RULE MODULE INHERITANCE WITH MODIFICATION RESTRICTIONS

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UNDERLYING RULE LANGUAGE - DATALOG± / VADALOG

- Datalog±
  - Simple yet powerful
  - Extended Datalog

+	-
Existentially quantified variables	Restrictions to be decidable
Negative constraints	
Equality-generating dependencies	

- Encompasses
  - Full Datalog
  - SPARQL under OWL 2 QL entailment
- Vadalog: Datalog± implementation with many extensions

MOTIVATION FOR RULE MODULES

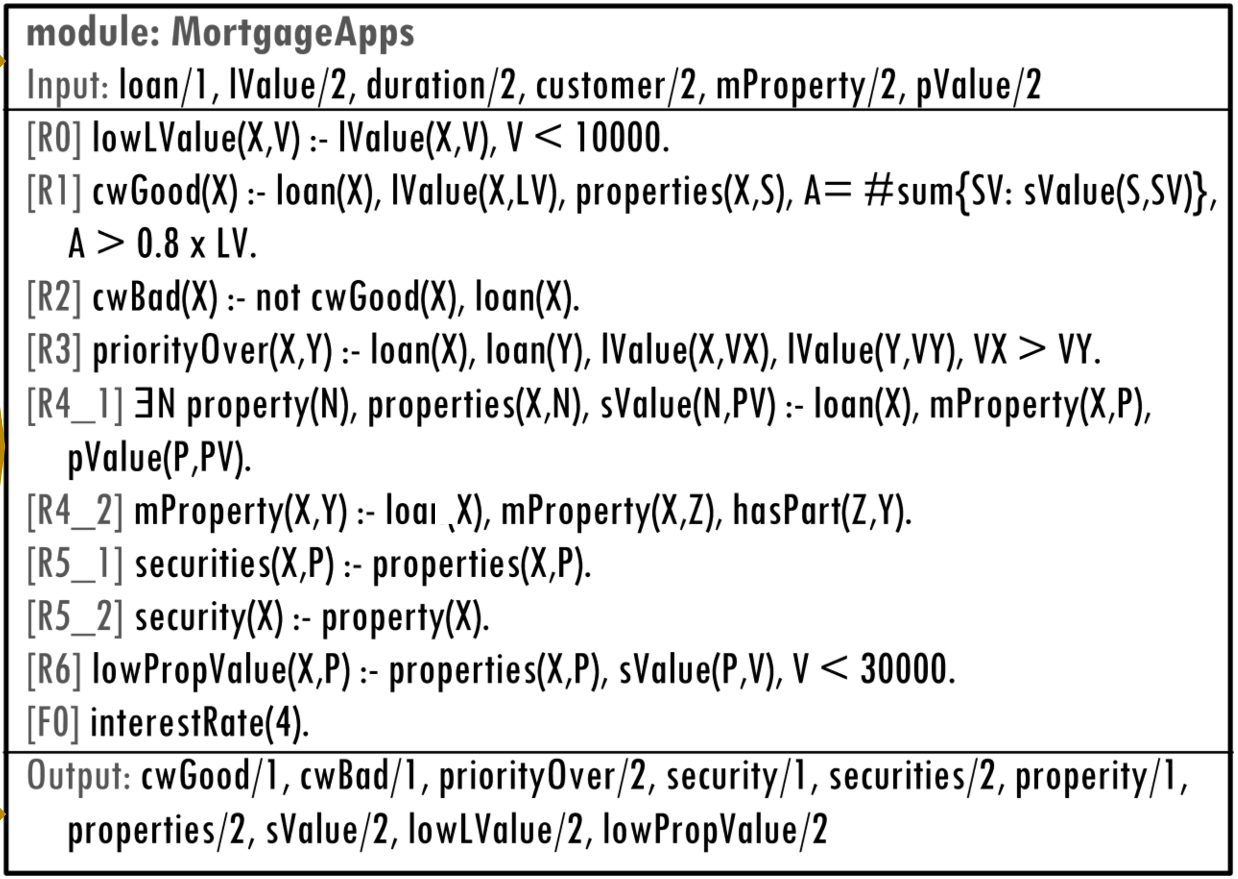
- Increasing number and complexity of rules
- Maintenance and adaption key challenges
- Separate rule-base knowledge from application code
- Clear interfaces are vital

RULE MODULES

Module Structure

Determining *Module Behavior*, i.e., derived facts in output for given input

Module Structure



```
module: MortgageApps
Input: loan/1, lValue/2, duration/2, customer/2, mProperty/2, pValue/2
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] cwGood(X) :- loan(X), lValue(X,LV), properties(X,S), A= #sum{SV: sValue(S,SV)},
    A > 0.8 x LV.
[R2] cwBad(X) :- not cwGood(X), loan(X).
[R3] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[R4_1] ∃N property(N), properties(X,N), sValue(N,PV) :- loan(X), mProperty(X,P),
    pValue(P,PV).
[R4_2] mProperty(X,Y) :- loan(X), mProperty(X,Z), hasPart(Z,Y).
[R5_1] securities(X,P) :- properties(X,P).
[R5_2] security(X) :- property(X).
[R6] lowPropValue(X,P) :- properties(X,P), sValue(P,V), V < 30000.
[F0] interestRate(4).
Output: cwGood/1, cwBad/1, priorityOver/2, security/1, securities/2, properity/1,
    properties/2, sValue/2, lowLValue/2, lowPropValue/2
```

