A Component Model for Architectural Programming

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Our Department in March 2006

Software Architecture

Structuring elements

- **components** as building blocks
- **connectors** as glue
- **ports** for communication

Development process

- "[. . .] a component is modeled throughout the development life cycle [. . .]" (*UML 2.0 Superstructure Specification*)
- preservation and refinement of components

Software Architecture in Development Processes

Analysis and Design

Architectural Description Languages:
Wright, Darwin, Rapide, SARA, etc.

Implementation

- various component models (SOFA, EJB, ...)
- **but**: Programming languages do not reflect components
- danger of **architectural erosion**

$\Rightarrow$ integrate architectural concepts into programming languages: **Architectural Programming**

Architectural Programming (I)

Architectural Programming Languages (APLs)

- integrate **components**, **ports**, **connectors** and **configurations** as *primitive language constructs*

APLs should support

- **strong encapsulation** (communication exclusively via ports)
- ports with **provided**, **required interfaces** and **protocols**
- **connectors** for building up **configurations**
- runtime **reconfiguration**

Architectural Programming (II)

Advantages of Architectural Programming

- **maintainability**
- **reusability**, **replaceability** and **independent deployment**
- **seamless transition** from model to code
- **separation** of application code and glue code

Architectural Programming (III)

Our approach

Architectural programming language **JAVA/A**

Implementable Component Models

- **SOFA**, **Fractal**:
  - support for software architectures
  - not programming languages: architectural erosion
- **EJB**, **JavaBeans**, **COM+**, etc.
  - no support for software architectures
  - component models without ports, etc.
  - here also: architectural erosion

Other APL

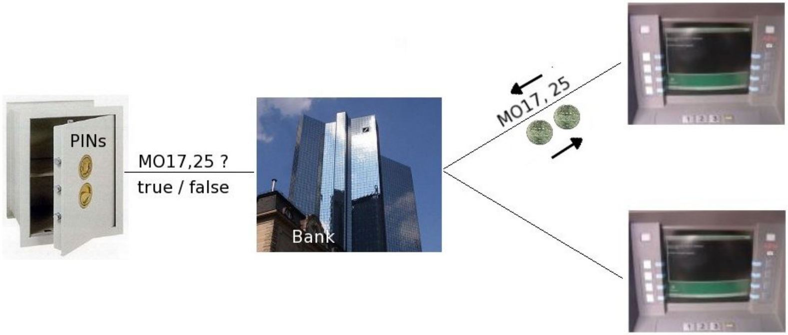
- **ArchJava** (D. Notkin et al., University of Washington)

Comparison of ArchJava and JAVA/A

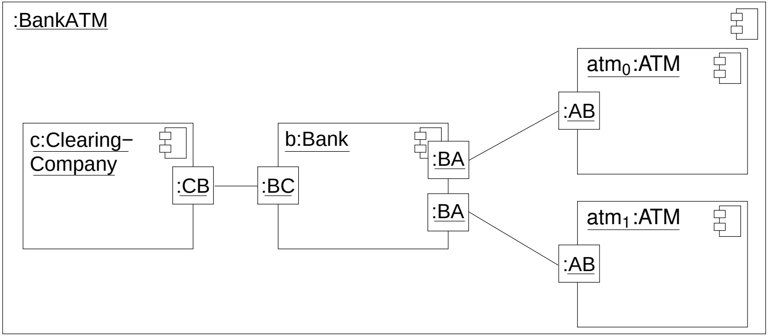
	components	*ports*	*configurations*	encapsulation
JAVA/A	yes	yes	explicit	yes
ArchJava	yes	yes	implicit	partial

	behavioural modeling	distributed applications	asynchronous communication
JAVA/A	yes	yes	yes
ArchJava	no	no	no

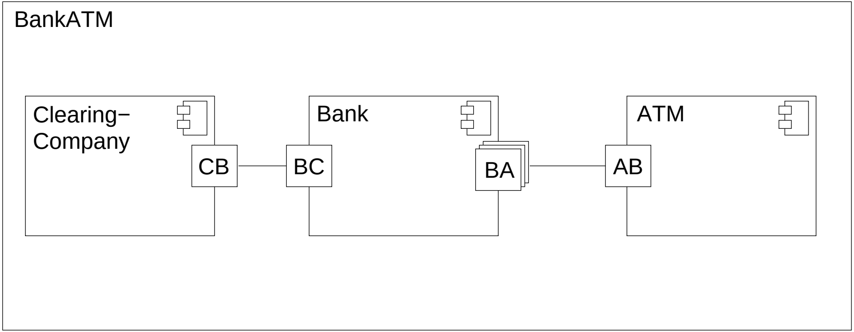
Example Bank–ATM (informal)



