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Testing Functional Requirements in UML Activity Diagrams

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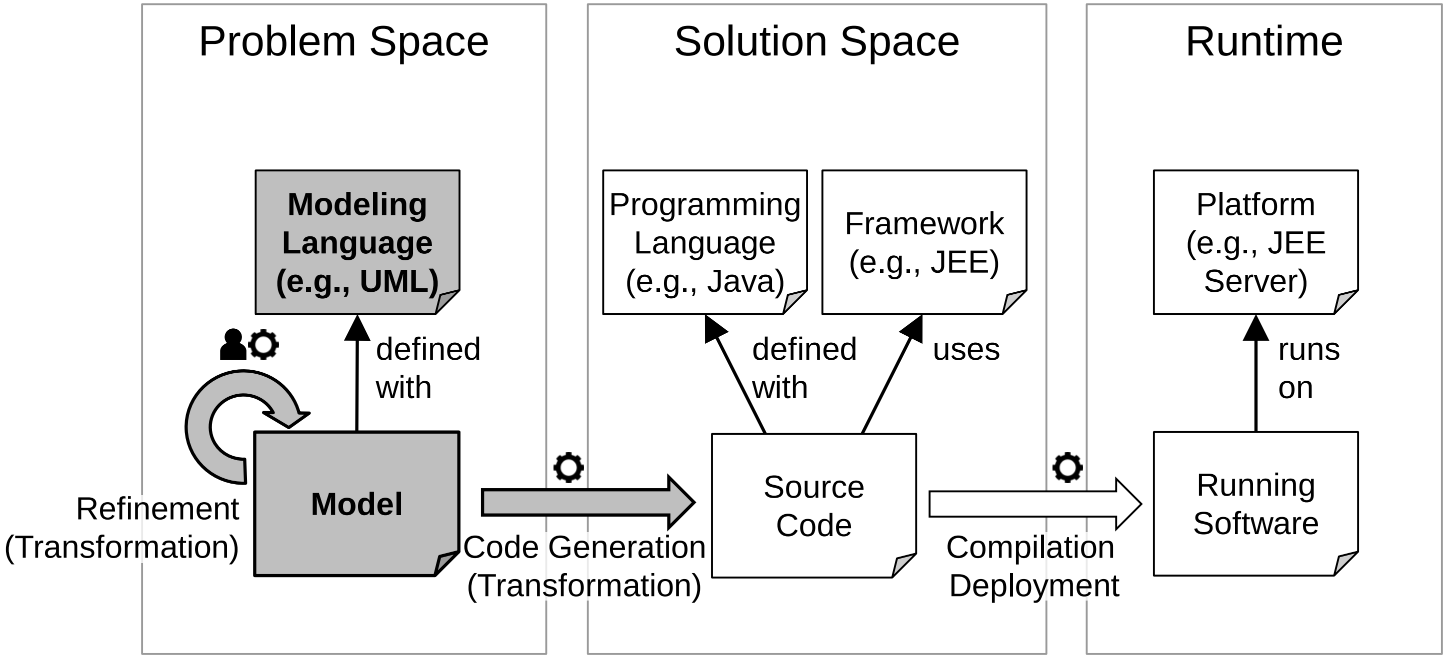


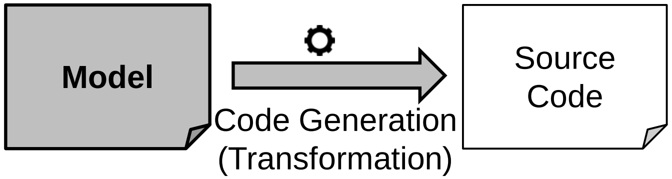
Goals of MDE

1. Cope with **complexity** through **abstraction**
2. Increase **productivity** through **automation**
3. Increase **quality** through early **model analysis**

D. C. Schmidt. Guest Editor's Introduction: Model-Driven Engineering. IEEE Computer, 39(2):25–31, 2006.
B. Selic. The Pragmatics of Model-Driven Development. IEEE Software, 20(5):19–25, 2003.

Increase quality through early model analysis

- Models are the central development artifacts
  - Models are the design, implementation, and documentation of software systems



- Quality of the software systems equates to the quality of the models
  - Any defect not detected at model level will be propagated to the code level
- Methods, techniques, and tools for developing high-quality models are crucial

→ Testing functional requirements in UML activity diagrams

Unified Modeling Language (UML)

- Most widely adopted general-purpose modeling language in MDE[1]
- Critique: No precise semantics

