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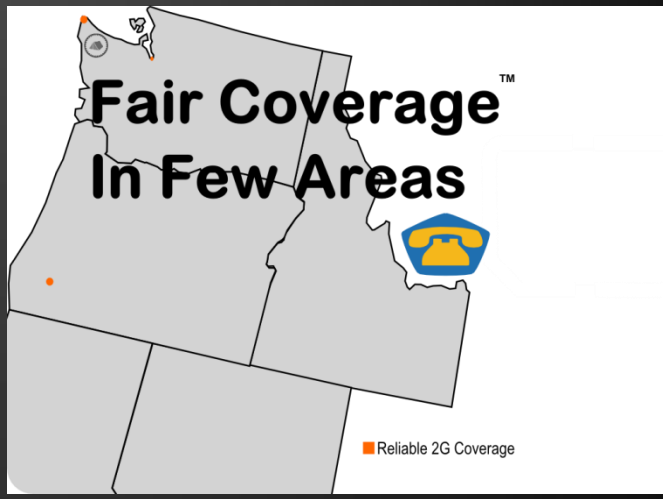
The Secret Life of SIM Cards

Writing, building, loading, and using code on SIM Cards.

Background Story

- Toorcamp 2012!
  - Hacker camp on WA coast
  - Project: Run a GSM network.
  - My task: Procure SIM Cards.



Background Story

- "Subscriber Identity Module"
- Contains an identity (IMSI) and symmetric key (Ki).
- "Secure" (key can't be extracted; can't be cloned)
- Used by GSM carriers and now LTE (Verizon)
- **Can also run apps?!**

SIM Apps?

- Long ago…
  - Applications live on your SIM card.
  - Phones are dumb hosts – UI and connectivity only.
  - Telcos own the SIMs, so they control the applications.
- Mostly obsolete today?

Why is this interesting?

Still around decade later, mostly unchanged.

Why is this interesting?

SIM Cards are mysterious little computers in your pocket that you don't control.

