MTAT.07.017
Applied Cryptography

Smart Cards (JavaCard)

University of Tartu

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Smart card security model

Parties involved in a smart card–based system:

- Cardholder
- Data owner
- Terminal owner
- Card issuer
- Card (software)manufacturer

Smart card threat models:

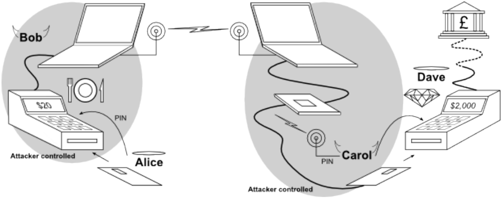
- attacks by the terminal against the cardholder
- attacks by the cardholder against the terminal
- attacks by the cardholder against the data owner
- attacks by the cardholder against the issuer
- attacks by the terminal owner against the issuer
- attacks by the issuer against the cardholder
- attacks by the (software)manufacturer against the data owner

`http://www.schneier.com/paper-smart-card-threats.html`

Estonian ID card

- Used to:
  - Store RSA/ECC private keys
  - Perform on-card signing/decryption
  - Authorize cryptographic operations (using PIN)
- Cardholder / Data owner / Terminal / Card issuer / Card (software)manufacturer
- Attacks:
  - by the terminal against the cardholder
  - by the cardholder against the terminal owner
  - by the cardholder against the data owner
  - by the issuer against the cardholder
  - by the (software)manufacturer against the data owner

Payment cards (EMV)



- Used to:
  - Store symmetric MAC key
  - Authentication of transactions (using PIN)
- Attacks:
  - by the terminal against the cardholder
    - Relay attacks
  - by the terminal owner against the issuer
  - by the issuer against the cardholder

Mobile phone SIM cards

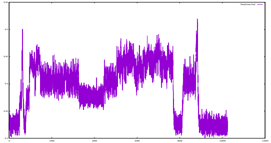
- Used to:
  - Store 128-bit symmetric subscriber authentication key
  - Perform RUN GSM ALGORITHM
  - Authorize operations (using PIN)
  - Store contacts and SMS messages
  - Store settings (operator information)
  - Mobile-ID
- Attacks:
  - by the cardholder against the data owner
  - by the terminal owner against the issuer
  - by the issuer against the cardholder

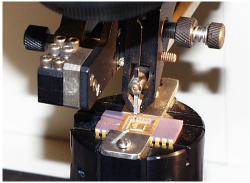
Pay TV

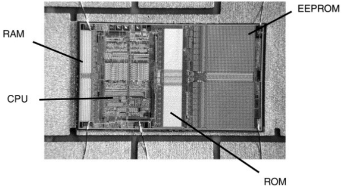
- Used to:
  - Decrypt TV signal
  - Store channel filters
- Attacks:
  - by the cardholder against the data owner/issuer
  - by the terminal owner against the issuer

Attacks against smart cards

- Side channel attacks:
  - Timing analysis
  - Power analysis
- Fault injection:
  - Voltage, clock rate, radiation
- Physical attacks:
  - Chemical etching
  - Chip re-wiring
  - Adding a track
  - Cutting a track
- Countermeasures:
  - Metal layers
  - Onboard sensors (temp, light, frequency)
  - ...





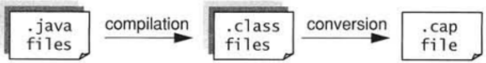


Common Criteria (CC) security certification

- Target of Evaluation (TOE) – a product that has to be evaluated
- Protection Profile (PP) – identifies security requirements for class of products
  - For example, PP for a Secure Signature Creation Device
- Security Target (ST) – identifies the security properties of TOE
- Evaluation Assurance Level (EAL) – level of verification (1 to 7 + augmentation)
- Evaluation facilities – certified IT security testing laboratories
- Certification Bodies – issue CC certificates (e.g., ANSSI and BSI)

