Bounded Model Checking and Feature Omission Diversity

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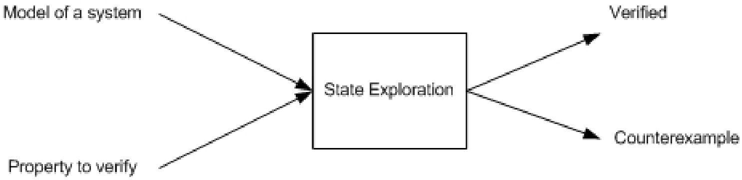
November 10, 2011

Model Checking

Model checking is a formal verification technique which inspects all reachable states for violations of a specification.



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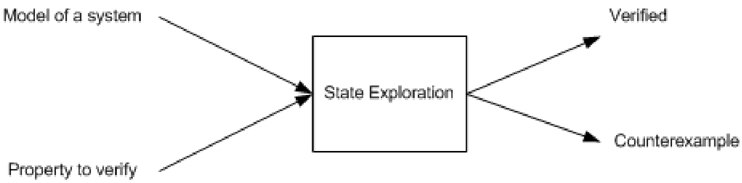

- The number of states is *exponential* in number of variables.
- The number of states is *exponential* in number of threads.

State-space explosion problem!

Remedies for state-space explosion problem

- *Symbolic model checking* uses binary decision diagrams to represent the transition system.
- *Abstraction* simplifies the model.
- *Partial order reduction* identifies the independent interleaving of threads.

Bounded Model Checking

In Bounded Model Checking (BMC) , the program is unrolled for a given length k and it is reduced to a SAT problem, s.t. the solution to the SAT problem is a counter-example for the program.

- Example: if R describes the relation between the current state and the next state and a safety property P, the SAT problem looks like:
  $I(S_0) \bigwedge$
  $(R(S_0, S_1) \wedge R(S_1, S_2) \wedge ... \wedge R(S_{k-1}, S_k)) \bigwedge$
  $(\neg P(S_0) \vee \neg P(S_1) \vee ... \vee \neg P(S_k))$

The problem is still there!

Even with the power of symbolic techniques, the state-space explosion is a fundamental problem for model checking:

- real-world systems have very large state spaces, and
- effective abstractions and symbolic representations are challenging to discover.

Realities to face

- There is usually limited time budget for model checking.
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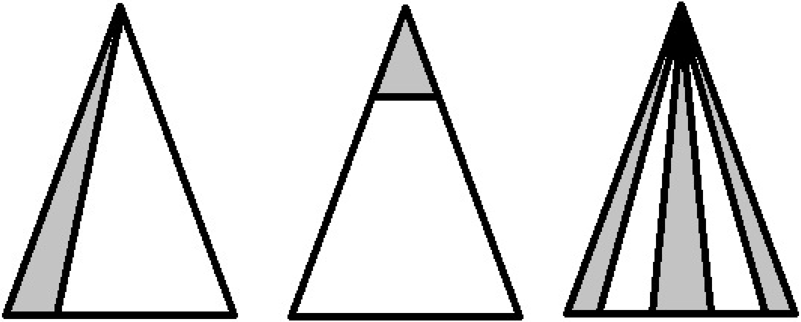
How to make them faster?

Swarm Verification

- Swarm verification exploits the multi-core processors to make exploration of new states faster by diversification of search strategies.
- *Key idea:* When no heuristic is known to speed of the search, try several diverse search strategies in parallel.

Diversification of Search Strategies



Depth First Search

Breadth First Search

Randomized Search

Features

Consider the following components in a program:

- functions,
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- particular range of valuations for variables.

Typically,a counterexample is made by some of them, not all of them!

Swarm Testing

Swarm testing generalizes the search diversification of swarm verification beyond the choice of a depth-first search strategy to the selection of *test features*.

- A test feature is a predicate over test cases, controlled by the test generation process.
  - *Example:* In test of a file system, a test feature might be whether the test case includes calls to `close`.
- Swarm testing tries several test sessions with different test features in parallel.
- Swarm testing achieves better fault detection and code coverage.

Swarm bounded model checking

Is there a way for swarm bounded model checking?

Example – stack

Assume log statements represent a feature.

```
#define SIZE 64
int s = 0;
int stack[SIZE];
int top() {
  log("top");
  return stack[s];
}
void push(int i) {
  log("push");
  stack[s++] = i;
}
void pop() {
  log("pop");
  if (s > 0) {
    s--;
  }
```

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Errors:

- Array out of bounds.