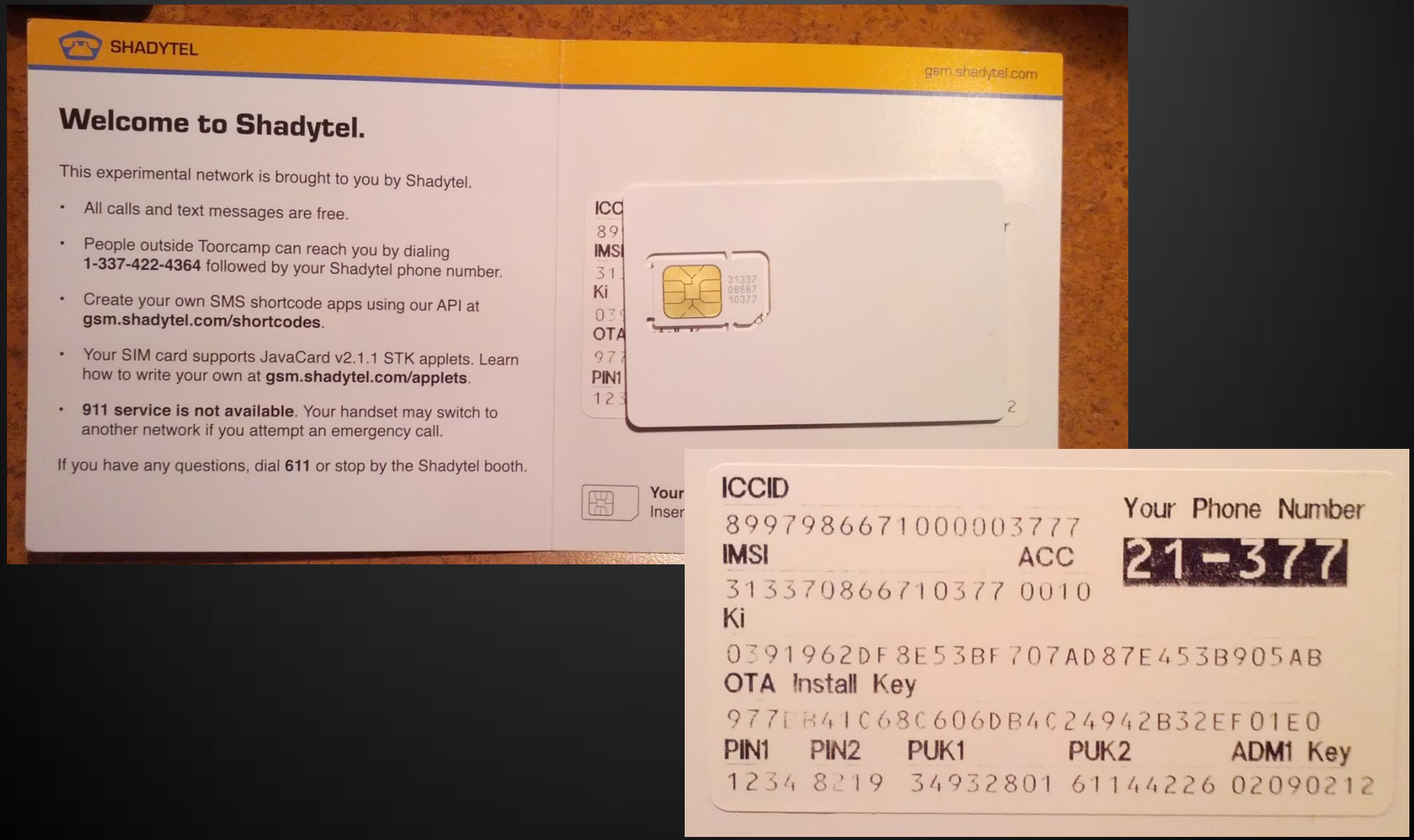
An Opportunity

- Needed SIMs for Toorcamp anyway, why not get SIMs that supported apps?
  - This ended up taking many months.
- Very little documentation about all this.
- After lots of research, finally figured out how to program the *#$!ing things.
- Learn from our misery.

Our SIM Cards

Chip Field	Description
Generic Description	64K JavaCard 2.1.1 WIB1.3 USIM
Platform	Atmel AT90SC25672RU
CPU Architecture	8-bit AVR
Technology	0.15uM CMOS
ROM	256KB ROM Program Memory
Non-volatile memory	72 KB EEPROM
RAM	6 KB
Internal operating frequency	Between 20 & 30 MHz
Endurance	Typically 500 000 write/erase cycles

Our SIM Cards



SIM Applications (Applets)

- Runs on SIM card CPU, separate from phone.
  - Connected directly to baseband.
- Can be silently remotely installed (by carrier).
- Supported by most carrier SIMs.
- Cards support multiple apps, selected by AIDs
  - Apps managed by a "master" card manager app
