SMART CARDS LAB
UCL M.Sc. in Information Security 2011

Nicolas T. COURTOIS
Room 7.06a., Computer Science, University College London,
Gower Street, WC1E 6BT, London, UK

n.courtois@ucl.ac.uk
http://www.cs.ucl.ac.uk/staff/N.Courtois/

Abstract

This is an interactive pdf form to fill. It is **not graded**.

The form can be filled with Acrobat Reader or with other appropriate software, see below. **BUT, beware:** All changes to the document are lost with Acrobat Reader, it is NOT able to save forms.

The document with changes can be saved reliably if it is opened with the full "professional" (paid) version of Adobe Acrobat. A free and tested alternative (recommended) is FoxIt 3.1 which can be downloaded for free from the Internet. Further alternatives include printing the document with a printer (real paper printer), or printing it as a pdf file with GNU pdf creator (free), but this usually fails if we try to print the whole document at once, which apparently can be circumvented by printing a selection of pages at one time.

1 Copyright

2 Structure of the Smart Cards Lab

Students may skip some parts or do them in a different order.

- Section 4: Software Setup.
- Section 7: Smart card commands ABC.
- Section 8: How to identify smart card products and individual smart cards by ATR and UID, anonymity issues. Anti-collision mechanisms.
- Section 11: Exploring an electronic passport.
- Section 12: Exploring RFID Memory Cards, Oyster Cards, Building Passes etc.
- Section 14: Exploring GSM SIM Cards.
- Section 16: Exploring Magnetic Stripe Cards.
- Section 15: Exploring Chip and PIN cards.
- Section 17: Smart card development with C++.
- Section 18 Example of a timing Attack Project.

3 Expected Learning Outcomes

1. Understand security protocols used in real-life products.
2. Be able to develop arbitrary applications on a PC which can communicate with arbitrary smart cards.
3. Encourage students to do further research on security of smart card products.
4. Have fun.

4 Hardware and Software Setup

4.1 PC/SC Interface for Smart Card Readers

PC/SC Interface in Windows

Smart card commands are called APDUs, see Section 7.

In Windows, the support for smart card commands (APDUs) is included through the so called PC/SC interface that is included in windows (uses winscard.dll) and does not require any installation.

The only thing that needs to be installed are drivers for specific smart card readers.

PC/SC Interface for Linux

The equivalent for Linux is called pcsc-lite. It needs to be installed (not tested).

4.2 Recommended Smart Card And Contactless Readers

There are many smart card readers on the market. Many are not PC/SC compliant, many are quite expensive, and many don't work very well. Here is the recommended selection of inexpensive, highly functional and highly compatible smart card readers.

1. For cards with contact, we can use a very cheap smart card reader PC/SC Silver PA748S (also sold under the brand Alcor Micro) which costs about 6 GBP and can be purchased on ebay. This reader covers both bank cards and SIM cards, however one should understand that all cheap smart card readers suffer from the "friction" problem: when we insert the smart card repeatedly, the contacts will become used and the smart card might eventually become damaged.

2. For contactless cards, we recommend ACR 122U or 122T (which is the same but smaller in size). Each of these models costs about 40-50 GBP.

3. There is also an all-in-one reader: Omnikey 5321 which costs about 80 GBP. It contains two readers in one: an ISO wired smart card, and an contactless RFID smart card. There are also adaptors to insert a SIM card to Omnikey 5321.

4.3 Drivers

For Windows:

For ACR122, and for Windows XP, drivers are in

`\Smart Cards Lab docs and free software\drivers\ACR 122 driver 09 2008\ACR122U_inst_Win_0101_P\`

For ACR122, and for Windows Vista or 7, the drivers sometimes are not needed (built-in CCID driver) and otherwise can be found in

`\Smart Cards Lab docs and free software\drivers\ACR122 Windows 7 drivers 2011\`

Also drivers can be found on the Internet, for example at:
http://www.nfc-reader.com/acr122-drivers.php

A generic driver for PC/SC Silver PA748S is found in our smart card lab folder (as well as on the original driver CDROM). The file name is SmartCardReader_Driver_Generic_AU9520_4OSVista(x86x64)_Setup_v1.2.4.27

For Omnikey 5321:
http://www.hidglobal.com/driverDownloads.php?techCat=19&prod_id=171

(Remark: For the little blue reader (SIM cards only) the driver name is Prolific USB-to-Serial Comm port but one should not use it. It does not work with most of our software... It does not seem PC/SC complaint and works with older software which communicates through the COM port directly).

For Linux drivers generally exist but we cannot guarantee if they actually work.

4.4 APDU Tools

Tools that allow to send APDU commands and receive the answer of the smart card.

APDU Tools - Linux

Not tested.

But we hear that: "The opensc-tool utility can be used from the command line to perform ... operations such as getting the card ATR or sending arbitrary APDU commands to a card."

http://linux.die.net/man/1/opensc-tool
Probably requires to install some packages such as openct and pcsc-lite...

APDU Tools - Windows (recommended)

Any of these can be used: (the first two are recommended):

1. A simple ready program `SCardDemo.exe` is provided in the folder `\APDUtools\SCardDemo.exe`. The source code for this program is essentially the same as the source code for TimingAttackDemo which is provided, see also Section 17.
2. Another tool is C# Scriptor, a part of the Spring card tools suite: quick install: http://www.springcard.com/download/usr/sdd4c0-ae.exe

   The package actually contains 3 free and open-source tools that work under windows.

   (a) PC/SC Diag, quick'n'dirty software to exchange APDUs. (Win32 native, Visual C++ with MFC).
   (b) C# Scriptor, a basic PC/SC scripting tool, a batch file or manual entries. (requires the .NET framework, written in C#).
   (c) SCardToolkit – an advanced APDU software, comes with an impressive list of the APDUs supported by contactless cards. (requires the .NET framework, written in C#).

   Full SDK with source code: http://www.springcard.com/download/find.php?file=pcsc-sdk.
3. CardEasy, included on a CD-ROM found in some books

5 rfidiot library

The rfidiot library is developed by Adam Laurie, a well-known English security researcher. It works under Windows, Mac and Linux.

It is based on pyscard, a French Python library by Jean-Daniel Aussel from Gemalto and a few other Python libraries such as pycrypt.

5.0.1 Installing and configuring rfidiot

We will only describe how to do things under Windows. Students can try Linux or Mac on their own (more pain and more risky, maybe not everything works).

Main page:
`http://http://rfidiot.org/`
Direct download for Windows:
`http://rfidiot.org/RFIDIOt-Windows-0.1x.zip`
Our recommended (older) version

```
\Smart Cards Lab docs and free software\drivers\
rfidiot\recommended\June 2009 with Python 25\
```

5.0.2 rfidiot - Installing Python

Install Python 2.5. There are problems with different versions of Python that are incompatible with other versions of rfidiot. Typically Python 2.6. does not work. Do use 2.5. May install from:

```
\Smart Cards Lab docs and free software\drivers\rfidiot\
recommended\June 2009 with Python 25\other packages needed\python-2.5.2.ms
```

5.0.3 rfidiot - Additional Python Libraries

Unless already included in Python distrib, typically the are not (needed for Python 2.5) then also we need the following libraries. An archive of all these cna be found at:

```
\Smart Cards Lab docs and free software\drivers\rfidiot\
recommended\June 2009 with Python 25\other packages needed\
```

The Python packages to be installed can also be found elsewhere:

1. Install Python Imaging http://www.pythonware.com/products/pil/
2. Install pyscard, http://pyscard.sourceforge.net/
3. Install pyserial, http://pyserial.sourceforge.net/
4. Install also pywin32-213.win32-py2.5 package (only sometimes needed). http://sourceforge.net/projects/pywin32/.
5. Install pycrypt http://www.amk.ca/python/writing/pycrypt/ and http://www.pythonware.com/products/pil/

   A ready installer for pycrypt is provided. It is BETTER than installers found elsewhere on the Internet.

   With other installers, to really install pycrypt, one does not have to copy the files, just run from the package directory directly (can be from a USB drive):

   ```
   setup.py build
   test.py
   ```

   This usually fails without Visual Studio 7 installed (might work with VS8 too)... Also known under names Visual Studio 7 == .NET == 2003. One might use another release by fiddling with the python/Lib/distutils/ msvccompiler.pyc file that detects the compiler...

5.0.4 rfidiot - Additional OpenSSL Install

Install openssl Python library. This is **only needed to access certain electronic passports**.

In our files it is found in

```
\Smart Cards Lab docs and free software\rfidiot\more\
Open SSL needed for certain passports only\openssl-0.9.8k\
```

See INSTALL.W32 for detailed instructions. It requires either of these two:

1. cygwin with a C compiler and Perl installed,
2. Microsoft Visual Studio version 7 or 8 (recommended), or 9 or 10, already installed, and ActiveState Perl, available from http://www.activestate.com/ActivePerl.

5.0.5 Installation Directory

Files from the rfidiot installation can be for example copied to

```
C:\Program Files\rfidiot
```

6 rfidiot Tips

Documentation: http://rfidiot.org/documentation.html

6.1 Change the Reader

Several Smart Card readers can be connected to a PC. Omnikey 5321 Actually contains two readers in one box. To change the smart card reader, use -r0 or -r1, with any command:

```
C:\Program Files\rfidiot>isotype.py -r0
  Reader: PCSC ACS ACR122 0
connecting to ACS ACR122 0
...
...
```

6.2 Sniff the APDUs

Use -d with any command:

```
isotype.py -d
...
...
>  FF CA 00 00 00
<  AC 23 FE 33 90 0
...
...
```

Here we recognize a basic standard command that works for most readers and most smart cards:

GET CARD SERIAL NUMBER

CLA	INS	P1	P2	Le
FF	CA	00	00	00

7 APDUs

Smart Card commands are called APDUs (Application Protocol Data Unit). They are strings of bytes, written in order of their transmission.

