT-based BMC in large embedded software
  - SMT-based BMC is more efficient than SAT-based BMC (but not uniformly)
  - introduced **continuous verification** for large systems
- evaluated the UW, schedule recording, and lazy approaches
  - add concurrency constraints lazily
    $\rightarrow$ *extremely fast for satisfiable instances*
  - memory overhead and slowdowns to extract the unsatisfiable cores

Results

- built and evaluated first SMT-based BMC for ANSI-C
- **UW**, **lazy** and **schedule recording** algorithms
- introduced **continuous verification** approach
- users.ecs.soton.ac.uk/lcc08r/esbmc/

Future Work

- partial order reduction (static and dynamic)
- data races detection (compatibility with compiler)
- Craig interpolation to generate threads scheduling