Formalizing an Efficient Runtime Assertion Checker for an Arithmetic Language with Functions and Predicates

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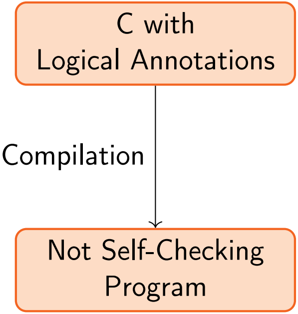
SAC-SVT 2023

RAC of Arithmetic in E-ACSL

Base Principle for Inline Monitoring

C with
Logical Annotations

Base Principle for Inline Monitoring



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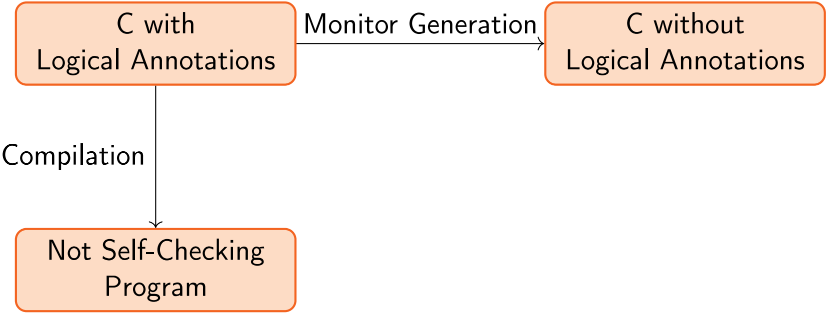

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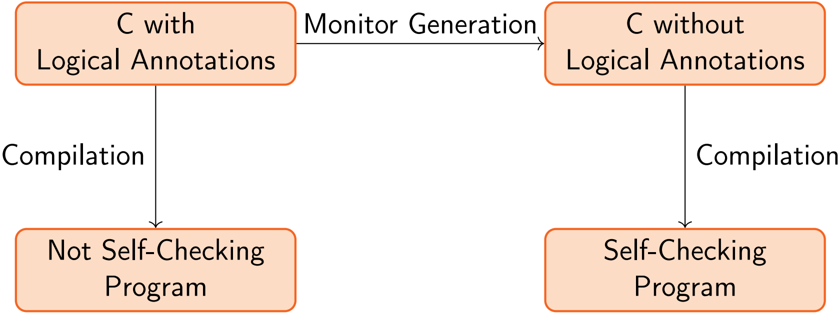

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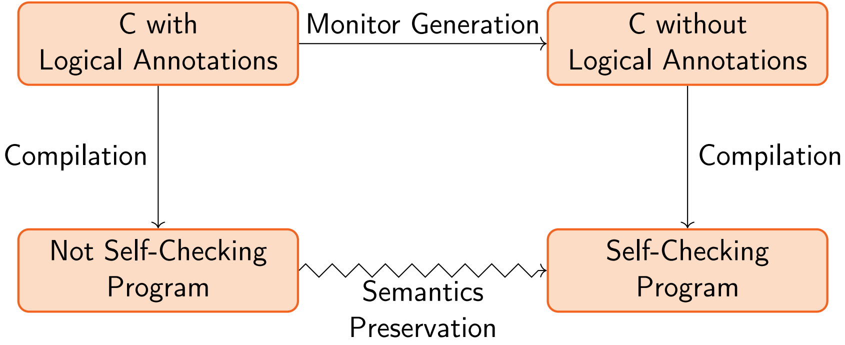

Minimal Example

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int main (){
  int x = 5;
  //@ assert x + 1 == 6;
  return 0;
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We are interested in the translation of a language containing the following constructs

- Comparison and arithmetic operators

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- Conditionals

  $p\ ?\ t_1\ :\ t_2$

- User-defined Functions and Predicates

```
logic integer f (integer x) = t        ...     f(y)
predicate p (integer x) = b            ...     p(y)
```

Correctness vs. Efficiency

Arithmetic Overflow Issues

Naive Approach :

```
// x is an int
//@ assert (x+1 == 0);
```

→

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$2^{31} == 0$

false

Arithmetic Overflow

Undefined Behavior

Solution : Arbitrary Precision Arithmetic

A correct translation generated using the GMP library :

```
// x is an int
//@ assert (x+1 == 0);
```

```
// x is an int
mpz_t y, z, o, r;
mpz_init_set_si(y, x);
mpz_init_set_si(o, 1);
mpz_init(r);
mpz_add(r, y, o);
mpz_init_set_si(z, 0);
int c = mpz_cmp(r, 0);
assert (c == 0);
mpz_clear(y);
mpz_clear(z);
mpz_clear(o);
mpz_clear(r);
```