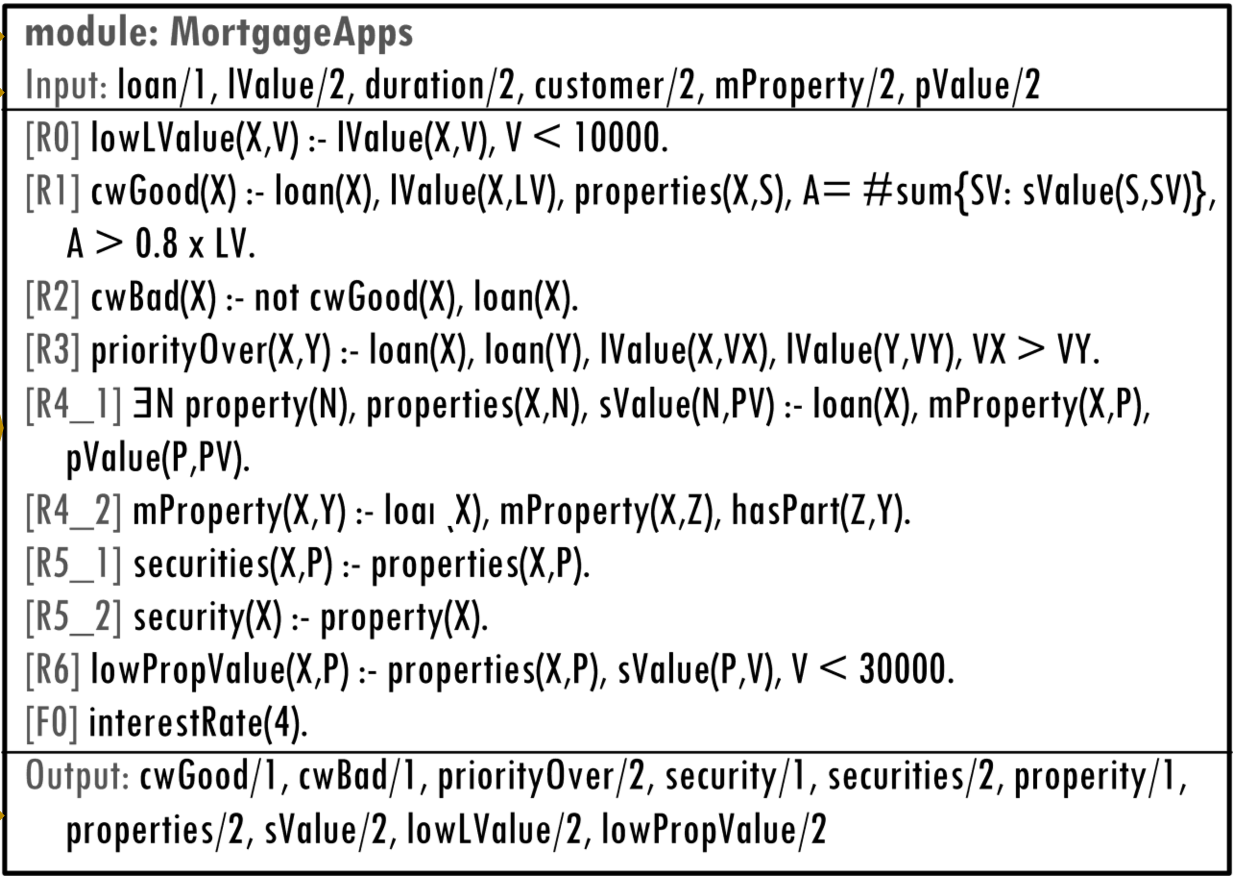
RULE MODULES

Module Name

Input Interface

Statements
- Rules
- Facts

Output Interface



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[R5_2] security(X) :- property(X).
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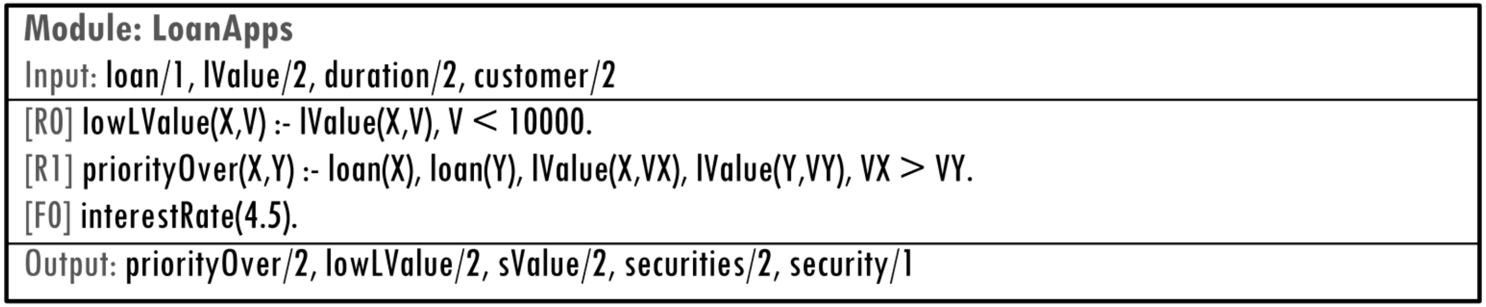
[F0] interestRate(4).
Output: cwGood/1, cwBad/1, priorityOver/2, security/1, securities/2, properity/1,
    properties/2, sValue/2, lowLValue/2, lowPropValue/2
```

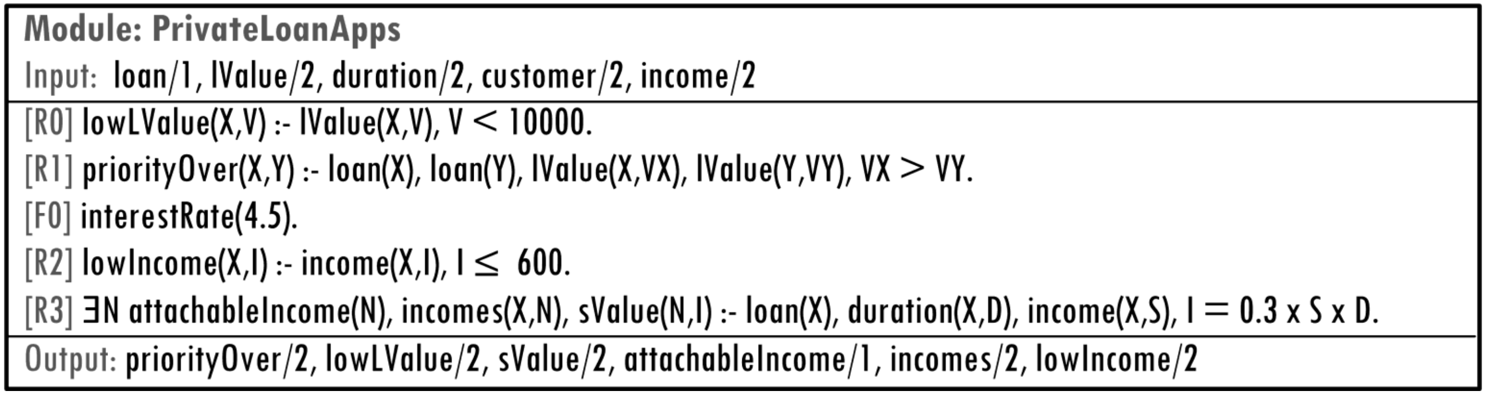
MOTIVATION FOR RULE MODULE INHERITANCE

- Module *LoanApps* describes rules and facts applying to all loan applications regardless the specific loan type
- Without inheritance, restating is necessary in *PrivateLoanApps*



Module: LoanApps