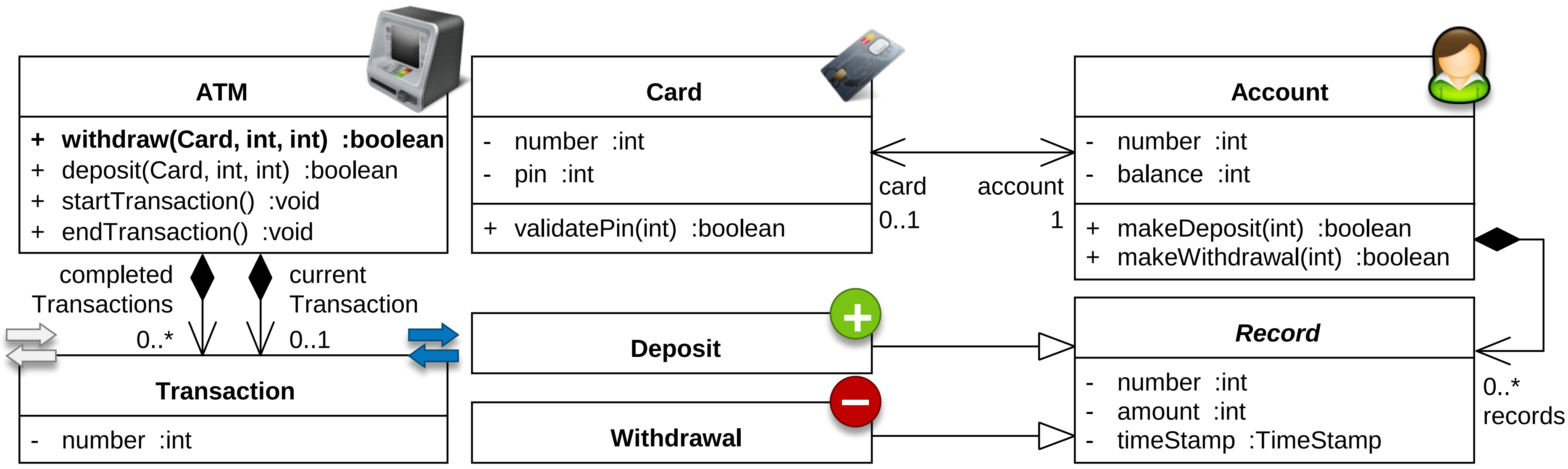
Foundational UML (fUML)

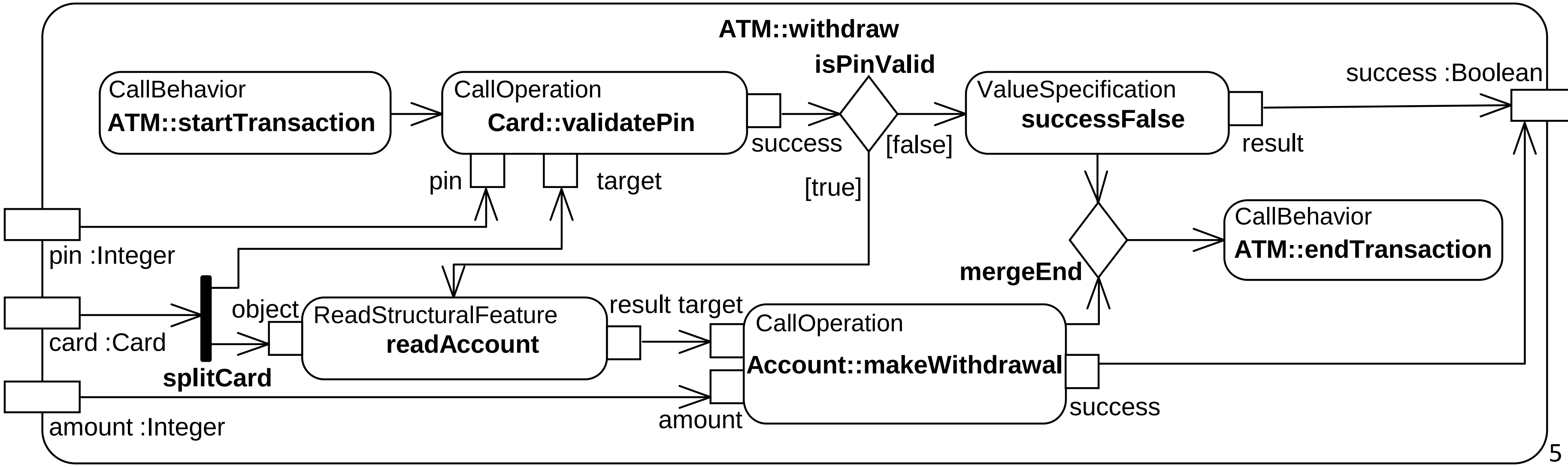
- Precise specification of behavioral semantics of **foundational UML subset**
- **Syntax**: Subset of UML defined with MOF-based metamodel
  - **Structural modeling**: Class diagrams (class, property, association, data type, etc.)
  - **Behavioral modeling**: Activity diagrams (activity, control nodes, actions, etc.)
- **Semantics**: Formal semantics and virtual machine
  - **Translational semantics** defined with first-order logic formalism **Process Specification Language (PSL)**
  - **Operational semantics** (virtual machine VM) defined with **fUML** itself
- **UML is turning into a programming language**[2]

