Procedure–Modular Verification of Control Flow Safety Properties

Siavash Soleimanifard
KTH, Stockholm

joint work with
Dilian Gurov
KTH, Stockholm
Marieke Huisman
University of Twente, The Netherlands

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Modular Software Design

Modularity is helpful

- Complex and large systems
- Facilitating the reuse of components

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Modularity in Software Verification

- Specifying components of a system, independently (locally)
- Specifying (global) property of the system
- Verifying the correctness of the system in independent two subtasks

  (I) verifying local specifications, independently

  (II) the composition of local specifications entails the global property

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Granularity

- Different levels of granularity
  - Procedure–Modular
    - Modules are methods, e.g., Hoare logic

Our Approach

Algorithmic Verification

- Our approach is algorithmic
  - Accepts an annotated Java program as input
  - Push-button tool support to verify the program
    - returns positive answer or negative answer with a counter example

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Properties

- We consider temporal safety properties of the control flow
  - Legal sequences of method invocations

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- A given method that changes certain sensitive data is only called from within another dedicated authentication method, i.e., unauthorized access is not possible
- In a voting system, candidate selection has to be finished, before the vote can be confirmed
- In a door access control system, the password has to be checked before the door is unlocked, and the password can only be changed if the door is unlocked

Example of Tool Usage, Local Property

```
/* @global_LTL_prop:
 *    even -> X ((even && !entry) W odd)
 */
public class Number {
   /* @local_interface: requires {odd}
    *
    *  @local_prop:
    *   nu X1. (([even call even]ff) /\ ([tau]X1) /\ [even caret odd]
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    */
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Example of Tool Usage, Global Property

in every program execution starting in method even, the first call is not to method even itself

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Verification result:

``YES''

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Verification result: ‘‘NO’’

