Automating Regression Verification

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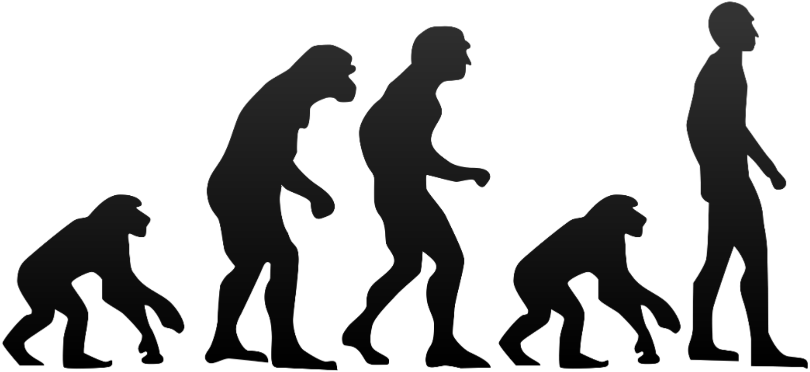
How to prevent regressions in software development?



How to prevent regressions in software development?

Formal Verification

Formally prove correctness of software
$\Rightarrow$ Requires formal specification

Regression Testing

Discover new bugs by testing for them
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- Goal: Proving the equivalence of two closely related programs
- No formal specification or test cases required
- Instead use old program version as reference
- Tools for proving function equivalence in a simple programming language using SMT solvers

Overview

1. Overapproximation using Uninterpreted Functions
2. Approximation using Uninterpreted Predicates
3. Results and Future Work

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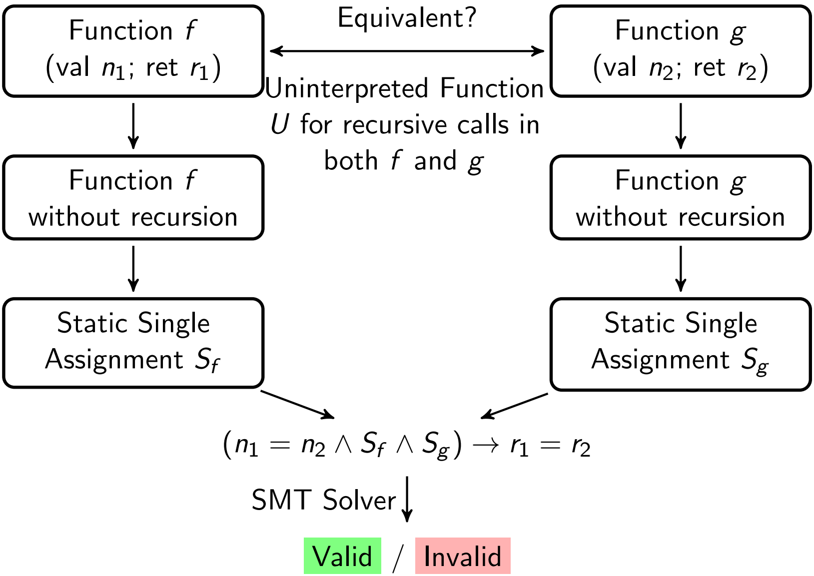
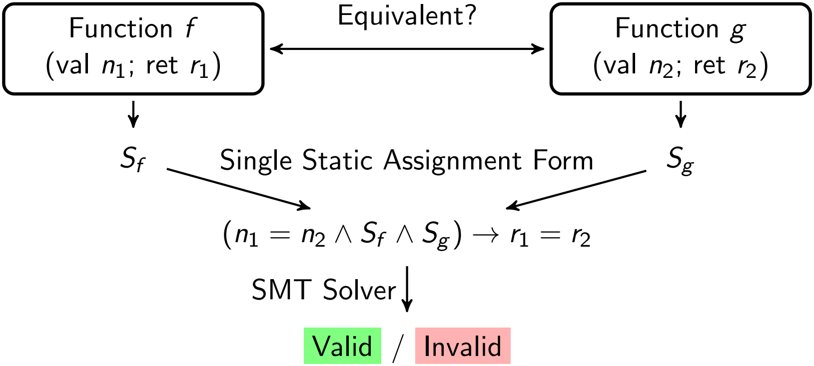
Function Equivalence