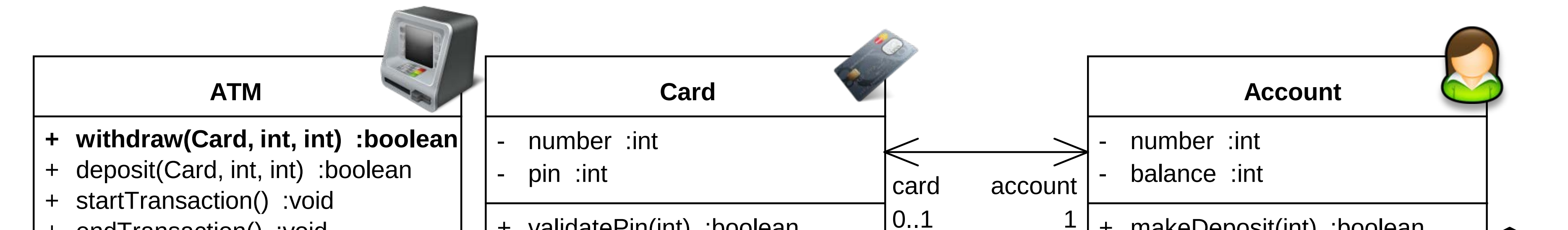
[1] J. Hutchinson, J. Whittle, M. Rouncefield, and S. Kristoffersen: Empirical Assessment of MDE in Industry. In: Proc. of ICSE’11, pp. 471–480, ACM, 2011.

[2] E. Seidewitz: Programming in UML: An Introduction to fUML and Alf. Tutorial, 2011-03-22, http://www.omg.org/news/meetings/tc/agendas/va/xUML_pdf/Seidewitz_Tutorial.pdf.

Motivating Example







Functional Requirements (FR) for Successful Withdrawal

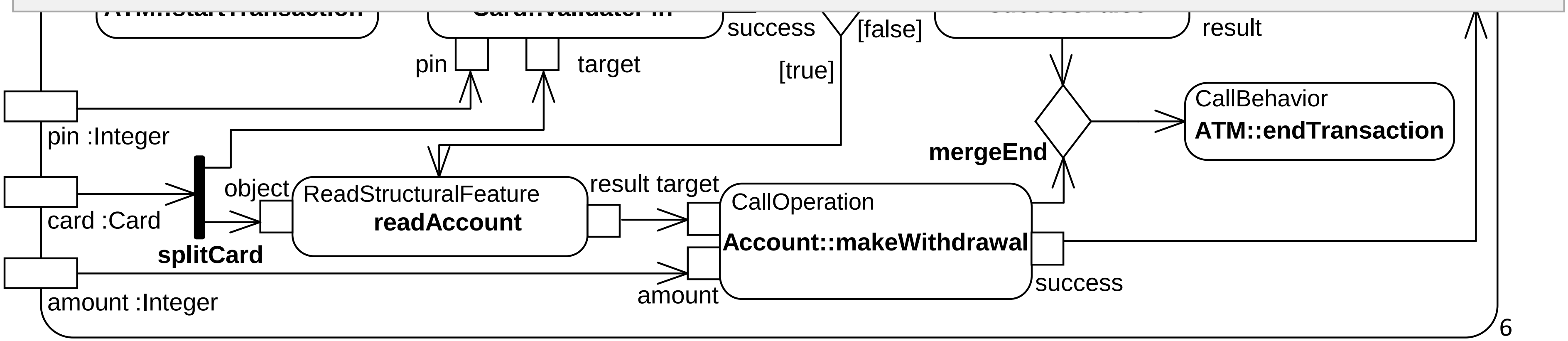
FR1 The pin has to be validated before the actual withdrawal is performed.

FR2 The account's balance has to be reduced by the provided amount of money.

FR3 The activity should return *true* indicating a successful withdrawal.

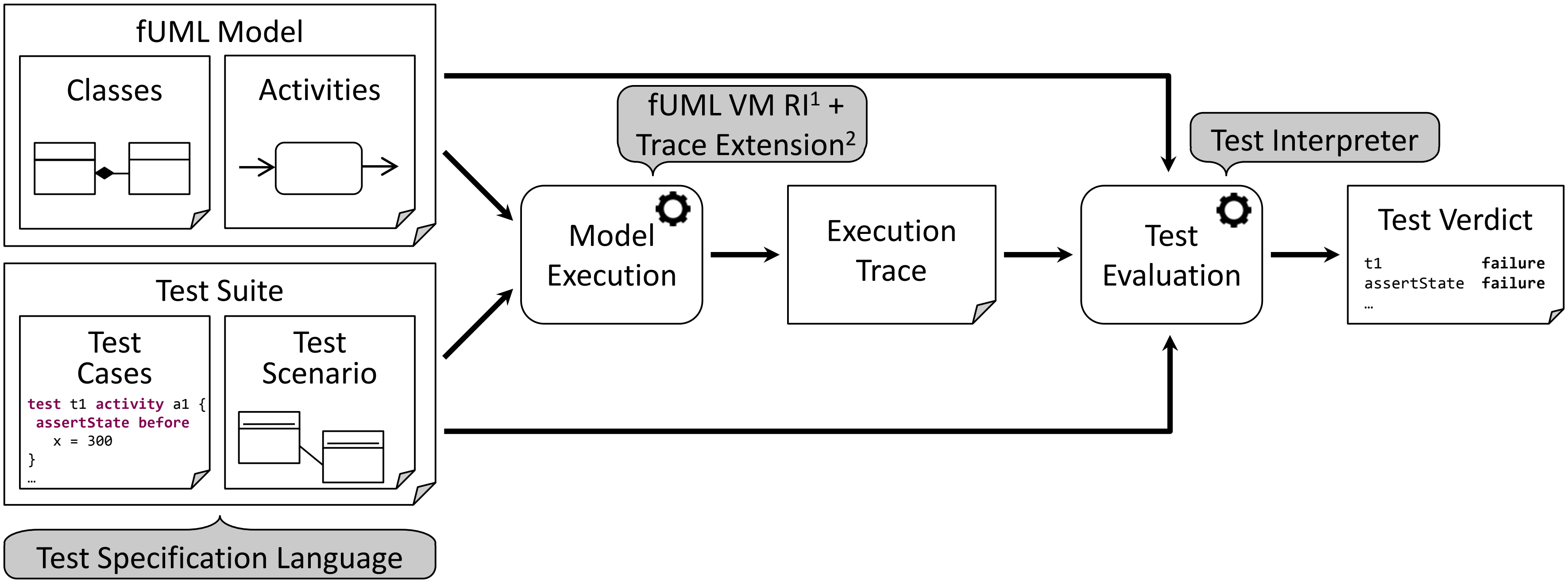
FR4 When the withdrawal is started, a new transaction should be created; once it is completed, the transaction should be ended and recorded.