- GSM "SIM" is actually just an applet on a UICC (the physical card).

What can a SIM Applet do?

- Rudimentary UI – display text, menus, play tones, read input.
  - Works with most modern smartphones.
  - Dumbphones too.
- Launch URLs.
- Send SMSes, initiate calls, initiate and use data services.
- Receive and act on events, such as call connected, call disconnected, etc.
- Interact with the rest of the SIM card.
- Run arbitrary AT commands on the phone.

What can a SIM Applet do?

- Not very common in US
- But used widely in the developing world
  - Mobile banking, etc.

Technologies involved

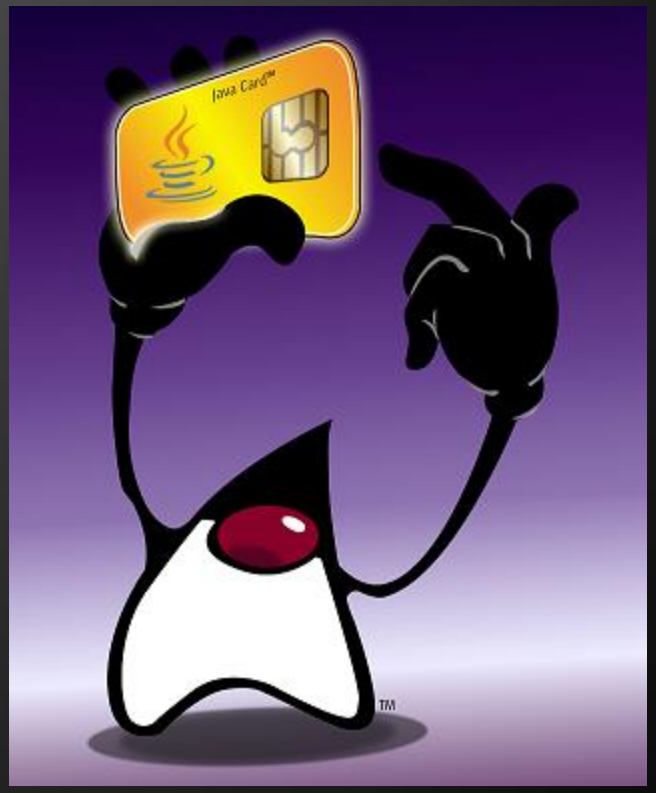
- **Smart Cards** – Physical connection between SIM and phone, same as any smart card.
- **Java Card** – Java for Smart Cards. Easiest way to write applets.
- **SIM Toolkit (STK) API** – Interface between applets and phone UI.
- **GlobalPlatform** – Standard for loading and managing applications on a card.

