FROM RESEARCH TO INDUSTRY

Sound and Quasi-Complete Detection of Infeasible Test Requirements

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Outline

Context

Testing process

- Generate a test input
- Run it and check for errors
- Estimate coverage : if enough stop, else loop

Coverage criteria [decision, mcdc, mutants, etc.] play a major role

- generate tests, decide when to stop, assess quality of testing
- definition : systematic way of deriving test requirements

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Coverage cr

- generat
- definiti

The enemy : Infeasible test requirements

- waste generation effort, imprecise coverage ratios
- cause : structural coverage criteria are ... structural
- detecting infeasible test requirements is undecidable

→ Recognized as a hard and important issue in testing

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Testing oriented *but* scope beyond that :
$\rightarrow$ **original combination of two formal methods**

Our goals and results

→ Focus on white-box *(structural)* coverage criteria

Goals : automatic detection of infeasible test requirements

- *sound* method [thus, incomplete]
- applicable to a large class of coverage criteria
- strong detection power, reasonable detection speed
- rely as much as possible on existing verification methods

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Results

- automatic, sound and generic method ✓
- **new combination of existing verification technologies** ✓
- experimental results : strong detection power [95%], reasonable detection speed [$\leq$ 1s/obj.], improve test generation ✓
- yet to be proved : scalability on large programs ?

  [promising results..]

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Take away

- VA $\oplus$ WP
- better than VA, WP
- plug-in Frama-C

Outline

Background : Labels

- Annotate programs with **labels** [ICST 2014]
  - predicate attached to a specific program instruction
- Label (loc, φ) is covered if a test execution
  - reaches the instruction at *loc*
  - satisfies the predicate φ
- **Good for us**
  - can easily encode a large class of coverage criteria [see after]
  - in the scope of standard program analysis techniques

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- **Good for us**
  - can easily encode a large class of coverage criteria [see after]
  - in the scope of standard program analysis techniques
  - infeasible label $(loc, \varphi) \Leftrightarrow$ valid assertion $(loc, \texttt{assert}\neg\varphi)$

```
int g(int x, int a) {
  int res;
  if(x+a >= x)
    res = 1;
  else
    res = 0;
  //l1: res == 0      // infeasible
}
```

Infeasible labels, valid assertions

```
int g(int x, int a) {
  int res;
  if(x+a >= x)
    res = 1;
  else
    res = 0;
  //@assert res ≠ 0      // valid
}
```

Standard coverage criteria

```
statement_1;
if (x==y && a<b)
    {...};
statement_3;
```

```
statement_1;
//l1: x==y && a<b
//l2: !(x==y && a<b)
if (x==y && a<b)
    {...};
statement_3;
```

Decision Coverage **(DC)**

```
statement_1;
//l1: x==y
//l2: !(x==y)
//l3: a<b
//l4: !(a<b)
if (x==y && a<b)
    {...};
statement_3;
```

Condition Coverage **(CC)**

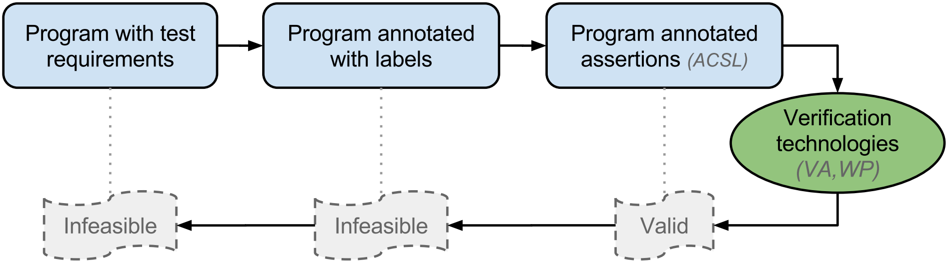
```
statement_1;
//l1: x==y && a<b
//l2: x==y && a>=b
//l3: x!=y && a<b
//l4: x!=y && a>=b
if (x==y && a<b)
    {...};
statement_3;
```

Multiple-Condition Coverage **(MCC)**

Also Weak Mutation, GACC *(weak MCDC)* etc.

