JML & ESC/Java case study : specifying the JavaCard APDU protocol in JML

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The JavaCard platform

$$\boxed{\begin{array}{c}\text{JavaCard platform}\\ \text{(JCRE)}\end{array}} = \boxed{\begin{array}{c}\text{JavaCard language}\\ \text{(JCVM)}\end{array}} + \boxed{\begin{array}{c}\text{JavaCard}\\ \text{API}\end{array}}$$

The JavaCard API provides

- some base classes and interfaces, eg. `Applet`
- some OS-like functionality, including the `APDU` class for communication with the smartcard terminal.

ISO 7816 and APDU's

Smartcard and terminal communicate by exchanging APDU's – sequences of bytes – as specified in ISO7816-4:

1. terminal sends a command APDU to smartcard

CLA	INS	P1	P2	LE	D_1	. . .	D_{LE}

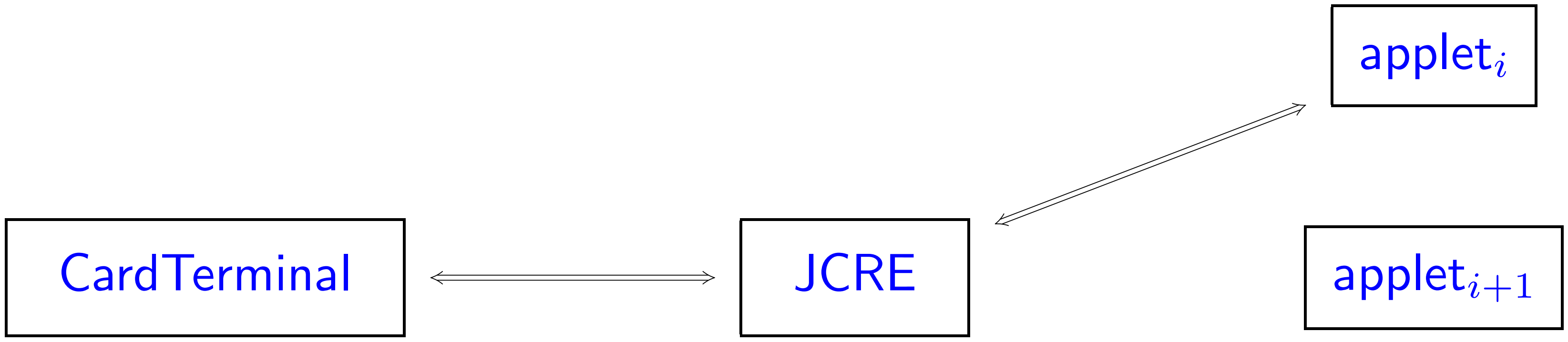
2. smartcard sends a response APDU back to terminal

3. back to 1.

Two variants, T=0 and T=1: byte and block transmission

ISO 7816 and APDU's for applets

The JCRE mediates between applets and terminal:



JCRE passes an APDU-object to the selected applet, by invoking its `process(apdu)` method.

An APDU-object is essentially a buffer, with methods for reading/writing/etc. in it.

The APDU class

So an applet receives an APDU, on which it can invoke

```
  public static byte[] getBytes()
  public static short getInBlockSize()
  public static short getOutBlockSize()
```

and

```
  public short setIncomingAndReceive()
  public short receiveBytes(short bOff)
  public short setOutgoing()
   public void setOutgoingLength(short len)
   public void sendBytes(short bOff, short len)
   ⋮
```

in a certain order!

Informal (javadoc) spec

receiveBytes

`public short receiveBytes(short bOff) throws APDUException`

> Gets as many data bytes as will fit without APDU buffer overflow, at the specified offset bOff. Gets all the remaining bytes if they fit.