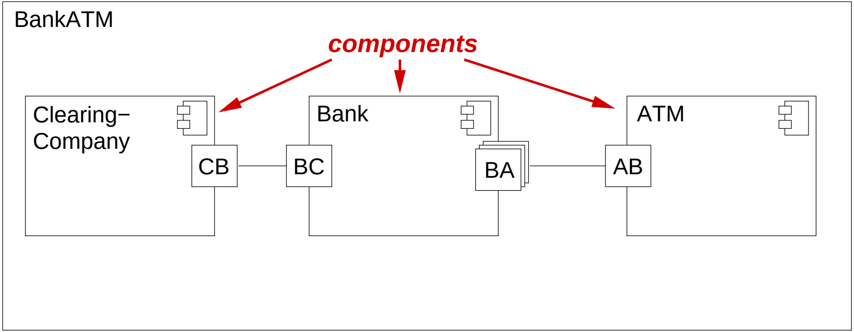
Example Bank–ATM: Configuration



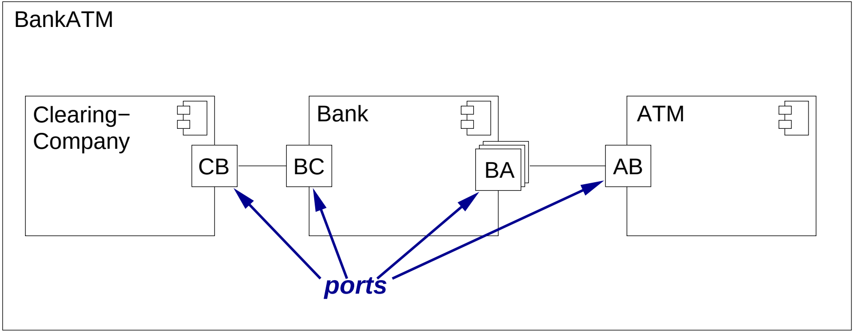
Example Bank–ATM: UML 2.0 Component Diagram



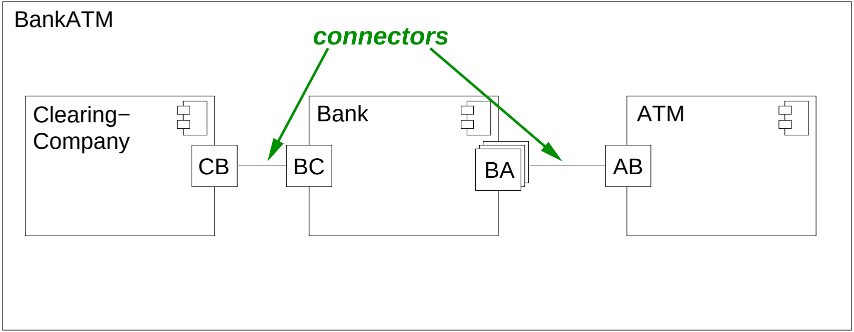
Example Bank–ATM: UML 2.0 Component Diagram



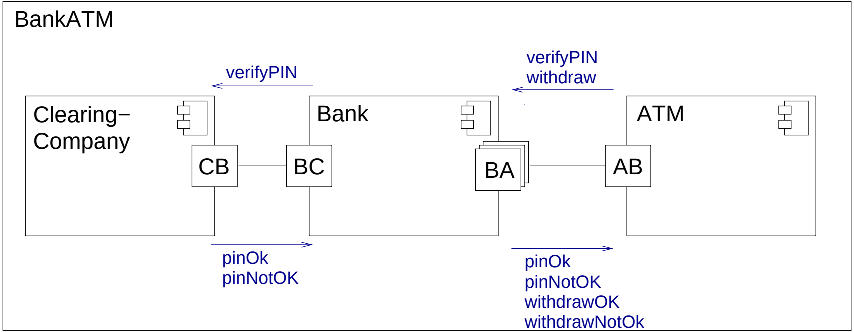
Example Bank–ATM: UML 2.0 Component Diagram



Example Bank–ATM: UML 2.0 Component Diagram



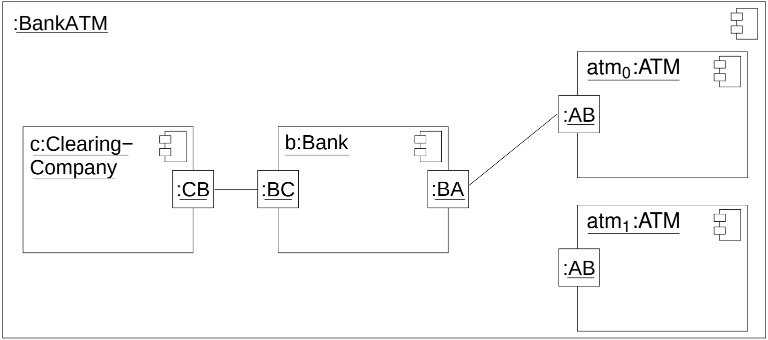
Example Bank–ATM: UML 2.0 Component Diagram



Example Bank–ATM: Dynamic Reconfiguration

Connecting components on demand

- ATMs are very often idle
- build up online connections only if necessary



Example Bank–ATM: Dynamic Reconfiguration

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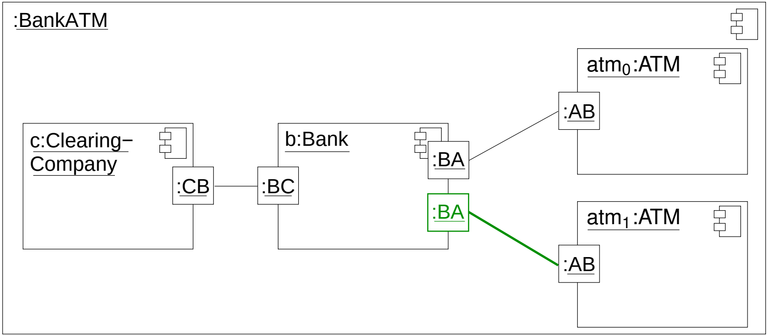