The card is only answering to commands (master/slave principle, half-duplex) and never initiates any communication.

Quiz We call an C-APDU a:

☐ APDU used in contactless smart cards ☐ string of bytes sent to the smart card.

Quiz We call an R-APDU a:

☐ string of bytes received from the smart card ☐ APDU that updates registers of the reader.

7.1 Industrial standards

Quiz Cross-industry standardized APDU commands are described in

☐ ISO 7816-1 ☐ ISO 7816-4.

Structure of an APDU

There are several possible cases, depending on the instruction.

Header - required				Body - optional		
CLA	INS	P1	P2	Lc	Data	Le

Explanations:

CLA is the byte that identifies the type of command, the application, and also indicates to what extent the command is complaint to ISO specs.

INS is a byte that encodes the instruction.

Quiz The optional field Lc is for:

☐ size of the input data ☐ length of the instruction.

Quiz The optional field Le is for:

☐ length of the instruction ☐ expected output size.

The size is always in bytes. Each field Lc or Le can be encoded on 1 or 3 bytes, but most of the time it is one byte and a number between 0 and 127. Any larger number requires encoding on 3 bytes.

If the command is successful, the answer should be:

Some Application Independent Error Messages

These or similar codes will be used in bank cards, GSM etc.
.

7.2 Vendor Extensions

Specific families of smart cards will only use or implement some parts of commands, that can have a slightly different behavior, or even differ considerably from ISO 7816-4.

For example:

Quiz The set of commands for GSM cards is specified in

☐ ISO 7816-17 ☐ ETSI GSM 11-11.

Quiz In 3G (UMTS) mobile phones the smart cards are called USIM. The set of commands for USIM cards is specified in

☐ ISO 7816-18 ☐ ETSI TS 51.011.

Both these standards have many further extensions...

8 How to Identify a Smart Card

Here there is no command. The command is to physically RESET the card (for example switch the power off and on, or connect RESET contact C2 to VCC for a short while). Then the card responds with a string of bytes. This is called **ATR** = Answer To Reset.

Quiz ATR is a nested structure defined in
☐ ISO 7816-1 ☐ ISO 7816-3.

ATR is a sort of unique ID of a smart card product. For example ATR is equal to 3B8F8001804F0CA000000306030001000000006A for MiFare Classic used in the London Oyster card. A tool to identify the type of the smart card from its ATR can be found at `http://smartcard-atr.appspot.com/`.

8.1 How to get ATR

Most smart card programs are able of displaying the ATR.

1. For example we can run `SCardDemo.exe` which will display ATR if we press the button RESET.
   it is included in our software distribution folder under is provided in the folder `\APDUtools\SCardDemo.exe`. This program does not require any installation and can be run directly.
2. A nice tool is PCSC diagnostic that comes with the free SpringCard tools suite that comes with our lab installation. It will automatically detect if a card was inserted and display the ATR.
3. Another method is to use *cardselect.py* or *isotype.py* that come with rfidiot library. The second program gives some extra explanations about the structure and the encoding of the ATR, as shown below.
4. And many other... including most APDU tools we have listed in Section 4.4.

8.2 Getting ATR With Rfidiot

Open a console box (**cmd.exe**, can for example be opened by clicking here: `file:///C:/windows/system32/cmd.exe`) and type the following:

```
cd C:\Program Files\rfidiot
isotype.py
```

This displays the ATR values and decodes them. This works well only for contactless cards, and a few other. If this does not work, we can try also

```
cd C:\Program Files\rfidiot
cardselect.py
```

If still no success, try to disconnect the reader from the USB port, close all the other applications that talk to smart cards, and connect only one PC/SC reader at a time. One can otherwise use APDU software provided such Spring Card tools, most programs display the ATR somewhere. If still no success try PCSC diagnostic from the free SpringCard tools suite.

8.3 ATR with Explanations

Example with a MiFare Classic card (for example an Oyster card) and isotype command:

```
C:\Program Files\rfidiot>
isotype.py -r1 -d
isotype v0.1h (using RFIDIOt v0.1t)
  Reader: PCSC ACS ACR122 0
connecting to ACS ACR122 0
>   FF CA 00 00 00
<   AC 23 FE 33 90 0

     ID: AC23FE33
       Tag is ISO 14443 A, part 3

    ATR: 3B8F8001804F0CA000000306030001000000006A
         3B  Initial Header
           8  No TA1, TB1, TC1 only TD1 is following
            F  15 bytes historical data follow
             8  No TA2, TB2, TC2 only TD2 is following
              0  T = 0
               0  No TA3, TB3, TC3, TD3 following
                1  T = 1
                 Detected STORAGECARD
     Historical: 804F0CA00000030603000100000000
                 80  Status indicator may be present (COMPACT-TLV
                   4F  Application Identifier presence indicator
                 0C  12 bytes follow
             RID:  A000000306  PC/SC Workgroup
                       PIX:  03000100000000
                        SS:  03  ISO 14443 A, part 3
                        Name:  0001  Mifare Standard 1K
                            RFU:  00000000
                            Checksum TCK: 6A (OK)
```

The Initial Header

It specifies the relationship between A/Z and 0/1 where Z=high voltage, A=low voltage.

This byte is either:

1. TS = '3B' for a direct convention [originates from Germany], where A=0, Z=1.
2. TS = '3F' for the inverse convention [originates from France], with A=1, Z=0.

Communication Protocols

The ATR specifies (among many other parameters) the protocol used in the communication between the smart card and the reader. The most popular protocols are T=0, T=1.

Quiz In GSM cards we use the:
☐ byte-oriented protocol T=0 ☐ block-oriented protocol T=1.

Quiz In bank cards we use the:
☐ byte-oriented protocol T=0 ☐ block-oriented protocol T=1.

The main difference between these two is that T=1 is more modern, has extra CRC checks, T=0 only has parity checks (9 bits transmitted per byte).

Typically we don't need to know if the serial communication between the smart card and the reader uses the standard T=0 or T=1. The PC/SC layer hides this detail from the programmer anyway, in both cases APDUs are sent and received in the same way. They are just the strings of bytes.

Quiz In communication with an RFID reader we typically use the:
☐ standard protocol T=0 ☐ we say that T=CL.

In fact with an RFID reader there is no serial communication between the card and the reader at all. The PC/SC layer and the reader basically simulate the presence of a smart cards, so that RFID smart cards are seen as normal smart cards with contact. So T=CL is just a convention to say it is something completely different than T=0 or T=1, Commands are translated by the reader's firmware in a non-transparent way. In fact this is an important security feature, part of the security of the system is implemented in a tamper-resistant chip on the smart card reader side. The hacker has no idea what the RFID tag is actually sending and receiving.

Quiz With a native USB smart card, from the point of view of the PC/SC layer, the card will appear as:

☐ always block-oriented T=1 ☐ we will say that T=CL.

With modern readers and software the choice of communication protocol is done automatically. The windows PC/SC layer hides the communication protocol from us, so that the only thing we have to worry about is to send and receive strings of bytes (APDUs).

8.4 Real-life ATR Examples

Again we type:

```
isotype.py
```

Example 1: London Oyster Card + ACR122 or Omnikey 5321 reader.
Your Oyster Card ATR:

The program will give you a number of explanations regarding the meaning of this ATR. Should be the same as in Section 8.3.

Example 2:
University building pass ATR (if different, type in manually):

Example 3:
Your bank card ATR (type in manually):

Copy here are the explanations given by the program:

Example 4: You SIM card ATR (with a USB SIM reader, or with a normal reader such as Omnikey 5321 and a simple adaptor. Type in the ATR obtained:

Copy here are the explanations given by the program:

8.5 ATR and ATS, RFID/Contacless Cards

With RFID cards, there is no ATR. But there is **ATS** = Answer To Select.

Many RFID cards still don't do have an ATS, then the windows PC/SC interface will simulate/synthetise the answer and return an ATR that contains an ATS (that can also be simulated if not implemented).

8.6 Variable ATS

Example 5: Your Electronic Passport ATR (if different, type in manually):

Encoding: In these examples it is possible to see that ATR is 3B8C8001 + 11 bytes ATS + checksum byte.

Remark: For older passports ATR is fixed, for more recent ones to protect people's privacy they are variable (!). However in order for the passport to provide a different ATR, one has to switch off and on the magnetic field that powers the passport (if the passport is continuously powered, the ATR stays the same).

Your own passport:

Country: ______, issued: ____ 2008,
⇒ UID is ____

VERY IMPORTANT:

For the ATR to change, you MUST remove the passport from the magnetic field, and put it back again.

This is equivalent to RESET, (or power off and back on) for a normal smart card with contact.

If the ATR for your passport is randomized, please provide 3 examples to compare which parts change:

9 Unique ID for RFID Tags:

It is fixed, usually stored in the first block, that is read-only, and can never be changed. This read-only feature is currently the main reason why a blank card cannot be used as a clone of an Oyster card (all the other data can be copied).