Parameters: `bOff` - the offset into APDU buffer.
Returns: number of bytes read. Returns 0 if no bytes are available.
Throws: APDUException - with the following reason codes:

- `APDUException.ILLEGAL_USE` if `setIncomingAndReceive()` not called or if `setOutgoing()` or `setOutgoingNoChaining()` previously invoked.
- `APDUException.BUFFER_BOUNDS` if not enough buffer space for incoming block size.
- `APDUException.T1_IFD_ABORT` if T=1 protocol is in use and the CAD sends in an ABORT S-Block command to abort the data transfer.

Reference implementation

The reference implementation of `APDU` uses 7 flags

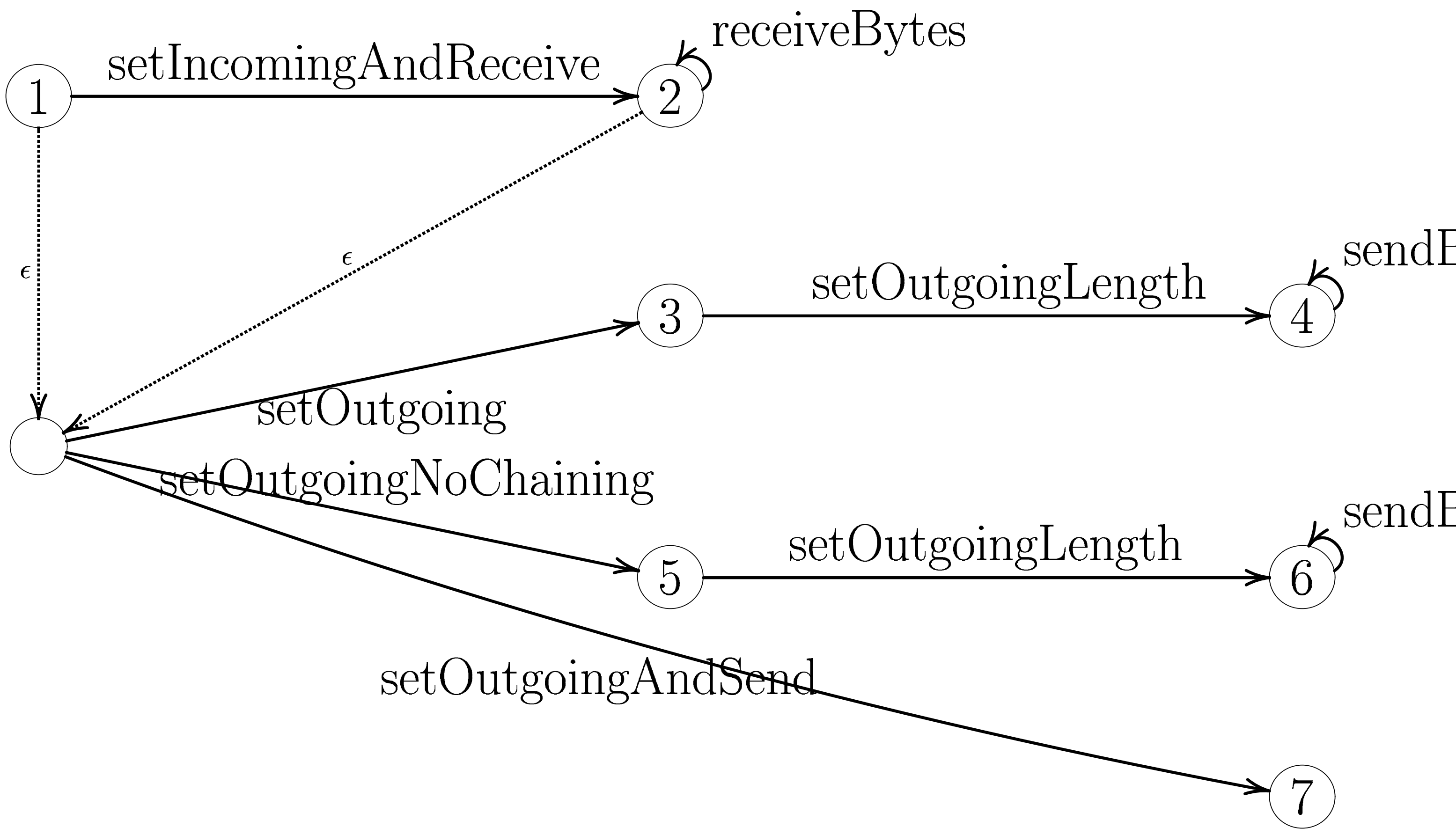
`incomingFlag, outgoingFlag, outgoingLenSetFlag, lrIs256Flag, sendInProgressFlag, noChainingFlag, noGetResponseFlag`