Smart Cards

- Designed for secure storage and computation
- Communication is via packets called APDUs

Java Card

- It's Java!
- … not really.
  - No garbage collection.
  - No chars, no strings, no floats, no multi-dimensional arrays.
  - ints are optional.
  - No standard API, no threads, etc.
  - Verification can be offloaded.
  - But there are Exceptions!
- Instance and class variables are saved in EEPROM, which has limited write cycles.



Building Java Card Apps

- There are specialized commercial IDEs for this, but you can do without.
- Download the Java Card Development Kit from Oracle (it's free).
- If you're using Eclipse, remove the JRE system library and add the Java Card library
- We also wrote tools to make things easier

Life of an STK app

- App is loaded onto the card.
- App registers itself with the SIM Toolkit API.
- Phone informs STK of its capabilities.
- STK informs the phone about registered apps.
- Selection of an app will trigger an event to be delivered to the app.
- App can then send UI requests back to phone.

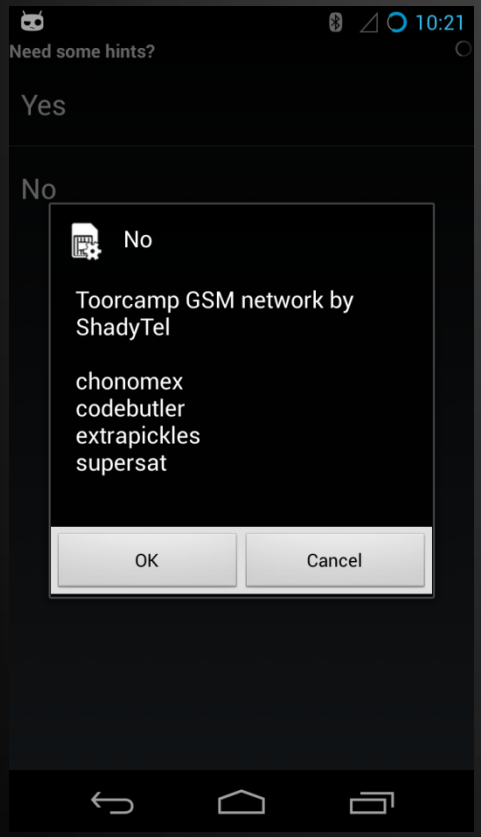
The JavaCard/STK API

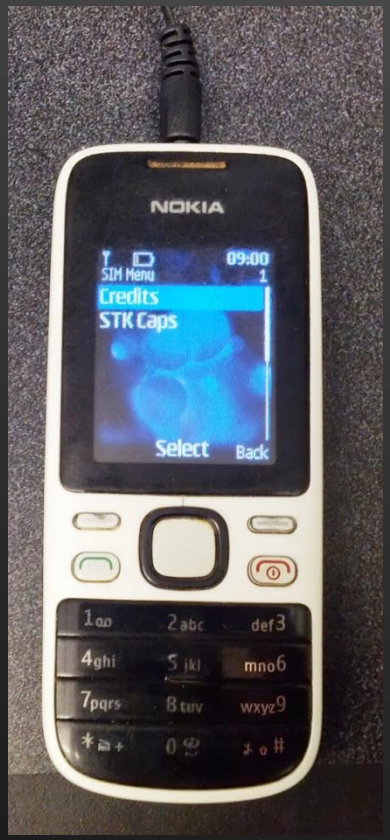
```
public class MyApplet
    extends Applet implements ToolkitInterface
{
    public static void install(
        byte[] bArray,
        short bOffset,
        byte bLength) { /* ... */ }

    public void process(APDU apdu)
        throws ISOException { /* ... */ }

    public void processToolkit(byte event)
        throws ToolkitException { /* ... */ }
}
```