FR5 After the completion of the withdrawal, the balance of the account should be equal to the difference between the sum of all recorded deposits and the sum of all recorded withdrawals.



- **Test Input Data** — **Test Scenarios**
  - Input values for **input parameters**
  - Initial system **state**
  - ***Example***: Amount of money to be withdrawn from account with balance € 100
- **Execution Order Validation** — **Order Assertions**
  - Validation of **chronological order** in which activity nodes are executed
  - ***Example***: FR1 The pin has to be validated before the actual withdrawal is performed.
- **Input / Output Validation** — **State Assertions**
  - Validation of **expected output** for given input
  - ***Example***: FR3 The activity should return *true* indicating a successful withdrawal.
- **State Validation** — **State Assertions**
  - Validation of the **runtime state during execution** of activity under test
  - ***Example***: FR4 When the withdrawal is started, a new transaction should be created; once it is completed, the transaction should be ended and recorded.

Test Specification Language & Test Interpreter



[1] Model Driven Solutions, Lockheed Martin Corporation. Foundational UML Reference Implementation. http://portal.modeldriven.org/content/fuml-reference-implementation-download.

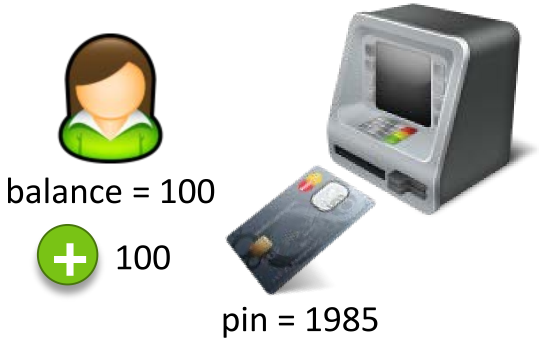
[2] T. Mayerhofer, P. Langer, G. Kappel: A Runtime Model for fUML. In: Proc. of MRT'12, pp. 53-58, ACM, 2012.

Syntax

```
TestScenario := scenario name { (TestObject | TestLink)* }
TestObject := object name : UML::Class {
                (UML::Property = UML::ValueSpecification)* }
TestLink := link UML::Association { UML::Property = TestObject
                UML::Property = TestObject}
```

Example

```
scenario atmTestData {
  object atmTD : ATM {}
  object cardTD : Card { pin = 1985; }
  object accountTD : Account { balance = 100; }
  object depositTD : Deposit { amount = 100; }
  link card_account { account = accountTD; card = cardTD; }
  link account_record { account = accountTD; records = depositTD; }
}
```

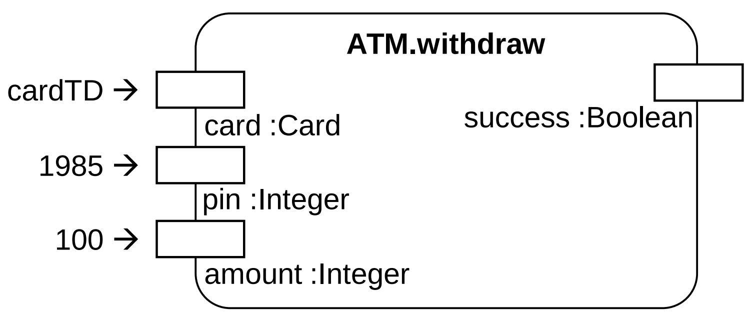


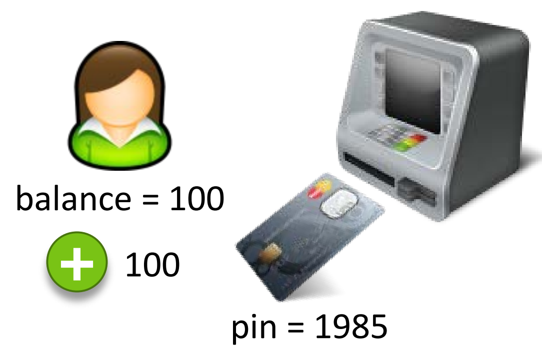
Syntax

```
Test := test name activity UML::Activity
        (UML::ActivityParameterNode = (TestObject | UML::ValueSpecification))*
        (on TestObject)? { … }
```