Existing approach by Strichman & Godlin



Our Contribution: Extensions



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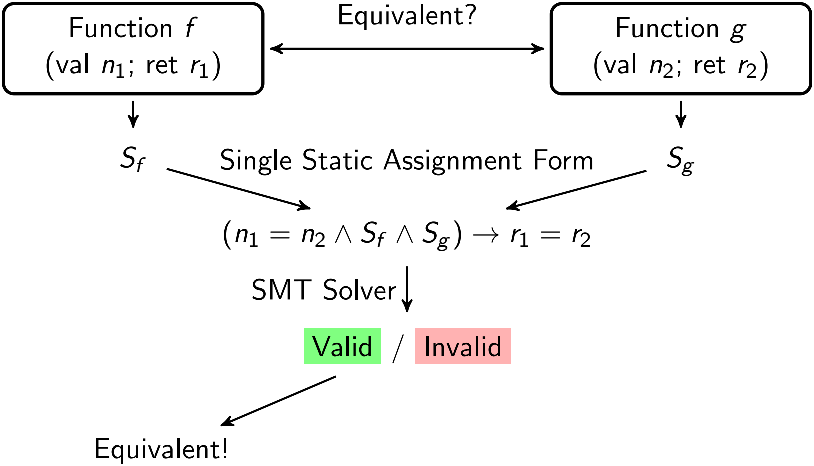

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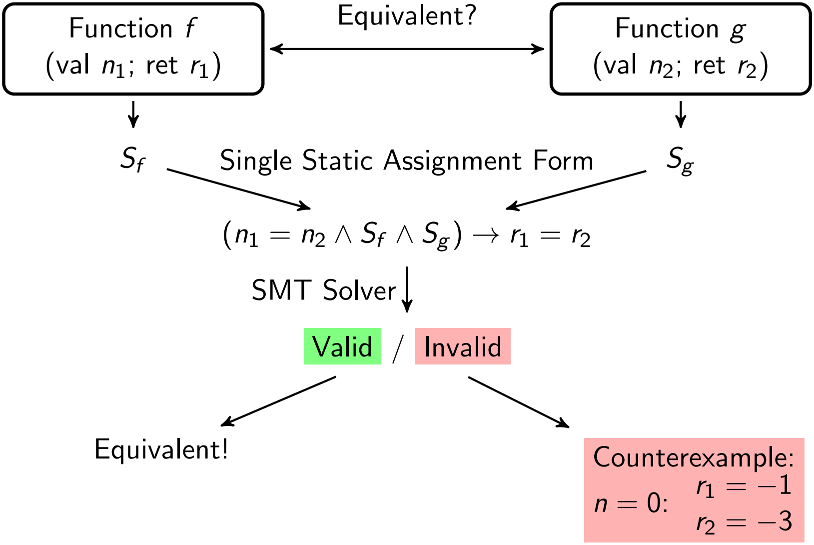

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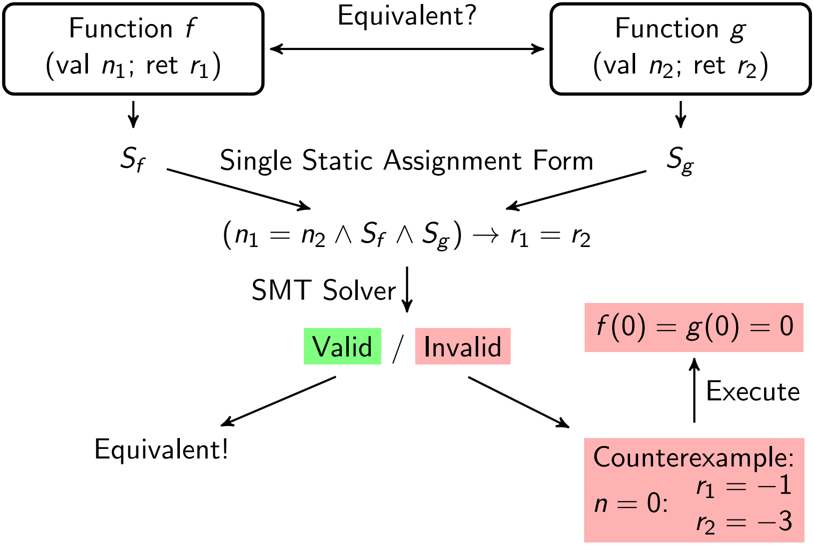

