Android – Dynamic Analysis

REVERSE ENGINEERING

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Dynamic Analysis

Static Analysis: Open the application and deduct how it works

Researcher must deduct the Data Flow

External Data or Actions may change the application behavior

- Change the code path
- Inject instructions

Issues may be found on the sequence of events, or on the state machine

Dynamic Analysis: Observe the application while it is running, allowing to obtain information about the dynamic characteristics.

Dynamic Analysis

- **Look into specific aspects of an application, while it is executing**
- **Objective**: Observe dynamic behavior of the application and determine the role of each code
- **What can be analyzed**
  - Messages exchanged with external servers (REST APIs, Web Sockets)
  - Intents sent or received
  - Logs printed (errors, debug messages)
  - Files accessed/created
  - Memory Content
  - With code instrumentation: calls to methods, especially Android API methods

Logs

- The Android log can be used to dynamically analyze relevant aspects of application execution
  - Explicit log entry produced by the application or by system components
  - Implicit logs produced with errors
    - Exceptions produce stack traces which expose call flow
  - Some system events
  - May be used to detect leaks

$ adb logcat

Network MiTM

- **Interactions with external APIs can be intercepted and analyzed**
  - Useful to identify communication with domains with low reputation
  - Useful to identify unprotected communications
    - Especially dangerous if dealing with authentication, private data or download of dynamic components

- **Black box approach**: observe how the app behaves
  - We may simply observe
  - … or we manipulate/filter traffic

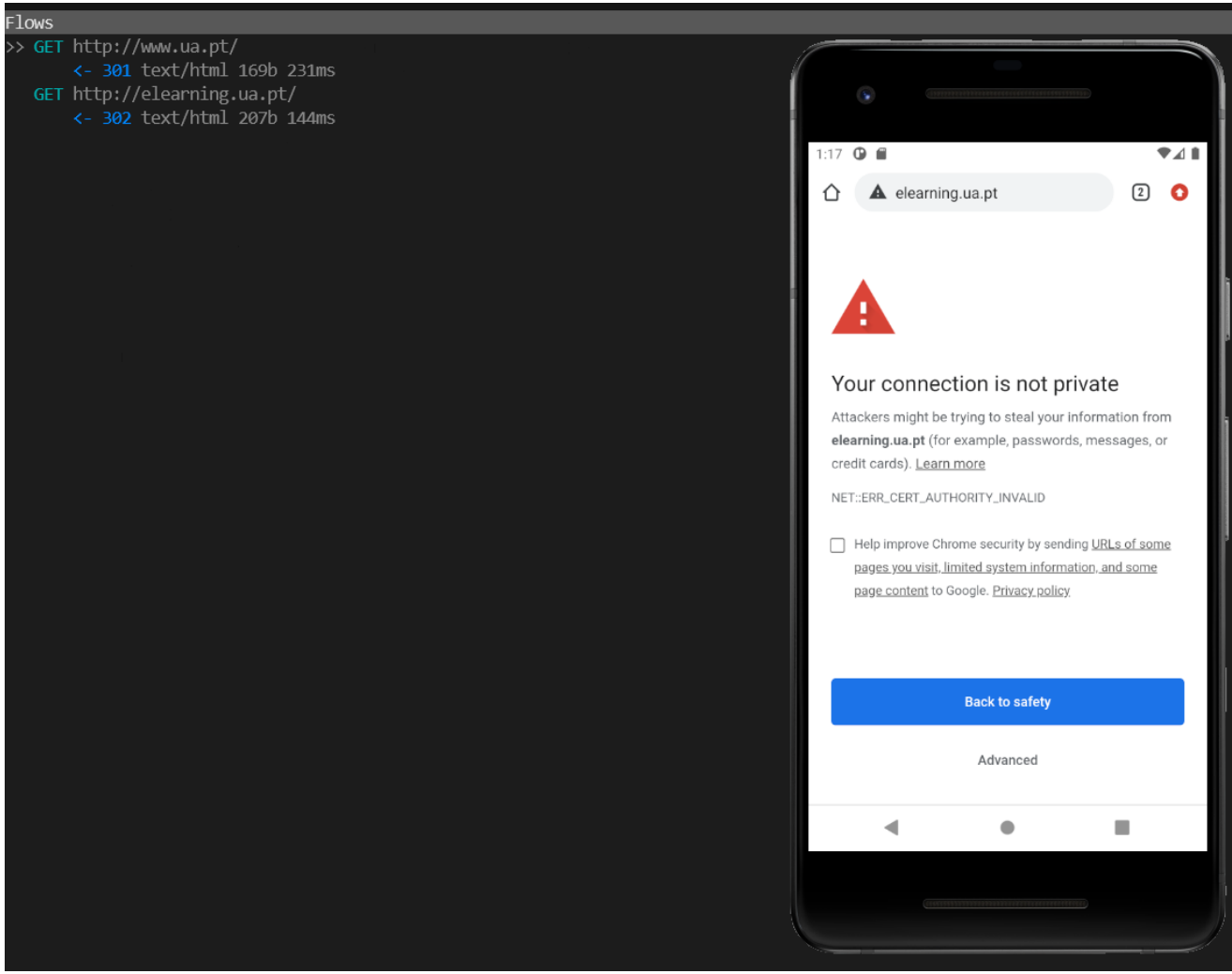
Network MiTM

- **Packet Dumps**
  - run applications and capture traffic with a packet sniffer
  - Non encrypted APIs can be analyzed with ease
    - The endpoint IP address may constitute an indicator by itself
      - Communication with flagged domains, validation that a service is invoked
  - Using wireshark (androiddump)