Example STK App: Toorcamp





Example STK App: Toorcamp

```
public class CryptoChallenge extends Applet implements
    ToolkitConstants, ToolkitInterface {

    private byte hintsGiven;
    private byte mainMenuItem;

    private static byte[] menuItemText = new byte[] {
        'C', 'r','e', 'd', 'i', 't', 's' };
    private static byte[] needHints = new byte[] {
        'N', 'e', 'e', 'd', ' ', 's', 'o', 'm', 'e', ' ',
        'h', 'i', 'n', 't', 's', '?'};
    private static byte[] yes = new byte[] { 'Y', 'e', 's' };
    private static byte[] no = new byte[] { 'N', 'o' };
    private static byte[] hints = new byte[] {
                                        'H', 'i', 'n', 't', 's' };
```

Example STK App: Toorcamp

```
private CryptoChallenge() {
    hintsGiven = 0;

    ToolkitRegistry reg = ToolkitRegistry.getEntry();
    mainMenuItem = reg.initMenuEntry(menuItemText, (short)0,
        (short)menuItemText.length, PRO_CMD_SELECT_ITEM, false,
        (byte)0, (short)0);
}

public static void install(byte[] bArray, short bOffset,
                           byte bLength) {
    CryptoChallenge applet = new CryptoChallenge();
    applet.register();
}
```

Example STK App: Toorcamp

```
public void processToolkit(byte event) throws ToolkitException {
    EnvelopeHandler envHdlr = EnvelopeHandler.getTheHandler();
    if (event == EVENT_MENU_SELECTION) {
        byte selectedItemId = envHdlr.getItemIdentifier();

        if (selectedItemId == mainMenuItem) {
            ProactiveHandler proHdlr =
                ProactiveHandler.getTheHandler();
            if (hintsGiven == 0) {
                proHdlr.initDisplayText((byte)0, DCS_8_BIT_DATA,
                    credits, (short)0, (short)(credits.length));
                proHdlr.send();

                hintsGiven = (byte)0x80;
                return;
            }
```

Example STK App: Toorcamp

```
proHdlr.init(PRO_CMD_SELECT_ITEM, (byte)0x00,
    (byte)ToolkitConstants.DEV_ID_ME);

proHdlr.appendTLV((byte)TAG_ALPHA_IDENTIFIER, needHints,
    (short)0x0000, (short)needHints.length);
proHdlr.appendTLV((byte)TAG_ITEM, (byte)1, yes, (short)0x0000,
    (short)yes.length);

proHdlr.appendTLV((byte)TAG_ITEM, (byte)2, no, (short)0x0000,
    (short)no.length);

proHdlr.send();

ProactiveResponseHandler rspHdlr =
    ProactiveResponseHandler.getTheHandler();
byte selItemId = rspHdlr.getItemIdentifier();
if (selItemId == 2) { // No
    proHdlr.initDisplayText((byte)0, DCS_8_BIT_DATA, credits,
        (short)0, (short)(credits.length));
    proHdlr.send();
}
```

Example STK App: Toorcamp

```
public void process(APDU apdu) throws ISOException {
    // ignore the applet select command dispached to the process
    if (selectingApplet())
        return;

    byte[] buffer = apdu.getBuffer();
    if (buffer[ISO7816.OFFSET_CLA] != (byte)0x80)
        ISOException.throwIt(ISO7816.SW_CLA_NOT_SUPPORTED);

    if (buffer[ISO7816.OFFSET_INS] == 0x61) {
        buffer[0] = hintsGiven;
        apdu.setOutgoingAndSend((short)0, (short)1);
        return;
    }

    ISOException.throwIt(ISO7816.SW_INS_NOT_SUPPORTED);
}
```

Building Java Card Apps

- You must target Java 1.1 bytecode! 1.3 source code compatibility is okay.

```
$ javac -cp javacard/lib/api21.jar \
    -target 1.1 \
    -source 1.3 \
    HelloApplet.java
```