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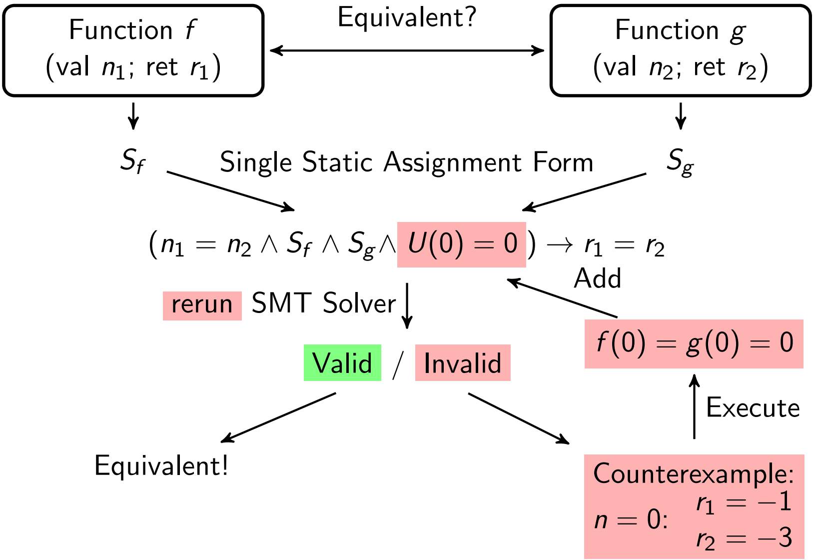

Overapproximation using uninterpreted functions

Approach

- Run the programs with input gathered from counterexamples
- Detect whether CE is spurious or not
- If spurious: Add additional constraints to the uninterpreted function

$\Rightarrow$ Is a simple form of *Counter Example Guided Abstraction Refinement (CEGAR)*

Successful when

- Finite number of constraints on the uninterpreted function imply equivalence
- These are often the "base cases" of recursive implementations

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Approximation using Uninterpreted Predicates

First approach (just shown)

- Overapproximate recursion by uninterpreted Function U:

$$\forall U.constraints(U) \land S_f \land S_g \land \ldots \rightarrow r_1 = r_2$$

New approach

- Infer a predicate C which couples recursive calls:

$$\exists C.(C(\ldots) \land \ldots \rightarrow r_1 = r_2) \land \text{“}C \text{ couples } f \text{ and } g\text{”}$$

- Use state-of-the-art SMT solvers (Eldarica, Z3) to automatically find such a C or prove that is does not exist

$\Rightarrow$ Example will show loops with coupling loop invariants

Automatic Invariant Inference

```
int f1(int n) {
  int r = 0;
  if (n == 0) return 1;
  while (n > 0) {
    n /= 10; r++;



  }
  return r;

}
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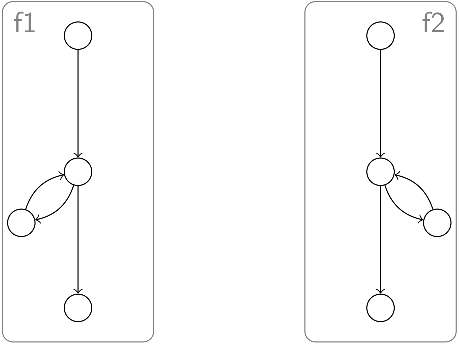
```
int f2(int n) {
  int r = 1;

