Compositional Verification of Product Families

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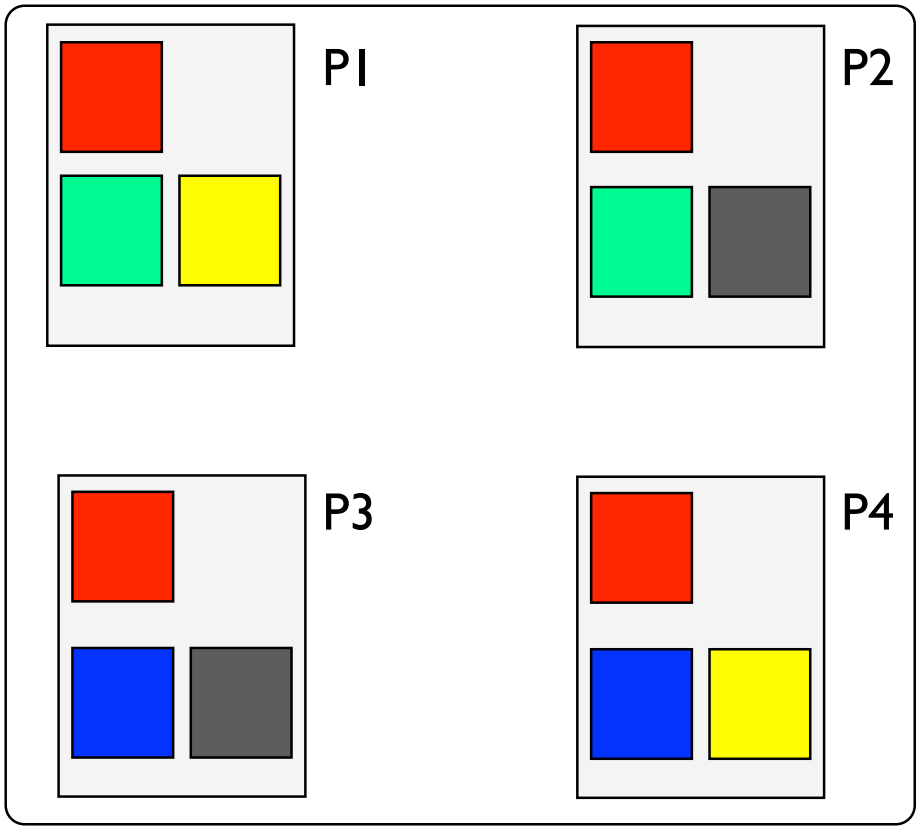
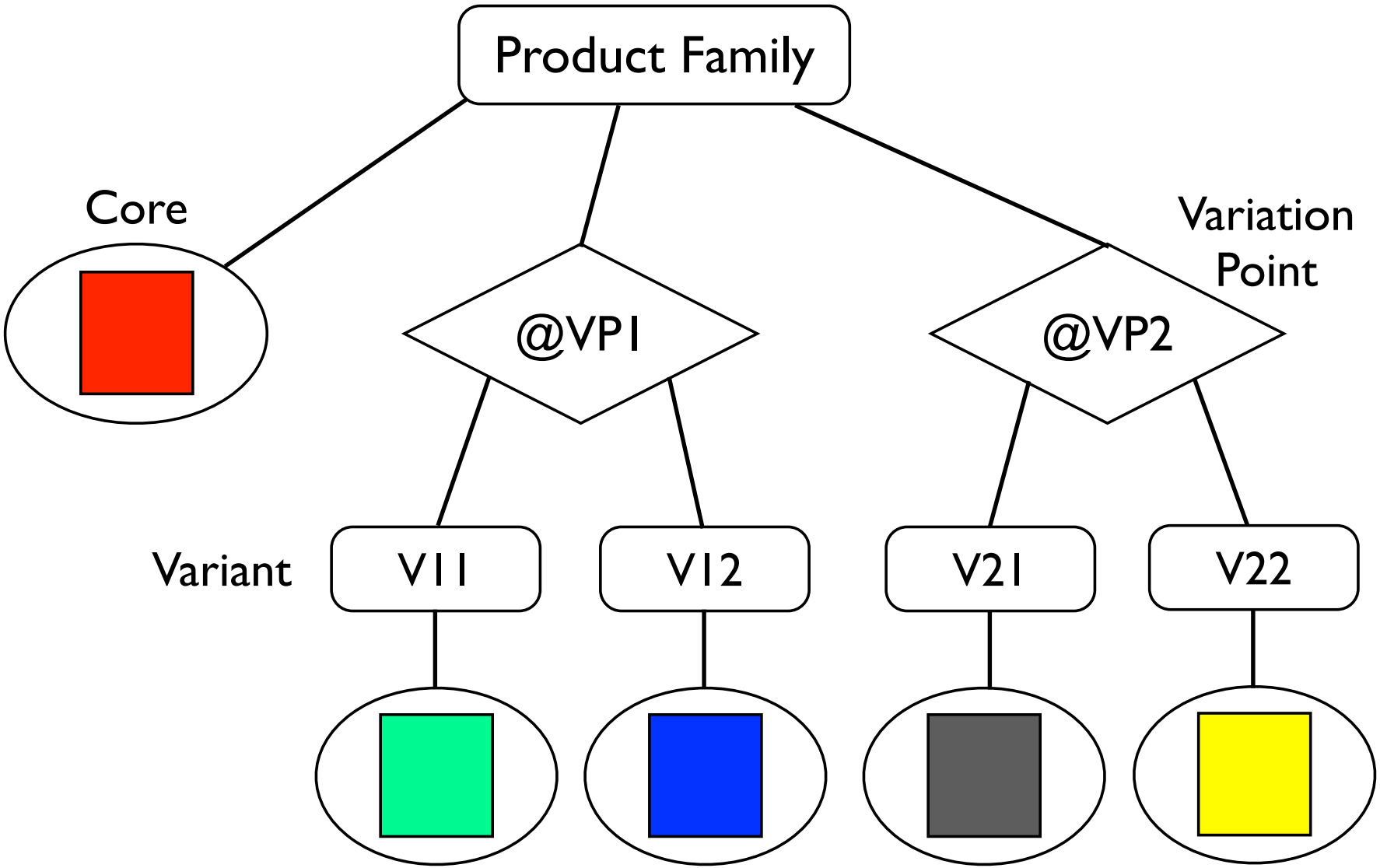
Motivation