```
Input: loan/1, lValue/2, duration/2, customer/2
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[F0] interestRate(4.5).
Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1
```



Module: PrivateLoanApps

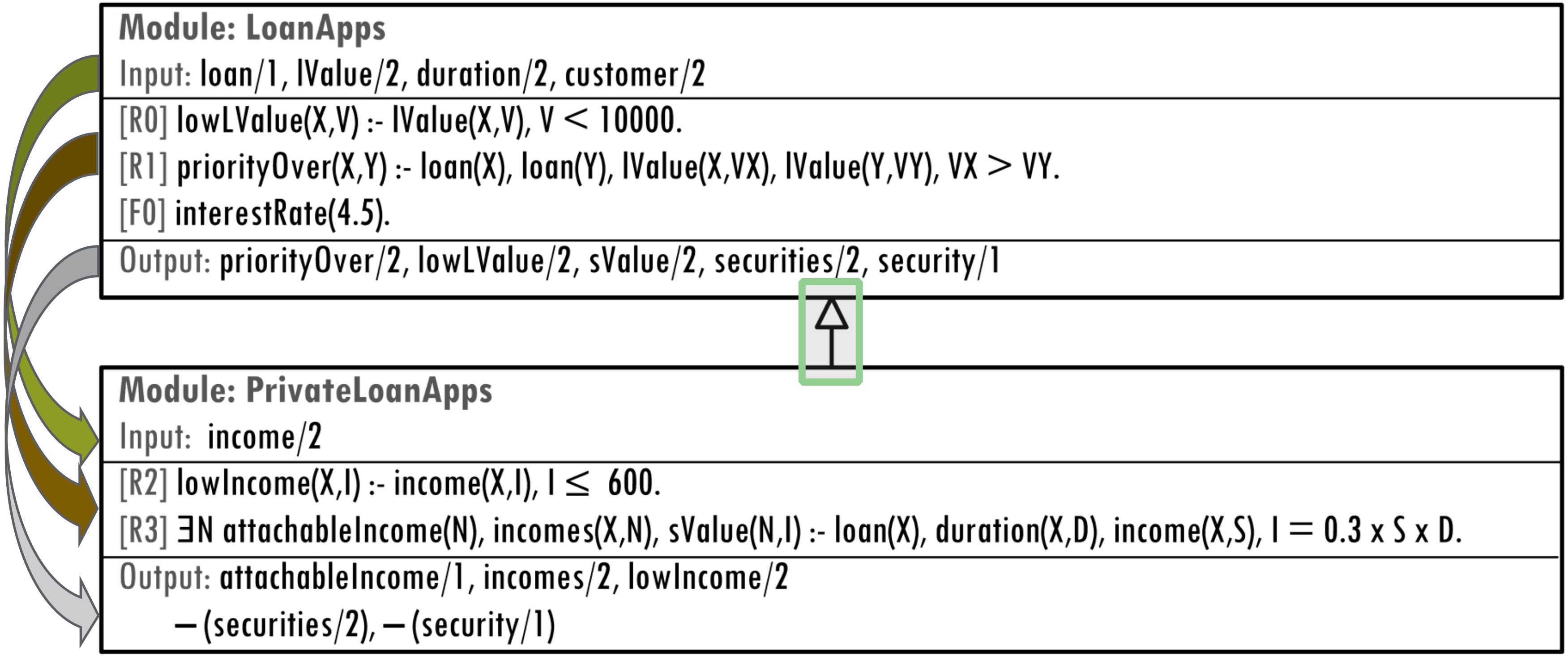
```
Input:  loan/1, lValue/2, duration/2, customer/2, income/2
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[F0] interestRate(4.5).
[R2] lowIncome(X,I) :- income(X,I), I ≤  600.
[R3] ∃N attachableIncome(N), incomes(X,N), sValue(N,I) :- loan(X), duration(X,D), income(X,S), I = 0.3 x S x D.
Output: priorityOver/2, lowLValue/2, sValue/2, attachableIncome/1, incomes/2, lowIncome/2
```

MOTIVATION FOR RULE MODULE INHERITANCE

- Reuse of existing rules (reduce redundancy)
- Easing maintenance
- Extract common rules, facts, and interface predicates from modules
- Adaption of modules by minor modifications
- Enables more sophisticated rule organization principles

RULE MODULE INHERITANCE

- Single downward inheritance of structure and behavior



Module: LoanApps

Input: loan/1, lValue/2, duration/2, customer/2

[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.

[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.

[F0] interestRate(4.5).

Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

Module: PrivateLoanApps

Input: income/2

[R2] lowIncome(X,I) :- income(X,I), I ≤ 600.

[R3] ∃N attachableIncome(N), incomes(X,N), sValue(N,I) :- loan(X), duration(X,D), income(X,S), I = 0.3 x S x D.

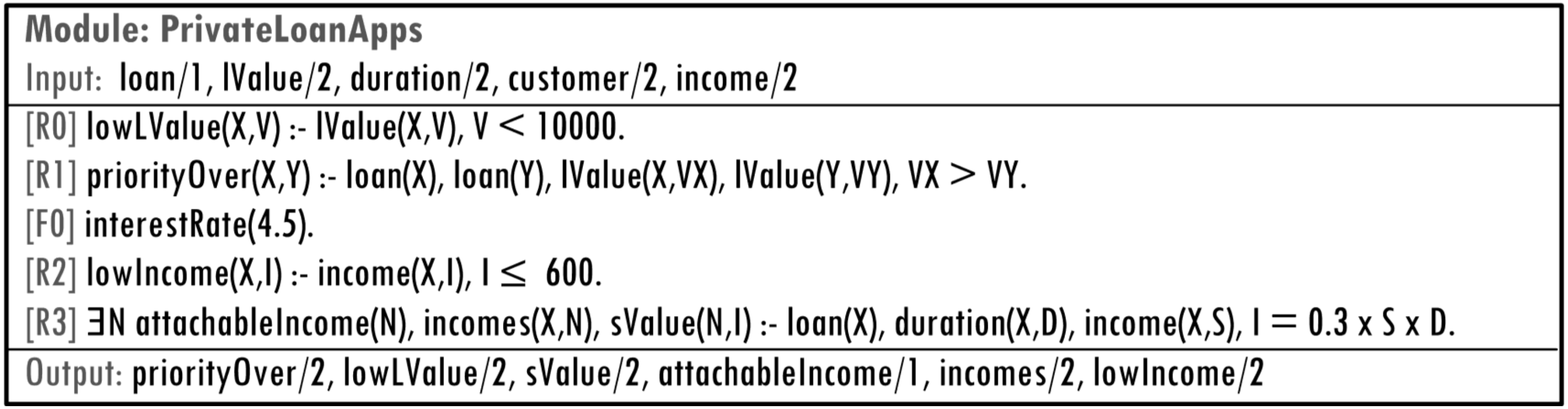
Output: attachableIncome/1, incomes/2, lowIncome/2

— (securities/2), — (security/1)

RULE MODULE INHERITANCE

- Single downward inheritance of structure and behavior

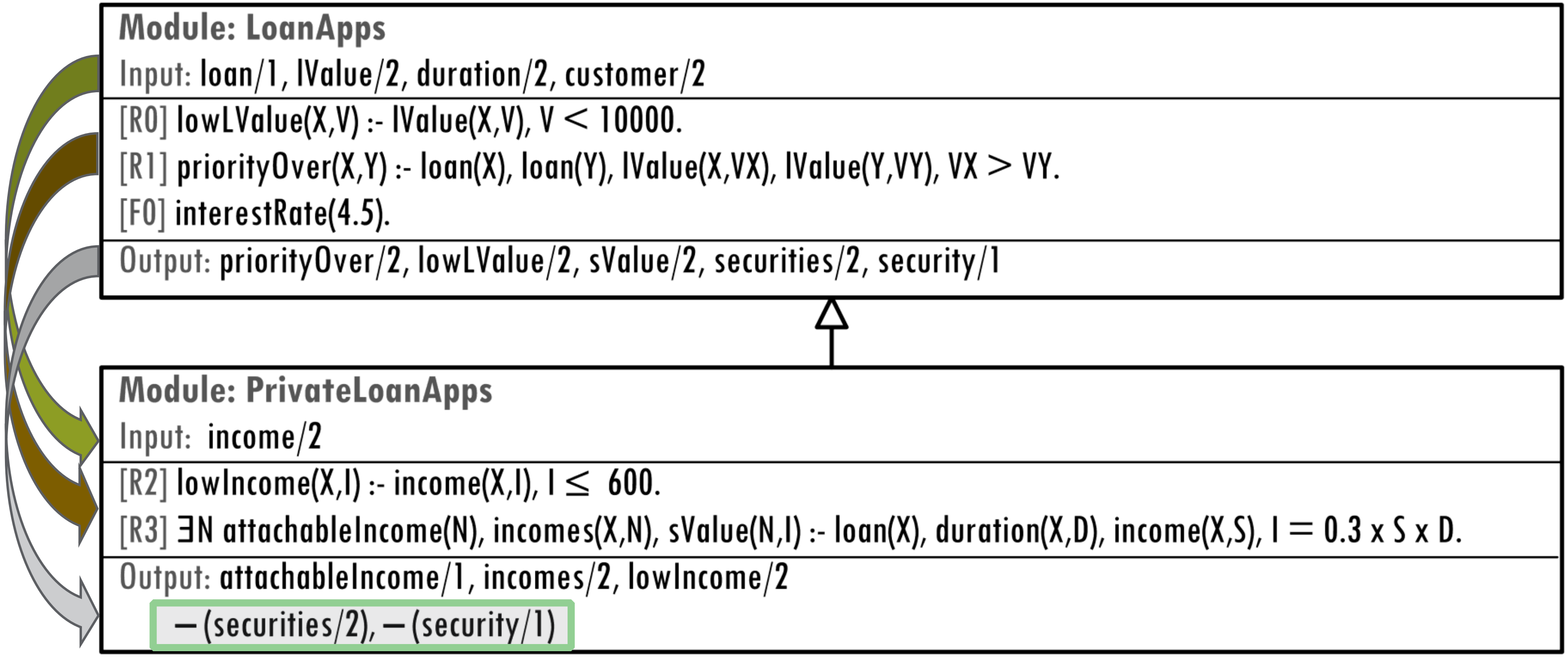
Module *PrivateLoanApps* with inheritance resolved



