# *Specification of a transacted memory for smart cards in Java and JML*


***Erik Poll***

***University of Nijmegen, NL***

***Joint work with***

***Pieter Hartel*** ***University of Twente***

***Eduard de Jong*** ***Sun Microsystems***

# *Outline*

**Case study in the use of Java and the specification language JML to implement/model/specify part of a smartcard OS.**

**Reasoning about JavaCard code subject to card tears.**

# *Background*

# *Smart cards*

**A smart card is a miniature computer with**

- **with limited resources (ROM,RAM,EEPROM)**
- **very limited I/O (ISO7816)**

**Smartcard contains a miniature operating system (OS).**

**JavaCard smartcard contains VM that can execute applets.**

# *Java Card*

**Superset of a subset of Java for programming smart cards**

- **no threads, floats, . . . , very limited API**

**but**

- **persistent and transient objects (EEPROM and RAM)**
- **transaction mechanism**

**and increased security:**

- **standard sandbox + firewall between applets.**

**Interesting target for formal methods: small programs, simple language, correctness of crucial importance**

# *Card tears & transactions*

**Tricky issue for smartcards:**

- **Possible power loss at any moment due to card tear**
- **OS must support transactions:**
  **atomic writes consisting of several EEPROM writes**
- **On power-up: OS performs clean-up of any unfinished transaction**
- **NB this clean-up can be interrupted by a card tear . . .**

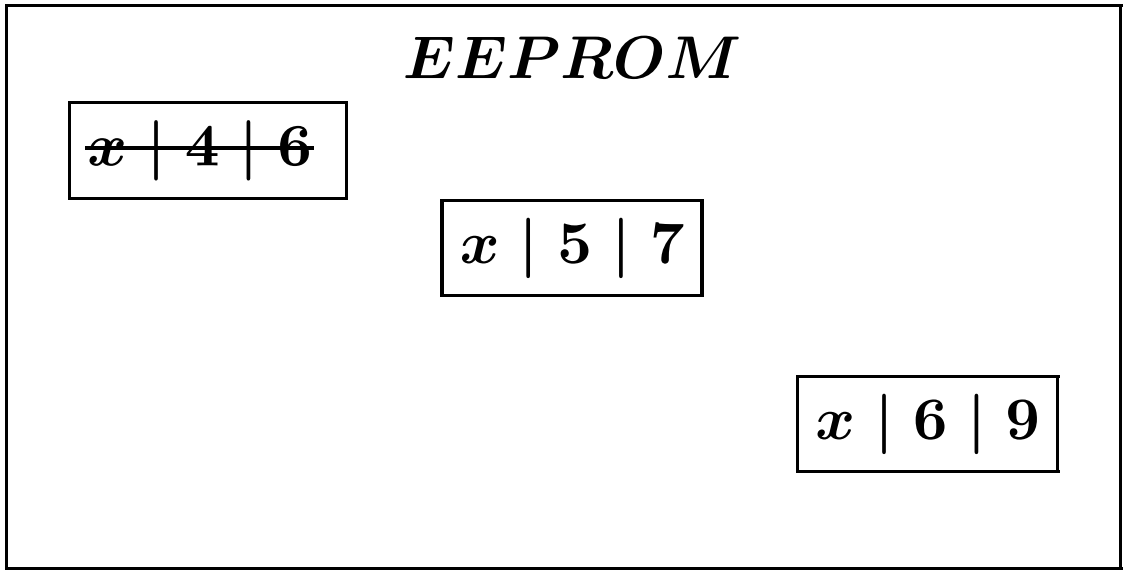
# *Challenges*

1. **How to implement a transaction mechanism?**
   **Smartcard constraints**
   - **limited RAM (eg 512 bytes)**
   - **EEPROM behaviour:**
     - **atomic write of given word size**
     - **limited life**
2. **How to specify and verify – and model – this?**
3. **How to specify and verify code that uses transactions?**

# *An implementation of Transacted Memory*

# Transacted Memory

**Idea for transacted memory by de Jong & Bos.**
**NB not as implemented in the JavaCard API.**




**Logging for free!**

# *Interface*

```
Tag       DNewTag(Size)
InfoSeq   Read(Tag)
void      Write(Tag, InfoSeq)
void      Commit(Tag)
InfoSeq   ReadGeneration(Tag, Gen)
void      Tidy()
```

# *Earlier work*


**Deficiencies:**

- **Z specs do not include card tears**
- **Big gap – and no real link – between Z specs and implementation**

# *This work*

**Initial idea:**

- **Translate C code to Java**
  **By hand; easy but boring.**
- **Translate Z specs to JML**
  **By hand; easy but boring. Uses JML**
- **Tie the two together**

# *Java Modeling Language JML*

**Specification language by Gary Leavens (Iowa Univ.) for annotating Java programs with**

- **pre- and postconditions** } **cf. Eiffel and Design by Contract**
- **invariants**
- **frame conditions (modifiability constraints)**
- **specification-only variables (model/ghost variables)**
- **...**