JavaCard

- Card capable of running code written in Java
- Stripped-down version of Java
  - Data types: boolean, byte, short
  - Not supported: char, String, float, int
  - One dimensional arrays
  - No threads
- Rich cryptography API available
  - Employs cryptographic coprocessor
  - Algorithm support depends on card (`https://www.fi.muni.cz/~xsvenda/jcalgtest/table.html`)
  - Side-channel protection guaranteed only for crypto API calls
- Java .class file has to be converted to .cap file



.java files

compilation

.class files

conversion

.cap file

- Estonian ID cards issued since 2011 are JavaCards

JavaCard applet

C-APDU: 00 00 00 00 01 03

R-APDU: F0 43 CA 90 00

```
$ cat TestApplet.java
package appcrypto;

import javacard.framework.*;
import javacard.security.*;
import javacardx.crypto.*;

public class TestApplet extends Applet {
    RandomData rnd;

    public static void install(byte[] ba, short ofs, byte len) {
        (new TestApplet()).register();
    }

    public void process(APDU apdu) {
        byte[] buf = apdu.getBuffer(); // contains first 5 APDU bytes

        switch (buf[ISO7816.OFFSET_INS]) {
        case (byte)0x00:
            if (buf[ISO7816.OFFSET_LC] != (byte)1) {
                ISOException.throwIt(ISO7816.SW_DATA_INVALID);
            }
            apdu.setIncomingAndReceive(); // read APDU data bytes
            short len = (short)(buf[ISO7816.OFFSET_CDATA] & (short)0xff); // get rid of sign
            rnd = RandomData.getInstance(RandomData.ALG_SECURE_RANDOM);
            rnd.generateData(buf, (short)0, len);
            apdu.setOutgoingAndSend((short)0, len); // return response data
            return;
        }
        ISOException.throwIt(ISO7816.SW_INS_NOT_SUPPORTED);
    }
}
```

Converting to CAP

```
$ sudo apt install opensc openjdk-8-jdk ant
$ wget https://github.com/martinpaljak/ant-javacard/releases/download/19.03.04/ant-javacard.jar
$ git clone https://github.com/martinpaljak/oracle_javacard_sdks

$ cat build.xml
<?xml version="1.0" encoding="UTF-8"?>
<project default="applet" basedir=".">

  <target name="jcpro">
    <taskdef name="javacard" classname="pro.javacard.ant.JavaCard" classpath="ant-javacard.jar"/>
  </target>

  <target name="applet" depends="jcpro">
    <javacard>
      <cap jckit="oracle_javacard_sdks/jc222_kit/" output="applet.cap"
          sources="/home/user/eclipse-workspace/appcrypto/src/">
        <applet class="appcrypto.TestApplet" aid="0102030405060708"/>
      </cap>
    </javacard>
  </target>
</project>

$ ant
applet:
      [cap] INFO: using JavaCard 2.2.2 SDK in oracle_javacard_sdks/jc222_kit
      [cap] INFO: Setting package name to appcrypto
      [cap] Building CAP with 1 applet from package appcrypto (AID: 0102030405)
      [cap] appcrypto.TestApplet 0102030405060708
  [compile] Compiling files from /home/user/eclipse-workspace/appcrypto/src
  [compile] Compiling 1 source file to /tmp/jccpro2232880529567474390
 [javacard] NB! Please use JavaCard SDK 3.0.5u3 or later for verifying!
   [verify] Verification passed
      [cap] CAP saved to /tmp/jc/applet.cap
BUILD SUCCESSFUL
Total time: 1 second
```

GlobalPlatform

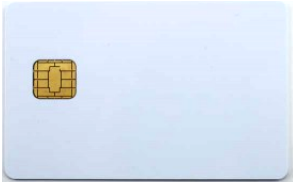
- Standard for applet management on JavaCards
- Multiple applets can be installed
  - Applet is SELECT'ed using Application Identifier (AID)
  - Applet can be set as the default applet (selected by default)
  - Applets are isolated (with exceptions – Shareable Interface)
- Applet can be deleted (usually), but never downloaded
- Security Domain (SD)
  - Every applet belongs to a SD
  - Card Issuer Security Domain (ISD)
  - Supplementary Security Domains (SSDs)
  - Secure Channel Protocol for communication with SD