Overview of the approach

- labels as a unifying criteria
- label infeasibility ⇔ assertion validity
- s-o-t-a verification for assertion checking



Outline

Checking assertion validity

Two broad categories of sound assertion checkers

- **Value Analysis :** state-approximation
  - compute an invariant of the program
  - then, analyze all assertions (labels) in one run
- **Weakest-Precondition calculus :** Goal-oriented checking
  - perform a dedicated check for each assertion
  - a single check usually easier, but many of them

	VA	WP
sound for assert validity	✓	✓
blackbox reuse	✓	✓
local precision	✗	✓
calling context	✓	✗
calls / loop effects	✓	✗
global precision	✗	✗
scalability wrt. #labels	✓	✓ (orange)
scalability wrt. code size	✗	✓

hypothesis : VA is interprocedural

VA and WP may fail

```
int main() {
  int a = nondet(0 .. 20);
  int x = nondet(0 .. 1000);
  return g(x,a);
}

int g(int x, int a) {


  int res;
  if(x+a >= x)
    res = 1;
  else
    res = 0;
//l1: res == 0
}
```

VA and WP may fail

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    res = 0;
//@assert res ≠ 0
}
```

VA and WP may fail

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int main() {
  int a = nondet(0 .. 20);
  int x = nondet(0 .. 1000);
  return g(x,a);
}

int g(int x, int a) {


  int res;
  if(x+a >= x)
    res = 1;
  else
    res = 0;
//@assert res ≠ 0     // both VA and WP fail
}
```

Proposal : VA $\oplus$ WP (1)

Goal = get the best of the two worlds

- idea : VA passes to WP the global info. it lacks

Which information, and how to transfer it ?

- VA computes (internally) some form of invariants
- WP naturally takes into account assumptions `//@ assume`

→ **Solution : VA exports its invariants on the form of WP-assumptions** *(Frama-C→ACSL)*

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Which information, and how to transfer it ?

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→ **Solution : VA exports its invariants on the form of WP-assumptions** *(Frama-C→ACSL)*

Notes : **No** manually-inserted WP-assumption

VA⊕WP succeeds!

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}

int g(int x, int a) {


  int res;
  if(x+a >= x)
    res = 1;
  else
    res = 0;
//l1: res == 0
}
```

VA⊕WP succeeds!

```
int main() {
  int a = nondet(0 .. 20);
  int x = nondet(0 .. 1000);
  return g(x,a);
}

int g(int x, int a) {
  //@assume 0 <= a <= 20
  //@assume 0 <= x <= 1000
  int res;
  if(x+a >= x)
    res = 1;
  else
    res = 0;
//@assert res != 0
}
```

VA⊕WP succeeds!

```
int main() {
  int a = nondet(0 .. 20);
  int x = nondet(0 .. 1000);
  return g(x,a);
}

int g(int x, int a) {
  //@assume 0 <= a <= 20
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  int res;
  if(x+a >= x)
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  else
    res = 0;
//@assert res != 0      // VA ⊕ WP succeeds
}
```

Proposal : VA $\oplus$ WP (2)

Exported invariants

- only names appearing in program
  - independent from memory size
- non-relational information
  - linear in VA
- only numerical information
  - sets, intervals, congruence

Proposal : VA $\oplus$ WP (2)

Soundness ok as long as VA is sound

Exhaustivity of "export" only affect deductive power

- Finding the right trade-off
- in practice : exhaustive export has very low overhead

Invariant export strategies

```
int fun(int a, int b, int c) {
  //@assume a [...]
  //@assume b [...]
  //@assume c [...]
  int x=c;



  //@assert a < b
  if(a < b)
    {...}
  else
    {...}
}
```

Parameters annotations

Invariant export strategies


```
int fun(int a, int b, int c) {



  int x=c;

  //@assume a [...]
  //@assume b [...]
  //@assert a < b
  if(a < b)
    {...}
  else
    {...}
}
```

Label annotations

Invariant export strategies

```
int fun(int a, int b, int c) {
  //@assume a [...]
  //@assume b [...]
  //@assume c [...]
  int x=c;
  //@assume x [...]
  //@assume a [...]
  //@assume b [...]
  //@assert a < b
  if(a < b)
    {...}
  else
    {...}
}
```

Complete annotations

Invariant export strategies