Product Family

Set of products with well–defined commonalities and variabilities



Hierarchical Variability Modelling for Product Families



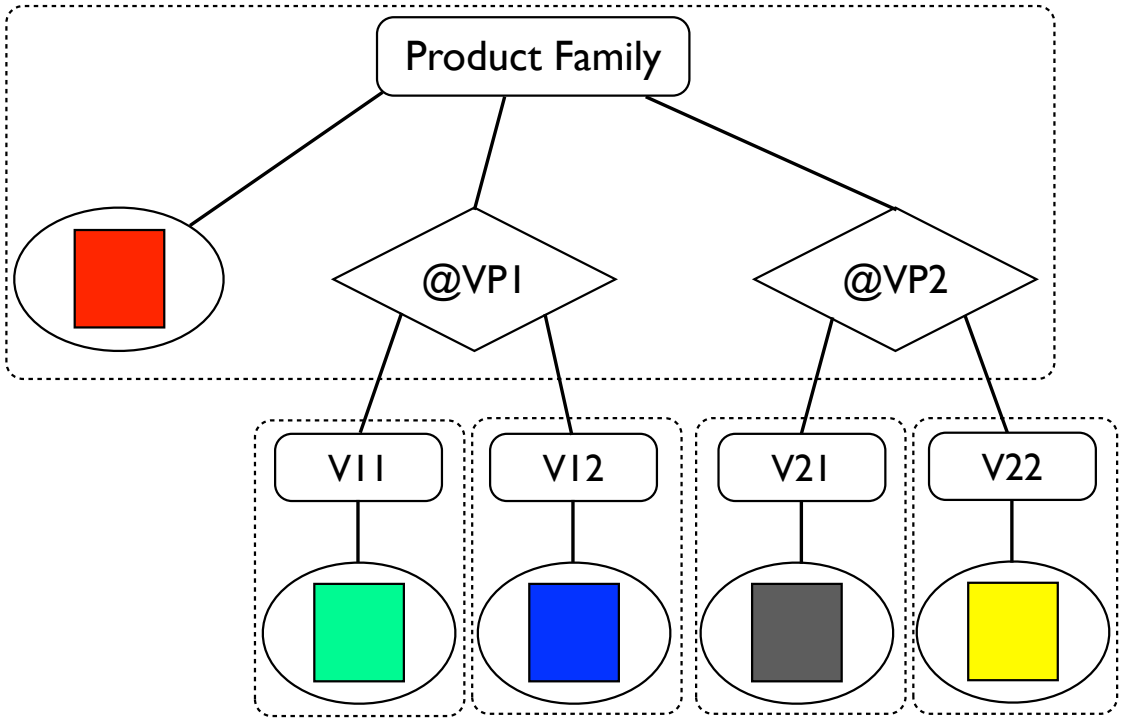
Analysis of Product Families

Non-Compositional Analysis

Verification tasks bound by $(\#variants)^{(\#VP)^{ND}}$

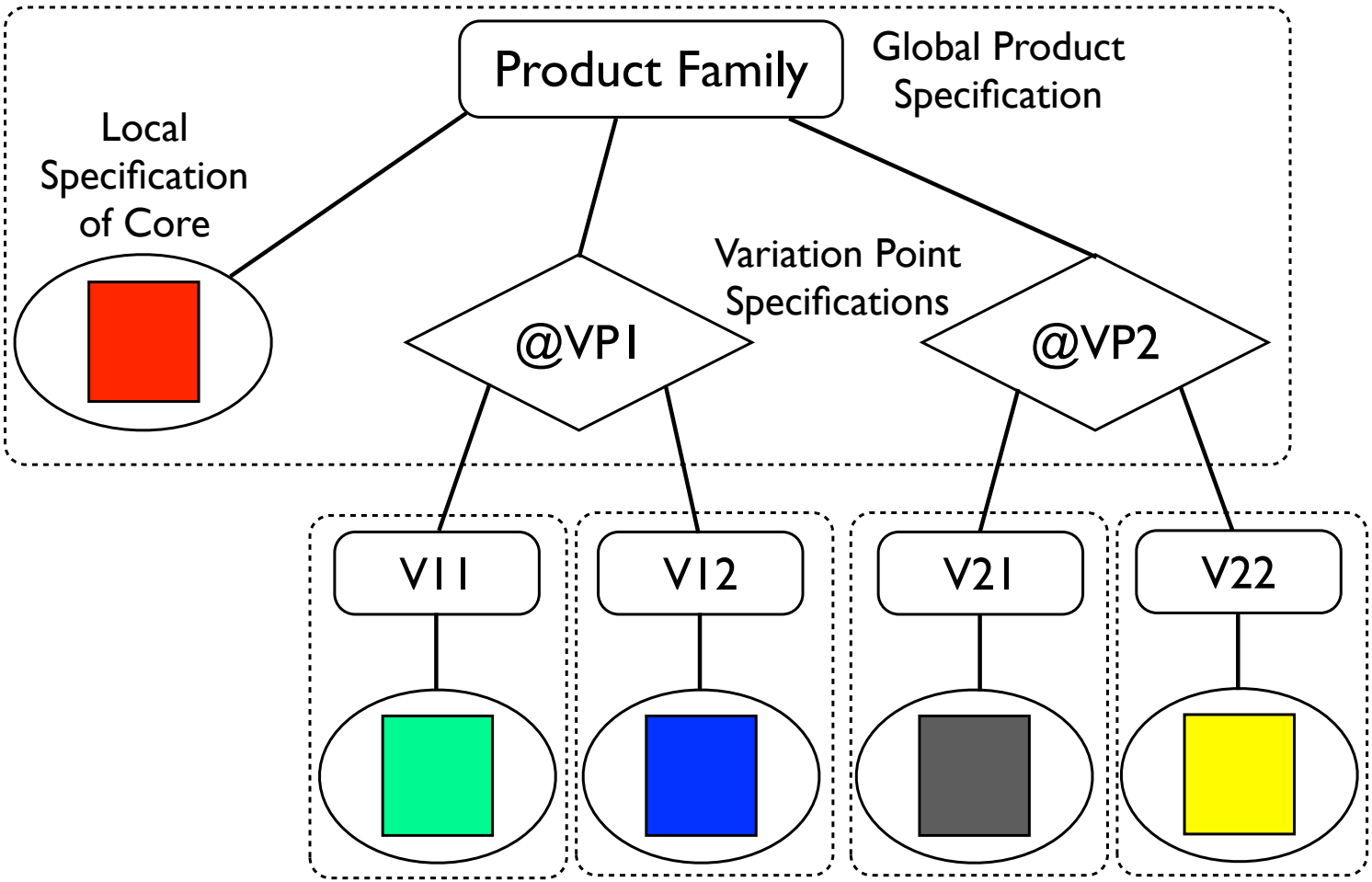
Compositional Analysis

Verification tasks bound by $(\#variants \times \#VP)^{ND}$



Compositional Analysis of Product Families

- Relativize Product Properties towards Variation Points
- Apply Compositional Analysis Technique



Outline

- Compositional Verification of Control Flow Safety Properties
- Hierarchical Variability Modelling
- Modular Specification of Core and Variation Point Properties
- Compositional Reasoning using Variation Point Properties

Compositional Verification of Control Flow Safety Prop.

Compositional Verification Technique by D. Gurov and M. Huisman[1]

Program Model

- flow graphs (no data)
- method call edges, return nodes
- infinite–state behaviour

Logic

- temporal logic for safety properties
- legal sets of sequences of method invocations

[1] Dilian Gurov, Marieke Huisman, and Christoph Sprenger: "Compositional Verification of Sequential Programs with Procedures", Journal of Information and Computation, 2008