Example

```
test atmTestSuccessfulWithdrawal activity ATM.withdraw (card=cardTD,
  pin=1985, amount=100) on atmTD {
  …
}
```





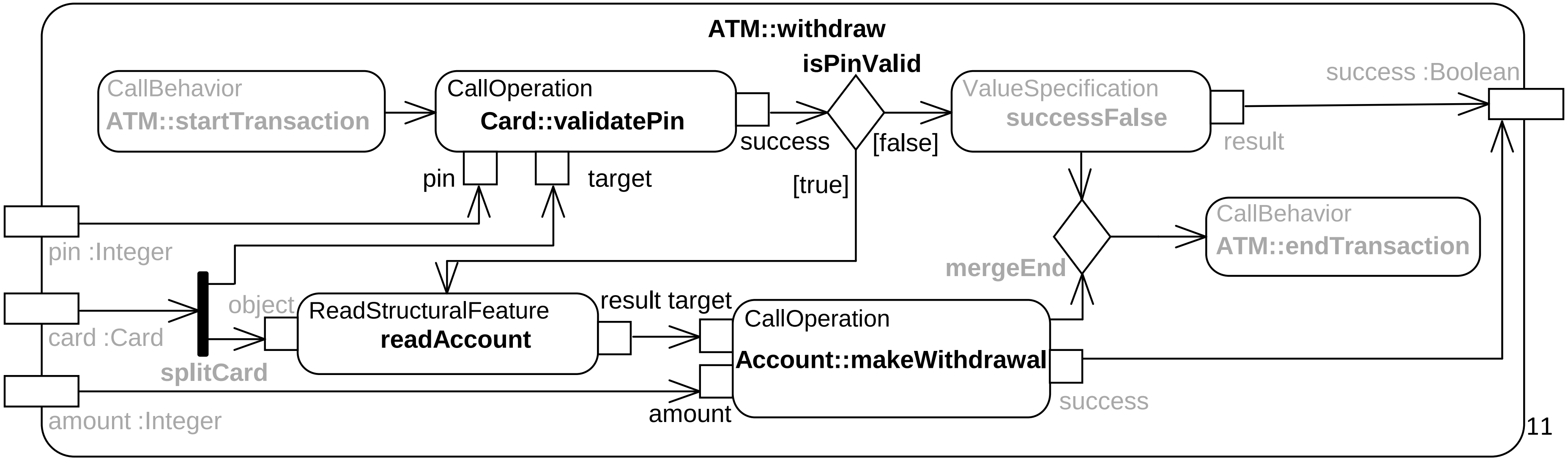
Syntax

```
OrderAssertion := assertOrder ( * | _ | UML::ActivityNode ) *
```

Example

FR1 The pin has to be validated before the actual withdrawal is performed.

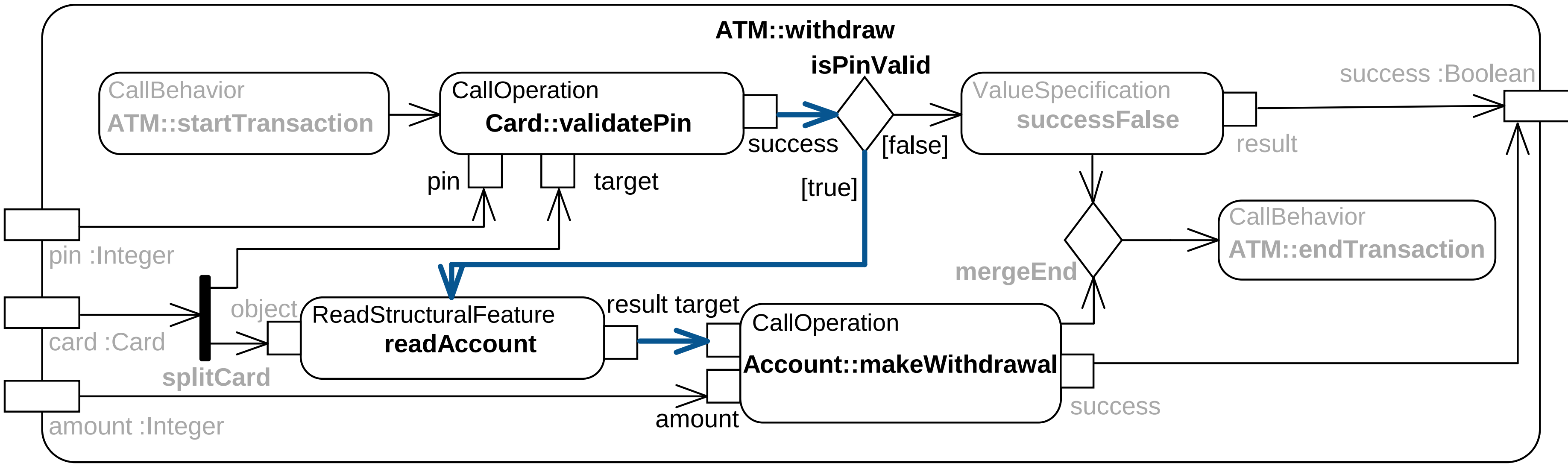
```
test atmTestSuccessfulWithdrawal activity ATM.withdraw (card=cardTD,
  pin=1985, amount=100) on atmTD {
  assertOrder *, validatePin , *, makeWithdrawal, *;
}
```



Test Evaluation

- **Challenge**
  - fUML VM delivers execution trace from one activity execution only
  - Considering execution order captured in single trace is insufficient in case of concurrency (false positives)
- **Solution**
  - Calculate concurrent branches based on input / output dependencies of executed activity nodes (control flow and data flow)
  - Capture dependencies in adjacency matrix
  - Evaluate order assertion based on adjacency matrix

FR1 The pin has to be validated before the actual withdrawal is performed.