```
int fun(int a, int b, int c) {
  //@assume a [...]
  //@assume b [...]
  //@assume c [...]
  int x=c;
  //@assume x [...]
  //@assume a [...]
  //@assume b [...]
  //@assert a < b
  if(a < b)
    {...}
  else
    {...}
}
```

Complete annotations

Conclusion: Complete annotation very slight overhead
(but label annotation experimentaly the best trade-off).

Summary

	VA	WP	VA $\oplus$ WP
sound for assert validity	✓	✓	✓
blackbox reuse	✓	✓	✓
local precision	✗	✓	✓
calling context	✓	✗	✓
calls / loop effects	✓	✗	✓
global precision	✗	✗	✗
scalability wrt. #labels	✓	✓	✓
scalability wrt. code size	✗	✓	?

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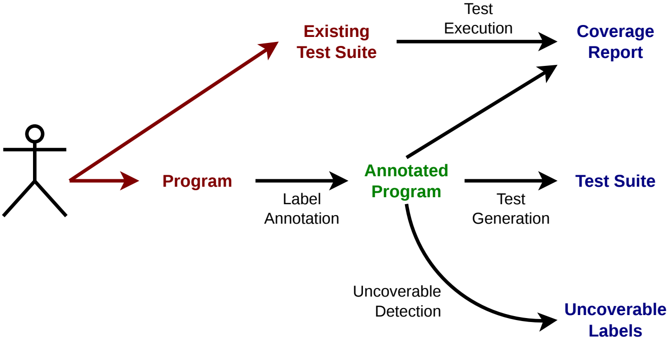
Implementation inside LTest



FRAMA-C plugin called LTEST

- sound detection !
- several modes : VA, WP, VA ⊕ WP
- based on PATHCRAWLER for DSE* and test generation

Service cooperation

- share label statuses
- `Covered`, `Infeasible`, `?`

Outline

Experiments

RQ1 : How effective are the static analyzers in detecting infeasible test requirements ?

RQ2 : To what extent can we improve test generation by detecting infeasible test requirements ?

Standard (test generation) benchmarks [Siemens, Verisec, Mediabench]

- 12 programs (50-300 loc), 3 criteria (**CC**, **MCC**, **WM**)
- 26 pairs (program, coverage criterion)
- 1,270 test requirements, 121 infeasible ones

RQ1 : detection power

	#Lab	#Inf	VA		WP		VA ⊕ WP	
			#d	%d	#d	%d	#d	%d
Total	1,270	121	84	69%	73	**60%**	118	**98%**
Min		0	0	0%	0	0%	2	**67%**
Max		29	29	100%	15	100%	29	100%
Mean		4.7	3.2	63%	2.8	**82%**	4.5	**95%**

#d : number of detected infeasible labels

%d : ratio of detected infeasible labels

- **Verif :** VA ⊕ WP perform better than VA or WP alone
- **Testing :** VA ⊕ WP achieves almost perfect detection

RQ2 : Impact on test generation

→ report a more accurate coverage ratio

	Coverage ratio reported by DSE*				
Detection method	**None**	**VA**	**WP**	**VA ⊕WP**	**Perfect***
Total	**90.5%**	96.9%	95.9%	**99.2%**	100.0%
Min **Max**	**61.54%** 100.00%	80.0% 100.0%	67.1% 100.0%	**91.7%** 100.0%	100.0% 100.0%
Mean	**91.10%**	96.6%	97.1%	**99.2%**	100.0%

* preliminary, manual detection of infeasible labels

→ speedup test generation

- Beware can be slower in the worse case
- Gain, max : 55x, mean :2.2x (wit RT)

Outline

Introduction

Overview

Checking assertion validity

Implementation

Experiments

Conclusion

Conclusion

Challenge

- detection of infeasible test requirements

Results

- automatic, sound and generic method ✓
  - rely on labels and a new combination VA $\oplus$ WP
- promising experimental results ✓
  - strong detection power [95%]
  - reasonable detection speed [$\leq$ 1s/obj.]
  - improve test generation [better coverage ratios, speedup]

Future work : scalability on larger programs

- explore trade-offs of VA $\oplus$ WP
- application for verification(safety), and security

$\rightarrow$ LTest available at `http://micdel.fr/ltest.html`

Questions ?

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