Motto: software cannot be protected by software.

```
cd C:\Program Files\rfidiot
cardselect.py
```

Example 1: Your Oyster Card UID:

Example 2: Your university smart card UID:

9.1 Electronic Passports

Thing are not exactly the same with electronic passports.

Depending on the country the UID will be fixed, random, or will be random and start with 08.

Your own passport:

Country: , issued: 2008,
⇒ UID is

10 Further Identification

In many cards it is difficult to change the unique ID that is written in the part of memory that can never be modified.

In addition it may be possible to further prove the authenticity of the smart card data by a cryptogram or a digital signature, similar to the SDA mechanism in bank cards. In fact typically the unique ID of the card that is returned by cardselect.py or by the standard command GET CARD SERIAL NUMBER we exploit later, is too short to achieve this goal (typically 4 bytes, sometimes 6). Thus it is necessary to have longer authentication data in smart cards. A full-fledged digital signature with public third-party verifiability requires at least 320 bits, and frequently much more.

Another point is that counterfeit smart card chips exist in large quantities. It is important to be able to know which smart cards are genuine, because though the functionality implemented may seem the same, the security will usually be degraded in cloned products.

Interestingly, such authentication data available inside the smart card, that can be protected against modification also by a hardware mechanism. Then one card cannot be reprogrammed to simulate another card.

10.1 Further Identification and Trace-ability and Examples

For example Philips/NXP have in addition to their UID on 4 bytes, 11 extra bytes in the first block of the card, that cannot be changed. This allows very easily for Philips NXP to identify counterfeit products, and for example Fudan cloned cards from China have at this place a constant string "08 04 00" followed by "b c d e f g h i" in ASCII. They make it very clear that these cards don't come from Pilips/NXP.

Another example is the London Oyster card, where the block 4 can never be modified AFTER the card issued, even if one knows all the secret keys of the card. We ignore what data exactly are contained in this block but for sure Oyster cards can be reliably traced.

11 Exploring an Electronic Passport

We are going to implement (with high-level standard APDUs) the first steps of a typical transaction between the RFID reader at the border, and an electronic passport.

With any APDU tool we execute the following sequence:

GET CARD SERIAL NUMBER

CLA	INS	P1	P2	Le
FF	CA	00	00	00

Write here the answer received:

And here are some error messages you may get:

.

Then we execute a specific version of ISO SELECT FILE command:

SELECT FILE by an AID

CLA	INS	P1	P2	Le	AID
00	A4	04	0C	07	A0 00 00 02 47 10 01

The answer should be:

Then we execute a specific version of ISO SELECT FILE to select the master file '01 1E' of the passport:

SELECT FILE by an FID

CLA	INS	P1	P2	Le	FID
00	A4	02	0C	02	01 1E

The answer should be:

11.1 Basic Access Control

Now the reader and the passport do a mutual cryptographic authentication as specified in the Basic Access Control. It is done following ISO 11770-2.

The high level description is as follows:

1. The passport and the terminal have a shared 224-bit double triple DES key (written on $2 \cdot 128$ bits)

   $$K = (K_{MAC}, K_{ENC}),$$

   computed from the MRZ.

2. The passport generates two randoms r_A on 64 bits and K_A on 128 bits.

   The passport sends to the reader the card random

   $$r_A \longrightarrow$$

   .

3. The reader also choses two randoms r_B on 64 bits and K_B on 128 bits.

   Then he computes the authenticated encryption cryptogram

   $$\longleftarrow EA_K(r_B, r_A, K_B)$$

   that is 64+64+128 bits. These 256 bits are sent to the card

4. Then the passport checks the MAC, decrypts the triple (r_B, r_A, K_B), checks if r_A is the same as his own.

   Then it computes and sends another authenticated cryptogram on 256 bits:

   $$EA_K(r_A, r'_B, K_A) \longrightarrow$$

5. Then the terminal checks R_B.

   If correct, the final shared key is $K_A \oplus K_B$ on 128 bits.

Here we will implement only the first step.

GET CHALLENGE

CLA	INS	P1	P2	Le
00	84	00	00	08

Where Le is the length of the expected answer, which is 64 bits.
The answer will be a 64-bit random:

We will stop the exploration 'by hand' here, one now needs to compute the correct cryptogram.

11.2 Basic Access Control with rfidiot

With rfidiot, the full Basic Access Control is implemented, and with the MRZ of the passport, it is possible to read the files inside.

Please type in the **second line** of the MRZ (Machine Readable Zone) of your passport (all the second line, including the eventual ¡¡¡¡¡¡ signs and the last two characters):

Now type (adding quotation marks to the MRZ):

```
cd C:\Program Files\rfidiot
mrpkey.py -r0"                                      "
```

This program displays all the info contained in the passport.

Remark: if we execute it with -d option, it also displays all the cryptographic computations.

11.3 Better Software

Much better software, with a graphical interface was very recently released, see http://sites.uclouvain.be/security/epassport.html.

Under windows it can sometimes be launched directly from the disk provided for students. Launch ePassportViewer.exe.

Remark: Both this program, and rfidiot can produce very good log files with all cryptographic computations detailed.

12 High-Level Exploration of RFID Memory Cards on the Example of MiFare Classic

We will be further exploring MiFare Classic cards.

12.1 Software and Hardware Setup and Troubleshooting

Again we use one of the APDU programs described in Section 4.4. (recommended software is one of the three SpringCard tools that contains 3 programs, and EACH of these 3 programs allows to do the exercises.)

The exercise can be done with either ACR122 or Omnikey 5321. With Omnikey 5321 one needs to be careful because it actually contains two readers in one. So one needs always to choose the right one at program startup, OMNIKEY CardMan 5x21-CL 0, which is the contactless version.

At the beginning one needs to select the right reader. then one needs to connect to the card.

If something goes wrong or a commands fail, one may to need to remove the card, put it back again.

Because many protocols are stateful, for example, once we have done a successful authentication some data can be read, otherwise the READ instruction fails. Therefore it is important to do everything in order.

Again it can be sometimes useful to disconnect/reconnect the reader and the card, (this is done at different levels with software buttons or with the USB cable) and sometimes it is necessary to restart the software.

12.2 Which Cards to Use

MiFare Classic cards are the same as used in buildings, London Oyster cards, OV-Chipkaarts in the Netherlands, Warsaw city cards, student cards at many universities etc.

Here it is recommended to use blank cards, because we will be actually modifying them, and it is very important to be careful and follow the instructions exactly and note the data obtained in the form so that we can restore the previous data after changing them.

The original is known as Philips/NXP MF1 IC S50 but it exists also many other "compatible" chips by various manufacturers, including unlicensed (illegal) clones manufactured in China, India and Russia (they are legal in these countries). More than 1 billion of these chips have been sold, 200 million are currently in circulation, and 70 % of all contactless cards worldwide are MiFare Classic.

Quiz MiFare Classic follows (partly and with important variations) the following standard:

☐ ISO 18000 ☐ ISO 14443 A

Quiz The MiFare Classic card energy comes from:

☐ a tiny battery ☐ radio transmission ☐ magnetic field

Quiz The MiFare Classic card radio communications operate at the frequency of:

☐ 13.56 MHz ☐ 125 KHz ☐ 900 MHz

Quiz The operating distance for MiFare Classic cards is up to

☐ 1 cm ☐ 10 cm ☐ 50 cm

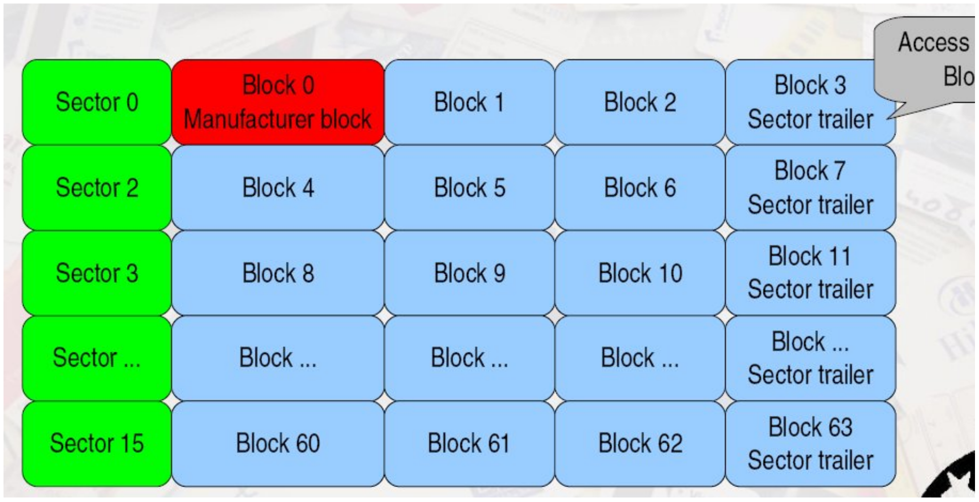
Can I Do It On a Real Card?

Students can also do it on their student card or badge or other cards they have including real transportation cards, if they know the key for it and if they are confident that they will not make a mistake that will disable or destroy your card. So one needs to be very attentive to instructions and also do not remove the card from the reader's field during write operations (according to the manufacturer this can permanently damage cards, or corrupt the data in such a way that the previous state cannot be restored).

Moreover, **you must** restore your card to the previous state.

12.3 Card Layout

MiFare Classic has 16 sectors with 4 blocks each, which makes 64 sectors total. Each block is 16 bytes which makes 1024 bytes total (1K).