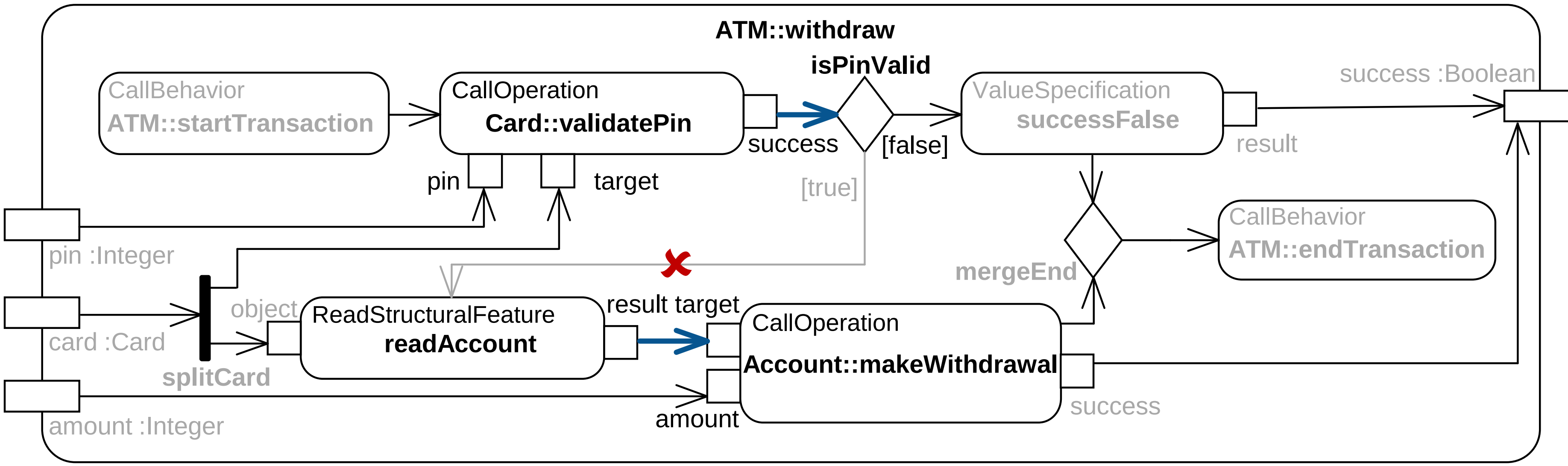


sender \ receiver	isPinValid	readAc-count	makeWith-drawal
validatePin	T		
isPinValid		T	
readAccount			T

```
assertOrder *, validatePin ,
   *, makeWithdrawal, *;
```

✓

FR1 The pin has to be validated before the actual withdrawal is performed.



	isPinValid	readAc-count	makeWith-drawal
validatePin	T		
isPinValid		✘	
readAccount			T

```
assertOrder *, validatePin ,
   *, makeWithdrawal, *;
```

✘

Challenges

- Precise **selection of relevant runtime states**
- **Evaluation of complex conditions** on selected runtime states

Solution

- Introduction of **temporal operators and quantifiers** for precise selection of runtime states (**temporal expressions**)
- Integration of **OCL** for specifying and evaluating complex conditions on runtime states (**state expressions**)

Syntax

```
StateAssertion := assertState TemporalExpression { StateExpression* }
```

TemporalExpression: Selection of runtime states

StateExpression*: Validation of runtime states

Syntax: Temporal Expressions

```
TemporalExpression := (always | sometimes | immediately | eventually)
   (after | until) (action UML::Action | constraint OCL::OclExpression)
```

Temporal Operators

after … selects states after the execution of action / fulfillment of condition

until … selects states before the execution of action / fulfillment of condition

Quantifiers

always … property has to hold for all selected states

sometimes … property has to hold in some of the selected states

immediately … property has to hold in the first / last selected state

eventually … property has to hold from some of the selected states on

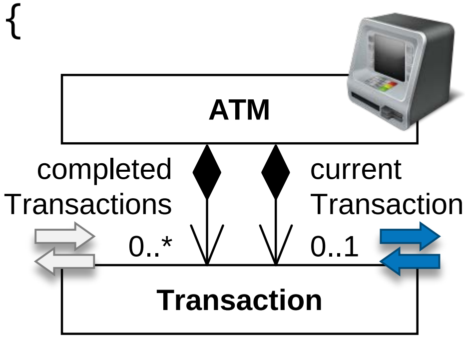
Syntax: State Expressions

```
StateExpression := check OCL::OclExpression {on UML::ObjectNode}?
```