```
Module: PrivateLoanApps
Input:  loan/1, lValue/2, duration/2, customer/2, income/2
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[F0] interestRate(4.5).
[R2] lowIncome(X,I) :- income(X,I), I ≤  600.
[R3] ∃N attachableIncome(N), incomes(X,N), sValue(N,I) :- loan(X), duration(X,D), income(X,S), I = 0.3 x S x D.
Output: priorityOver/2, lowLValue/2, sValue/2, attachableIncome/1, incomes/2, lowIncome/2
```

RULE MODULE INHERITANCE

- Single downward inheritance of structure and behavior
- Inherited rule module structure and behavior may be modified



Module: LoanApps

Input: loan/1, lValue/2, duration/2, customer/2

[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.

[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.

[F0] interestRate(4.5).

Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

Module: PrivateLoanApps

Input: income/2

[R2] lowIncome(X,I) :- income(X,I), I ≤ 600.

[R3] ∃N attachableIncome(N), incomes(X,N), sValue(N,I) :- loan(X), duration(X,D), income(X,S), I = 0.3 x S x D.

Output: attachableIncome/1, incomes/2, lowIncome/2

− (securities/2), − (security/1)

ABSTRACT PREDICATES AND ABSTRACT RULE MODULES

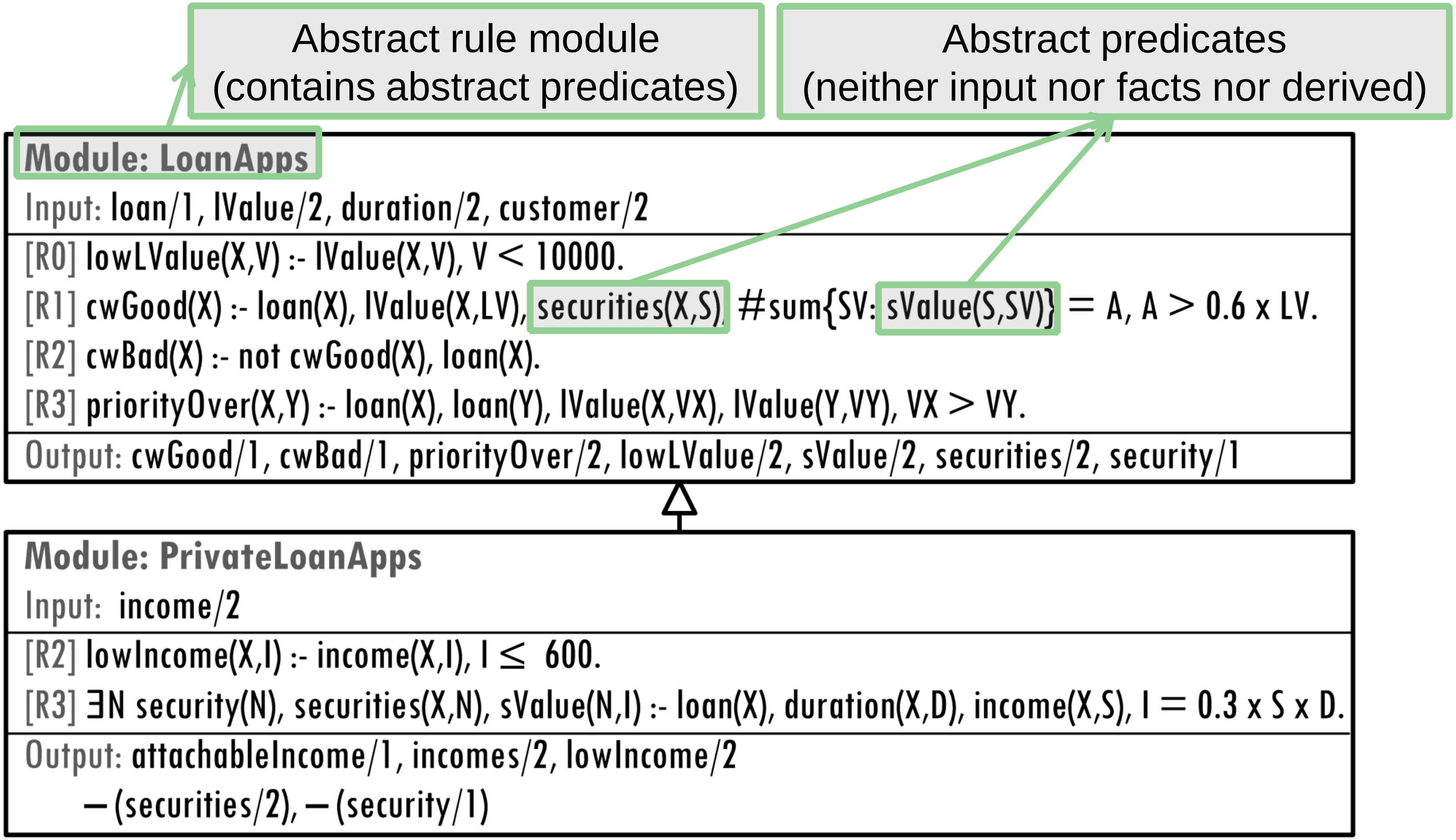
- Abstract in OO: signature defined but not implemented

- *Concrete predicate*:
  - input predicate
  - predicate with asserted facts
  - head of derivation rule(s) with only concrete predicates in body

