Efficient Elimination of False Positives using Static Analysis

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Background

- Static analysis - scalable but imprecise
- Model checking - precise but not scalable
- Static analysis + model checking $\Rightarrow$ better results
- False positives elimination using model checking[1]
  - Generate an assertion corresponding to each warning
  - Verification in incremental context
  - Scalable to some extent but a lot many model checking calls
  - Time consuming

[1] Hendrik Post et al. "Reducing False Positives by Combining Abstract Interpretation and Bounded Model Checking". In: *ASE*. 2008, pp. 188–197.

A Motivating Example

```c
const int arr[]
        ={0,2,5,9,14};
int var, factor; char ch;

void f1(){
 unsigned int i, j;

 i = lib1();
 j = lib2();
 var = lib3();

 if(j < 5 && i < j){
  factor= arr[j]-arr[i];
  f2();
 }
}
```

```c
int f2(){
  if(var==factor )
    f3(var);
  ...
}
```

```c
int f3(int p){
 int a, b, denom=1;
 if(ch < 5)
  denom = p;
 else
  denom = 10;

 assert(denom!=0);
 a = 100/denom;//warning
}
```

Context Expansion: Call 1

```
p = nondet_int();
ch = nondet_char();
```

Verifying the assertion

in the context of $f3$

results in

Counterexample

by assigning 0 to p

```
int f3(int p){
 int a, b, denom=1;
 if(ch < 5)
  denom = p;
 else
  denom = 10;

 assert(denom!=0);
 a = 100/denom;//warning
}
```

Context Expansion: Call 2

```
var = nondet_int();
factor = nondet_int();
ch = nondet_char();
```

```
int f2(){
  if(var==factor )
    f3(var);
  ...
}
```

```
int f3(int p){
 int a, b, denom=1;
 if(ch < 5)
  denom = p;
 else
  denom = 10;

 assert(denom!=0);
 a = 100/denom;//warning
}
```

Verifying the assertion

in the context of *f2*

results in

Counterexample

by assigning 0 to *var* and *factor*

Context Expansion: Call 3

Assertion holds when verified in the context of $f1$.

```
ch = nondet_char();
```

```
const int arr[]
        ={0,2,5,9,14};

void f1(){
 unsigned int i, j;

 i = lib1();
 j = lib2();
 var = lib3();

 if(j < 5 && i < j){
  factor= arr[j]-arr[i];
  f2();
 }
}
```

```
int f2(){
  if(var==factor )
    f3(var);
  ...
}
```

```
int f3(int p){
 int a, b, denom=1;
 if(ch < 5)
  denom = p;
 else
  denom = 10;

 assert(denom!=0);
 a = 100/denom;//warning
}
```

Motivation

- The problem
  - Large number of model checking calls
  - Hence, time consuming
- Observation
  - If **any arbitrary value** is allowed for an assertion variable at the assertion point, the assertion verification **results in a counterexample**.

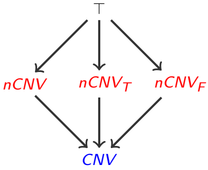
Our Approach

- Complete-range Non-deterministic Value (cnv) variables
  - Taking complete-range of non-deterministic values
  - Any arbitrary value is allowed
  - No value assignment/restriction through program code
- Complete-range Non-deterministic Value (cnv) expressions
  - $(x+10)$, $(x++)$, and $(x+y)$ **are** *cnv* expressions when $\{x,y,z\}$ are *cnv* variables.
  - $(x+10)$, and $(x++)$ **are not** *cnv* expressions when $\{y,z\}$ are *cnv* variables.
  - $(x/100)$, $(x\%2)$, and (100) in n **are not** *cnv* expressions even if x is a *cnv* variable.
- Identify redundant verification calls (RVCs) and skip them
  - using cnv variables

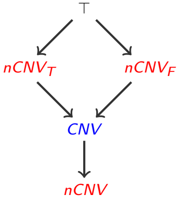
Computation of cnv variables

- Depends on
  - Context sensitivity
  - Flow sensitivity
  - May/Must reachability
  - Data and **control** dependance
- Using Data Flow Analysis
  - Lattice structure

```
void f(int x){
  //x ↦ CNV
  if(x < 10){
    //x ↦ nCNV_T
  }else{
    //x ↦ nCNV_F
  }
  //x ↦ CNV
}
```



(a) May cnv variables



(b) Must cnv variables

RVCs Identification

If all assertion variables are *cnv* variables, the call is redundant.

```
const int arr[]
        ={0,2,5,9,14};
int var, factor; char ch;

void f1(){
 unsigned int i, j;

 i = lib1();
 j = lib2();
 var = lib3();

 if(j < 5 && i < j){
  factor= arr[j]-arr[i];
  f2();
 }
}
```

```
int f2(){
  if(var==factor )
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```
int f3(int p){
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 if(ch < 5)
  denom = p;
 else
  denom = 10;

 assert(denom!=0);
 a = 100/denom;//warning
}
```

Influence of cnv variables

```
void foo(){
 b = 0;
 if(v == 1){
  a = 10;
  b = 10;
 }
```

```
if(v == 1)
 assert(a != 0);//May Vs Must

if(b == 10)
 assert(v != 0);//O-AEP

if(x < 100)
  assert(x < 10);//Insufficiency
}
```