JAVA/A: An Architectural Programming Language (I)

Characteristics of JAVA/A

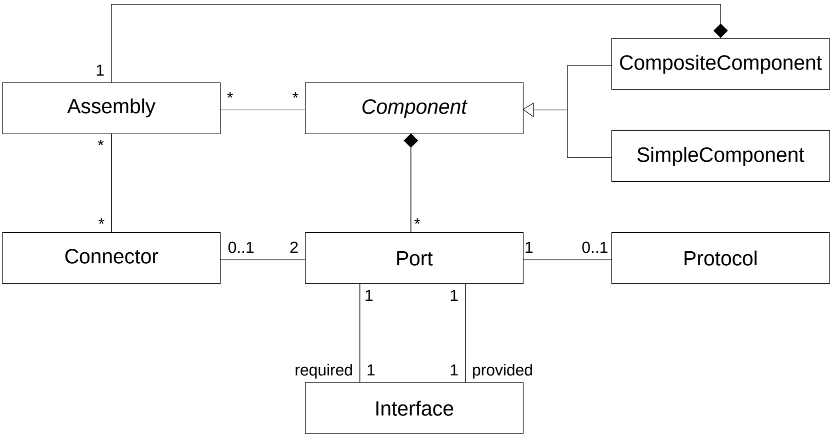
- components with ports (**strong encapsulation**)
- ports with **provided** and **required** interfaces, port **protocols**
- **hierarchical** composition
- **reconfiguration** at runtime
- **loose coupling** (independent deployment)
- **model checking support** for connectors (between ports)
- predefined **connector types** (local and distributed)

JAVA/A: An Architectural Programming Language (II)

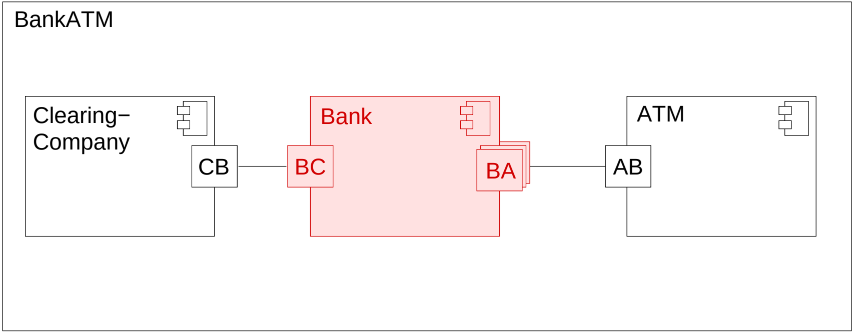
Current JAVA/A tool support

- compiler **jaac**
- Component Composition Platform (**CCP**):
  - building and editing configurations and components
- **coordination** and **management** framework
  - start and stop distributed applications

JAVA/A: Component Meta-Model



Example Bank–ATM: Implementation using JAVA/A



Example Bank–ATM: Implementation using JAVA/A

```
simple component Bank {
    Queue pending = new LinkedList();
    BA current = null;
    Set verifieds = new HashSet();
    Map balance = new HashMap();

    dynamic port BA {
        provided {
            signal verifyPIN(IBAN iban, int pin);
            signal withdraw(IBAN iban, Money amount);
        }
        required {
            void pinOk(); void pinNotOk();
            void withdrawOk(); void withdrawNotOk();
        }
    }
```

Example Bank–ATM: Implementation using JAVA/A

```
port BC {
    provided {
        void pinOk(); void pinNotOk();
    }
    required {
        void verifyPIN(IBAN iban, int pin);
    }
}
```

Example Bank–ATM: Implementation using JAVA/A

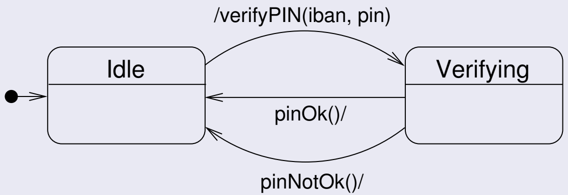
```
signal verifyPIN(BA incoming, IBAN iban, int pin)
            implements BA.verifyPIN(IBAN, int) {
   pending.offer(new Object[]{incoming,iban,pin});
   // wait until current == null
   Object[] request = (Object[])pending.poll();
   current = (BA)request[0];
   BC.verifyPIN((IBAN)request[1],
               ((Integer)request[2]).intValue());
}

void pinOk() implements BC.pinOk() {
   verifieds.add(current);
   current.pinOk();
   current = null;
   // notification that current == null
}
```

Specification of Port BC

- Ports are specified with UML 2.0 protocol state machines.