- *Abstract predicate*: predicate not concrete

- *Abstract module*: module containing abstract predicates

ABSTRACT PREDICATES AND ABSTRACT RULE MODULES



Abstract rule module
(contains abstract predicates)

Abstract predicates
(neither input nor facts nor derived)

Module: LoanApps

Input: loan/1, lValue/2, duration/2, customer/2

[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] cwGood(X) :- loan(X), lValue(X,LV), securities(X,S), #sum{SV: sValue(S,SV)} = A, A > 0.6 x LV.
[R2] cwBad(X) :- not cwGood(X), loan(X).
[R3] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.

Output: cwGood/1, cwBad/1, priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

Module: PrivateLoanApps

Input: income/2

[R2] lowIncome(X,I) :- income(X,I), I ≤ 600.
[R3] ∃N security(N), securities(X,N), sValue(N,I) :- loan(X), duration(X,D), income(X,S), I = 0.3 x S x D.

Output: attachableIncome/1, incomes/2, lowIncome/2
−(securities/2), −(security/1)

MOTIVATION FOR MODIFICATION RESTRICTIONS

- Restrict modifications allowed in child rule modules
- Vital to represent organizational constraints
- Considering parent module and restrictions gives a good overview

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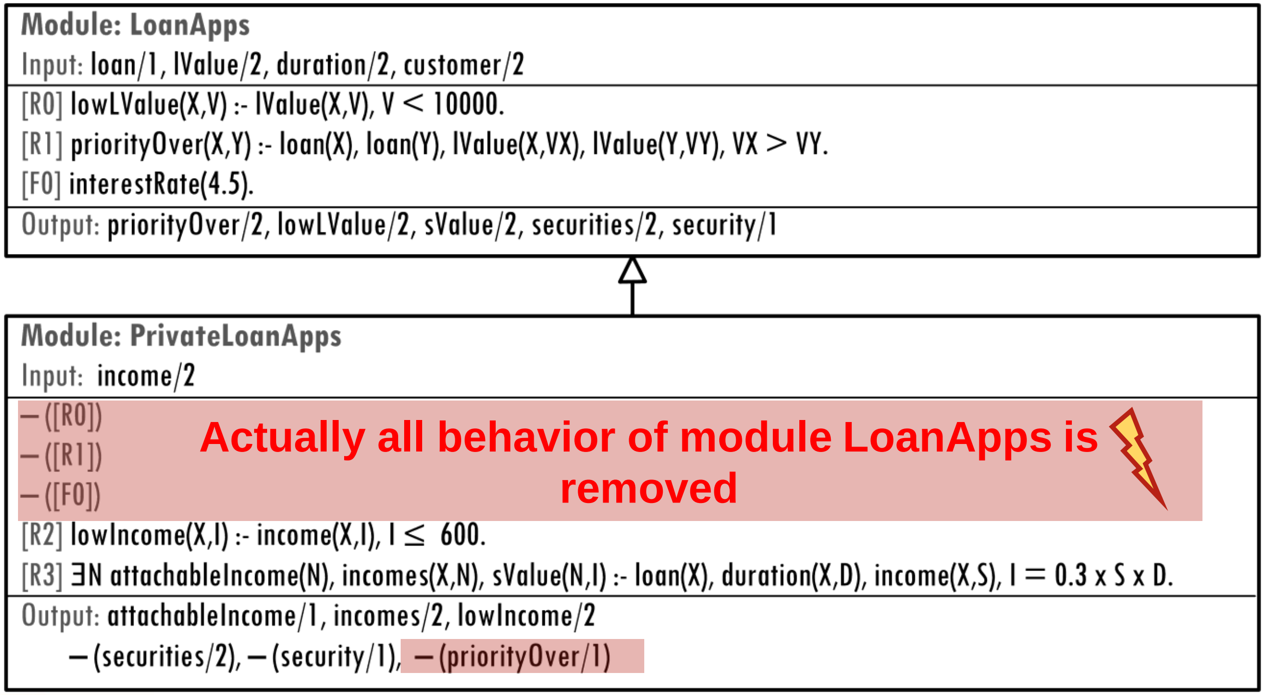


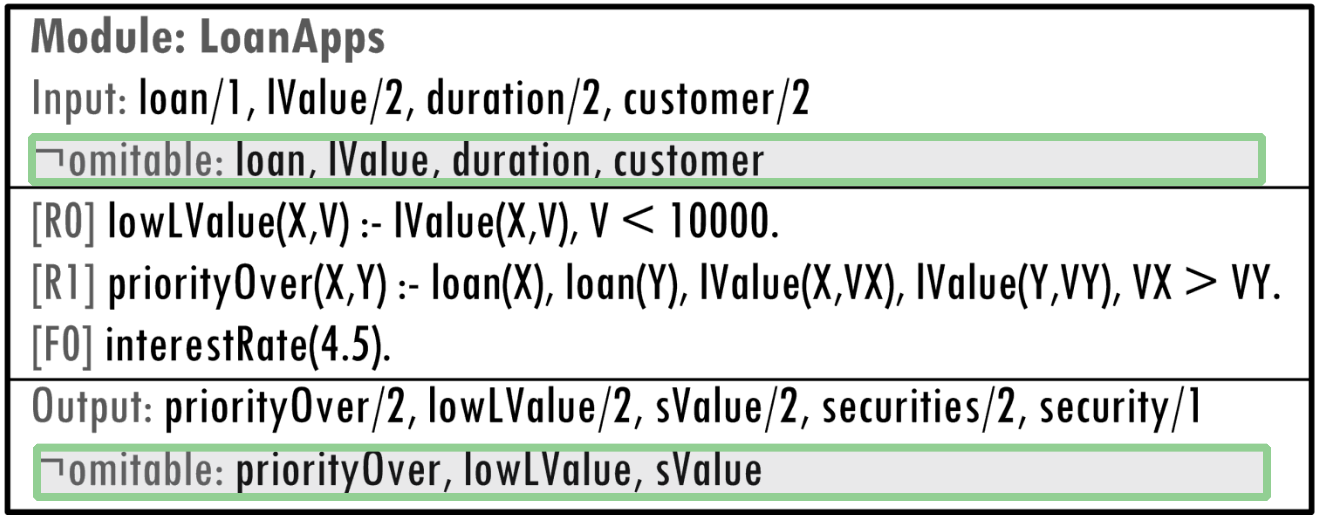
Module: LoanApps
Input: loan/1, lValue/2, duration/2, customer/2
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[F0] interestRate(4.5).
Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

Module: PrivateLoanApps
Input: income/2
−([R0])
−([R1])
−([F0])
[R2] lowIncome(X,I) :- income(X,I), I ≤ 600.
[R3] ∃N attachableIncome(N), incomes(X,N), sValue(N,I) :- loan(X), duration(X,D), income(X,S), I = 0.3 x S x D.
Output: attachableIncome/1, incomes/2, lowIncome/2
−(securities/2), −(security/1), −(priorityOver/1)

Actually all behavior of module LoanApps is removed

STRUCTURAL MODIFICATION RESTRICTIONS

- Consider rule module interfaces
  - □ ¬extensible input
  - □ ¬extensible output
  - □ ¬omitable
- Conformance check
  - □ Simple comparison of interface predicate sets



Module: LoanApps

Input: loan/1, lValue/2, duration/2, customer/2

¬omitable: loan, lValue, duration, customer

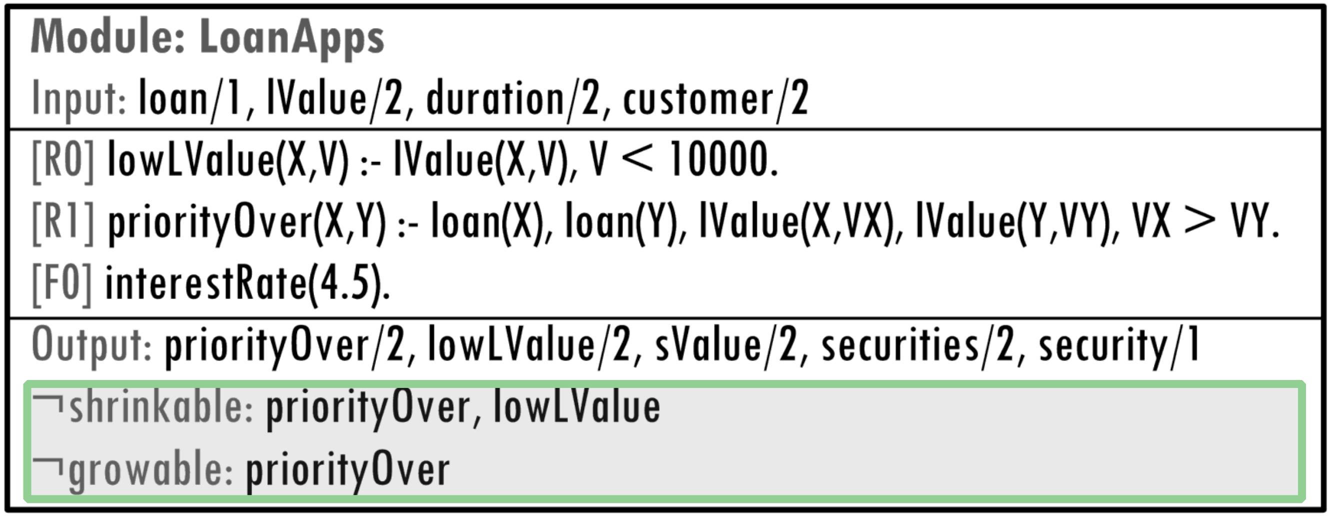
```
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[F0] interestRate(4.5).
```

Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

¬omitable: priorityOver, lowLValue, sValue

BEHAVIORAL MODIFICATION RESTRICTIONS

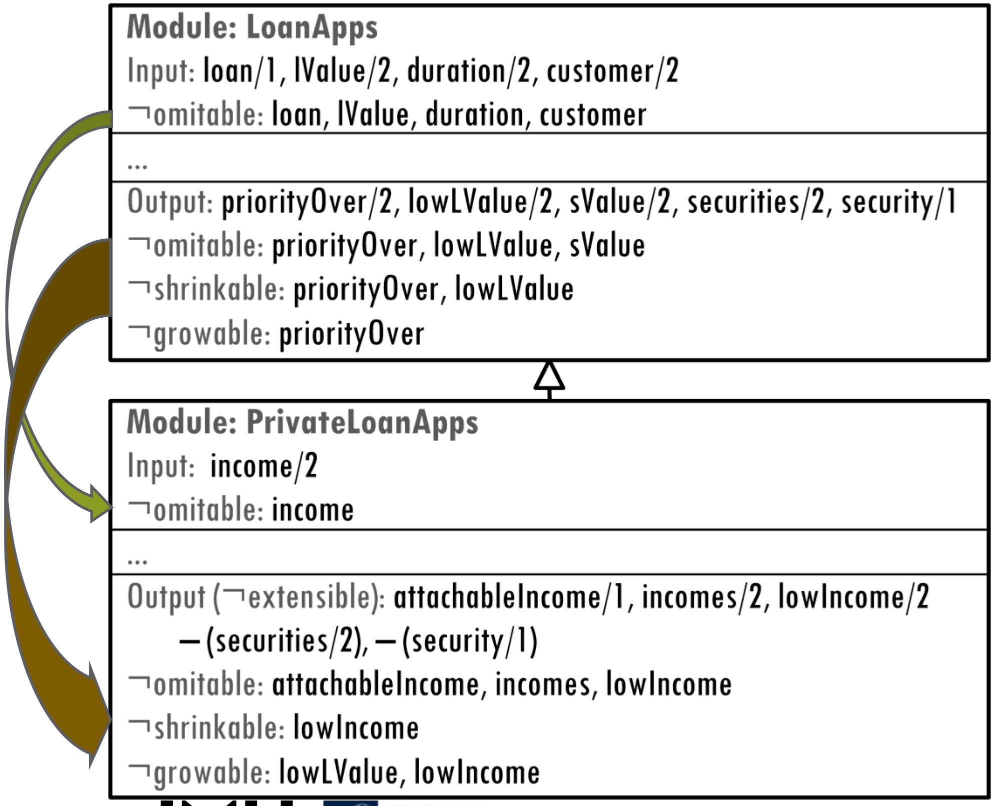
- Consider rule module behavior (derived facts for output predicates)
  - □ Prohibit additional facts for output predicate (¬growable)
  - □ Prohibit omission of facts for output predicate (¬shrinkable)
- Conformance check
  - □ Detecting modification (static, dynamic, manual)
  - □ Compare detected modification with restrictions