  while (true) {
    if(n < 10) return r;
    if(n < 100) return r+1;
    if(n < 1000) return r+2;
    if(n < 10000) return r+3;
    n /= 10000;
    r += 4;
  }
}
```

Automatic Invariant Inference

Loop synchronisation



- **To show:** Equal input gives equal output

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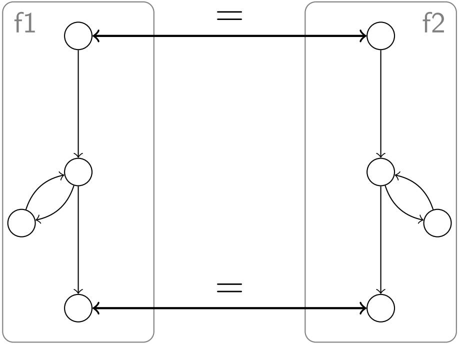

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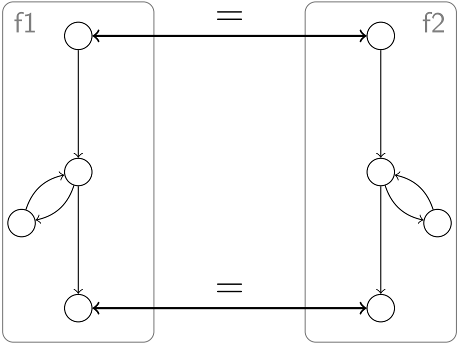

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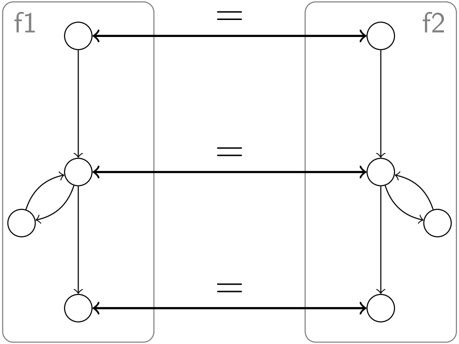

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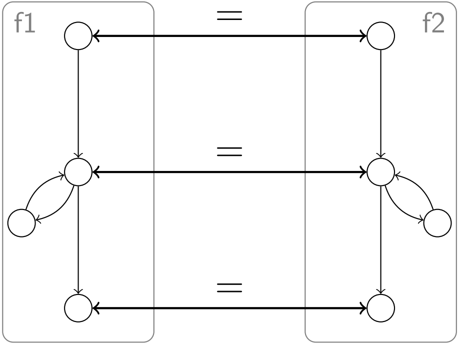

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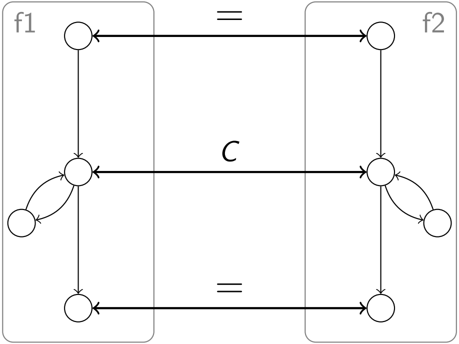

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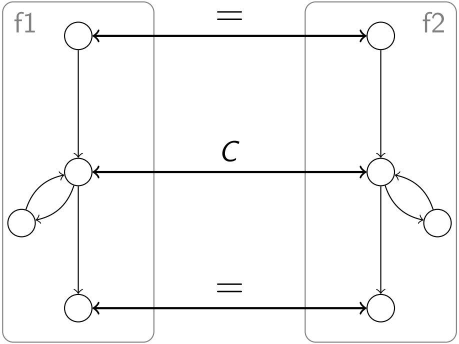

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($\rightarrow$*coupling invariant*)

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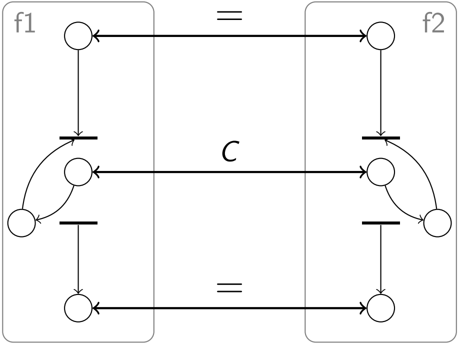

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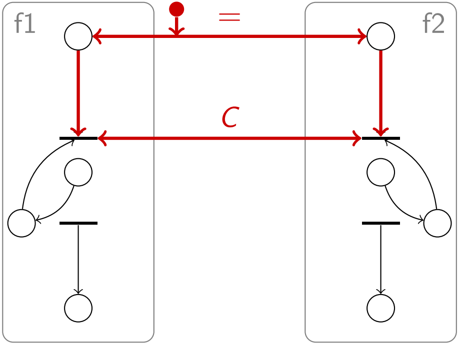

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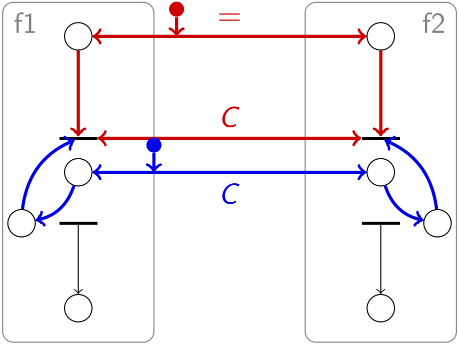

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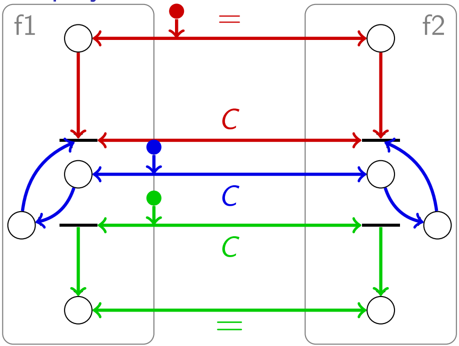

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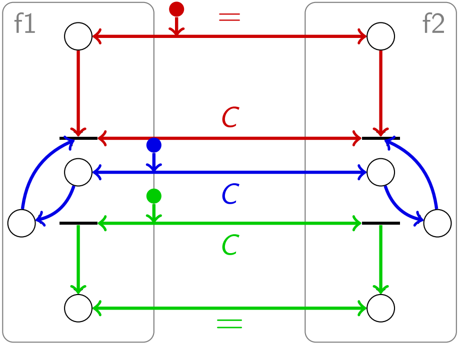

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⇒ Use C as **loop invariant** for **both** programs.