to enforce invocation order, eg.

```
public short receiveBytes(short bOff) throws APDUException
{ if (!getIncomingFlag() || getOutgoingFlag() )
       APDUException.throwIt( APDUException.ILLEGAL_USE );
   ...
```

but protocol has $<< 2^7$ states !

FSM for APDU


setIncomingAndReceive
receiveBytes
1
2
ϵ
ϵ
3
setOutgoingLength
4
sendB
setOutgoing
setOutgoingNoChaining
5
setOutgoingLength
6
sendB
setOutgoingAndSend
7

Using a model field and FSM to specify `APDU`

```
//@ public model int _APDU_state;

 /*@    requires _APDU_state == 1 && ... ;
   @     ensures _APDU_state == 2 && ... ;
   @*/
public short setIncomingAndReceive()


 /*@     requires _APDU_state == 2 && ... ;
   @     ensures _APDU_state == 2 && ... ;
   @*/
public short receiveBytes(short bOff)
```

Relating reference implementation to formal spec

Invariants relating the abstract state to its concrete representation, eg:

```
/*@ invariant
  @       _APDU_state == 2
  @  <==>
  @         getIncomingFlag() && !getOutgoingFlag();
  @*/
```

More detailed JML spec of `receiveBytes(short bOff)`

```
/*@ requires _APDU_state == 2                                 &&
  @            0 <= bOff                                       &&
  @            bOff + getInBlockSize() <= BUFFERSIZE;
  @
  @ assignable _APDU_state, _Lc, buffer[bOff..bOff+\result-1];
  @
  @  ensures _APDU_state == 2                                  &&
  @            0 <= \result && \result <= \old(_Lc)             &&
  @            _Lc == \old(_Lc) - \result                      &&
  @            bOff + \result <= BUFFERSIZE                    &&
  @            (* data received in buffer[bOff..bOff+\result-1] *);
  @
  @  signals (APDUException e) e.getReason() == APDUException.IO_ERROR
  @                         || e.getReason() == APDUException.T1_IFD_ABORT
  @*/
```

Here model field _Lc is the length of incoming command.

Relating reference implementation to formal spec

Length of the incoming command in JML spec:

```
//@ public model int _Lc;
//@ public invariant 0 <= _Lc && _Lc < 256;
```

Representation in the reference implementation:

```
private byte getLc()
 { return ramVars[LC]; }
```

NB. byte-int conversion yields `getLc()` $\in [-128..127]$. So

```
//@ private invariant _Lc == (getLc()&0xFF)
```

and **not** `_Lc == getLc()`.

Bug in reference impl. of `receiveBytes`

The reference implementation does NOT meet this spec, but requires a stronger precondition than

```
bOff + getInBlockSize() <= BUFFERSIZE,
```

namely

```
bOff + getInBlockSize() <  BUFFERSIZE.
```

This is probably a bug.

Conclusions

- (Still incomplete) formal specs for APDU protocol:
  400 lines code, 400 lines javadoc, 170 lines public JML spec
- State transitition diagram nice way to specify the APDU protocol.
  Why isn't it used anywhere in the existing documentation ??
- Whenever possible, our specs do not say "exception E_i is thrown, if P_i holds", but insist on "$\neg P1$&& . . . &&$\neg P_n$" as precondition.