Installing CAP file

```
$ wget https://github.com/martinpaljak/GlobalPlatformPro/releases/download/v0.3.5/gp.jar

$ java -jar gp.jar --install applet.cap --default
CAP loaded

$ java -jar gp.jar --list
[..]
AID: 0102030405060708 (........)
     App SELECTABLE: Default selected

AID: 0102030405 (.....)
     ExM LOADED: (none)
     0102030405060708 (........)

$ opensc-tool -s 00:00:00:00:01:05:00
Received (SW1=0x90, SW2=0x00):
47 62 C6 A1 E3 Gb...

$ opensc-tool -s 00:00:00:00:01:a0:00
Received (SW1=0x90, SW2=0x00):
CD 12 03 41 BA 22 69 32 1D 43 1E 46 21 26 76 8C ...A."i2.C.F!&v.
1B D5 E1 F5 A6 6C 65 7E 87 68 B7 36 D9 6B 61 B0 .....le˜.h.6.ka.
07 E5 CF E6 D0 CE E2 28 9A 53 F4 6C 3B CB 3C 0F .......(.S.l;.<.
C7 E4 5D 9C EC FE 94 7D 07 6A 90 20 A1 F6 2E E4 ..]....}.j. ....
26 D1 23 79 3F D2 F1 93 0E 1C 5E 11 8E 60 3E FB &.#y?.....ˆ..‘>.
1D 23 C4 E7 04 CB E2 67 96 77 48 F0 AF E2 30 00 .#.....g.wH...0.
F9 E9 C4 63 10 D5 C0 6E 6F A4 4C 3B C6 54 75 99 ...c...no.L;.Tu.
0B 42 6D C8 2F 40 D5 FD 2D CB 70 8C 1F 3C 30 4D .Bm./@..-.p..<0M
D2 88 5F 68 3B 43 1C 85 D9 AD C0 B7 EC 01 3C 0E .._h;C........<.
D4 EE 01 F0 B5 EB 5E 8D B2 5C F4 D1 2E 09 77 BC ......ˆ..\....w.

$ java -jar gp.jar --deletedeps --delete 0102030405
```

Blank JavaCard (Infineon)

- 40 cards available



Infineon jTOP SLE78
(SLJ52GCA150)

- Chip: Infineon SLE78
- EEPROM: 150K
- RAM: ?
- JavaCard 3.0.4
- GlobalPlatform 2.2.1
- DES/3DES/AES256
- MD5/SHA1/SHA256/SHA512
- RSA-2048 (on-card generation)
- ECC-521 (on-card generation)
- CC EAL5+ high certification

Warning: Infineon RSA key generation flaw!

Blank JavaCard (Feitian)

- 16 cards available

Feitian FT-Java/D11CR

- Chip: ST31
- EEPROM: 50K
- RAM: 5K
- JavaCard 2.2.2
- GlobalPlatform 2.1.1
- DES/3DES/AES128
- MD5/SHA1/SHA224/SHA256
- RSA-2048 (on-card generation)
- ECC-256 (on-card generation)
- Contactless Interface
- Garbage collector
- No security certifications

Warning: On-card RNG flawed!

Task: JavaCard applet – 6p

Write a JavaCard applet that performs on-card RSA 2048-bit key generation and decryption:

```
$ ./test_applet.py
[+] Selected reader: Gemalto PC Twin Reader (E0660B9A) 00 00
[+] Infineon jTOP SLE78 (SLJ52GCA150)
[+] Generating 2048-bit RSA key...
[+] Key generated in 15.01943 seconds!
[+] Retrieving public key...
[+] n=1907947716745697801984296668306272913349298245522576117840417272520071383935970391495
[+] e=65537
[?] Enter message to encrypt: secret message!
[+] Encrypted message: 912d7285385d51c5511d3c108bd3b2361f7895d8f5f1b32192e3194afed22002225
[+] Sending ciphertext to card...
[+] Message decrypted in 0.742395 seconds!
[+] Decrypted message (15 bytes): secret message!
```

Commit TestApplet.java to your repository.

