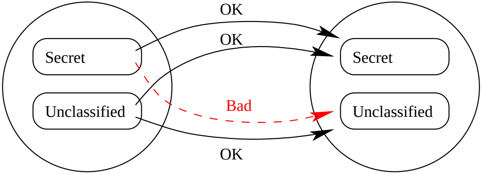
Mechanized Information Flow Analysis through Inductive Assertions

Sandip Ray
Department of Computer Sciences
University of Texas at Austin
sandip@cs.utexas.edu
http://www.cs.utexas.edu/users/sandip

(Joint Work with Warren A. Hunt, Jr., Robert B. Krug, and William D. Young)

Goal

Information flow policies restrict inappropriate access to sensitive information.



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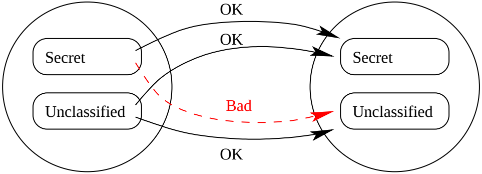

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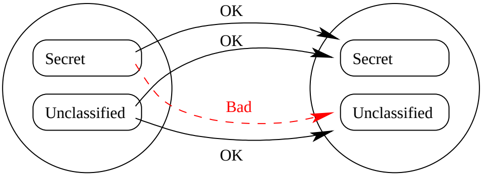

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Our Contribution: A generic, compositional, mechanized infrastructure for verifying information flow properties of software implementations.

Formalizing Information Flow: Background

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Nointerference naturally extends to a lattice of security levels.

Formalizing Information Flow: Definitions

Quick Preliminaries:

- A state is a valuation of variables.
- If l is a variable, $l(s)$ is the value of l in state s.
- $step(s)$ returns the state after one transition from s.

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Some Definitions:

$$pre(s, s') \triangleq poised(s) \wedge poised(s') \wedge (\textstyle\bigwedge_{l \in L} l(s) = l(s'))$$
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Noninterference Condition:

If s and s' satisfy *pre*, and a final state t is reached from s, then a corresponding final state t' is reached from s and t and t' satisfy *post*.

Approach

Our approach is based on **inductive assertions**.

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Key observation: Noninterference involves proving certain binary relation is preserved by the code along the computations from s and s'.

This property can be proven by proving the following:

- The relation is preserved along each straight-line code fragment.
- A loop invariant (on pairs of states) preserves the relation along each loop iteration.
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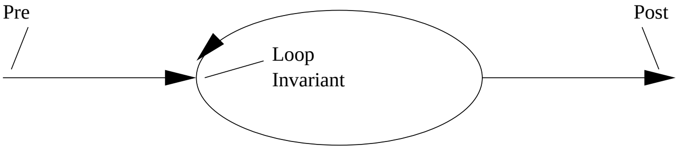
This is the essence of inductive assertions.

Inductive Assertions by Symbolic Simulation



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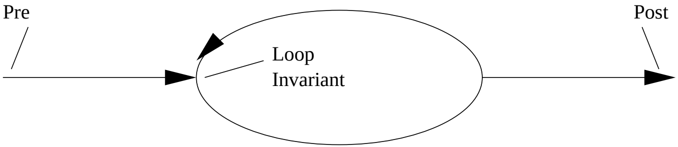

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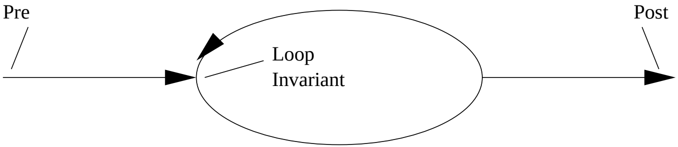

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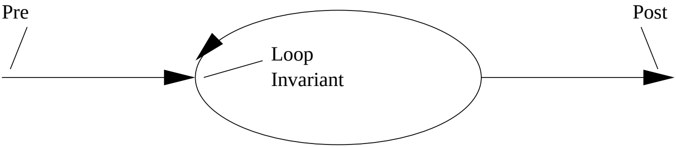

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The symbolic simulation framework now has to guarantee that the pair of computations is in sync.

Verification Conditions for Noninterference

1. $pre(s, s') \Rightarrow C(s, s') \wedge cut(s) \wedge cut(s') \wedge assert(s, s')$
2. $exit(s) \Rightarrow cut(s)$
3. $cut(s) \wedge cut(s') \wedge assert(s, s') \wedge C(s, s')$
   $\wedge \neg exit(s) \wedge exit(run(s, n))$
   $\Rightarrow assert(nextc(step(s)), nextc(step(s')))$
4. $cut(s) \wedge cut(s') \wedge assert(s, s') \wedge C(s, s')$
   $\wedge \neg exit(s) \wedge exit(run(s, n))$
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5. $assert(s, s') \wedge exit(s) \wedge C(s, s') \Rightarrow exit(s')$
6. $assert(s, s') \wedge exit(s) \wedge C(s, s') \Rightarrow post(s, s')$

Noninterference follows from 1-6.

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Noninterference follows from 1-6.

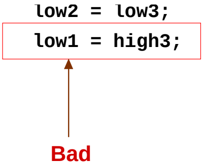
Each condition can be discharged by symbolic simulation using an operational semantics.

SSR1: $\neg cut(s) \Rightarrow nextc(s) = nextc(step(s))$

SSR2: $cut(s) \Rightarrow nextc(s) = s$

Type-based Approaches

- Classify program variables into different security types.
- Check that a low variable is not assigned the value of a high variable.



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low1 = high3;
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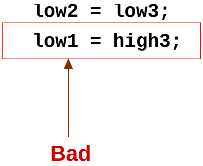

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But information flow properties are often conflated with functional correctness.

```
 <big hairy code>;
if (result !=1) then {
 low = high;
}
```

Extending Axiomatic Semantics

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Our approach makes use of the same operational semantics framework as used for functional correctness.

An Illustrative Example

This example is taken from Amtoft and Banerjee's paper.

```
Procedure tricky1 (int high, low, n) {
  int temp = low;
  for i = 0 to n do {
    if even(i) {
      out = out + temp;
      temp = high;
    } else {
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  }
  out = out + 7;
  return out;
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We could easily verify this code with respect to a pre-existing JVM model.

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We can handle frame conditions by an additional symbolic simulation that produces fake functional characterization.

Details in the paper.

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- multithreaded programs