Example

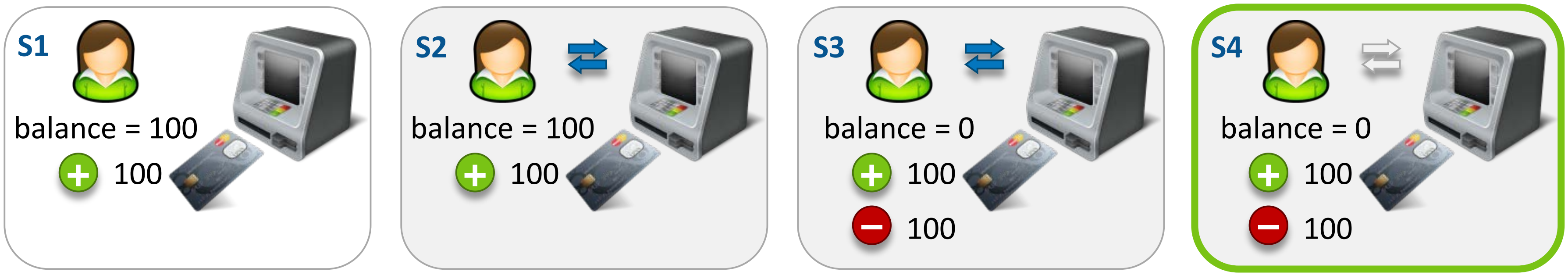
FR4 When the withdrawal is started, a new transaction should be created; once it is completed, the transaction should be ended and recorded.

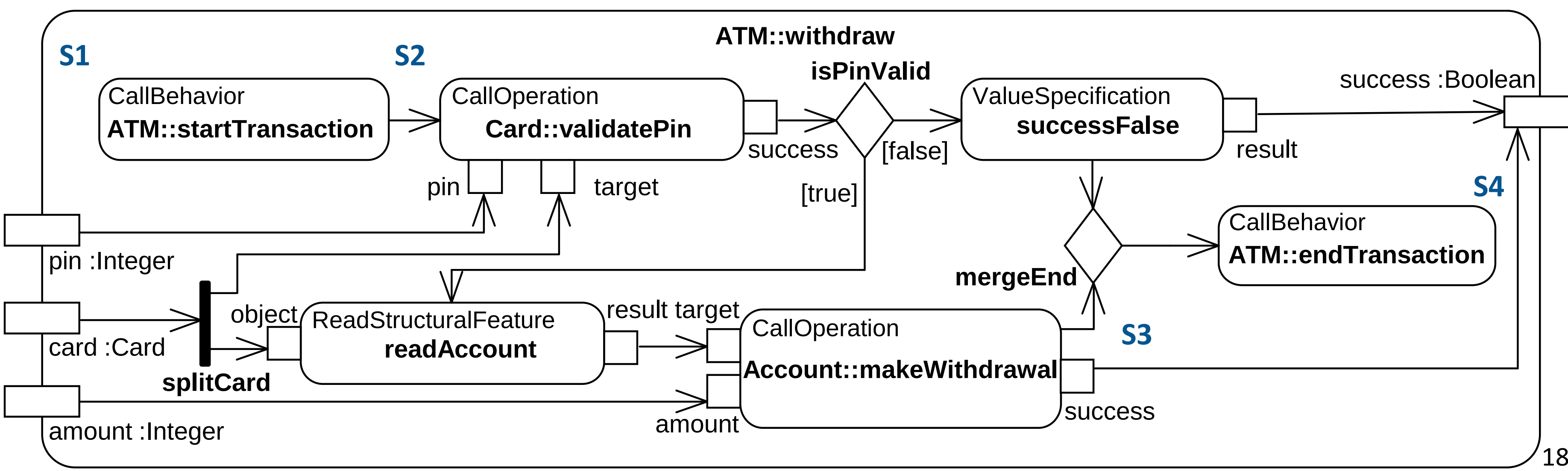
```
assertState eventually after constraint TransactionCreated {
    check TransactionEnded, TransactionRecorded;
}

context ATM
exp TransactionCreated : currentTransaction <> null
exp TransactionEnded : currentTransaction = null
exp TransactionRecorded : completedTransactions -> size() = 1
```




```
assertState eventually after constraint atm.currentTransaction <> null {
    check atm.currentTransaction = null, completedTransactions -> size() = 1;
}
```

```
assertState eventually after constraint atm.currentTransaction <> null {
    check atm.currentTransaction = null, completedTransactions -> size() = 1;
}
```





Criteria

1. **Ease of use**: How easy is it to use the testing framework for testing UML activity diagrams?
2. **Usefulness**: Are test results useful for detecting and correcting defects in UML activity diagrams?