Sector 0	Block 0 Manufacturer block	Block 1	Block 2	Block 3 Sector trailer
Sector 2	Block 4	Block 5	Block 6	Block 7 Sector trailer
Sector 3	Block 8	Block 9	Block 10	Block 11 Sector trailer
Sector ...	Block ...	Block ...	Block ...	Block ... Sector trailer
Sector 15	Block 60	Block 61	Block 62	Block 63 Sector trailer

See mifare.pdf that is distributed with rfidiot library. Depending on installation directory it could be here: `file:///C:/Program%20Files/rfidiot/mifare.pdf`).

Each sector with 4 blocks can be accessed using the same key. We can choose to use key A or key B. Here below we will be only using keys A. These two keys assigned to each sector of 4 blocks are stored in the last block of each sector (sector trailer) but typically (depending on access conditions) cannot be read, can only be written.

12.4 More Details on MiFare Classic

A detailed specification of the MiFare Classic card including low-level commands cna be found here:

```
\Smart Cards Lab docs and free software\
documents\manufacturer data sheets\
```

It is also included with some CDs distributed with ACR 122 reader.

```
\Smart Cards Lab docs and free software\additional software packages\
Smart Card Focus ACR122 starter Kit with Sample C++ Code CD 2011\
User Manuals and Reference Materials\
```

A ready Python script for reading cards and copying them, provided that they use default keys, is discussed in Section 13.11. A ready software for Windows which allows to explore any card for which we know some cryptographic keys and to study and understand access conditions is discussed in Section 13.12.

12.5 Which Block to Use

One cannot write on the block 0 that is read-only, and which is enforced by the manufacturer in hardware and cannot be changed.

Please do not write on sector trailer blocks that are: 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63 because they contain secret keys that will be overwritten

In UCL cards one can freely write on blocks 4-59 that are NOT used.

From now on we will be working on block number (some recommended values are suggested):
3A ▼

12.6 Which Key to Use

Please enter the key A for block 3A of your card (or leave the default value):
FFFFFFFFFFFF

13 Accessing MiFare Classic Cards

From now on, everything should work both with ACR122 and Omnikey 5321 readers.

13.1 Accessing MiFare Classic Cards - 1 Card

We send the following command:

GET CARD SERIAL NUMBER

CLA	INS	P1	P2	Le
FF	CA	00	00	00

Write here the answer bytes received:

13.2 Accessing MiFare Classic Cards - 2 Cards

In presence of two cards, for example the two card UIDs obtained in Section **??** (they are and) or any other two cards.

The reader will as a matter of fact use exactly one of them.

Everything below will work with one card, and also in the presence of the second card, except that we will **NOT** be able to choose which card we will working with. The reader does this choice during the anti-collision stage which is hidden from us.

Write here the answer bytes received:

13.3 Installing the Key in the Reader Registers

The reader contains a chip with an implementation of Crypto-1 cipher that needs to be initialized with the correct key.

Our key A for block 3A is: FFFFFFFFFFFF

We send the following command:

LOAD KEY IN RAM REGISTERS

CLA	INS	P1	Kt	Le	Key
FF	82	20	00	06	FFFFFFFFFFFF

Here P2=Kt is the key number, should be 0.
The answer should be:

13.4 Mutual Authentication

We use the following command:

MIFARE CLASSIC AUTHENTICATE

CLA	INS	P1	P2	Nb	Kt
FF	88	00	3A	60	00

Remark: We need to replace 60 by 61 if we are using the alternative key B.

The answer should be:

13.5 Reading One Block

We use the following command:

MIFARE CLASSIC READ

CLA	INS	P1	P2	Le
FF	B0	00	3A	10

Where Le is 16 = 0x10, the length of the answer expected.
Write the answer obtained here:

13.6 How Much Money is On Your Oyster Card?

This section can only be executed if the student knows one actual cryptographic key of their Oyster card. This is not easy because each Oyster card has a different key. Several attacks allowing one to recover the key have been developed, by the researchers at the Dutch university of Nijmegen. However the fastest and the most practical attack, which does not require a costly pre-computation is the so called "Dark Side" attack by Courtois published in SECRYPT 2009. Some open source implementations of this attack exist, see http://www.libnfc.org/community/topic/98/mifare-classic-key-recovery-tool-dark-side-attack/

Assuming that we know the key for a given Oyster card, how can we know how much money there is currently on our card? First of all, the exact amount cannot always be determined with certitude. This not as much because of the complex pricing system used by Transport For London with price capping and penalties for not touching out. But rather because in the real life transactions are not always guaranteed to be billed properly. People are frequently charged more than they should be, and if people complain they get some of their money refunded, and therefore the current balance written in the card may be altered. However we are able to get the figure which in a typical case and if the card indeed has been used correctly, and after touching-out, will be exactly the balance of a given card.

For this we need to read block 5 and block 6 of the Oyster card. We repeat the sequence LOAD KEY IN RAM REGISTERS, MIFARE CLASSIC AUTHENTICATE described above (unless the key AND the block number requested is the same as before.

Then we need to issue MIFARE CLASSIC READ twice for block 5 and 6, that according to MiFare Classic specification always use the same key. 2 x MIFARE CLASSIC READ for blocks 5 and 6

CLA	INS	P1	P2	Le
FF	B0	00	05	10

CLA	INS	P1	P2	Le
FF	B0	00	06	10

We get:

05.

06.

Now we need to look and the second block (not the third as it seems) with numbering $1, 2, 3, 4, 5 \ldots$ byte starting from the left, in each of these blocks. It is a counter, and one of these two counters will be higher, for example first will be 0x41 and the other will be 0x40. This means that we need to use block 5 and discard block 6. Now we look at the two following bytes 4th and 5th in the same block. The formula to compute the credit of our card is as follows:

$$\text{credit} = \frac{b5 \cdot 256 + b4}{200,0} \quad \text{in British pounds}[\pounds]$$

13.7 Writing One Block

We use the following command:

MIFARE CLASSIC WRITE

CLA	INS	P1	P2	Lc	Data
FF	D6	00	3A	10	

Where Data= must be exactly 16 bytes.

The answer should be:

13.8 Reading The Block Again

We can verify if writing was done correctly:

MIFARE CLASSIC READ

CLA	INS	P1	P2	Le
FF	B0	00	3A	10

Write the answer obtained here:

and compare to the data written:

13.9 Writing Again to Restore Previous Value

We do again:

UPDATE

CLA	INS	P1	P2	Lc	Data
FF	D6	00	3A	10	

The answer should be:

13.10 Reading The Block Again

We can verify if writing was done correctly:

MIFARE CLASSIC READ

CLA	INS	P1	P2	Le
FF	B0	00	3A	10

Write the answer obtained here:

and compare to the data written:

13.11 Reading Script

To read several blocks at once with one key we can use the following program: (with Omnikey we need -r1 option)

```
cd C:\Program Files\rfidiot
readmifaresimple.py -r0 0 64 FFFFFFFFFFFF AA
```

This reads all blocs from 0 to 63 with key A, or those for which the key provided is correct.

We can try this with a building card and with key beeing either FFFFFFFFFFFF (Philips/NXP default key) or with another popular default key A0A1A2A3A4A5A6 (known as the Infineon default key).

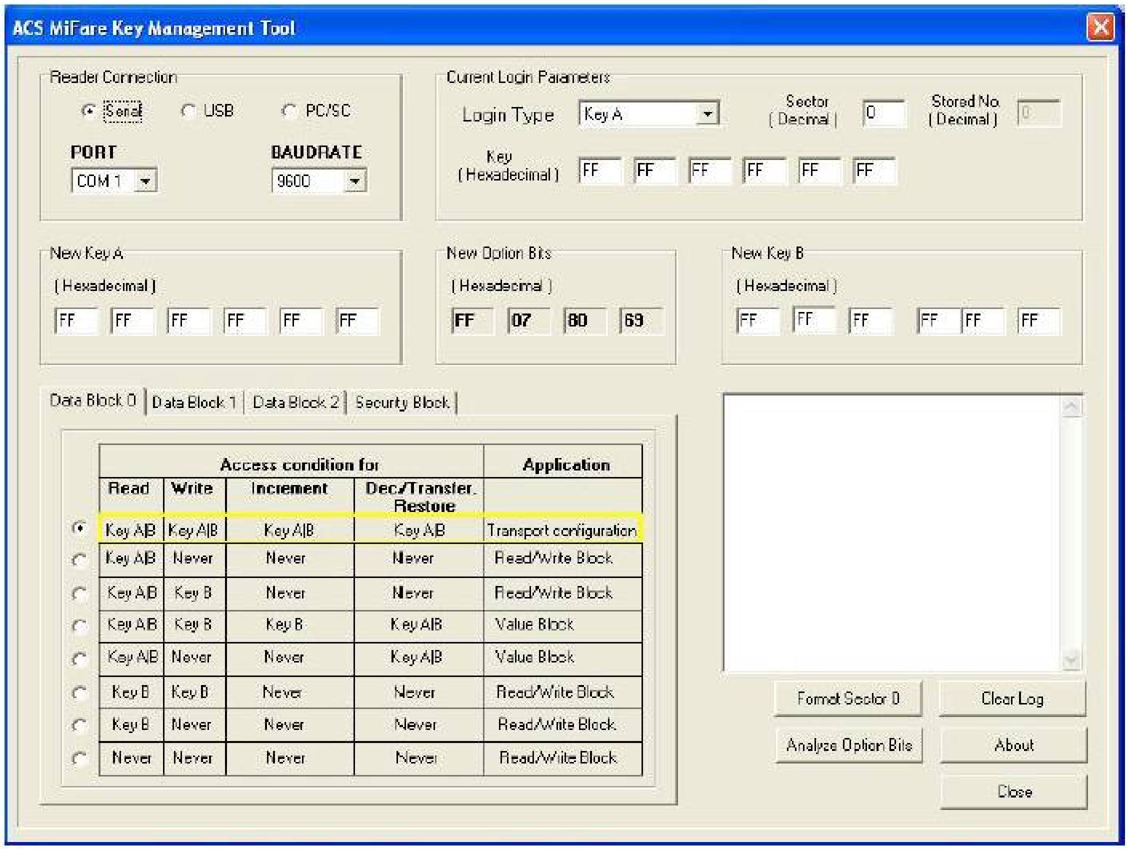
Typically at least one block is accessible with a default key, in many cards all blocks 0-59 except 60-63 are accessible with one of the default keys, and in some buildings all blocks without exception will be accessible with one of the default keys.