Simple Hierarchical Variability Model

Inductively defined as

(*i*) a core model consisting of a set of methods

$$M_C = (M_{pub}, M_{priv})$$

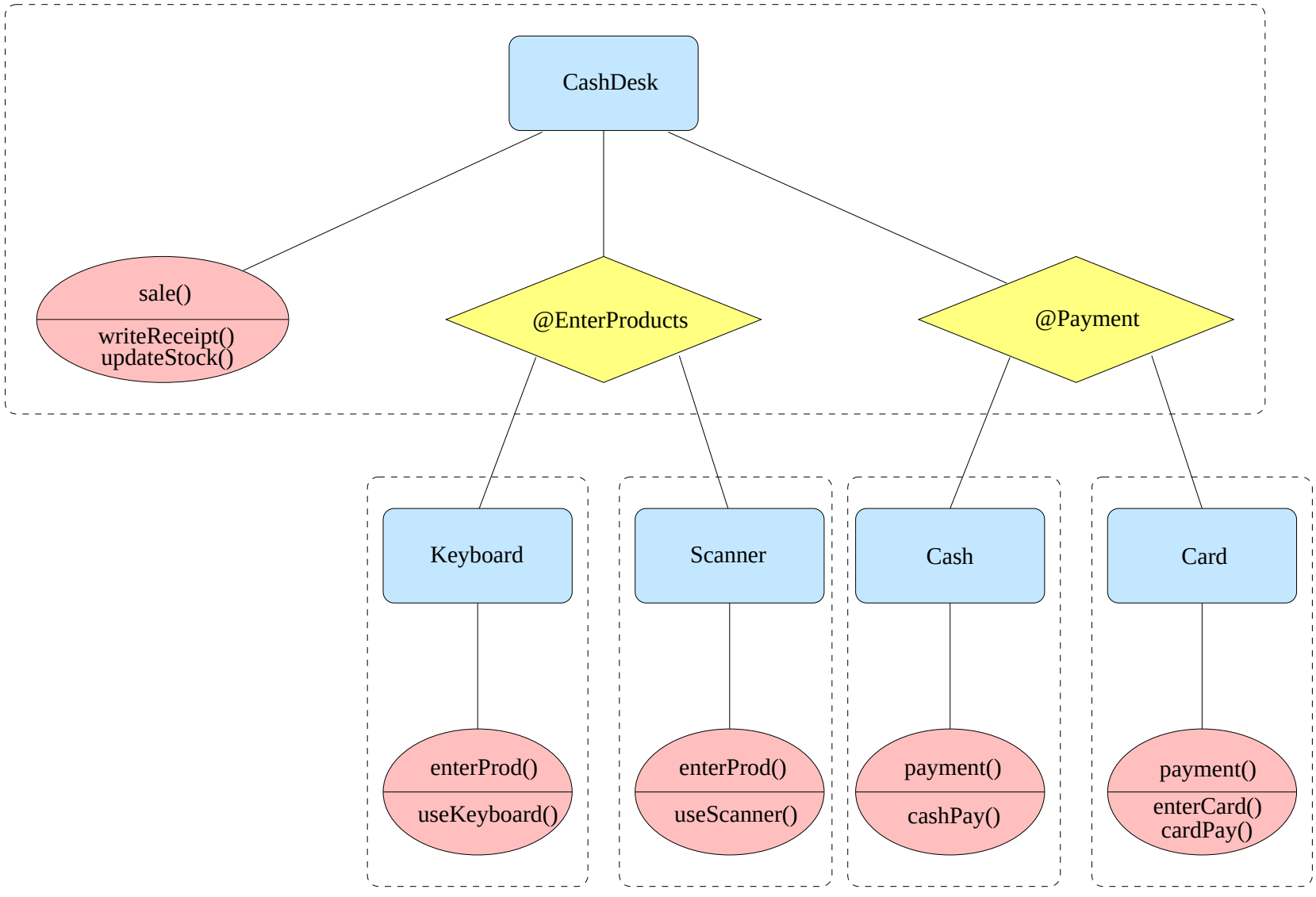
divided into disjoint set of public methods $M_{pub} \subseteq Meth$ and private methods $M_{priv} \subseteq Meth$

(*ii*) a hierarchical model consisting of a pair

$$(M_C, \{VP_1, \ldots, VP_N\})$$

such that $M_C = (M_{pub}, M_{priv})$ is a core model and $\{VP_1, \ldots, VP_N\}$ is a non–empty set of *variation points*, where every variation point VP_i is a set of (at least 2) *variants*, each one being an SHVM itself.

Example: Cash Desk Product Family



Why **Simple** Hierarchical Variability Model?

- At each variation point, select exactly one variant.
- No dependencies between variants and variation points.
- Same interface for all variants at a variation point.
  (same set of public provided methods)

Specification for Compositional Reasoning

We have to provide

- a global product property at the top-most SHVM node.
- local specifications for every core method.
- variation point specifications for every variation point.
- each variant inherits the property of its variation point.

Specification Language sLTL

The formulae of sLTL are inductively defined by:

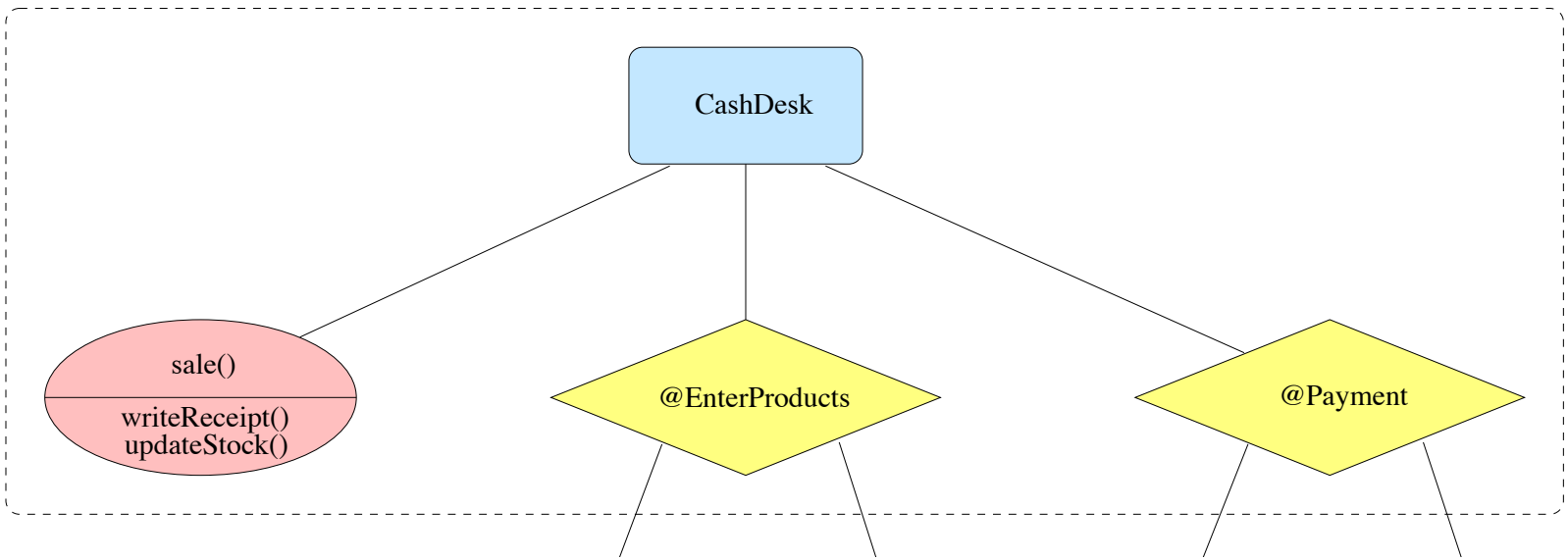
$$\phi ::= p \mid \neg p \mid \phi_1 \wedge \phi_2 \mid \phi_1 \vee \phi_2 \mid \mathtt{X}\,\phi \mid \mathtt{G}\,\phi \mid \phi_1\,\mathtt{W}\,\phi_2$$

Specification of Example

Global Product Property of `Cash Desk`

Entering of products must be completed before payment:

$$sale \rightarrow (\neg payment \ \mathrm{W} \ (r \wedge enterProd \wedge \mathrm{X} \ sale))$$

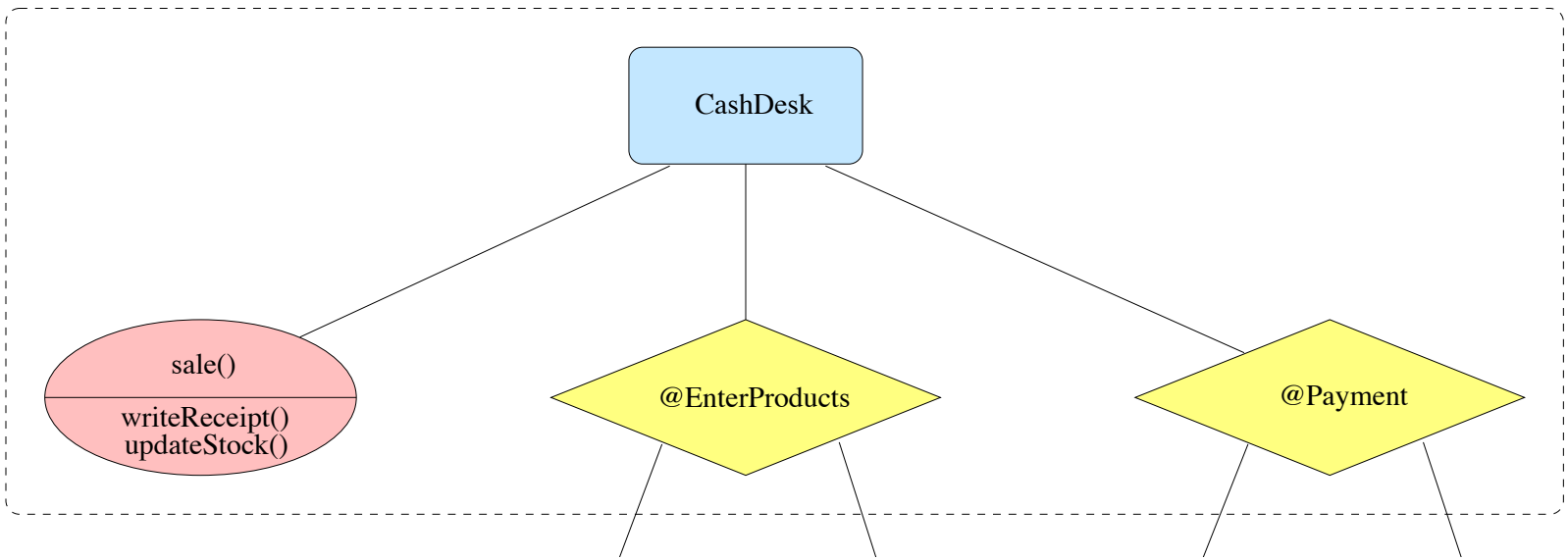


Specification of Example (2)