Setup

1. **Introduction** to fUML and testing framework
2. **Self-assessment** of experience with UML, OCL, and unit testing
3. **Testing tasks**
    a) **Ease of use**: Write test cases for validating predefined functional requirements in given and correct UML activity diagrams
    b) **Usefulness**: Resolve defects in UML activity diagrams based on given test cases and test results
4. **Questionnaire** on experienced ease of use and usefulness

Testing Task 1: Writing Test Cases (Ease of Use)

- Minor issues with some concepts of test specification language
  - E.g., purpose of test scenarios, jokers in order assertions
- Most issues could be resolved by trial and error, and consultation of introductory material

→ Gentle learning curve of test specification language

→ Improvements of concrete syntax and editor support (e.g., validation)

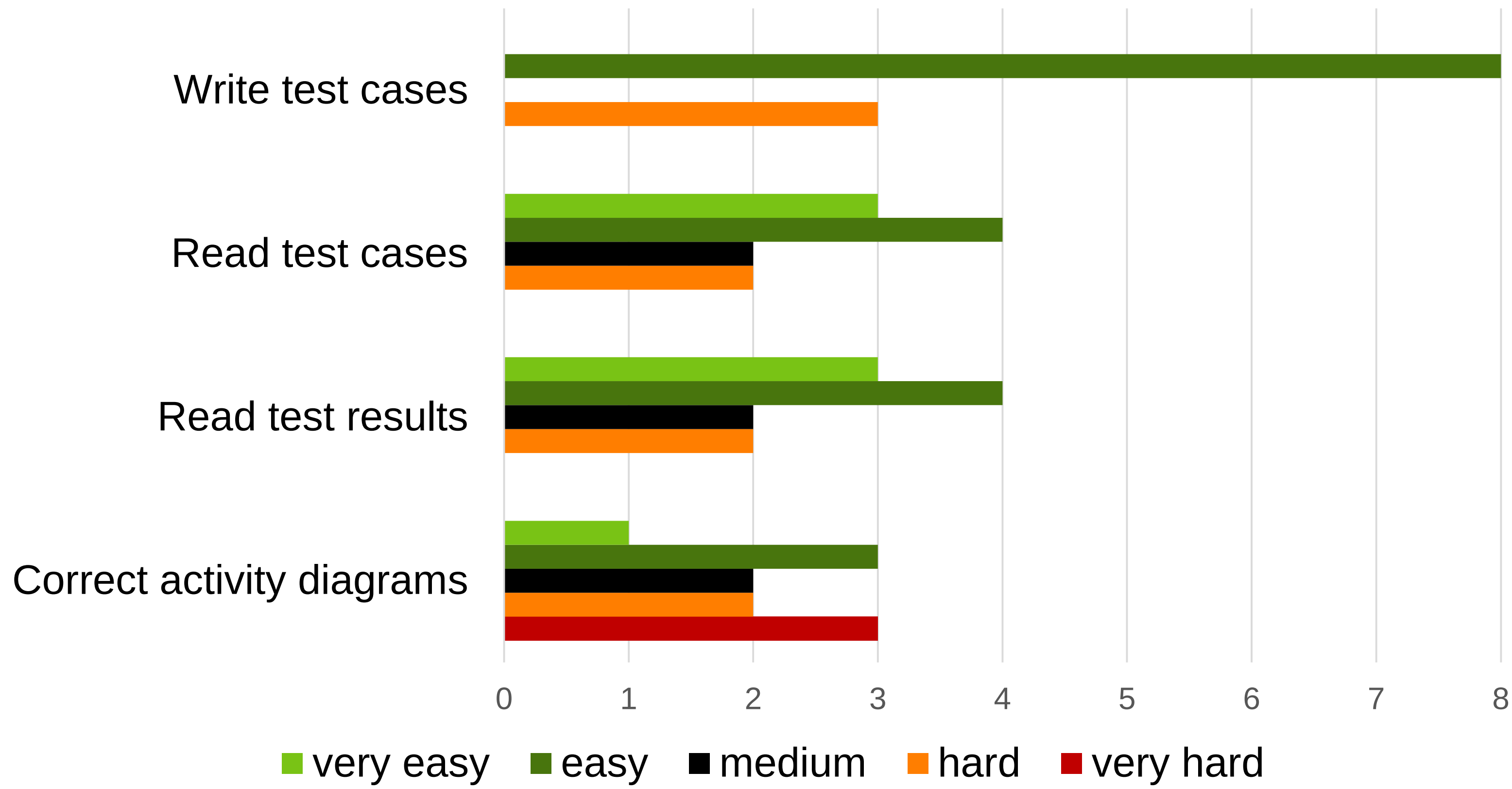
Testing Task 2: Resolving Defects Based on Test Results (Usefulness)

- Understanding test cases: Participants were able to identify tested functional requirements
- Understanding test results: 59% of defects were resolved on average

→ Indication that test results are useful for locating and resolving defects

→ Improvements of visualization of test results (supplementary debugging support is important!)

Questionnaire on experienced ease of use and usefulness



Summary

- **Validation and verification** of models are essential in MDE
- **Testing** framework for validating the fulfillment of **functional requirements** in **UML activity diagrams**
  - Test scenarios for defining test input data
  - Order assertions for validating execution order of actions
  - State assertions for validating runtime state of system during execution, and output of activities and actions

Future Work

- Extensions of testing framework with **additional testing capabilities** (e.g., conditions on differences between distinct runtime states)
- Improvement of **feedback on test results** (e.g., visualization of runtime states, failure cause analysis)
- Support for **further executable sublanguages of UML**

Thank you!

Model Execution Based on fUML

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