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  }
```

Errors:

- Array out of bounds.
- `top` returns an invalid value!

Example – stack (Cont'd)

```
#define TLEN 100
int main () {
  int v, action;
  for (int i = 0; i < TLEN; i++) {
    action = nondet_int();
    assume ((action >= 0) && (action <= 2));
    switch (action) {
    case 0:
      v = top();
      break;
    case 1:
      v = nondet_int();
      push(v);
      break;
    case 2:
      pop();
      break;
    }
```

Algorithm For Swarm Bounded Model Checking

Input: program p, set F of features

```
while budget allows
    for all processors available
        Pick a random set F_i ⊆ F
        Build sp by replacing log statements in p for F_i with
            assume(false) and Remove other log statements from
        Propagate assumptions and slice sp
        Perform BMC on sp
```

Intuition: By omitting features in a program's execution, we can produce smaller and more easily checked SAT instances.

Example – Omitting the top feature in the stack

```
int top() {
  __CPROVER_assume(false);
  return stack[s];
}
void push(int i) {
  stack[s++] = i;
}
void pop() {
  if (s > 0) {
    s--;
  }
}
```

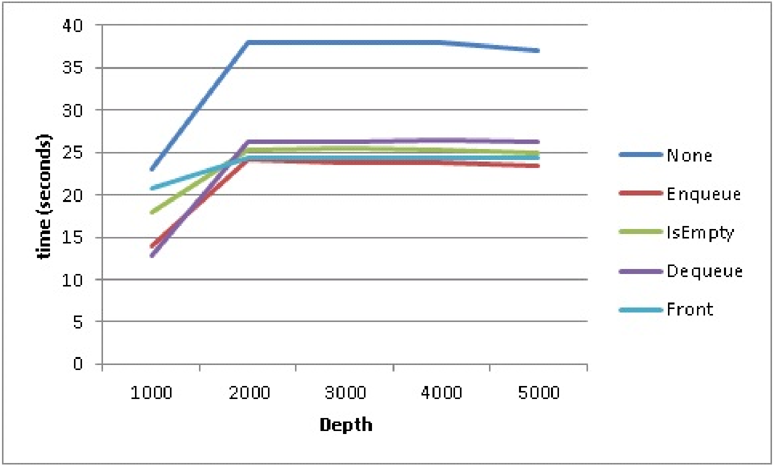
Experimental results

We used CBMC version 4.0 for bounded model checking on a four-processor Intel 2.8GHz system with 8 GB RAM on some data structures.
Early experiment results suggest that the swarm bounded model checking are faster in detecting counterexamples.

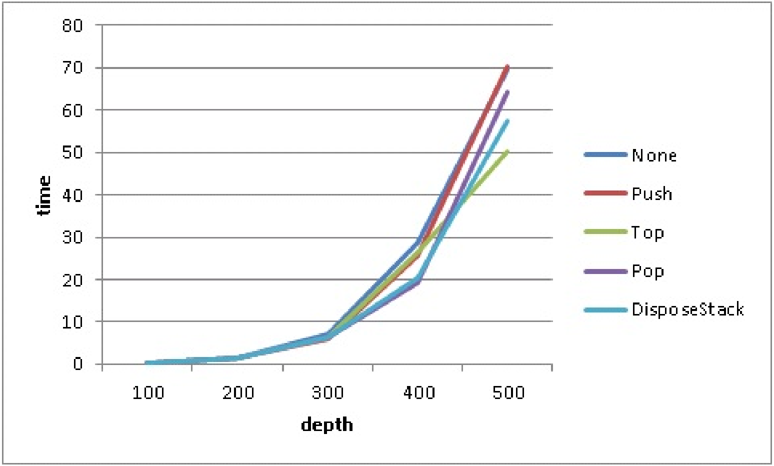
Result of swarm bounded model checking on stack example

Omitted Feature	Time without Slicing (Seconds)	Time with Slicing (Seconds)	Verification Status
–	325	49	Counterexample
push	40	4	Verified
pop	101	14	Counterexample
top	291	48	Counterexample

Experimental Results – Array Queue



Experimental Results – Stack List



Related work

- Swarm Verification:
  - Dwyer et al. *Parallel randomized state-space search.* ICSE 2007.
  - Holzmann et al. *Swarm verification techniques.* TSE 2010.
- Swarm Testing: Groce et al. *Swarm Testing*.
- Conditional Verification: Beyer et al. *Conditional Model Checking.* University of Passau Tech report, (2011).

Conclusion

- By omitting features in a program's execution, we can produce smaller and more easily checked SAT instances, while often preserving at least one counterexample trace.
- Early results suggest that bounded model checking with feature omission outperforms the traditional BMC in returning a counterexample. However, we need to apply swarm BMC to larger, more realistic examples that challenge the abilities of current BMC tools.