Specification of Port BC (Bank)



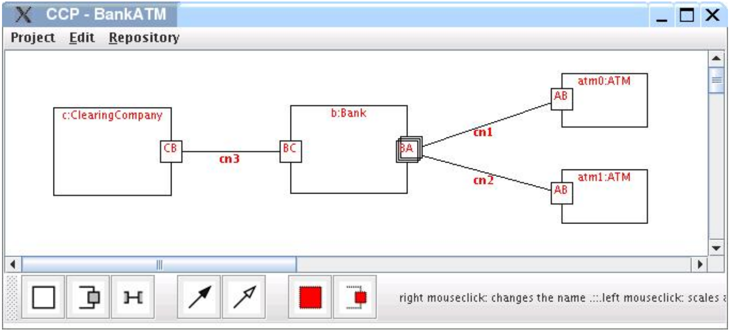
Example Bank–ATM: Configuration in JAVA/A

```
composite component BankATM {
  assembly {
    components { ATM, Bank, ClearingCompany }
    connectors { (ATM.AB, Bank.BA);
                 (Bank.BC, ClearingCompany.CB) }
    initial configuration {
      ATM atm0 = new ATM();
      ATM atm1 = new ATM();
      Bank bank = new Bank();
      ClearingCompany cc =
        new ClearingCompany();
      Connector cn0 = new Connector();
      cn0.connect(atm0.AB, bank.BA);
      Connector cn1 = new Connector();
      cn1.connect(atm1.AB, bank.BA);
      Connector cn2 = new Connector();
      cn2.connect(bank.BC, cc.CB); } } }
```

Example Bank–ATM: Reconfiguration in JAVA/A

```
try {
    Component bank = componentLookUp(this, "Bank");
    Port ba = bank.getPort("BA");
    ConnectionRequest cr =
        new ConnectionRequest(this,
            this, AB, bank, ba, new Connector());
    reconfigurationRequest(cr);
}
catch (ReconfigurationException e) {
    ...
}
```

Seamless Development



CCP: Component Composition Platform

- code generation
- round-trip engineering
- model checker integration for architectural analysis

A Model for AP: Overview (I)

Ports

- Signatures
  - provided interface $I = (\Sigma^{\mathrm{pro}}, Op^{\mathrm{pro}})$
  - required interface $O = (\Sigma^{\mathrm{req}}, Op^{\mathrm{req}})$
- Models: labelled transition systems
  - transitions: labelled by operation calls of provided and required operations $op(v)/$, $/op(v)$

A Model for AP: Overview (II)

Components

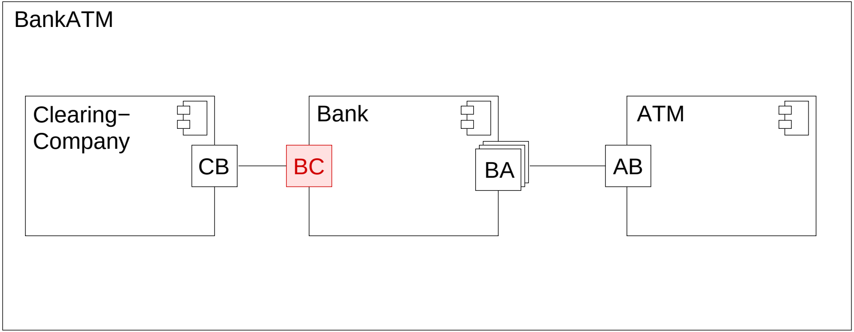
- Signatures
  - algebraic signature $\Sigma = (S, F)$ for internal states
  - port declarations of the form $P : \Sigma_P$
- Models: labelled transition systems
  - states: algebras over the internal state signature
  - transitions: labelled by operation calls on port instances $p.op(v)/$, $/p.op(v)$

A Model for AP: Overview (III)

Assemblies

- Signatures
  - algebraic signature for internal state
  - component declarations of the form $C : \Sigma_C$
  - connector declarations of the form $Con : \Sigma_{Con}$
- Models: labelled transition systems
  - states: algebras over the internal state signature (of the assembly)
  - transitions: labelled by operation calls on port instances of component instances with synchronization on connected ports $(c_1.p_1, c_2.p_2).op(v)$

Example: Signature Σ_{BC} for Port BC (Bank)



Example: Signature Σ_{BC} for Port BC (Bank)

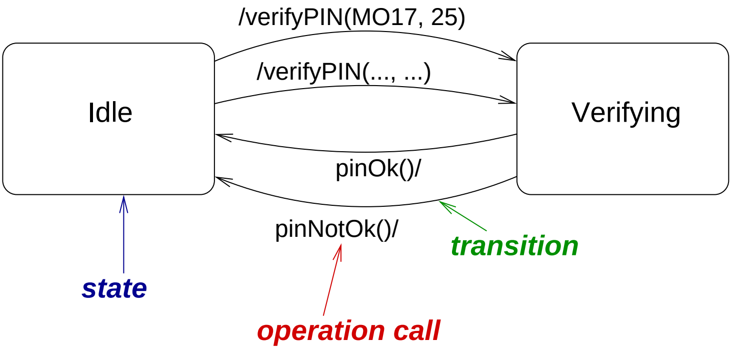
Provided Interface I_{BC}

- **sorts & funs:** $\emptyset$
- **operations:** `pinOk()`, `pinNotOk()`

Required Interface O_{BC}

- **sorts:** `int`, `IBAN`
- **funs:** $\mathcal{F}_{\texttt{int}}, \ldots$
- **operations:** `verifyPIN(iban: IBAN, pin: int)`

Example: A Model for Port BC (Bank)