Building Java Card Apps

- After you have your .class files, you need to convert them to Java Card bytecode.
  - Use the converter tool in the SDK
  - Need to specify application ID (more on this in a minute), API export directory, etc.

- ```
  java -jar javacard/bin/converter.jar \
    -exportpath javacard/api21_export_files \
    -applet 0xde:0xfc:0x09:0x20:0x13:0x01 \
    com.example.HelloCard.HelloApplet \
    com.example.HelloCard 0xde:0xfc:0x09:0x20:0x13 1.0
  ```
  ```

Building Java Card Apps

- We also have Makefiles for your convenience!
  - http://simhacks.github.io
- Converter outputs a CAP file, which is a ZIP archive of CAP components (JavaCard bytecode).

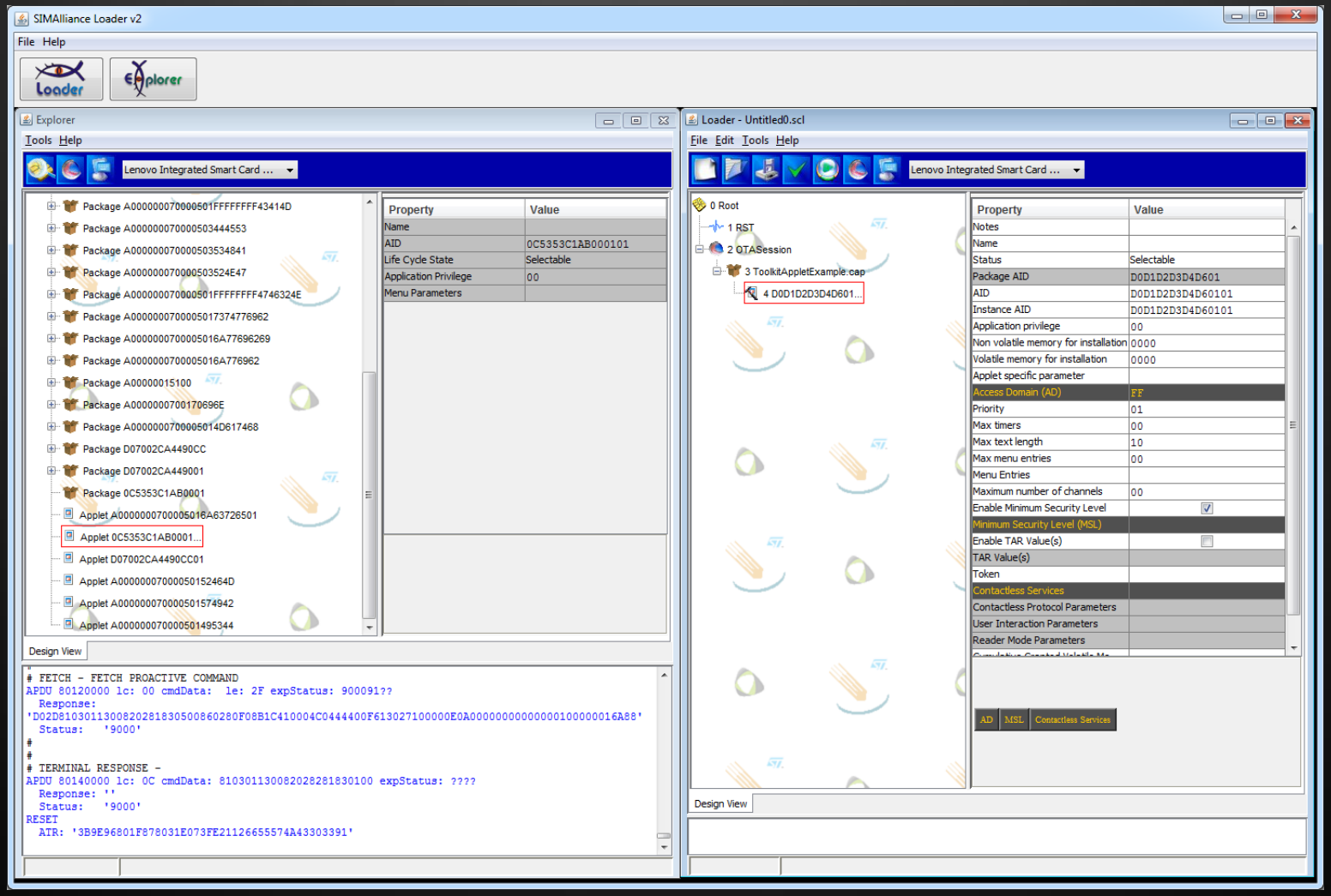
Interfacing with SIM Cards

- Two types of readers:
  - PCSC (PC/Smartcard API)
  - Serial
- Doesn't really matter, but PCSC will be more flexible.
- All readers are the same, so get a cheap one.
  - I like the SCR3500 because it folds up ($8 on ebay).

Interfacing with SIM Cards

- Had an applet ready to go, couldn't get it loaded!
- Tried using popular GPShell tool, no success.
- SIM vendor had recommended software
  - Was no longer available anywhere.
  - They wanted $600 (and they don't even own it…)

SIM Alliance Loader



GlobalPlatform

- A standard for loading and managing apps on Java Cards.
- Defines the *card manager* app.
  - Protocols and commands used.
  - Authentication and encryption.
- Also deals with off-card responsibilities.
  - e.g. issuer needs to verify applet binaries.

GlobalPlatform

- All apps are loaded and authorized by the *Issuer Security Domain* – in practice this means that you can't load apps onto a card you didn't issue yourself :(
  - … or maybe you can – see Karsten Nohl's work!
- On pure GlobalPlatform cards, the ISD is the default app on pre-personalized cards
  - Accessing it on our SIM cards is a lot harder

GlobalPlatform

- Installing an app is a two-step process:
  - Load the binary (LOAD)
  - Instantiate the app (INSTALL)
- Loading an app first requires authorization through the INSTALL for LOAD command
- The individual CAP components are concatenated together and sent in blocks with LOAD
- There are THREE AIDs involved:
  - Application AID – associated with the load file
  - Module AID – associated with the main class
  - Instance AID – used to select a particular instance

Dealing with #$&!ing SIM cards

- The only way to talk to the SIM's ISD is through the over-the-air update mechanism
  - i.e. SMS packets
- We don't have to actually send SMSes, but we need to generate commands to the card with SMS packets

Turtles all the way down (GSM 03.48)

- CAT ENVELOPE (A0 C2)
  - SMS-PP Download (D1)
    - Device Identities
    - SMS-TPDU (GSM 03.40)
      - Header
      - User Data
        - Header
        - Command Packet
          - Header (Security parameters, app selection)
            - Uses a 3 byte TAR ID
              - Holy shit powerpoint supports this much nesting
                - This is the actual limit
          - APDU

Remote OTA

- In case you missed it, you can use this exact mechanism to remotely send APDUs to a SIM card(!!!)
- Cell broadcast can also be used
- Normally you need to authenticate to do this
  - Karsten Nohl: Many errors come back with crypto, which can be used to brute-force the DES key

Shadysim Loader Script

- Python
- Works on OSX, Linux, Windows

- Load:

```
$ shadysim.py \
    --pcsc \
    -l CryptoChallenge.cap
```

Shadysim Loader Script

- Install:

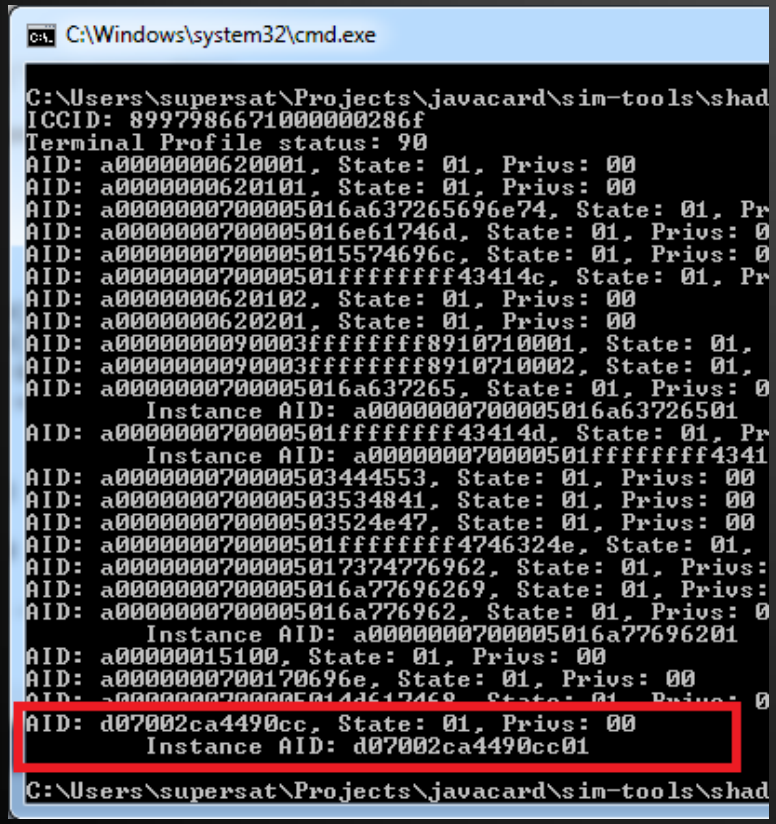
```
$ shadysim.py \
      --pcsc \
      -i CryptoChallenge.cap \
      --module-aid d07002ca4490cc01 \
      --instance-aid d07002ca4490cc0101 \
      --enable-sim-toolkit \
      --max-menu-entries 1 \
      --max-menu-entry-text 10 \
      --nonvolatile-memory-required 0100 \
      --volatile-memory-for-install 0100
```

Shadysim Loader Script

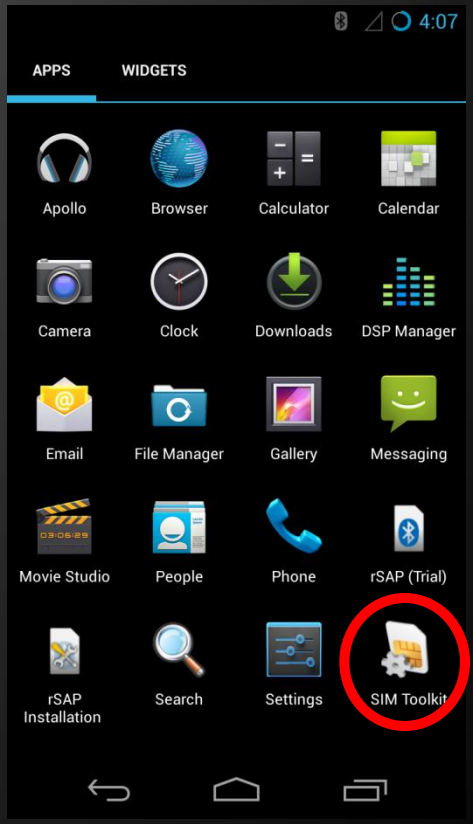
- List apps (not instances):