13.12 Ready Software - EasyKey

A ready Windows program to explore MiFare Classic cards is provided by ACS, the manufacturer of ACR122 reader. It is called EasyKey, and is also known as ACS MiFare Key Management Tool.

```
\Smart Cards Lab docs and free software\
APDU tools\ACR122U NFC Reader complete SDK with tools\setup.exe
```

During the installation select 'Advanced Installation' and install only the tools.



Reader Connection: [✓ Serial] USB PC/SC

PORT: COM 1 BAUDRATE: 9600

Current Login Parameters

Login Type: Key A Sector (Decimal): 0 Stored No. (Decimal): 0

Key (Hexadecimal): FF FF FF FF FF FF

New Key A (Hexadecimal): FF FF FF FF FF FF

New Option Bits (Hexadecimal): FF 07 80 69

New Key B (Hexadecimal): FF FF FF FF FF FF

	Access condition for				Application
	Read	Write	Increment	Dec/Transfer, Restore	
●	Key A|B	Key A|B	Key A|B	Key A|B	Transport configuration
○	Key A|B	Never	Never	Never	Read/Write Block
○	Key A|B	Key B	Never	Never	Read/Write Block
○	Key A|B	Key B	Key B	Key A|B	Value Block
○	Key A|B	Never	Never	Key A|B	Value Block
○	Key B	Key B	Never	Never	Read/Write Block
○	Key B	Never	Never	Never	Read/Write Block
○	Never	Never	Never	Never	Read/Write Block

It is a tool which allows to do arbitrary operations on MiFare Classic cards. In particular it allows to understand various access conditions for various sectors. (MiFare Classic has 16 sectors with 4 blocks each). The reader must be warned that many operations will be irreversible and can render the card impossible to use.

14 GSM SIM Card Exploration

We mean a classical (2G) SIM card, what we present here also works on many (but not all as it seems) 3G cards that are (not always?) backwards compatible with 2G phones.

Quiz SIM stands for:

☐ Standard ICC for Mobile (phones) ☐ Subscriber Identity Module

Bibliography: The exact specifications of how a mobile phone communicates with a SIM card can be found in the ETSI GSM 11-11 document.

14.1 GSM SIM Card During a Phone Call

We will perform the following sequence of operations:

1. Select the file DF_{GSM}, which is one of the two main directories on each SIM card, the second being $DF_{TELECOM}$.
2. Verify the PIN (not needed if PIN inactive).
3. Run the GSM algorithm to obtain cryptographic keys for the authentication and encryption during the current phone call.

This is the strict minimum that needs to be executed for each phone call (the phone does NOT know the secret key of the card and therefore cannot replace the SIM card in these 3 operations, it can however cache the PIN so that the user does not have to enter it each time).

14.2 Accessing DF_{GSM}

First we execute the following:

GSM SELECT FILE (by FID)

CLA	INS	P1	P2	Le	FID
A0	A4	00	00	02	7F 20

Where the FID of DF_{GSM} is '7F 20'.

The answer should be:

SW1	SW2
9F	☐

Where ☐ is the length of the response data that we will now recover with GET RESPONSE command:

GET RESPONSE

CLA	INS	P1	P2	Le
A0	C0	00	00	

The answer is the FCI of the DF_{GSM} directory.

Handling Errors

All the above should work for any 2G SIM card and for many if not all 3G cards.

In case we recall some standard error messages:

.

Specific products and specific commands also frequently have special error codes, one example will be seen below.

Decoding of Certain Bytes

According to GSM specs we can here look at certain bytes in FCI.

Byte 14 =

Byte 19 =

From these we learn that: The most significant bits of is 0 if an only if PIN1 is disabled.

Th byte 19 = is the "CHV1 status" Typically the value of this byte is '83' where 8 means that the PIN1 has been initialized, and that there are 3 cardholder verification attempts left for this PIN.

14.3 Cardholder Verification

This should be done ONLY if the PIN1 is enabled, i.e. is bigger than '80'. Otherwise we skip this subsection.

GSM VERIFY CHV1

CLA	INS	P1	P2	Le	CHV
A0	20	00	01	08	

where the PIN is encoded in ASCIII and extended to 8 bytes by FF FF FF FF. For example the PIN 1234 is encoded as 31 32 33 34 FF FF FF FF.

The answer should be:

.

After 3 presentations of an incorrect PIN (that can be in different sessions, this counter is preserved in non-volatile memory) the card will be blocked (but can be unblocked with UNBLOCK CHV function).

However if the PIN is correct, the counter for the number of CHV attempts will be reset to 3.

14.4 Cryptographic Functionality of a SIM Card

Imagine that the base station in GMS sends to the mobile phone a 16-byte random. Choose one example or write your own (the length MUST be 16 bytes):

RUN GSM ALGORITHM

CLA	INS	P1	P2	Le	RAND
A0	88	00	00	10	

This command will work ONLY if DF_{GSM} or a sub-directory is selected, and if cardholder verification was performed.

The answer should be:

SW1	SW2
9F	

Where is the length of the response data that we will now recover with GET RESPONSE command:

GET RESPONSE

CLA	INS	P1	P2	Le
A0	C0	00	00	

The answer should now be split as 4+8+2:

first 4 bytes remaining 8 bytes

Here SRES = first 4 bytes = A3(Ki,RAND) and
Kc= remaining 8 bytes = A8(Ki,RAND)

Starting from now, SRES will be sent to the base station, and the phone conversation will be encrypted using A5/x algorithm with key Kc.

14.5 An Embarrassing Discovery

If we do the above steps and are able to run RUN GSM ALGORITHM for a SIM card from a number of countries the Kc keys obtained are typically NOT random (!).

For example, depending on the card, the operator and the country, we will see that no matter how many times we try, certain bits of the key will always be 0. Thus, many SIM cards in various countries have been **deliberately** weakened to generate weaker keys, probably so that to make GSM communications easier to eavesdrop for the government.

To see this, just repeat the last RUN GSM ALGORITHM command and change some bytes in the random. Repeat several times.

You may write below the results obtained:

Remark 1. This fact is known among some well-informed security professionals, but it is NOT in general known to the public of the concerned countries...

Remark 2. In contrast, UK SIM cards typically have keys on 64 bits.

15 Bank Card Magnetic Stripe Exploration

Warning: your bank card belongs to your bank, not to you. It is specifically written in card contracts. You are NOT allowed to do what you want with your card. You are NOT allowed to hack your bank card.

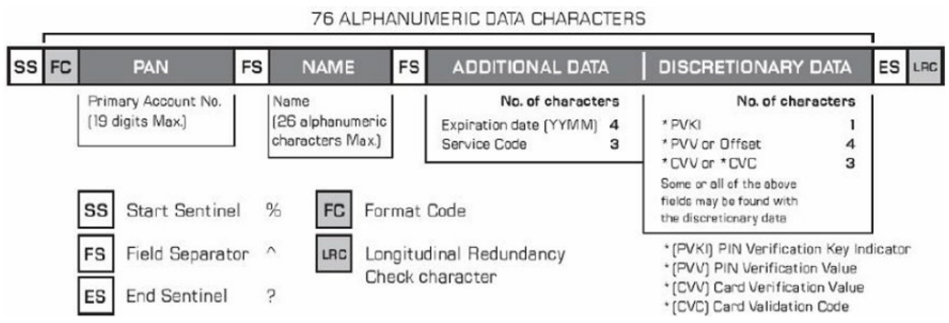
Students are asked not to try anything with their current UK bank card. We will experiment with some old and foreign bank cards.

Reading the magnetic stripe of your card:

15.1 Track 1

High resolution track.

We can only decode it if it is in the standard and popular format B. Other formats are proprietary.



76 ALPHANUMERIC DATA CHARACTERS
SS
FC
PAN
FS
NAME
FS
ADDITIONAL DATA
DISCRETIONARY DATA
ES
LRC
Primary Account No. (19 digits Max)
Name (26 alphanumeric characters Max)
No. of characters
Expiration date (YYMM) 4
Service Code 3
No. of characters
* PVKI 1
* PVV or Offset 4
* CVV or * CVC 3
Some or all of the above fields may be found with the discretionary data
SS Start Sentinel %
FS Field Separator ^
ES End Sentinel ?
FC Format Code
LRC Longitudinal Redundancy Check character
* (PVKI) PIN Verification Key Indicator
* (PVV) PIN Verification Value
* (CVV) Card Verification Value
* (CVC) Card Validation Code

One can split it as follows:

PAN:

NAME:

Expires: Service Code:

PVKI: PVV: CVV:

15.2 Track 2

Low resolution ABA track. More or less the same, except the name.