```
Module: LoanApps
Input: loan/1, lValue/2, duration/2, customer/2
[R0] lowLValue(X,V) :- lValue(X,V), V < 10000.
[R1] priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX), lValue(Y,VY), VX > VY.
[F0] interestRate(4.5).
Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1
¬shrinkable: priorityOver, lowLValue
¬growable: priorityOver
```

MODIFICATION RESTRICTIONS

- Modification Restrictions are inherited
- Imposed restrictions cannot be revoked



Module: LoanApps

Input: loan/1, lValue/2, duration/2, customer/2

¬omitable: loan, lValue, duration, customer

...

Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

¬omitable: priorityOver, lowLValue, sValue

¬shrinkable: priorityOver, lowLValue

¬growable: priorityOver

Module: PrivateLoanApps

Input: income/2

¬omitable: income

...

Output (¬extensible): attachableIncome/1, incomes/2, lowIncome/2
— (securities/2), — (security/1)

¬omitable: attachableIncome, incomes, lowIncome

¬shrinkable: lowIncome

¬growable: lowLValue, lowIncome

MODIFICATION RESTRICTIONS

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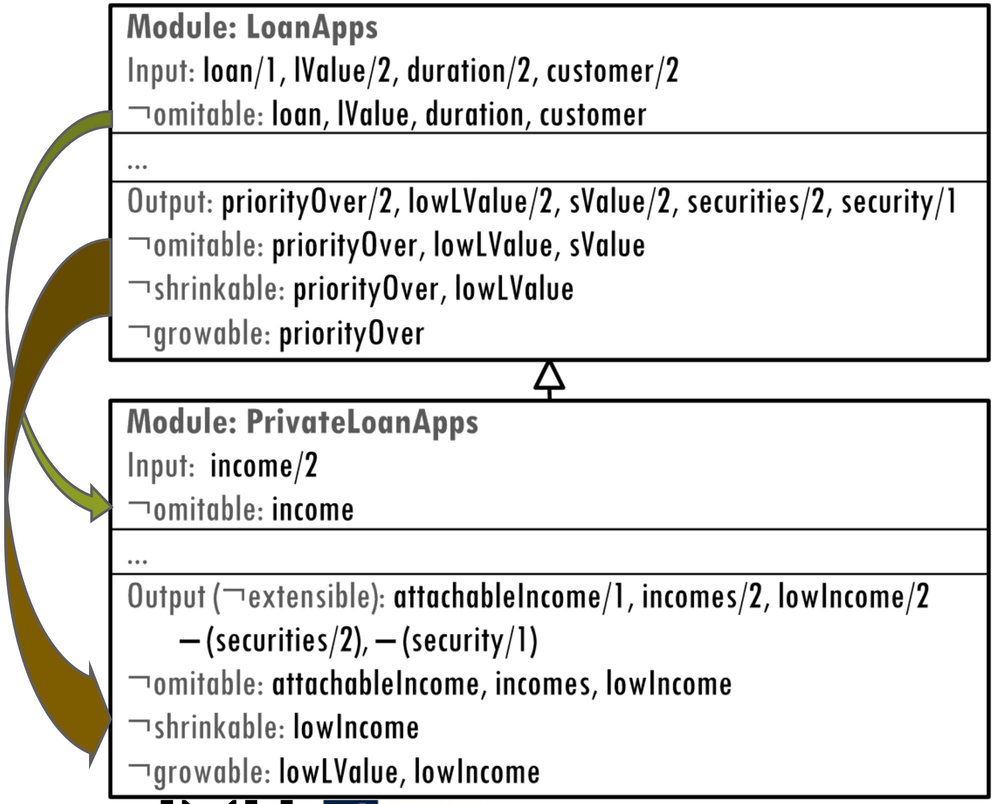

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¬omitable: loan, lValue, duration, customer

...

Output: priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1

¬omitable: priorityOver, lowLValue, sValue

¬shrinkable: priorityOver, lowLValue

¬growable: priorityOver

Module: PrivateLoanApps

Input: income/2

¬omitable: income

...

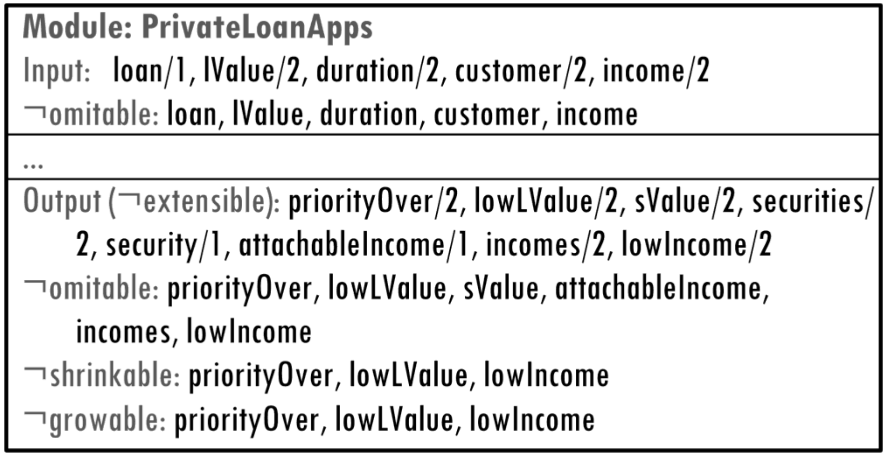
Output (¬extensible): attachableIncome/1, incomes/2, lowIncome/2 −(securities/2), −(security/1)

¬omitable: attachableIncome, incomes, lowIncome

¬shrinkable: lowIncome

¬growable: lowLValue, lowIncome

PrivateLoanApps with inheritance resolved



Module: PrivateLoanApps

Input: loan/1, lValue/2, duration/2, customer/2, income/2

¬omitable: loan, lValue, duration, customer, income

...

Output (¬extensible): priorityOver/2, lowLValue/2, sValue/2, securities/2, security/1, attachableIncome/1, incomes/2, lowIncome/2

¬omitable: priorityOver, lowLValue, sValue, attachableIncome, incomes, lowIncome

¬shrinkable: priorityOver, lowLValue, lowIncome

¬growable: priorityOver, lowLValue, lowIncome

CONCLUSION

- Investigated inheritance of rule modules to
  - Increase reuse of rules and facts
  - Simplify adaptation
  - Ease maintenance
- Investigated modification restrictions to
  - Restrain modifications to rule module structure and behavior
  - Represent organizational constraints
  - Ease and simplify obtaining an overview of the rule base
- Potential Application Areas
  - Business rule systems
  - Knowledge graph management
  - Web data extraction

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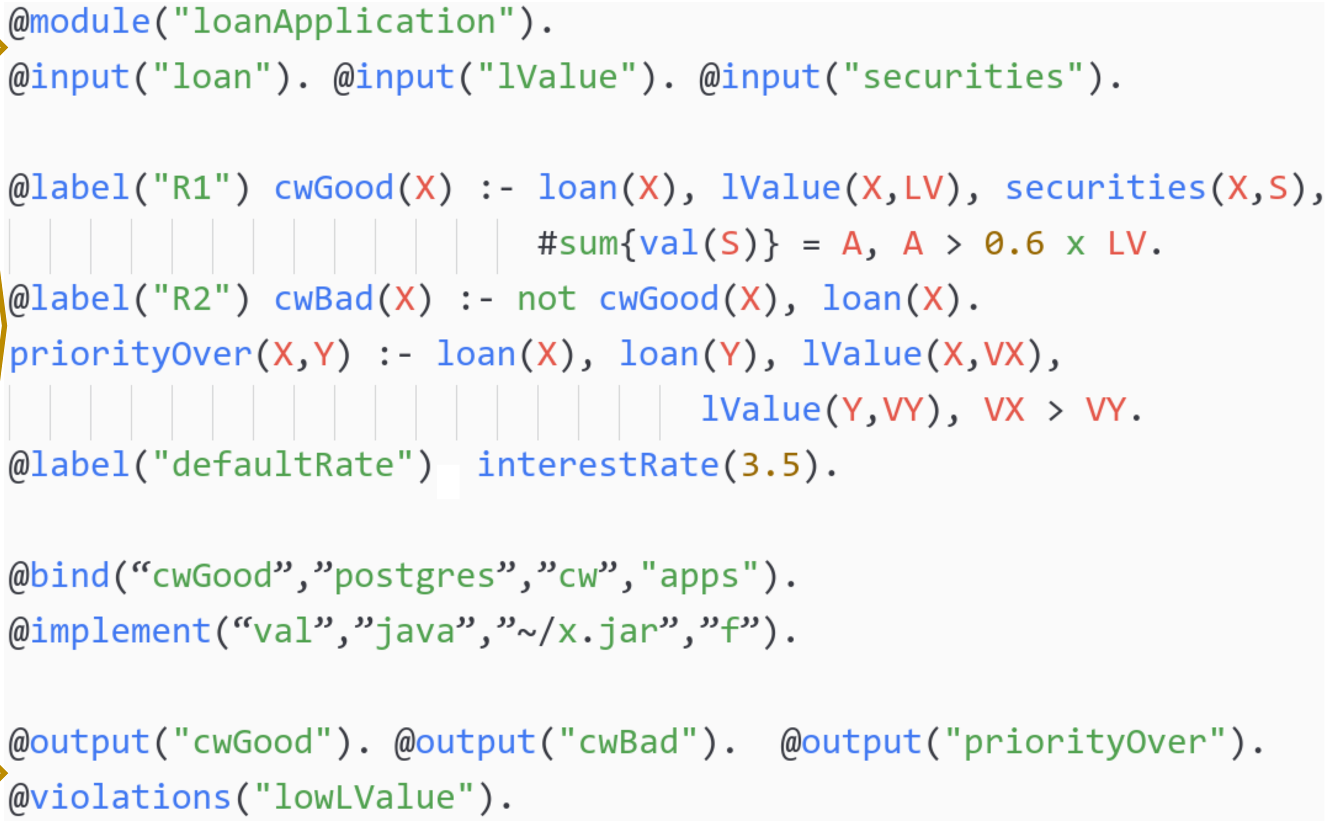
BUSINESS RULE MODULES

Module Structure

Determining Module Behavior, i.e.,

derived facts in output for given input

Module Structure