```
$ shadysim.py \
    --pcsc \
    -t
```

It worked!


C:\Windows\system32\cmd.exe
C:\Users\supersat\Projects\javacard\sim-tools\shad
ICCID: 89979866710000000286f
Terminal Profile status: 90
AID: a0000000620001, State: 01, Privs: 00
AID: a0000000620101, State: 01, Privs: 00
AID: a00000007000005016a637265696e74, State: 01, Pr
AID: a00000007000005016e61746d, State: 01, Privs: 0
AID: a00000007000005015574696c, State: 01, Privs: 0
AID: a00000007000005 01ffffffff43414c, State: 01, Pr
AID: a0000000620102, State: 01, Privs: 00
AID: a0000000620201, State: 01, Privs: 00
AID: a00000000900003ffffffff8910710001, State: 01,
AID: a00000000900003ffffffff8910710002, State: 01,
AID: a00000007000005016a637265, State: 01, Privs: 0
Instance AID: a00000007000005016a63726501
AID: a00000007000005 01ffffffff43414d, State: 01, Pr
Instance AID: a00000007000005 01ffffffff4341
AID: a00000007000005 03444553, State: 01, Privs: 00
AID: a00000007000005 03534841, State: 01, Privs: 00
AID: a00000007000005 03524e47, State: 01, Privs: 00
AID: a00000007000005 01ffffffff4746324e, State: 01,
AID: a00000007000005017374776962, State: 01, Privs:
AID: a00000007000005016a77696269, State: 01, Privs:
AID: a00000007000005016a776962, State: 01, Privs: 0
Instance AID: a00000007000005016a77696201
AID: a00000015100, State: 01, Privs: 00
AID: a00000007001706 96e, State: 01, Privs: 00
AID: d07002ca4490cc, State: 01, Privs: 00
Instance AID: d07002ca4490cc01
C:\Users\supersat\Projects\javacard\sim-tools\shad


Settings
Phone
Calls
Call Forwarding
Call Waiting
Show My Caller ID
TTY
OFF
SIM PIN
SIM Applications
AT&T Services


4:07
APPS
WIDGETS
Apollo
Browser
Calculator
Calendar
Camera
Clock
Downloads
DSP Manager
Email
File Manager
Gallery
Messaging
Movie Studio
People
Phone
rSAP (Trial)
rSAP Installation
Search
Settings
SIM Toolkit

Applet Testing flow

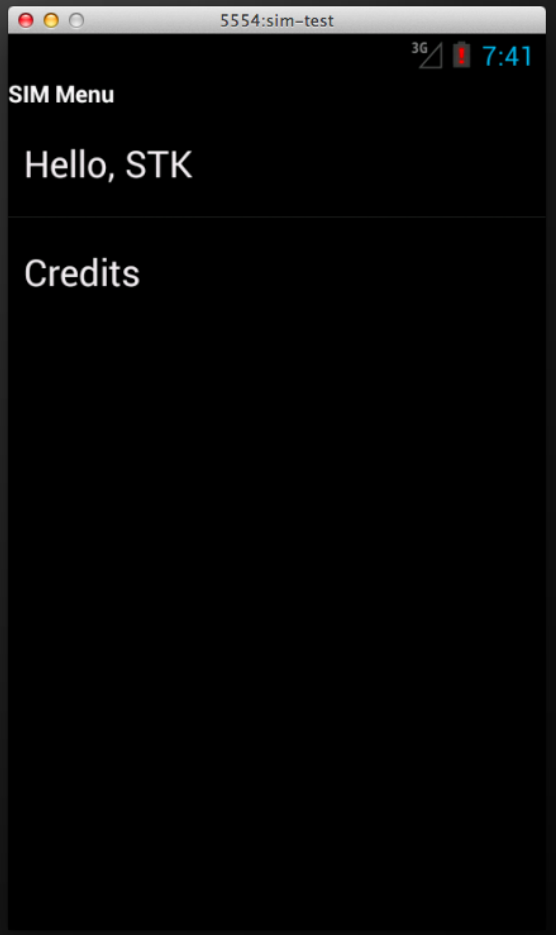
- Turn off phone
- Take out SIM card (and often battery too).
- Put SIM card into reader.
- Load new code.
- Take SIM card out of reader.
- Place back into phone (and replace battery).
- Wait for phone to boot.
- See if code works.

Testing flow: Yikes.

- Can we do any better?

SIM Cards in Android Emulator!

- SEEK: Open-source Android SDK for smart cards.
- Includes patches to Android emulator for SIM access using USB PCSC reader!
- Avoid hassle of swapping SIM between computer and phone.



Using phone as reader?

- Most radio interfaces don't provide support for this.
- Remote SIM Access Protocol may provide solution.
  - Reverse-engineered protocol/auth scheme.
  - Need to write app that sends/receives APDUs.

Future Directions

- STK apps are pretty limited, but there is potential for awesomeness
  - SIM card botnet?
- Integrating Android apps with SIM applets
  - SSH private keys secured on your SIM?
  - Secure BitCoin transactions?
  - What else?
    - Of course, we need carriers to get on board
- Android app for OTA installs?

Future Directions: NFC

- SWP: Single Wire Protocol
  - Direct connection between SIM card and NFC controller.

- SIM Card acts as "secure element".
- Used by ISIS (mobile payment system from telcos/banks)
- Attempt by carriers to regain control lost from app stores.

Future Directions: Secure Element

- Chip inside most android phones today.
- Typically part of the NFC controller
- Same technology as SIM cards.
- Used by Google Wallet.

More info at:
http://nelenkov.blogspot.com/2012/08/accessing-embedded-secure-element-in.html

Learning More

- We've made it easy to get started.
- Few hardware requirements (<$20).
- See us for SIM cards (EFF donation)!

http://simhacks.github.io/

- These slides.
- Much more technical details.
- JavaCard makefiles.
- Scripts for managing applets.
- Patched Android emulator/system image.
- Much more!

Thanks!

Please contact us with any questions.

- Karl Koscher – @supersat
- Eric Butler – @codebutler