**Pre-, postconditions, and invariants in JML are Java boolean expressions, extended with `\forall`, `\exists`, `==>`, `\old( )`, ...**

# *Translating abstract Z spec*

# Z spec

$$
\begin{array}{|l}
\hline
\Delta\, MemSys \\
t? : tags \\
\hline
t? \in dom\, assoc \\
assoc\, t? \neq \langle\rangle \\
committed' = committed \cup \{t?\} \\
\hline
\end{array}
$$

# *JML spec*

**Using JML library for sets, functions, relations, etc. Z specs can be translated to JML**

```
public void ACommit(Tag t)
/*@ requires assocs.domain().has(t) &&
  @          ! assocs.apply(t).isEmpty() ;
  @ ensures  committed.equals(
  @             \old(committed).insert(t));
  @*/
```

# *Z vs JML*

**Z vs JML:**

- **Z looks much prettier**
- **JML distinguishes pre- and postcondition**
- **JML can be easily be made executable**

# *Modelling card tears in Java*

- **card tear is like an exception**
- **clean-up is like the exception handler**
- **card tear is uncatchable exception, caught only in the main repetition of the OS**
- **Modelling card tear inside language, allows testing, specification, and verification**

# *annotated Java implementation*

```
/*@ ensures Read(tag).equals(is);
  @ signals (CardTearException)
  @         TidyRead(tag).equals(is)
  @     || TidyRead(tag).equals(\old(Read(tag)));
  @*/
  public void Write (Tag tag, InfoSeq is)
                        throws CardTearException
```

**Expresses atomicity of write operation**
**Specs still incomplete: nothing said about previous generations**
**JML assertion checker can cope with this.**

# *Java impl with JML assertions*

**Bugs found:**

- **one typo - giving ‘version number’ instead of ‘generation number’**
  **Found during typechecking Java code**
- **clumsy interface - 4 write operations with disjoint preconditions**
  **Found writing JML assertions**
- **one serious error - card tear at certain point**
  **Found using runtime assertion testing**

# *Java impl with JML specs*

**By translating**

1. **abstract Z spec to (executable) JML spec**
2. **C implementation to Java implementation**

**abstract spec & implementation in same language.**
**We can tie them together, by**

- **running same test scenario on 1. and 2.**
- **including 1. in 2. using ghost/model variables**

***Conventional programming language (Java) useful to built formal model (of VHDL implementation).***

# *Using Transacted Memory*

# *The LOOP project*

**Currrent JavaCard API offers transactions**

```
beginTransaction();

beginTransaction();

abortTransaction();
```

# *The LOOP project*

**Verification of JML-annotated Java(Card) programs based on**

- **a denotational semantics for sequential Java,**
- **a compiler – the LOOP tool – which translates `A.java` to `A.pvs` describing its semantics.**
- **a Hoare logic for reasoning about JML,**
- **associated WP calculus,**

**All formalised in PVS: ie. a shallow embedding of Java and JML in PVS**

**How to allow for card tears?**

**Trick to model card tear as an exception also work when specifying and verifiying Java Card code.**

**For example**

```
/*@ ensures \old(x+y) == x+y;
  @ signals (CardTearException)  \old(x+y) <= x+y;
  @*/
 void bla(){
   x++ ; y--;
 }
```

# *Invariants*

**Java:**
**Invariant may temporarily be violated, but must hold at end of method - *also if an exception is thrown***

**JavaCard:**
**Invariant may never be violated, except during transactions**

$$\frac{\begin{pmatrix} \textbf{requires} & = & P \\ \textbf{statement} & = & s_1 \\ \textbf{ensures} & = & P' \wedge Q_{excp} \\ \textbf{signals} & = & Q_{excp} \end{pmatrix} \qquad \begin{pmatrix} \textbf{requires} & = & P' \\ \textbf{statement} & = & s_2 \\ \textbf{ensures} & = & Q \\ \textbf{signals} & = & Q_{excp} \end{pmatrix}}{\begin{pmatrix} \textbf{requires} & = & P \\ \textbf{statement} & = & s_1; s_2 \\ \textbf{ensures} & = & Q \\ \textbf{signals} & = & Q_{excp} \end{pmatrix}}$$

# *Syntactic desugaring*

```
beginTransaction();
x++ ; y--;
endTransaction();
```

**can be desugared into**

```
x’=x; y’=y;
try {
x++ ; y--;
} catch (CardException e) {
  x=x’; y=y’;
  throw e;
}
```

# *Limits of this approach*

**It can't deal with**

```
void mn() {
  m(); n();
}
void m() {
  beginTransaction();
  x++
}
void n() {
  y--;
  endTransaction();
}
```

# *Alternative*

**Alternative approach:**
**including transactions in denotational semantics**
**Easy enough, but coming up with associated proof rules isn’t.**

# *Conclusions*

**Conventional programming language (Java) maybe an interesting formal model**
**Future work:**

- **fixing bug**
- **verification of Transacted Memory using PVS & LOOP coping with model variables in LOOP**
- **verification of applets incl. card tears**
- **VHDL implementation**

**Worry: ensuring C code = Java code = VHDL code**