Example: Signature Σ_{Bank} for Component Bank

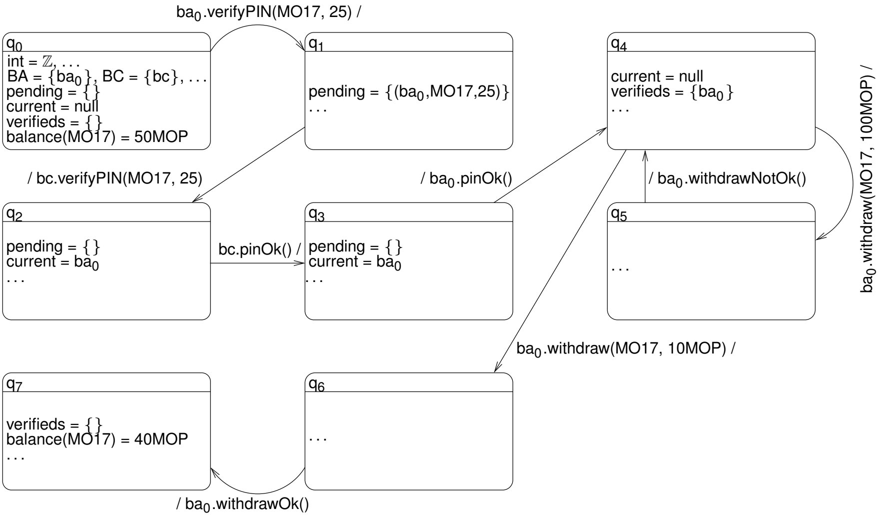
Port declarations

- BA : Σ_{BA}, BC : Σ_{BC}

Internal signature $\Sigma^{\mathrm{int}}_{Bank}$

- **sorts:** BA, BC, Queue, Set, Map, int, IBAN, Money
- **funs:**
  pending: → Queue,
  current: → BA,
  verifieds: → Set,
  balance: → Map,
  $\mathcal{F}_{\mathtt{int}}$, ...

Example: Part of a Model for Component Bank



Relationship between Ports and Components

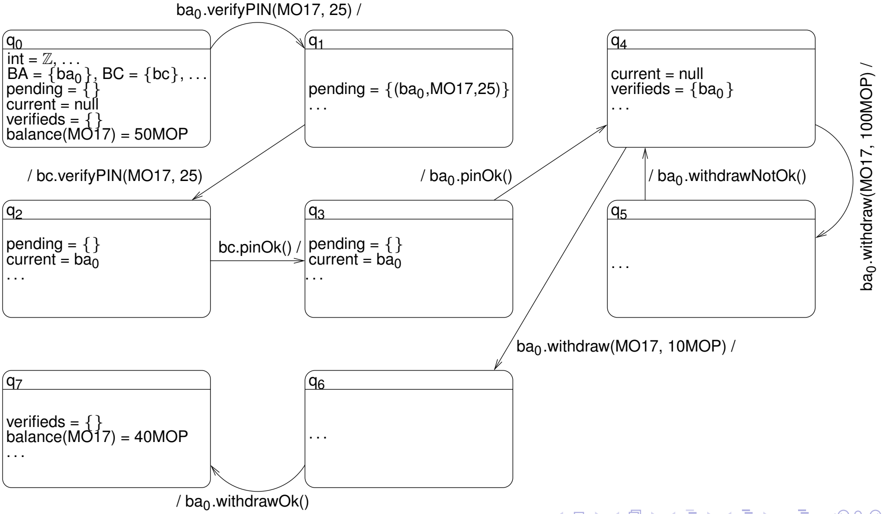
Component – Port

- a component has to **implement** all its ports
- ports can be dynamically **created**
- ports can be dynamically **destroyed**

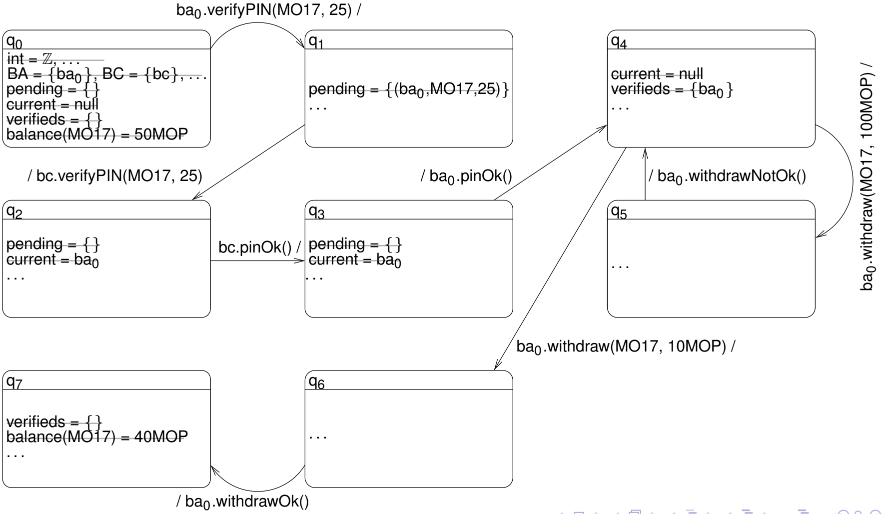
Implementation Correctness

- reduction of a component model to a port instance must be a model of the port (up to observ. equiv.)