One can split it as follows:

PAN:

Expires: Service Code:

PVKI: PVV: CVV:

15.3 Decoding Service Code - 3 Digits

D1: Interchange and technology.
D2: Authorization processing.
D3: Range of goods and PIN requirements.
Example:

2: International, with IC that should be used when feasible.

0: Transactions authorized following normal rules.

1: No restrictions.

Glossary:
RFU = Reserved for Future Use,
IC = Intergrated Circuit, or chip
when feasible = each time the terminal accepts it, if the chip is broken or missing the financial transaction should not be handled

Note: We see that second LS bit of D1 indicates that the chip is present and must be used. Ross Anderson reported that by modifying this code one could with certain terminals circumvent the chip and make the card much easier to clone.

16 Bank Card Chip Exploration

Warning: your bank card belongs to your bank, not to you. It is specifically written in card contracts. You are NOT allowed to do what you want with your card. You are NOT allowed to hack your bank card.

Here we will do some very simple tests with reading some public zones of the card to establish the basic capabilities of each card. The functional specifications of bank cards are public (EMV Co), and in addition the cards also contain a lot of proprietary data objects (which we cannot decode).

Students are asked not to try anything with their current UK bank card. We will experiment with some old and foreign bank cards.

16.1 Select The Master File

We will implement the beginning of a bank transaction.

The main file in a bank card is always called: 1PAY.SYS.DDF01 or in hex: 31 50 41 59 2E 53 59 53 2E 44 44 46 30 31

We will send the following command:

SELECT FILE by an AID

CLA	INS	P1	P2	Lc	DataIn
00	A4	04	00	0E	31 50 41 59 2E 53 59 53 2E 44 44 46 30 31

16.2 Answer Status

Answer: .

The answer is typically:

SW1	SW2
61	Le

Where

61 == Normal Processing.

Le = the length of the file 1PAY.SYS.DDF01.

Errors:

Some cards return a proprietary error message, for example 6E 00.

It can also be one of the standard error messages:

.

Other cards answer with

SW1	SW2
6A	82

which means FILE NOT FOUND. For example certain cards from MasterCard. For these at least, all is not lost. We we can skip this and the next sub section and **go directly to Section 16.5** (!).

16.3 Select The Master File

In the case of Normal Processing (61 Le) one can issue a next command:

GET RESPONSE

CLA	INS	P1	P2	Le
00	C0	00	00	Le

Only then we get the actual file 1PAY.SYS.DDF01. It is always like this with smart cards, very few commands ever return data, especially when the length of the data is long or unknown in advance. One frequently needs to use GET RESPONSE to get the 'response' data from the previous command.

Response obtained:

16.4 FCI

The response here is the so called FCI: File Control Info = status of the file 1PAY.SYS.DDF01 selected.

Exists in many products, in bank cards uses specific conventions. General philosophy:

TLV objects: Tag - Length - Value.
FCI is a sequence of nested TLV objects of the form
6F Ln [8X Ln Object] [8X Ln Object] [8X Ln Object] 90 00
Objects can be nested.

Example from one bank card with some explanations:

```
6F1A 840E 3150..........3031  A508 880102 5F2D 02 656E 9000
 6F: FCI on 26 bytes:
   84: DF Name (14 bytes): 1PAY.SYS.DDF01
   A5: Proprietary Information (8 bytes):
     88: Short File Identifier (1 bytes): 02
     5F2D: Language Preference (2 bytes): en
```

Your own example split into pieces:

16.5 Select The Application

Typically a bank card supports several applications. Applications are identified by AIDs.

Examples of AIDs:

VISA:	a0 00 00 00 03
VISA Debit/Credit:	a0 00 00 00 03 10 10
VISA Credit:	a0 00 00 00 03 10 10 01
VISA Debit:	a0 00 00 00 03 10 10 02
VISA Electron:	a0 00 00 00 03 20 10
VISA Interlink:	a0 00 00 00 03 30 10
VISA Plus:	a0 00 00 00 03 80 10
VISA ATM:	a0 00 00 00 03 99 99 10
MASTERCARD:	a0 00 00 00 04 10 10
Maestro:	a0 00 00 00 04 30 60
Maestro UK:	a0 00 00 00 05 00 01
Maestro UK:	a0 00 00 00 05 00 01 00??
Maestro TEST:	b0 12 34 56 78
Self Service:	a0 00 00 00 24 01
American Express:	a0 00 00 00 25
ExpressPay:	a0 00 00 00 25 01 07 01
Link:	a0 00 00 00 29 10 10
Alias AID:	a0 00 00 00 29 10 10

The application that will be used in a bank transaction is the one that both the card and the terminal support, and the one with the highest priority.

For most UK bank cards, from the logo on the card, it is quite easy to guess that the supported application will be at least one of these:

VISA:	a0 00 00 00 03
MASTERCARD:	a0 00 00 00 04 10 10
Maestro:	a0 00 00 00 04 30 60

Thus we will use AID = .

Its length in bytes is: .

Select The Application by AID

We send the following command:

SELECT FILE by an AID

CLA	INS	P1	P2	Lc	DataIn
00	A4	04	00		

Answer obtained:

SW1	SW2
61	

If the answer was indeed of form '61 Le', we can issue a next command:

GET RESPONSE

CLA	INS	P1	P2	Le
00	C0	00	00	

Response obtained:

16.6 About CLA

Quiz In very standard ISO 7816-4 commands we have typically:

☐ INS=00 ☐ INS=04

Quiz In GSM commands we have typically:

☐ INS=00 ☐ INS=A0

Quiz Nonstandard/proprietary commands and specific commands defined in the EMV standard use frequently:

☐ INS=80 ☐ INS=00

16.7 Initiate Application Processing

This informs the card that a new transaction will begin.

The terminal executes GET PROCESSING OPTIONS with a parameter, that are OPTIONAL optional terminal-resident data objects (specified by a PDOL object provided by the card). We will assume here that this option is not used (most of time it is the case) and therefore there will be no terminal-resident data objects.

We send the following command:

GET PROCESSING OPTIONS

CLA	INS	P1	P2	Lc	DataIn	Le
80	A8	00	00	02	8300	00

where Le = 0 is assumed.

Answer obtained:

SW1	SW2
61	

If the answer was indeed of form '61 Le', we will be able to recover the answer:

GET RESPONSE

CLA	INS	P1	P2	Le
00	C0	00	00	

Response obtained:

Here the card returns both:

1. Application Interchange Profile (AIP): supported functions (for example that the card supports SDA or DDA, and if the card supports Cardholder verification)
2. Application File Locator (AFL): pointers to application data available

(At this stage the terminal also sees if the card has stored records of transactions preformed offline. These will be taken into account in Terminal Risk Management).

16.8 Read Application Data

Now the terminal may read from the card all the data specified by the AFL.

If one objects repeats, some AFL object is missing, or some mandatory object is not in AFL, or any kind of errors occurs, the terminal terminates the transaction.

However according to the EMV spec it is not required that card verifies that the terminal conforms to all of this

Therefore we skip this stage.

16.9 Offline Data Authentication

Here SDA, DDA or CDA can be performed.

This part is optional, or more precisely it can be performed later, and typically the card does not check if it was performed.

We skip this part too.

16.10 Cardholder Verification

In EMV many cardholder authentication methods are supported. But by default most cards with PIN support the simplest **unencrypted** PIN verification (the PIN is sent in cleartext to the card).

Warning: typically, **if one enters incorrect PIN 3 times, the card chip will be blocked forever !**

Before we try the PIN verification, let's check how many trials are left.

Checking PIN Limits

Now we are able to read the field that contains the number of trials left for PIN checking. We issue the following EMV command in two parts, first is needed the determine the size of the file to retrieve:

EMV GET DATA OBJECT '9F 17'

CLA	INS	P1	P2	Le
80	CA	9F	17	00

Answer obtained:

SW1	SW2
6C	

If the answer was indeed of form '6C Le', we will be able to recover the answer:

EMV GET DATA OBJECT '9F 17'

CLA	INS	P1	P2	Lc
80	CA	9F	17	

Response obtained:

FID	Le	Result	OK
9F 17	01		

Thus there are ____ PIN tries left.

Checking the PIN

One should only do it if one actually knows the PIN and one is absolutely certain if it is correct. Otherwise after ____ tries the card will never work again.

To verify the PIN, we will use a standard ISO command (that also exists in GSM cards and in many other cards). Here the PIN is the PIN pertaining to a the current application, (not to the whole multi-application card), and for this reason P2='80'.

One needs also to know how to encode the PIN and the special padding that extends it to 8 bytes.

The encoding is somewhat strange, we simply write the decimal PIN as text, treat it as a hex number, 4 digits makes 2 bytes, then we prepend '24', and append five times 'FF'. Thus we get 8 bytes.

VERIFY CHV with DF-specific password (P2=80)

CLA	INS	P1	P2	Lc	DataIn
00	20	00	80	08	24 (PIN in text) FF FF FF FF FF

The answer will be:

If the PIN is correct, the answer should be 90 00.

Please **don't** try to find out what is the answer when the PIN is incorrect. This is very risky. If the PIN is already blocked, the answer is:

SW1	SW2
69	84

This bank card will not work anymore.