Task: JavaCard applet

- Find out the communication protocol from `test_applet.py`
- JavaCard API calls to use:

```
keypair = new KeyPair(KeyPair.ALG_RSA, KeyBuilder.LENGTH_RSA_*);
keypair.genKeyPair();

pub = (RSAPublicKey) keypair.getPublic();
pub.getExponent(byte[] buffer, short offset);
pub.getModulus(byte[] buffer, short offset);

rsa = Cipher.getInstance(Cipher.ALG_RSA_PKCS1, false);
rsa.init(keypair.getPrivate(), Cipher.MODE_DECRYPT);
rsa.doFinal(byte[] inBuff, short inOffset, short inLength,
                           byte[] outBuff, short outOffset);
```

Task: JavaCard applet

- Size limit for data APDU body is 255 bytes
  - The first two bytes of ciphertext are embeded in P1 and P2
  - Make the ciphertext continuous using:

```
Util.arrayCopyNonAtomic(byte[] src, short srcOff, byte[] dest,
                                    short destOff, short length);
```

- Avoid memory leaks – initialize objects only once!
- Make sure that keypair is generated only once
  - Ignore (without error) repeated keygen requests
- Java has signed types – cast byte to short using `0xff` mask
- Debugging is possible only via the data or SW returned!

JavaCard: memory management

EEPROM (or flash):

- Slow writes, subject to wear
- Preserves data on power loss

Persistent Objects:

- Class-member variables
- Static variables
- Array data

RAM:

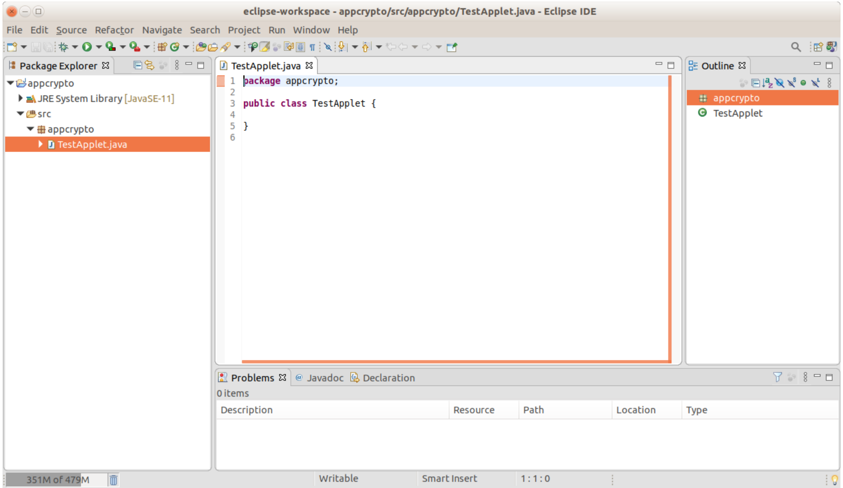
- Fast writes (1000x faster)
- Loses data on power loss
- Small storage space

Transient Objects:

- Local variables
- Method parameters
- Transient array data (`makeTransientByteArray()`)
- APDU buffer

JCRE may not include a garbage collector
(space of unreferenced objects is not reclaimed).