Reduct from the Model of Bank to Port Instance bc



Reduct from the Model of Bank to Port Instance bc



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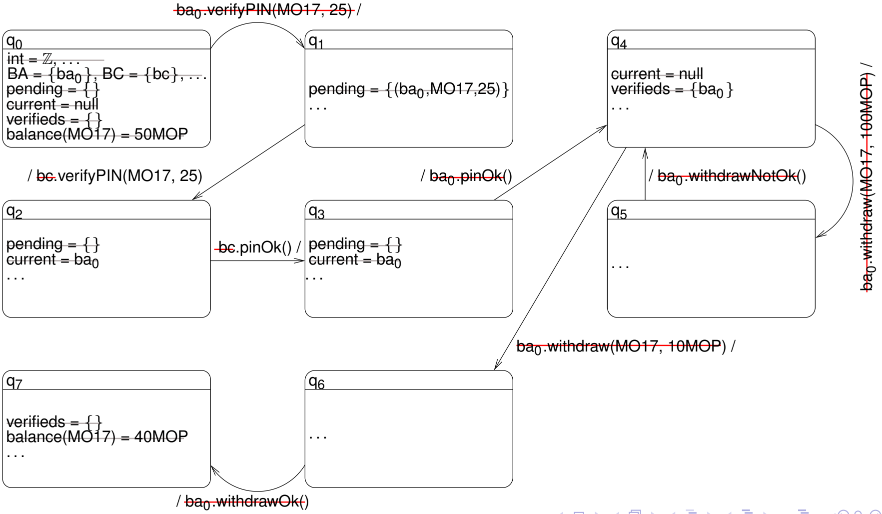
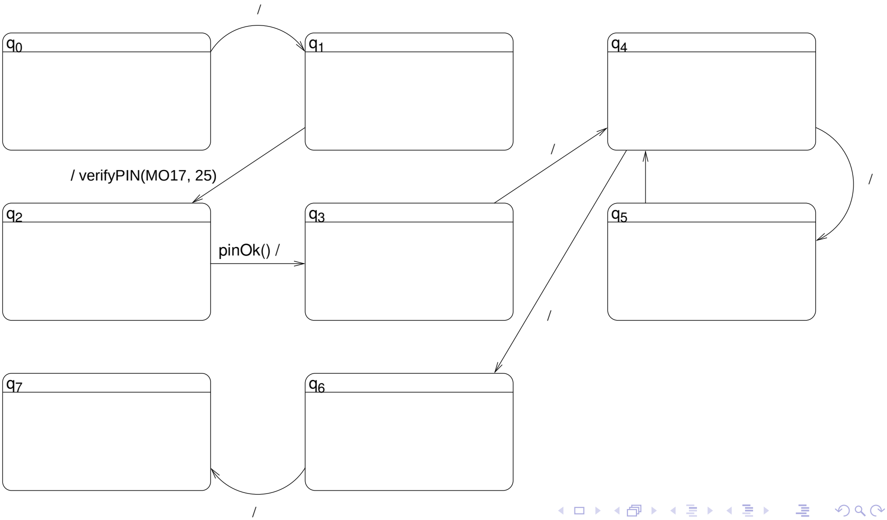
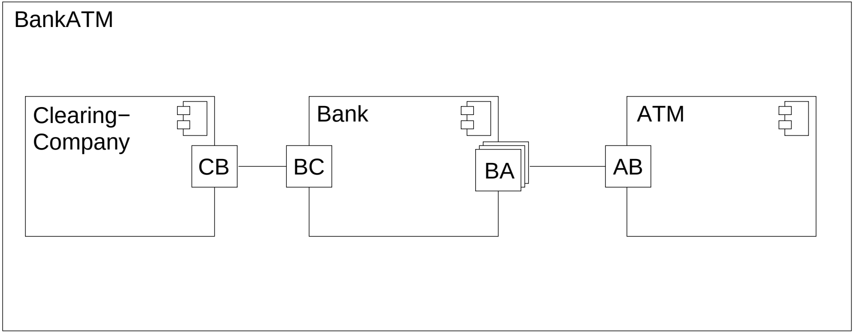


Reduct from the Model of Bank to Port Instance bc



Example: Signature $\Sigma_{BankATM}$ for Assembly of Bank–ATM



Example: Signature $\Sigma_{BankATM}$ for Assembly of Bank–ATM

Component Declarations

ATM : Σ_{ATM}, Bank : Σ_{Bank}, ClearingCompany : $\Sigma_{ClearingCompany}$

Connector Declarations

ABBA : (AB, BA), BCCB : (BC, CB)

Internal Signature

- **sorts:** `ATM, Bank, ClearingCompany,`
  `AB, BA, BC, CB, ABBA, BCCB, ...`
- **funs:** `pending: Bank` $\rightarrow$ `Queue,`
  `current: Bank` $\rightarrow$ `BA,`
  `verifieds: Bank` $\rightarrow$ `Set,`
  `balance: Bank` $\rightarrow$ `Map, ...`

Example: Part of a Model for Assembly of Bank–ATM (I)

Component instances

$\mathrm{ATM} = \{\mathrm{atm}_0, \mathrm{atm}_1\}$, $\mathrm{Bank} = \{\mathrm{b}\}$, $\mathrm{ClearingCompany} = \{\mathrm{c}\}$