If the PIN is incorrect, but we have still several cardholder verification attempts left, the answer will be:

SW1	SW2
63	C

Where is the number of PIN attempts left before the card will block itself forever.

Remark: From this we see that current bank cards have the capacity to process at least twice longer PINs than commonly used (could be also be longer with a better encoding). However very few banks use longer PINs.

16.11 Further Exploration: chap.py

Adam Laurie wrote an open-source program to explore a bank card. It is far from being perfect and 100 % compatible. Use at your own risk.

```
cd C:\Program Files\rfidiot
chap.py -h
```

```
 ChAP.py [options] [PIN]

If the optional numeric PIN argument is given,
the PIN will be verified
(note that this updates the PIN Try Counter
and may result in the card being PIN blocked).

Options:

        -a              Bruteforce AIDs
        -A              Print list of known AIDs
        -d              Debug - Show PC/SC APDU data
        -e              Bruteforce EMV AIDs
        -f              Bruteforce files
        -h              Print detailed help message
        -o              Output to files ([AID]-FILExxRECORDxx.HEX)
        -p              Bruteforce primitives
        -r              Raw output - do not interpret EMV data
        -t              Use T1 protocol (default is T0)
        -v              Verbose on
```

Warning: with the wrong PIN one can block the card totally!

17 How to Become a Smart Card Developer

Any student vaguely familiar with Microsoft Visual Studio should be able start developing smart card applications in 10 minutes. Below we explain how and give example source code. More examples are found in the files provided to students.

17.1 How to Send and Receive Commands

In fact, very little is needed to make an application that is able to communicate with a smart card, everything is implemented in a Microsoft winscard library and winscard.dll which is included by default in all modern versions of Windows and does not require any installation.

To use it we need the following two lines:

```
#include "winscard.h"
#pragma comment(lib, "winscard.lib")
```

This will give us PC/SC Support in our program: we will have access to functions such as SCardConnect, SCardBeginTransaction, SCardStatus, SCardTransmit etc. A number of examples on how to use these functions is given in the Microsoft MSDN documentation. However this documentation is insufficient to produce working code. in fact these instructions need to be used in a certain sequence in order to work properly. In the most recent book about Smart Cards edited by Keith Mayes *et al* from Royal Holloway, authors provide a short example source code showing the right sequence. However the code in the printed version of the book is incorrect and has several bugs that are not easy to fix. We give a corrected version below.

```
//written by NCourtois based on MSDN help files
//and RHUL 2006 book example code (none worked initially)
#include "winscard.h"
#pragma comment(lib, "winscard.lib")

typedef unsigned int        ui32;
#define PCSC_ERROR(rv, text) \
if (rv != SCARD_S_SUCCESS) \
{ \
printf(text ": %s (0x%lX)\n", pcsc_stringify_error(rv), rv); \
} \
else \
{ \
printf(text ": OK\n\n"); \
}
void print_hex(const byte* pbtData, const ui32 uiBytes)
{
  ui32 uiPos;

  for (uiPos=0; uiPos < uiBytes; uiPos++)
  {
    printf("%02X ",pbtData[uiPos]);
  }
  printf("\n");
}
void print_hex_nocr(const byte* pbtData, const ui32 uiBytes)
{
  ui32 uiPos;

  for (uiPos=0; uiPos < uiBytes; uiPos++)
  {
    printf("%02X ",pbtData[uiPos]);
  }
  //printf("\n");
}

int readhex(BYTE *bSend,char *Text)
{
int i=0,j=0;
while(Text[j])
{
while(!IsHex(Text[j]) && Text[j])
j++;
if(Text[j]) if(IsHex(Text[j]))
{
if(IsHex(Text[j+1]))
{
bSend[i]=(ReadHex(Text[j])<<4) + ReadHex(Text[j+1]);
j+=2;
}
else
{
```

```
bSend[i]=ReadHex(Text[j]);
j++;
};
i++;
};
};
return i;
};

int PCSCExample(int readernb)
{
SCARDCONTEXT hContext;  LONG lReturn,lReturn2;
// Establish the context.
lReturn = SCardEstablishContext(SCARD_SCOPE_USER,NULL,NULL,&hContext);
if ( SCARD_S_SUCCESS != lReturn )
PCSC_ERROR(lReturn, "SCardEstablishContext")
else
{
// Use the context as needed.
SCARDHANDLE     hCardHandle;
DWORD           dwAP;

//now list the readers
LPTSTR  pmszReaders = NULL;//16-bit UNICODE characters
LPCTSTR AReader = NULL; LPCTSTR LastReader = NULL;
LPCTSTR MyReader = NULL;
//char WantReader2[] = "ACS ACR122";
DWORD           cch = SCARD_AUTOALLOCATE;
SCARD_IO_REQUEST *pioSendPci=NULL;
SCARD_IO_REQUEST *pioRecvPci=NULL;

lReturn = SCardListReaders(hContext,NULL,(LPTSTR)&pmszReaders,&cch );
if ( lReturn == SCARD_S_SUCCESS )
{
int nbReaders=0;
AReader = pmszReaders;
while ( '\0' != *AReader )
{
LastReader=AReader;
nbReaders++;
```

```
// Display the value.
/*sprintf(CurrReader,"%S", AReader );
if(
strnicmp(CurrReader,WantReader1,6)==0 ||
strnicmp(CurrReader,WantReader2,6)==0
)
break;//*/
if(readernb==nbReaders-1)
{
MyReader=AReader;
}
// Advance to the next value.
AReader = AReader + wcslen(AReader) + 1;
};
if(readernb>nbReaders-1 && nbReaders>0)
{
MyReader=LastReader;
};
//now take MyReader
if(nbReaders>0)
{
printf(" Reader: %S\n", MyReader );
lReturn = SCardConnect( hContext,
(LPCTSTR)MyReader,SCARD_SHARE_SHARED,
SCARD_PROTOCOL_T0 | SCARD_PROTOCOL_T1,
&hCardHandle,&dwAP );
if ( SCARD_S_SUCCESS != lReturn )
{
PCSC_ERROR(lReturn, "SCardConnect")
return -1;  // Or other appropriate action.
}
// Use the connection.
// Display the active protocol.
switch ( dwAP )
{
case SCARD_PROTOCOL_T0:
printf("Active protocol T=0\n");
break;
case SCARD_PROTOCOL_T1:
printf("Active protocol T=1\n");
```

```
break;
case SCARD_PROTOCOL_UNDEFINED:
default:
printf("Active protocol unnegotiated or unknown\n");
break;
};

lReturn = SCardBeginTransaction( hCardHandle );
if ( SCARD_S_SUCCESS != lReturn )
PCSC_ERROR(lReturn, "SCardBeginTransaction")

if(1)//determine ATR, does not give anything with contactless
{
WCHAR szReader[200];DWORD cch = 200;
BYTE  bAttr[32]={0};DWORD cByte = 32;
DWORD dwState, dwProtocol;LONG  lReturn;

// Determine the status.
// hCardHandle was set by an earlier call to SCardConnect.
lReturn = SCardStatus(hCardHandle,
szReader,&cch,&dwState,&dwProtocol,
(LPBYTE)&bAttr,&cByte);
if ( SCARD_S_SUCCESS != lReturn )
{
     PCSC_ERROR(lReturn, "SCardStatus")
return -2;     // or other appropriate action
}
else
{
switch ( dwState )
{
case SCARD_ABSENT:
printf("Card absent.\n");
break;
case SCARD_PRESENT:
printf("Card present.\n");
break;
case SCARD_SWALLOWED:
printf("Card swallowed.\n");
break;
case SCARD_POWERED:
printf("Card has power.\n");
break;
case SCARD_NEGOTIABLE:
printf("Card reset and waiting PTS negotiation.\n");
break;
case SCARD_SPECIFIC:
printf("Card has specific communication protocols set.\n");
break;
default:
printf("Unknown or unexpected card state.\n");
break;
}
printf("ATR: ");
print_hex_nocr(bAttr,cByte);
printf("\n");
};
}
switch(dwAP)
{
case SCARD_PROTOCOL_T0:
pioSendPci = SCARD_PCI_T0;
break;
case SCARD_PROTOCOL_T1:
pioSendPci = SCARD_PCI_T1;
break;
default:
printf("Unknown protocol\n");
return -1;
}
//now transmit a single APDU
{
BYTE bSend[256]={0};
DWORD dwSend=0;
BYTE bRecv[32]={0};
DWORD dwRecv=0;
dwRecv = sizeof(bRecv);

dwSend=readhex(bSend, "FF CA 00 00 00");
                      //GET CARD SERIAL NUMBER
```

```
printf("APDU: ");
print_hex_nocr(bSend,dwSend);
printf("\n");
lReturn = SCardTransmit(hCardHandle,
pioSendPci,bSend,dwSend,pioRecvPci,bRecv,&dwRecv );
if ( SCARD_S_SUCCESS != lReturn )
{
PCSC_ERROR(lReturn, "SCardTransmit")
return -3;   // or other appropriate error action
}
else
{
printf("  RE: ");
print_hex_nocr(bRecv,dwRecv);
printf("\n");
};
}
lReturn = SCardEndTransaction(hCardHandle,SCARD_UNPOWER_CARD);
if ( SCARD_S_SUCCESS != lReturn )
PCSC_ERROR(lReturn, "SCardEndTransaction")
lReturn = SCardDisconnect(hCardHandle,SCARD_RESET_CARD);
if ( SCARD_S_SUCCESS != lReturn )
{
PCSC_ERROR(lReturn, "SCardDisconnect")
return -4;  // Or other appropriate action.
};
}
lReturn2 = SCardFreeMemory( hContext,
pmszReaders );
if ( SCARD_S_SUCCESS != lReturn2 )
PCSC_ERROR(lReturn2, "SCardFreeMemory")
}
//When done,
lReturn = SCardReleaseContext(hContext);
if ( SCARD_S_SUCCESS != lReturn )
PCSC_ERROR(lReturn2, "SCardReleaseContext")
};
return 0;
};
//#include <pcsclite.h>//needed only for pcsc_stringify_error
```

```
char* pcsc_stringify_error(const long pcscError)
{
static char strError[75];

switch (pcscError)
{
case SCARD_S_SUCCESS:
(void)strncpy(strError, "Command successful.", sizeof(strError));
break;
case SCARD_E_CANCELLED:
(void)strncpy(strError, "Command cancelled.", sizeof(strError));
break;
case SCARD_E_CANT_DISPOSE:
(void)strncpy(strError, "Cannot dispose handle.", sizeof(strError));
break;
case SCARD_E_INSUFFICIENT_BUFFER:
(void)strncpy(strError, "Insufficient buffer.", sizeof(strError));
break;
case SCARD_E_INVALID_ATR:
(void)strncpy(strError, "Invalid ATR.", sizeof(strError));
break;
case SCARD_E_INVALID_HANDLE:
(void)strncpy(strError, "Invalid handle.", sizeof(strError));
break;
case SCARD_E_INVALID_PARAMETER:
(void)strncpy(strError, "Invalid parameter given.", sizeof(strError));
break;
case SCARD_E_INVALID_TARGET:
(void)strncpy(strError, "Invalid target given.", sizeof(strError));
break;
case SCARD_E_INVALID_VALUE:
(void)strncpy(strError, "Invalid value given.", sizeof(strError));
break;
case SCARD_E_NO_MEMORY:
(void)strncpy(strError, "Not enough memory.", sizeof(strError));
break;
case SCARD_F_COMM_ERROR:
(void)strncpy(strError, "RPC transport error.", sizeof(strError));
break;
case SCARD_F_INTERNAL_ERROR:
```

```
(void)strncpy(strError, "Internal error.", sizeof(strError));
break;
case SCARD_F_UNKNOWN_ERROR:
(void)strncpy(strError, "Unknown error.", sizeof(strError));
break;
case SCARD_F_WAITED_TOO_LONG:
(void)strncpy(strError, "Waited too long.", sizeof(strError));
break;
case SCARD_E_UNKNOWN_READER:
(void)strncpy(strError, "Unknown reader specified.", sizeof(strError));
break;
case SCARD_E_TIMEOUT:
(void)strncpy(strError, "Command timeout.", sizeof(strError));
break;
case SCARD_E_SHARING_VIOLATION:
(void)strncpy(strError, "Sharing violation.", sizeof(strError));
break;
case SCARD_E_NO_SMARTCARD:
(void)strncpy(strError, "No smart card inserted.", sizeof(strError));
break;
case SCARD_E_UNKNOWN_CARD:
(void)strncpy(strError, "Unknown card.", sizeof(strError));
break;
case SCARD_E_PROTO_MISMATCH:
(void)strncpy(strError, "Card protocol mismatch.", sizeof(strError));
break;
case SCARD_E_NOT_READY:
(void)strncpy(strError, "Subsystem not ready.", sizeof(strError));
break;
case SCARD_E_SYSTEM_CANCELLED:
(void)strncpy(strError, "System cancelled.", sizeof(strError));
break;
case SCARD_E_NOT_TRANSACTED:
(void)strncpy(strError, "Transaction failed.", sizeof(strError));
break;
case SCARD_E_READER_UNAVAILABLE:
(void)strncpy(strError, "Reader is unavailable.", sizeof(strError));
break;
case SCARD_W_UNSUPPORTED_CARD:
(void)strncpy(strError, "Card is not supported.", sizeof(strError));
```

```
break;
case SCARD_W_UNRESPONSIVE_CARD:
(void)strncpy(strError, "Card is unresponsive.", sizeof(strError));
break;
case SCARD_W_UNPOWERED_CARD:
(void)strncpy(strError, "Card is unpowered.", sizeof(strError));
break;
case SCARD_W_RESET_CARD:
(void)strncpy(strError, "Card was reset.", sizeof(strError));
break;
case SCARD_W_REMOVED_CARD:
(void)strncpy(strError, "Card was removed.", sizeof(strError));
break;
/* case SCARD_W_INSERTED_CARD:
(void)strncpy(strError, "Card was inserted.", sizeof(strError));
break;
case SCARD_E_UNSUPPORTED_FEATURE:
(void)strncpy(strError, "Feature not supported.", sizeof(strError));
break;//*/
case SCARD_E_PCI_TOO_SMALL:
(void)strncpy(strError, "PCI struct too small.", sizeof(strError));
break;
case SCARD_E_READER_UNSUPPORTED:
(void)strncpy(strError, "Reader is unsupported.", sizeof(strError));
break;
case SCARD_E_DUPLICATE_READER:
(void)strncpy(strError, "Reader already exists.", sizeof(strError));
break;
case SCARD_E_CARD_UNSUPPORTED:
(void)strncpy(strError, "Card is unsupported.", sizeof(strError));
break;
case SCARD_E_NO_SERVICE:
(void)strncpy(strError, "Service not available.", sizeof(strError));
break;
case SCARD_E_SERVICE_STOPPED:
(void)strncpy(strError, "Service was stopped.", sizeof(strError));
break;
case SCARD_E_NO_READERS_AVAILABLE:
(void)strncpy(strError, "Cannot find a smart card reader.", sizeof(strErro
break;
default:
/*(void)snprintf(strError, sizeof(strError)-1, "Unkown error: 0x%08lX",
pcscError);//*/
(void)sprintf(strError, "Unkown error: 0x%08lX",
pcscError);
};

/* add a null byte */
strError[sizeof(strError)-1] = '\0';

return strError;
}
```