$$(\text{even}, \varepsilon) \xrightarrow{\texttt{even call odd}} (\text{odd}, \text{even}) \xrightarrow{\texttt{odd ret even}} (\text{even}, \varepsilon)$$

Overview

- Model and Logic
- Compositional Verification
- ProMoVer
- Case Study
- Conclusion

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Flow Graphs: *represents the control flow structure*

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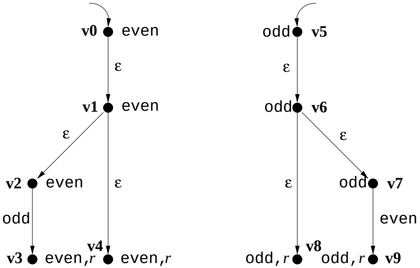

Figure: Flow graph of Number

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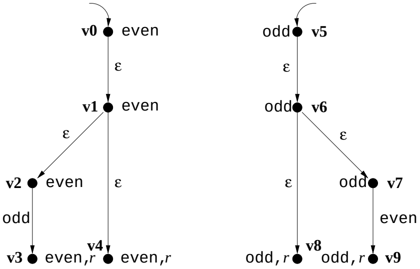

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Flow Graph Operator

Flow Graph Composition ($\uplus$): *disjoint union of flow graphs*

Flow Graph

Flow Graph Behavior

- Flow graph induces push down automaton (PDA)
  - configurations (v, σ): pairs of control point v and call stack σ
  - production induced by
    - non-call edges
    - call edges
    - return nodes
- Flow graph behavior is the behavior of induced PDA

Behavior of Closed Flow Graph

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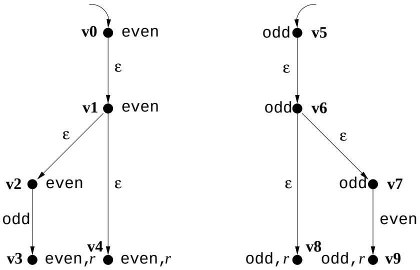

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$$(v_0, \varepsilon) \xrightarrow{\tau} (v_1, \varepsilon) \xrightarrow{\tau} (v_2, \varepsilon) \xrightarrow{\texttt{even call odd}} (v_5, v_3) \xrightarrow{\tau} (v_6, v_3) \xrightarrow{\tau}$$
$$(v_8, v_3) \xrightarrow{\texttt{odd ret even}} (v_3, \varepsilon)$$

Simulation Logic

$$\phi ::= p \mid \neg p \mid X \mid \phi_1 \wedge \phi_2 \mid \phi_1 \vee \phi_2 \mid [a]\phi \mid \nu X.\, \phi$$

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- Example property in simulation logic

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Weak LTL

$$\phi ::= p \mid \neg p \mid \phi_1 \wedge \phi_2 \mid \phi_1\ \vee\ \phi_2 \mid \texttt{X}\ \phi \mid \texttt{G}\ \phi \mid \phi_1\ \texttt{W}\ \phi_2$$

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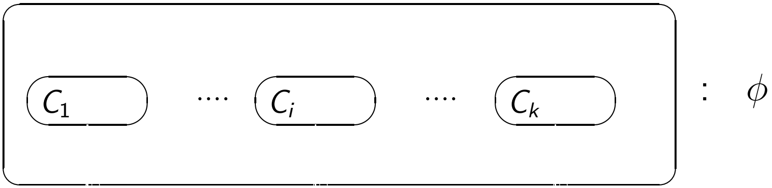
Compositional Verification



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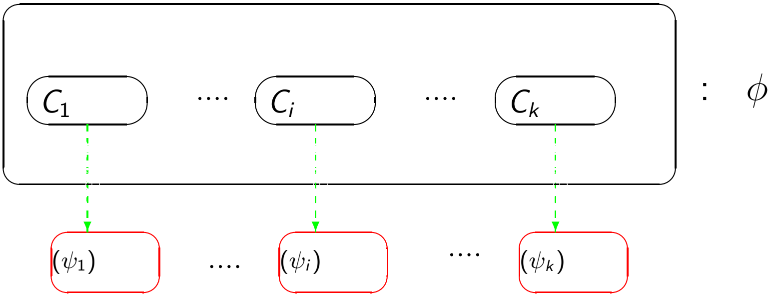

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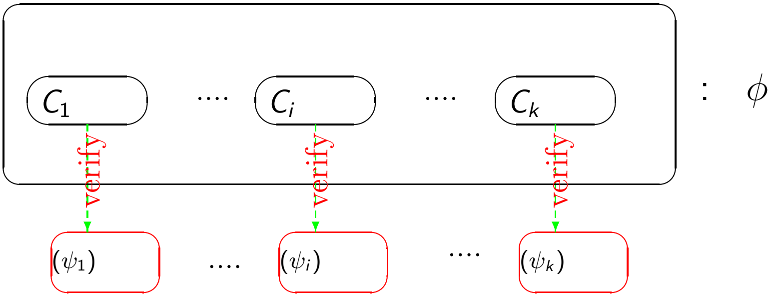

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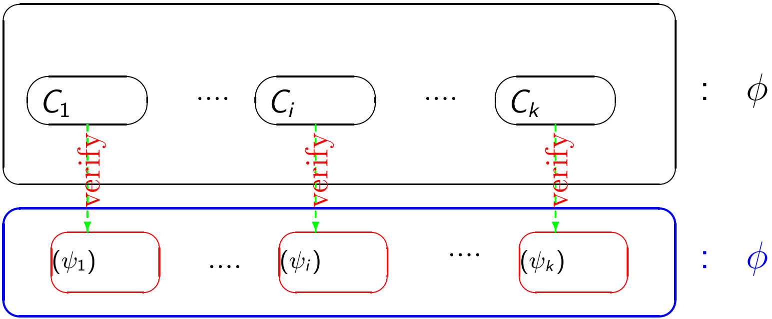
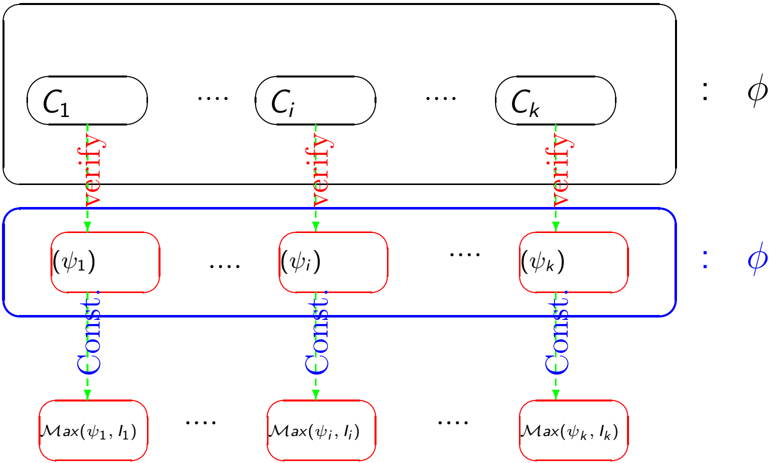


Compositional Verification Based on Maximal Flow Graphs



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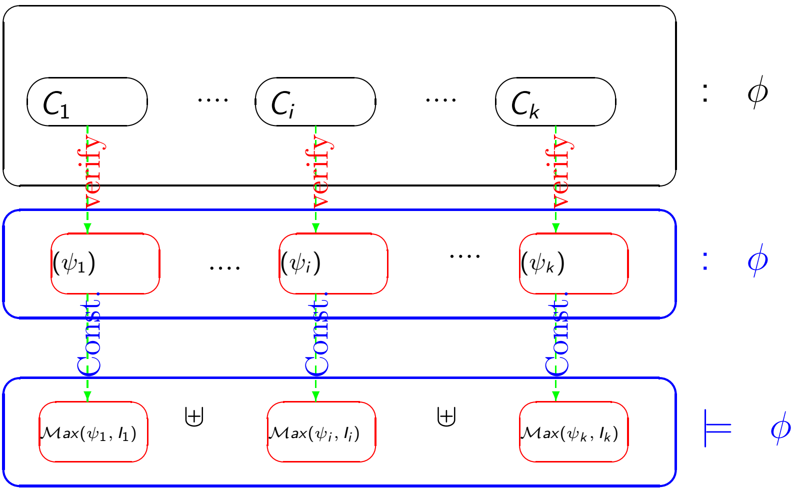