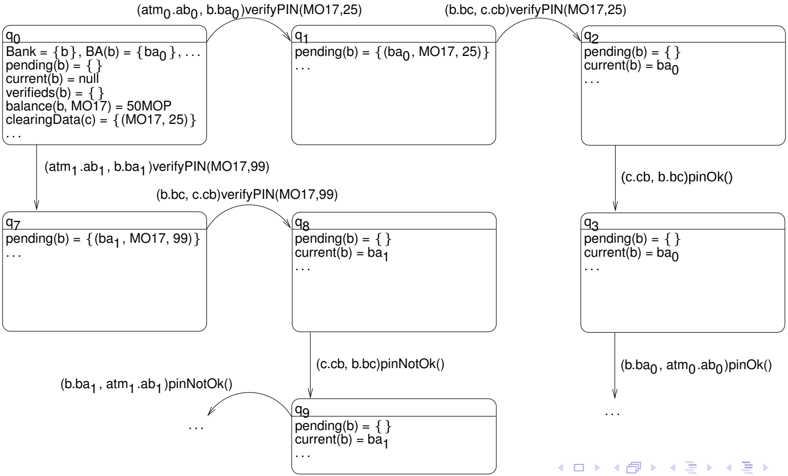
Port instances

$\mathrm{AB}(\mathrm{atm}_0) = \{\mathrm{ab}_0\}$, $\mathrm{AB}(\mathrm{atm}_1) = \{\mathrm{ab}_1\}$,
$\mathrm{BA}(\mathrm{b}) = \{\mathrm{ba}_0, \mathrm{ba}_1\}$, $\mathrm{BC}(\mathrm{b}) = \{\mathrm{bc}\}$, $\mathrm{CB}(\mathrm{b}) = \{\mathrm{cb}\}$

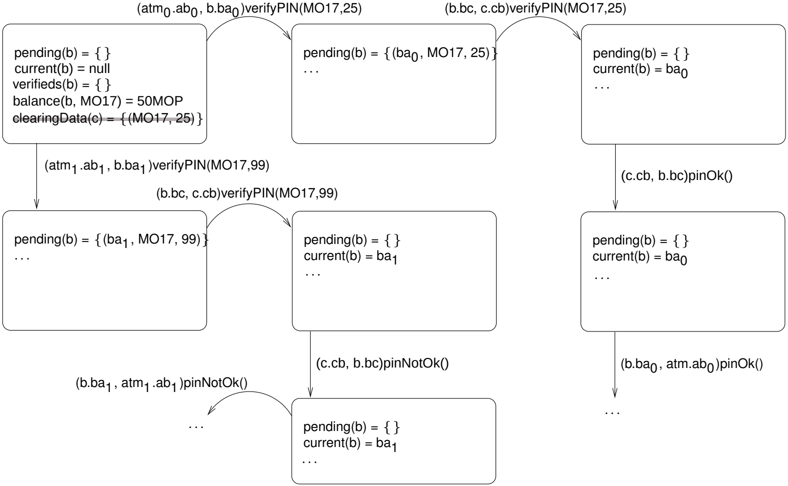
Connector instances

$\mathrm{ABBA} = \{(\mathrm{ab}_0, \mathrm{ba}_0), (\mathrm{ab}_1, \mathrm{ba}_1)\}$, $\mathrm{BCCB} = \{(\mathrm{bc}, \mathrm{cb})\}$

Example: Part of a Model for Assembly of Bank–ATM (II)



Reduct from Model Bank–ATM to Component b



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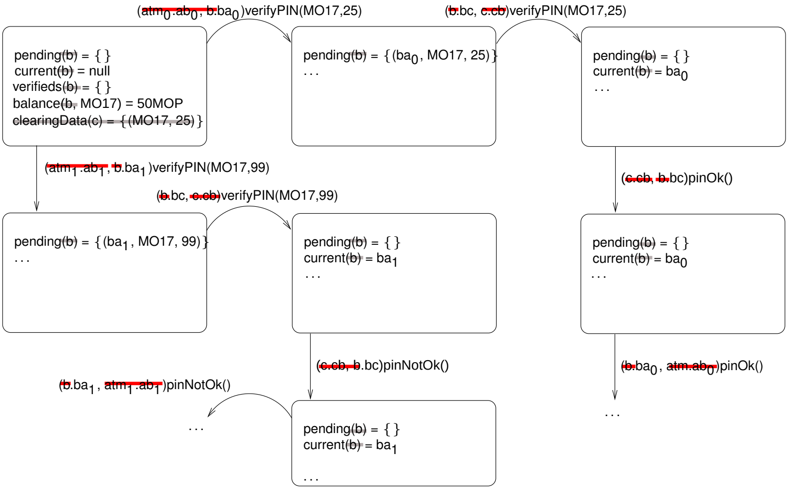