17.2 More Examples

Many ready Visual Studio and other development projects examples are provided with our collection of software. Thus one can easily develop Windows applications with or without GUI which talk to smart cards.

1. Many examples can be found in the ACS 122 Software Development Kit which contains examples of code for Borland Delphi 7, Java, MS Visual Basic 6.0, MS Visual Basic.NET 2005, MS Visual C#.NET 2005, MS Visual C++ 2005 (x64) and MS Visual C++ 6.0. See

   ```
   \Smart Cards Lab docs and free software\additional software packages\
   Smart Card Focus ACR122 starter Kit with Sample C++ Code CD 2011
   \Sample Codes\
   ```

2. The source code for several of Spring Card tools and other related ready projects for Microsoft Visual Studio can be found on the Internet or in:

   ```
   \Smart Cards Lab docs and free software\
   APDU tools\SpringCard tools\SDK\pcsc-sdk_1-04\pcsc-sdk_1-04\
   ```

3. Other examples can be found on the Internet (Google code, Source Forge etc.)

4. For example, based on another open source code project, we have developed a simple open-source timing attack that students can extend or improve. It is further discussed below and can be found in

   ```
   \Smart Cards Lab docs and free software\
   APDU tools\TimingAttackDemo\
   ```

18 Timing Attacks

On almost any APDU command in the smart card lab one can try to do a timing attack.

Remark: Please note that most smart card products are protected against timing attacks.

18.1 A Simple Timing Attack Project

For this we use the following program provided to students on a flash disk, and based on a known open-source PC/SC project. The **source code** is also given (so students can directly modify it by opening the .dsw file.)

To simply run it:

```
TimingAttackDemo.exe
```

which can be found in:

```
\Smart Cards Lab docs and free software\APDU tools\
TimingAttackDemo\sources\SCardDemo-Modif\Release\
```

How to use it: First open a reader and then type in an APDU command. Then press APDU button.

The timing information is displayed only in a log file, which will be opened automatically at the end, after the program is closed by pressing OK button.

Important: This timing attack is VERY imperfect, due to the latency of the Windows OS, the USB port and the firmware of the smart card reader. In order to get a precise result, one needs to repeat each command a large number of times. this is also why it appears to freeze or it is slow.

The software provided is very simple: it can only do a loop on a single command, it cannot execute a sequence of commands in a loop, and it cannot power off or reset the card. Please improve it to execute sequences of commands...

18.2 A Timing Attack on MiFare

This is just a very basic demonstration of the core principle. It does not break MiFare authentication but shows that important timing differences can be observed for real life products with extremely simple tools.

Here we will be executing a sequence of just two commands. It does not matter the our tool will also repeat the first command 100 times to have more precise timing.

Let's take a MiFare Classic card with a known key, for example FFFFFFFFFFFF, that is charged into memory. Then we will authenticate for block 0. this gives, for example

```
APDU: FF82200006FFFFFFFFFFFF
Resp:  (90 00)
```

```
T ms: 31.210

APDU: FF8800006000
Resp:  (90 00)
T ms: 62.759
```

In contrast, if the key is wrong, the second command takes much longer:

```
APDU: FF82200006FFFFFF000000
Resp:  (90 00)
T ms: 31.779

APDU: FF8800006000
Resp:  (90 00)
T ms: 136.417
```

Thus somebody that does not have the access to the USB port communications but only to their timing, can infer some information with certainty (for example if the result of some cryptographic check is correct or not).