```
@module("loanApplication").
@input("loan"). @input("lValue"). @input("securities").

@label("R1") cwGood(X) :- loan(X), lValue(X,LV), securities(X,S),
                          #sum{val(S)} = A, A > 0.6 x LV.
@label("R2") cwBad(X) :- not cwGood(X), loan(X).
priorityOver(X,Y) :- loan(X), loan(Y), lValue(X,VX),
                                  lValue(Y,VY), VX > VY.
@label("defaultRate")  interestRate(3.5).

@bind(“cwGood”,”postgres”,”cw”,"apps").
@implement(“val”,”java”,”~/x.jar”,”f”).

@output("cwGood"). @output("cwBad").  @output("priorityOver").
@violations("lowLValue").
```

BUSINESS RULE MODULES

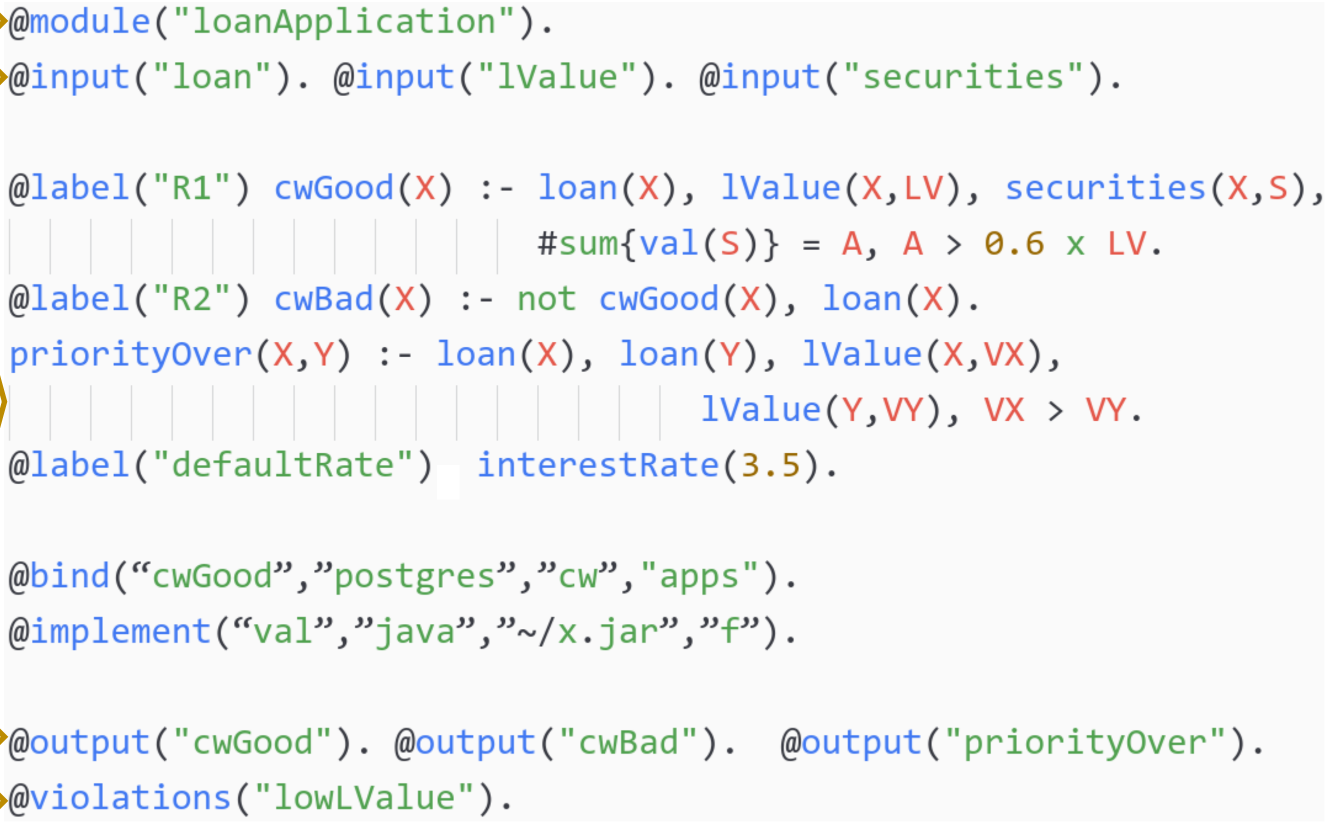
Module Name

Input Interface

Statements
- Rules
- Facts
- Annotations

Output Interface

Violation Interface



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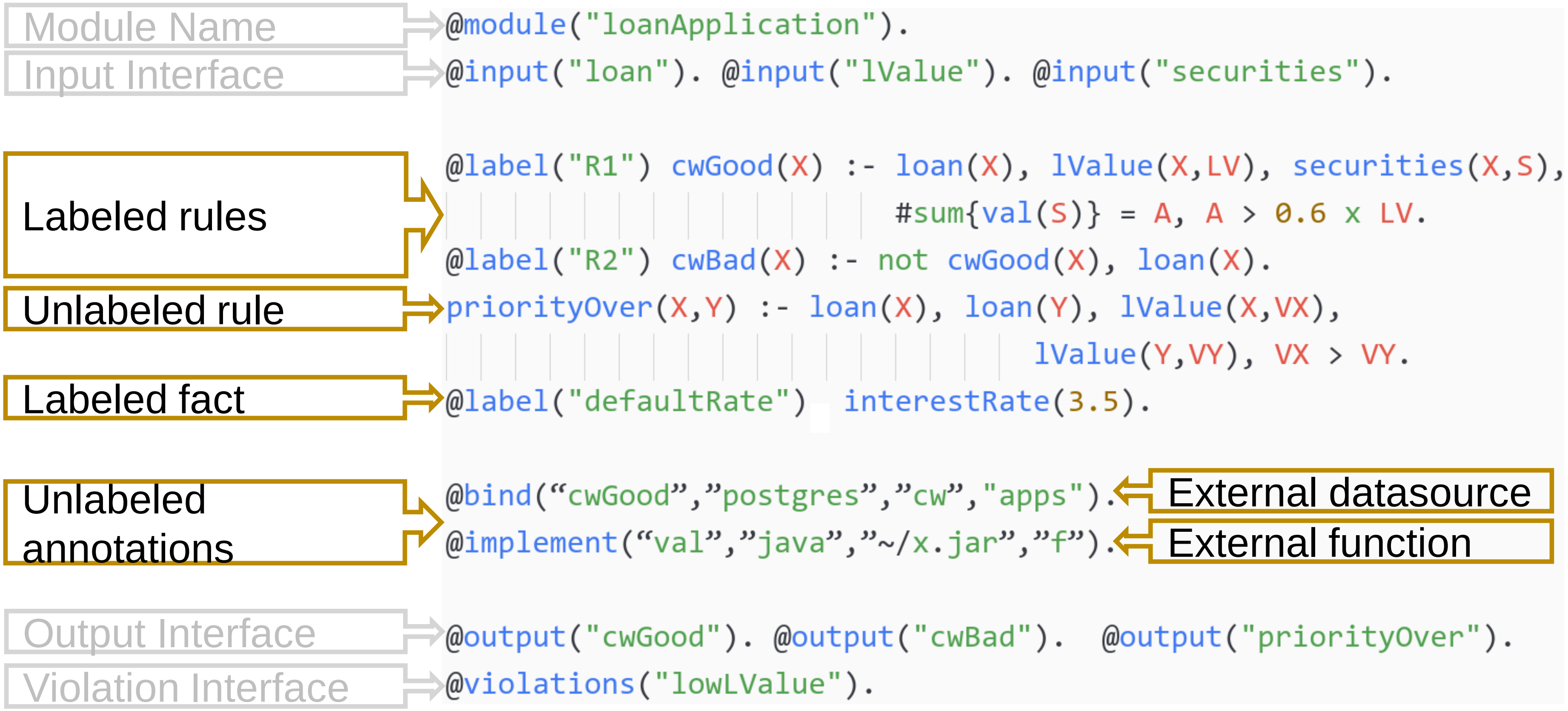
BUSINESS RULE MODULES



Module Name

Input Interface

Labeled rules

Unlabeled rule

Labeled fact

Unlabeled annotations

External datasource

External function

Output Interface

Violation Interface

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@output("cwGood"). @output("cwBad").  @output("priorityOver").
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```

MOTIVATION

- Separate rule-based knowledge and applications
  → rule modules with interfaces
- Redundancy – rules applying in several settings
  → inheritance of rule modules
- Uncontrolled modification of inherited rules
  → modification restrictions

- Potential Application Areas
  - □ Business rule systems
  - □ Knowledge graph management
  - □ Rule-based information tailoring
  - □ Web data extraction
  - □ Internet of things