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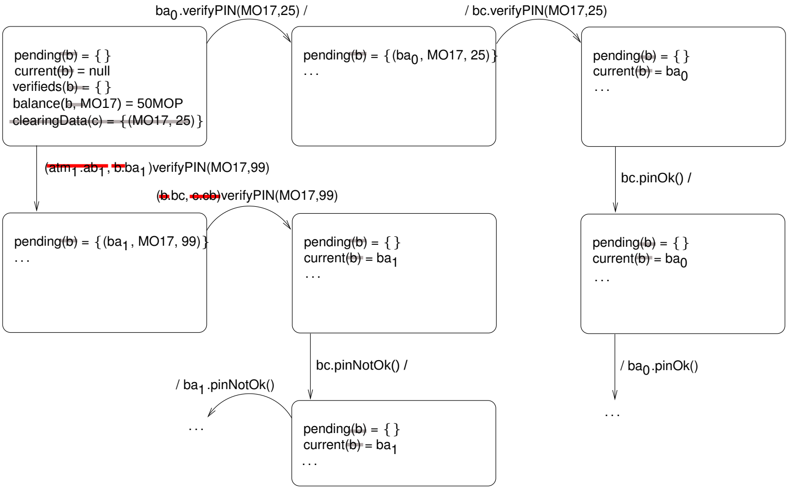
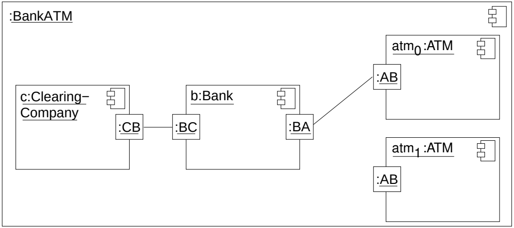


Example Bank–ATM: Reconfiguration



Port instances:

$AB(atm_0) = \{ab_0\}$,
$AB(atm_1) = \{ab_1\}$,
$BA(b) = \{ba_0\}$

Connector instances:

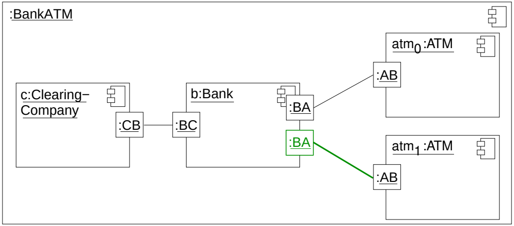
$ABBA = \{(ab_0, ba_0)\}$

Port instances:

$AB(atm_0) = \{ab_0\}$,
$AB(atm_1) = \{ab_1\}$,
$BA(b) = \{ba_0, ba_1\}$

Connector instances:

$ABBA = \{(ab_0, ba_0), (ab_1, ba_1)\}$



Checking Connectors for JAVA/A

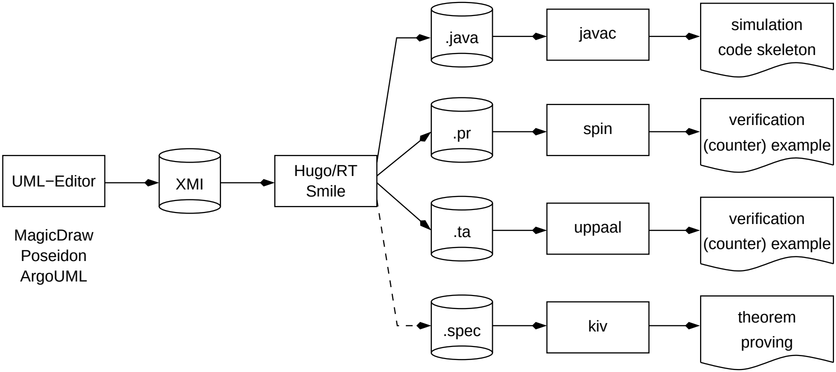
What is checked?

- Syntactically: interface conformance
- Semantically: absence of deadlocks

How is it checked?

- interface conformance: by the compiler
- absence of deadlocks: model checking using Hugo/RT
    - for finite state systems only . . .

Hugo/RT


UML−Editor
MagicDraw
Poseidon
ArgoUML
XMI
Hugo/RT
Smile
.java
.pr
.ta
.spec
javac
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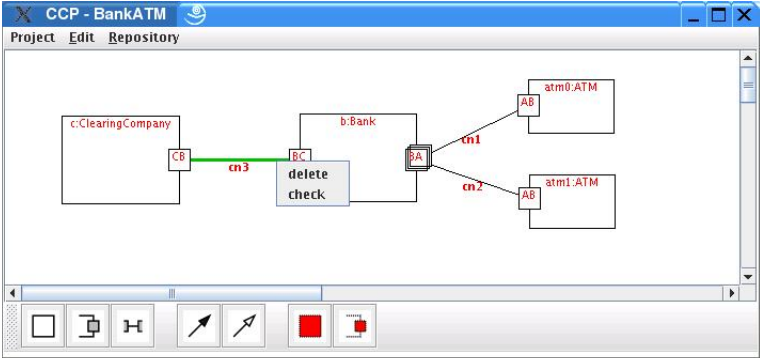
Applying Hugo/RT in CCP



Model checking connnectors

- “one-click”
- no model checking knowledge necessary

Correctness of (Static) Configurations

Theorem

Let Ξ_1 and Ξ_2 be port specifications. Let Γ be a configuration containing two component instances c_1 and c_2, such that c_1 has a port instance p_1 satisfying Ξ_1 and c_2 has a port instance p_2 satisfying Ξ_2 and p_1 and p_2 are connected.

$$\Xi_1 \parallel \Xi_2 \models \neg\delta \quad \Rightarrow \quad \Gamma \models \neg\delta$$

Conclusions and Future Work

Architectural Programming with Java/A

- bridging the gap between software architecture and programming languages
- based on an algebraic component model

Future Work

- extensions: ”explicit” ports of composite components, n-ary connectors, shared components, . . .
- specification framework: for reconfigurations, internal component behavior, . . .
- proof techniques (for refinements, . . .)
- black box and glass box semantics