(→*coupling invariant*)

Automatic Regression Verification:

Do not specify C but infer it automatically.

Automatic Invariant Inference

Three cases to consider:

1. Initially coupling loop invariant C holds
2. After both loop steps (or one if other finished), C holds
3. After both loops finished, C implies equality of results

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Automatically inferred coupling loop invariant:
(Using Eldarica)

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\begin{aligned}
&(n_1 > 0 \rightarrow (n_1 = n_2 \wedge r_1 + 1 = r_2)) \\
\wedge &(n_2 \leq 0 \rightarrow \mathit{return}_2 = r_1) \\
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- Compare to loop invariant: $n = \frac{n_0}{10^r}$
- Coupling invariant is not trivial, but linear and inferable!

Overview

Evaluation and Results

Approaches implemented for a subset of C: simplRV, Rêve
Usable with webinterface: `http://formal.iti.kit.edu/improve/deduktionstreffen2014/`

Rêve evaluation (uninterpreted predicates)

- 32 short benchmarks of integer programs (10-50 lines)
- Collected from literature
- Good performance on most equivalent programs
- Finds counterexample for non-equivalent programs as well

Conclusion

Regression Verification

- Initial approach limited to strongly coupled recursions or user feedback
- Automatic Invariant Inference: More powerful, using recent techniques in SMT solvers like Eldarica and Z3

Future Work

- More examples (larger)
- Support arrays, heaps, objects