Local Specification of `sale()`

`sale()` only calls `payment()` after returning from `enterProd()`:

$$\mathit{sale}\ \mathtt{W}\ \mathit{enterProd}\ \mathtt{W}\ \mathit{sale}\ \mathtt{W}\ \mathit{payment}\ \mathtt{W}\ (\mathtt{G}\ \mathit{sale})$$



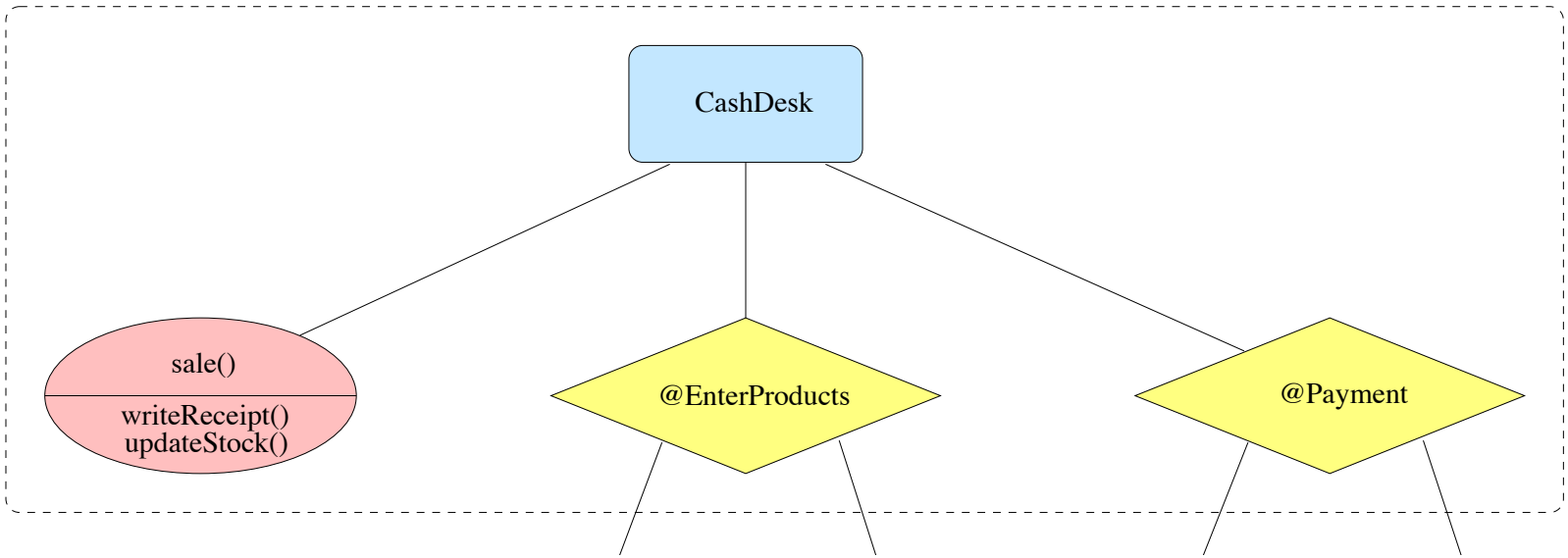
Specification of Example(3)

VP Specification of @EnterProducts

`enterProd()` never calls `payment()`: G ($\neg$*payment*)

VP Specification of @Payment

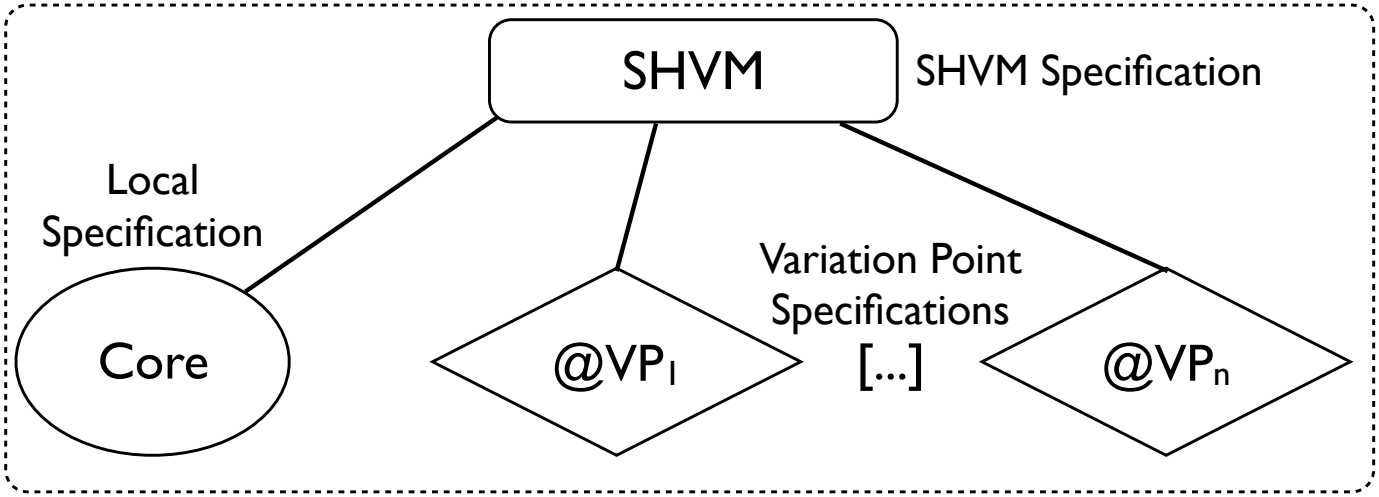
`payment()` never calls `enterProd()`: G ($\neg$*enterProd*)