- Is RVCs identification accurate?
  - *may-cnv* variables Vs *must-cnv* variables
  - Impact of over-approximition of execution paths (O-AEP)
  - Insufficiency of *cnv* variables
- Define two parameters
  - Precision $= \dfrac{\text{number of } \textbf{\textit{correctly}} \text{ identified RVCs}}{\text{total number of identified RVCs}}$
  - Recall $= \dfrac{\text{number of } \textbf{\textit{correctly}} \text{ identified RVCs}}{\text{number of actual calls violating the assertions}}$

Effect on False Positives Elimination

- Define two parameters
  - Time saving $= 1 - \frac{\text{Time taken in } eFPE}{\text{Time taken by } FPE_{orig}}$
  - Elimination loss $= 1 - \frac{\text{False positives eliminated in } eFPE}{\text{False positives eliminated by } FPE_{orig}}$
- Trade-off
  - Precision Vs Recall
  - Time saving Vs Elimination loss

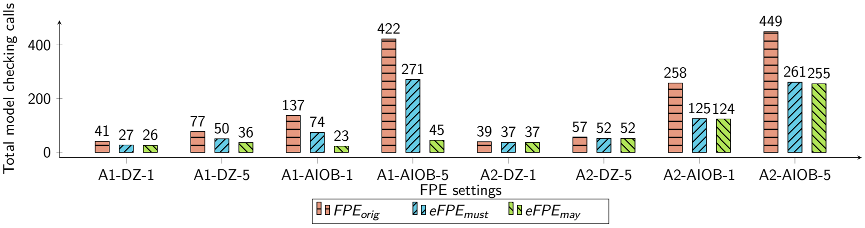
Experimental Set up

- *cnv* variables computation - implementation in TCS ECA[2]
- CBMC as the model checker[3]
- Two applications (50 KLOC and 40 KLOC)
- Two properties (DZ and AIOB)
- False positives elimination in three settings
  - FPE_{orig}, $eFPE_{may}$, and $eFPE_{must}$
- Each setting with two context levels
  - maxCCL $=1$, and maxCCL $=5$
- Assumptions
  - assertions are reachable
  - code is sliced and every slice corresponds to a single assertion

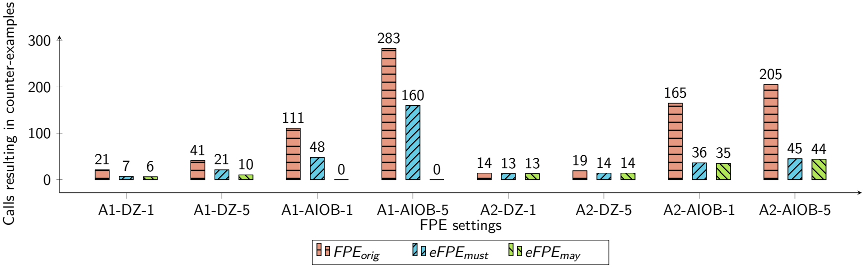
[2] *TCS Embedded Code Analyzer (TCS ECA)*. . http://www.tcs.com/offerings/engineering_services/Pages/TCS-Embedded-Code-Analyzer.aspx.

[3] CBMC. http://www.cprover.org/cbmc/.

Experimental Results

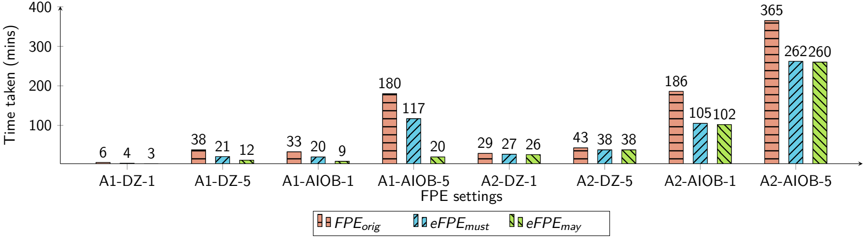


Total model checking calls

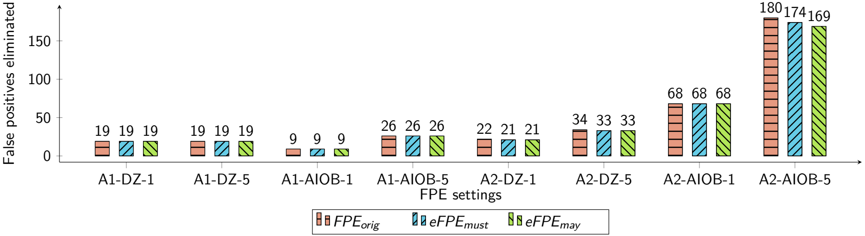


Model checking calls resulting in counter-examples

Experimental Results



False positives elimination time



False positives eliminated by FPE settings

Observations

- RVCs identification
  - 76% recall with 97.3% precision
  - Total model checking calls reduced by 49.49%
  - Calls resulting in counterexamples
    - original-FPE=58%, efficient-FPE=31%
- False positives elimination time reduced by 39.28%
  - Missed elimination of 21/754 false positives
- Trade-off:
  - Efficiency 39.28% Vs Elimination loss 2.78%
  - Failed cases require manual reviewing
- Constraining over One Vs All assertion variables
  - both choices applicable in practice

Summary

- The problem
  - large number of model checking calls
  - poor performance in false positives elimination
- Our Solution
  - Introduced a concept of *cnv* variables
  - Identification of redundant verification calls
- Experimental evaluation
  - Trade-off: Efficiency (39.28%) Vs Elimination loss (2.78%)
  - Spectrum of trade-offs
    - May Vs Must *cnv* variables
    - Single Vs Multiple variables
  - Choice depending on requirement in practice

Thank you!

Questions or Suggestions?

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