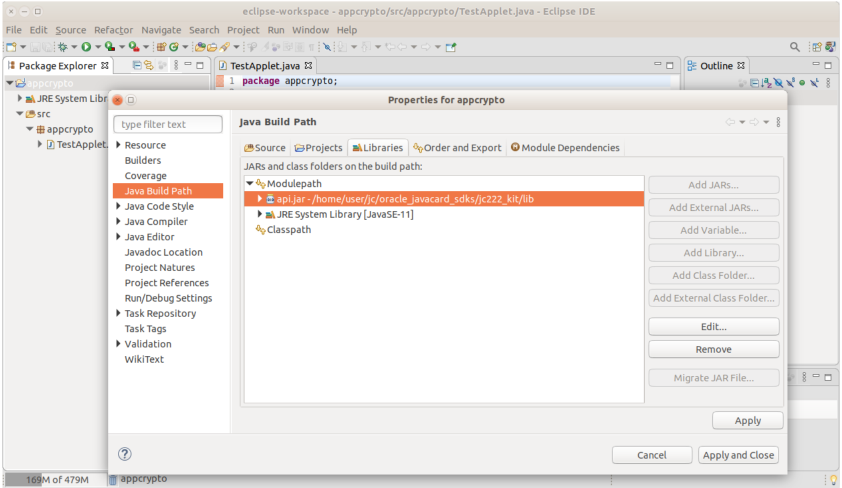
JavaCard development under Eclipse



```java
package appcrypto;

public class TestApplet {

}
```

- `sudo snap install eclipse --classic`
- Create a project: "File – New – Java Project – Project name: appcrypto".
- Right-click on the project "New – Class – Name: TestApplet, Package: appcrypto".

JavaCard development under Eclipse



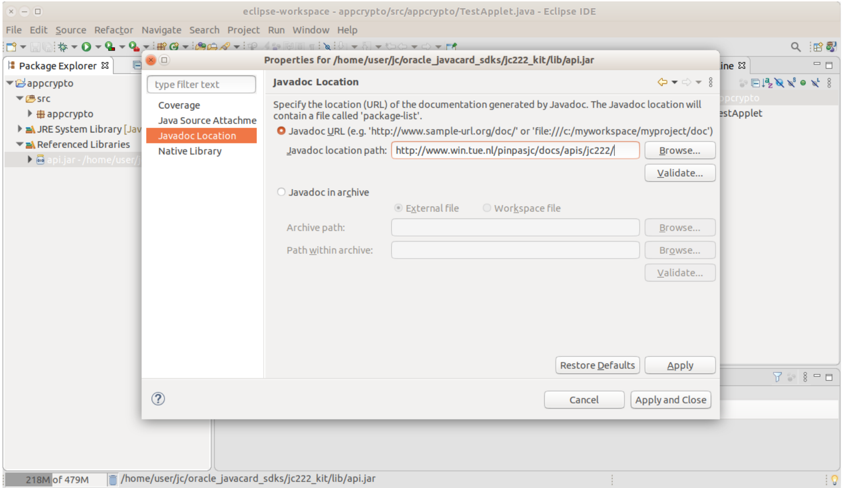
```
package appcrypto;
```

JARs and class folders on the build path:

- Modulepath
  - api.jar - /home/user/jc/oracle_javacard_sdks/jc222_kit/lib
  - JRE System Library [JavaSE-11]
- Classpath

- Right-click on your project “Build Path – Configure Build Path… – Libraries – Add External JARs” and add `oracle_javacard_sdks/jc222_kit/lib/api.jar`. This will enable JavaCard code validation and completion.

JavaCard development under Eclipse



eclipse-workspace - appcrypto/src/appcrypto/TestApplet.java - Eclipse IDE

Properties for /home/user/jc/oracle_javacard_sdks/jc222_kit/lib/api.jar

Javadoc Location

Specify the location (URL) of the documentation generated by Javadoc. The Javadoc location will contain a file called 'package-list'.

● Javadoc URL (e.g. 'http://www.sample-url.org/doc/' or 'file:///c:/myworkspace/myproject/doc')

Javadoc location path: http://www.win.tue.nl/pinpasjc/docs/apis/jc222/

○ Javadoc in archive

● External file ○ Workspace file

Archive path:

Path within archive:

/home/user/jc/oracle_javacard_sdks/jc222_kit/lib/api.jar

- Right-click on `api.jar` – "Properties – Javadoc Location – Javadoc location path:" and specify `http://www.win.tue.nl/pinpasjc/docs/apis/jc222/`.
  This will enable javadoc for JavaCard API calls.