Compositional Verification Process

For every SHVM $(M_C, \{VP_1, \ldots, VP_N\})$:

- For each core method $m \in M_C$, verify local specification.
- For every module, verify SHVM specification under the assumption of core method specifications and variation point specifications.



Verification of Core Specifications

For every SHVM $(M_C, \{VP_1, \ldots, VP_N\})$ and for every public method $m \in M_{pub}$:

- extract the method graph $\mathcal{G}_m$ from the implementation of m
- inline the already extracted graphs for the private methods
- model check the resulting method graph against the specification ψ_m of m to establish $\mathcal{G}_m \models \psi_m$ by standard finite–state model checking

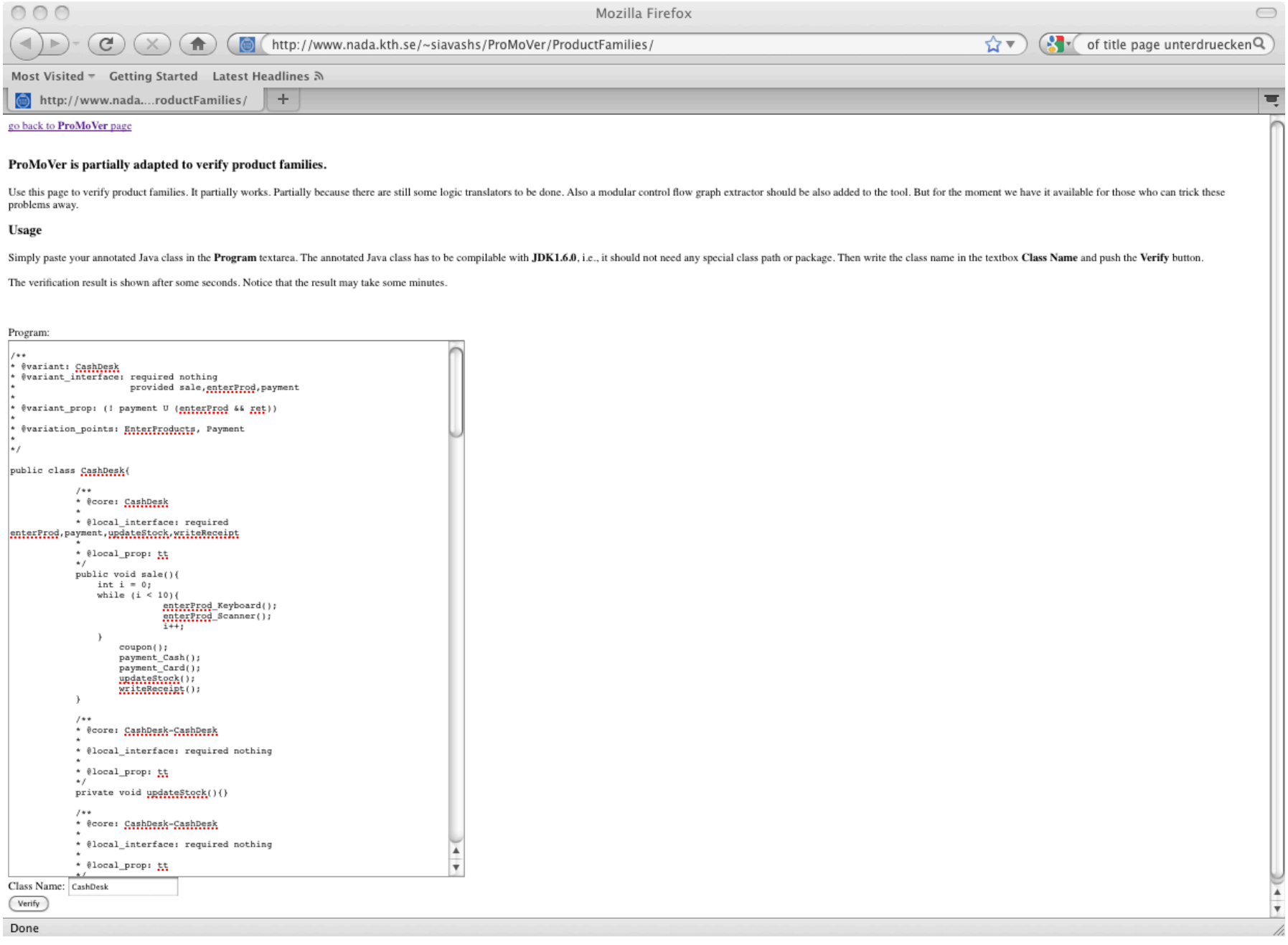
Compositional Verification of SHVM

For every SHVM $(M_C, \{VP_1, \ldots, VP_N\})$:

- for all public methods $m \in M_{pub}$ with specification ψ_m, construct the maximal method graphs $\mathcal{M}ax(\psi_m, I_m)$ wrt. interface I_m
- for all variation points VP_i with specification ψ_{VP_i} construct the maximal flow graphs $\mathcal{M}ax(\psi_{VP_i}, I_{VP_i})$ wrt. interface I_{VP_i}
- compose the graphs, resulting in flow graph $\mathcal{G}_{\mathcal{M}ax}$, and model check the latter against the SHVM property ϕ using the model checker MOPED.

$$\left(\biguplus_{m \in M_{pub}} \mathcal{M}ax(\psi_m, I_m) \uplus \biguplus_{VP_i \in \{VP_1, \ldots, VP_N\}} \mathcal{M}ax(\psi_{VP_i}, I_{VP_i}) \right) \models \phi$$

Tool Support: ProMoVer for ProductFamilies



Tool Support: ProMoVer for ProductFamilies

Program:

```
/**
* @variant: CashDesk
* @variant_interface: required nothing
*                     provided sale,enterProd,payment
*
* @variant_prop: (! payment U (enterProd && ret))
*
* @variation_points: EnterProducts, Payment
*
*/

public class CashDesk{

            /**
            * @core: CashDesk
            *
            * @local_interface: required
enterProd,payment,updateStock,writeReceipt
            *
            * @local_prop: [...]
            */
            public void sale(){
                int i = 0;
                while (i < 10){
                            enterProd();
                            i++;
                }
                    payment();
                    updateStock();
                    writeReceipt();
            }


            /**
            *
            * @variation_point: EnterProducts_CashDesk
            *
            * @variation_point_interface: required nothing
            *                             provided enterProd
            *
            * @variation_point_prop: [...]
            *
            * @variants: Keyboard,Scanner
            *
            *
            *
            * @variant: Keyboard=EnterProducts
            *
            * @variant_interface:   required nothing
            *                      provided enterProd
            *
            * @variant_prop: true
```

Class Name: CashDesk

Verify

Input for Cash Desk Example

Variant Annotations:

```
/**
* @variant: CashDesk
*
* @variant_interface: required
*                     provided sale,enterProd,payment
*
* @variant_prop:
*    sale --> ( !payment W (r && enterProd && X sale))
*
* @variation_points: EnterProducts, Payment
*/
public class CashDesk{ ...
```

Input for Cash Desk Example (2)

Core Annotations:

```
/**
* @core: CashDesk
*
* @local_interface: required enterProd,payment
*
* @local_prop:
*     (sale W enterProd W sale W payment W (G sale))
*/
  public void sale(){
    int i = 0;
    while (i < 10){
       enterProd();
       i++;
    }
    payment();
    updateStock();
    writeReceipt();
}
```

Input for Cash Desk Example (3)

Variation Point Annotations:

```
/**
* @variation_point: EnterProducts_CashDesk
*
* @variation_point_interface: required
*                             provided enterProd
*
* @variation_point_prop: G !payment
*
* @variants: Keyboard,Scanner
**/
```

Analysis Result for Cash Desk Example

```
PREPROCESSOR TIME IS: 1.52 seconds

FLOW GRAPH EXTRACTOR TIME IS: 3.12 seconds

the method sale.CashDesk matches its implementation
the method enterProd.Keyboard-EnterProducts matches its implementation
the method enterProd.Scanner-EnterProducts matches its implementation
[...]

FIRST TASK TIME IS: 3.58 seconds // for verification of local specifications


Verifying variant Keybord-EnterProducts
THE VERIFICATION RESULT IS: YES.

Verifying variant Scanner-EnterProducts
THE VERIFICATION RESULT IS: YES.

[...]

Verifying variant CashDesk
THE VERIFICATION RESULT IS: YES.

THE WHOLE VERIFICATION TIME IS: 25.37 seconds
```

Evaluation

We compositionally verified different product families:

- CD - Simple Cash Desks
- CD/CH - Cash Desks with Coupon Handling
- CD/CT - Cash Desks with Credit Cards
- CD/CT/CH - Cash Desks with Credit Cards and Coupon Handling

Analysis Results:

Product Line	Depth	# Modules	# Products	t_{ind}[s]	t_{comp}[s]
`CD`	1	5	4	101	26
`CD/CH`	1	7	8	206	28
`CD/CT`	2	9	11	281	29
`CD/CH/CT`	2	11	20	518	30

Conclusion

Summary

- Compositional analysis of product families defined by HVM
- Verification of control flow safety properties for SHVM

Future Work

- Relax restrictions of SHVM
- Improvements of ProMoVer tool
- Use approach with other compositional reasoning techniques