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- $\mathcal{I}(t)$ is contained in the integers representable by machine
  Can safely use machine integers

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Today : the analysis is a blackbox $\mathcal{I}$: term $\rightarrow$ interval

- $\mathcal{I}(t)$ is contained in the integers representable by machine
  Can safely use machine integers
- Otherwise
  Use GMP integers in case there is an overflow

The Problem With Functions

Translating Functions

- Generate a C function that translate the ACSL function

```
logic integer p (integer x) = x + 1000000000;
```

$\downarrow$

```
int p (int x) {x + 1000000000;}
```

Translating Functions

- Generate a C function that translate the ACSL function

```
logic integer p (integer x) = x + 1000000000;
```

↓

```
int p (int x) {x + 1000000000;}
```

- Same issue with arithmetic overflows

```
/*@ assert p(1) == 1000000001; */ //OK
/*@ assert p(5000000000) > 0;   */ //Not OK
/*@ assert p(2000000000) > 0;   */ //Not OK
```

One Function Per Call-Site

- Generate a different C function for each call-site

```
/*@ assert p(1) == 1000000001; */ // -> p_1
/*@ assert p(5000000000) > 0;  */ // -> p_2
/*@ assert p(2000000000) > 0;  */ // -> p_3
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- Issues :
  - Code duplication

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/*@ assert p(1) == p(1); */ //Generate the
    same function twice!
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- Issues :
  - Code duplication

    ```
    /*@ assert p(1) == p(1); */ //Generate the same function twice!
    ```

  - Unclear for recursive functions

    ```
    /*@ logic integer f (integer x) =
          x >= 5000000000 ? 0 : f(x + 1) + 1 */
    ...
    //@ assert f(0) = 5000000000 // the recursive call escapes the type int
    ```

One Function Per Call-Context

- Generate a C function for each call-context
  A call context is the data of the interval $\mathcal{I}(t)$ for every argument of the function

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- Generate a C function for each call-context
  A call context is the data of the interval $\mathcal{I}(t)$ for every argument of the function
- Conservative in reuse of function

```
/*@ assert p(1) == p(1); */ //reuse the function
/*@ assert p(2) != p(1); */ //one new function
```

Dealing With Recursion

Assumption

The oracle $\mathcal{I}$ gives an interval adapted to recursive functions

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The oracle $\mathcal{I}$ gives an interval adapted to recursive functions

For instance :

```
/*@ logic integer f (integer x) =
      x >= 5000000000 ? 1 : f(x + 1) + 1 */
// -> interval for x+1: [1..5000000001]
...
//@ assert f(0) = 5000000000
// -> interval for 0: [0..5000000000]
```

Functional Correctness

A Complex Translation

- Starting from simple idea, the translation became non-trivial
  - Complex code using GMP
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  - Subtle argument for reusing function
- How to ensure the translation is correct ?

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Example :

$\mathbb{Z}\_\mathrm{assgn}(\tau_z, v, z) :=$

```
MATCH τz WITH :
  CASE int :
    v = z;
  CASE mpz :
    mpz_set_string(v,"z");
```

Assumptions

There exists a semantics the language we consider (see article) :
C programs, ACSL annotations, GMP library calls

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Assumption

The inference given is sound : All possible semantics of t belong to $\mathcal{I}(t)$

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Theorem

The translation of the subset of ACSL to the subset of C with calls to GMP library that we have defined preserves the semantics.

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Avoid combinatorial blowup by proving the functional correctness of the macros independently !

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- Formalize and prove the oracle $\mathcal{I}$
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- Formalize and prove the oracle $\mathcal{I}$
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- Study interaction between memory properties [5] and arithmetic ones

Thank you

References I

[1] P. Baudin et al. "The Dogged Pursuit of Bug-Free C Programs : The Frama-C Software Analysis Platform". In : *Communications of the ACM* (2021).

[2] P. Baudin et al. *ACSL : ANSI/ISO C Specification Language*. Rapp. tech. CEA List et Inria. url : https://frama-c.com/download/acsl.pdf.

[3] J. Signoles. *E-ACSL Version 1.18. Implementation in Frama-C Plug-in E-ACSL 26.1*. http://frama-c.com/download/e-acsl/e-acsl-implementation.pdf. 2022.

[4] N. Kosmatov, F. Maurica et J. Signoles. "Efficient Runtime Assertion Checking for Properties over Mathematical Numbers". In : *International Conference on Runtime Verification (RV)*. 2020.

References II

[5] D. Ly et al. "Verified Runtime Assertion Checking for Memory Properties". In : *International Conference on Tests and Proofs (TAP)*. 2020.