Procedure–Modular Verification

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(*I*)
- Extract flow graph for each method and model check it against its local property

(*II*)
- Construct maximal model from local property and interface of each method
- Compose the maximal models and model check the composition result against global property

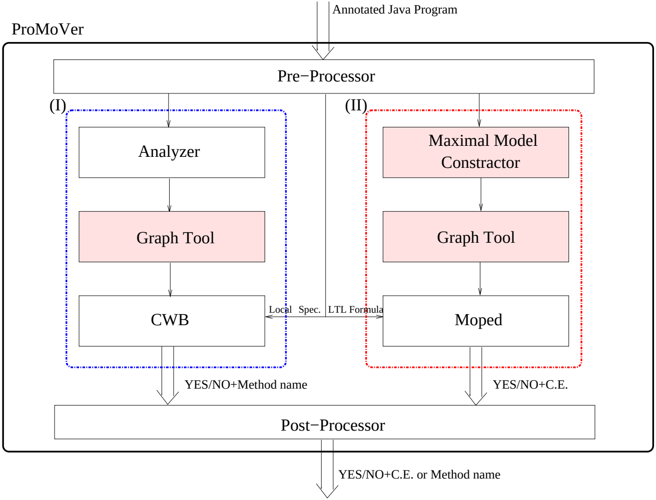

Figure: Overview of ProMoVer and its underlying tool set

Case Study

Program

- JavaPurse: a Java Card application for electronic purse
- Uses Transaction mechanism for atomic update operations
- 19 methods
- Around 1000 lines of Java code
- With 222 method invocations, 21 method calls to `NonAtomic` methods

Case Study

Global Property

- non-atomic array operation should not be invoked within a transaction

$$\mathtt{G}\,(\mathtt{beginTransaction} \rightarrow \neg\mathtt{NonAtomicOp}\;\mathtt{W}\;\mathtt{commitTransaction})$$

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Local Specifications

- The implementation was available
- Specification: capture the method invocation ordering
- It is possible to write specification independent from the implementation

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Verification Result

- Positive answer in 150 seconds
- Task(I) performed in 142 seconds
  - Analyzer(Soot) needed 141 seconds
- Task(II) performed in 4 seconds

Conclusions

ProMoVer

An automated tool for procedure–modular verification

- Verifies temporal safety properties
- Gets annotated Java programs
- Fully automated

- We evaluated ProMoVer by a small but realistic case study
  - The results seem promising
    - Handle a real case study

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Improvements Needed

- Replace Analyzer(Soot)
- To support for alternative notations

Future Work

Prove Reuse

To provide support for prove reuse

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Investigate the *scalability* of the approach

- Evaluate our approach by a larger case study
- Interface abstraction by in-lining private methods

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Wider Range of Properties

To find more interesting properties

- by adding data
    - by using Boolean programs

Questions

Maximal Flow Graphs

Maximal Flow Graph for property ψ, is a flow graph that simulates all flow graphs holding ψ.

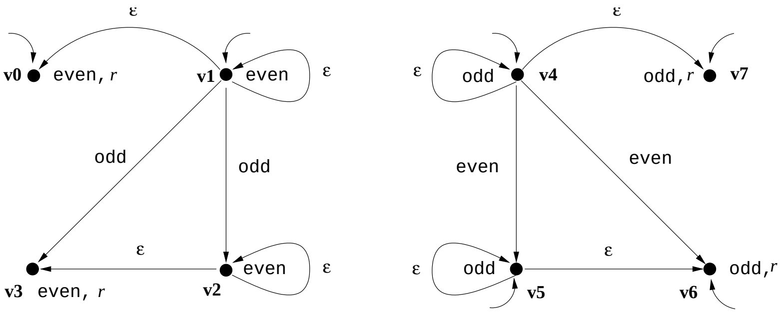

Figure: Maximal Flow graph of Number