- **Traffic flows**
  - run applications with a HTTP/HTTPS proxy configured to intercept all traffic
  - injecting a CA Certificate in the device allows generating custom certificates for secure endpoints

Traffic Flows

- Using an HTTP proxy with Active TLS interception capability
  - Proxy will generate certificates for all hosts accessed
  - Certificates are signed by a single CA
  - CA must be installed to the device



Using mitmproxy, without CA installed
Alternatives: Charles, ZAP, Burp

Trusted Certificates

- Standard X509 certificates in PEM format
  - Preinstalled by the manufacturer
  - Cannot be changed by users
  - Users can add custom certificates, but they are frequently ignored by the applications
- On an Android system, trusted roots are at `/system/etc/security/cacerts`
  - Folder with PEM certificates
- /system partition is read only on release devices
  - In recent versions of Android the same is also true for the emulator
  - Alternative: mount a tmpfs at the certificate location
    - But changes are lost on reboot

Using mitmproxy, with CA installed

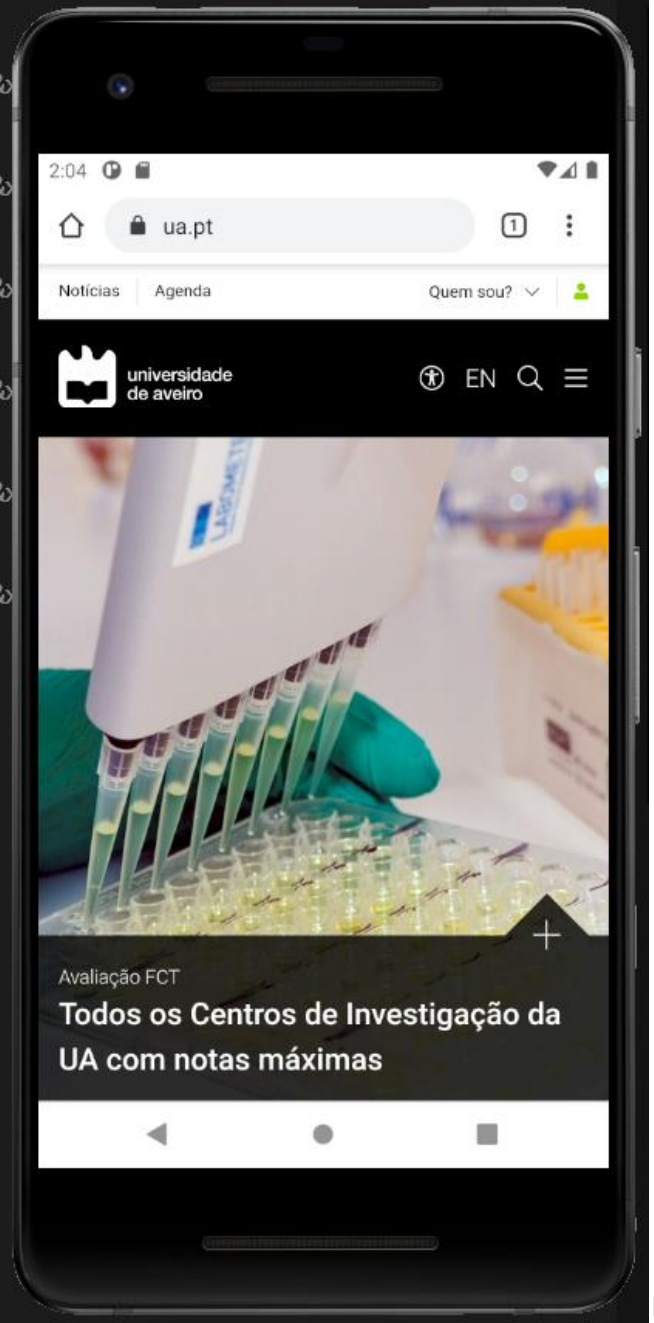
```
com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&xssi=t&q=&oit=0&gs_rn=42&sugkey=AIzaSyBOti4m

ript 95b 199ms
com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&

GET https://www.google.com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&
    w5A8wcQ… HTTP/2.0
    <- 200 text/javascript [content missing] 1ms
GET https://www.google.com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&
    _w5A8wc… HTTP/2.0

GET https://www.google.com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&
    =_w5A8w… HTTP/2.0
    <- 200 text/javascript [content missing] 1ms
GET https://www.google.com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&
    psi=_w5… HTTP/2.0

GET https://www.google.com/complete/search?client=chrome&gs_ri=chrome-mobile-ext-ansg&
    2&psi=_… HTTP/2.0
    <- 200 text/javascript 104b 190ms
GET https://www.ua.pt/ HTTP/2.0
    <- 304 [no content] 263ms
GET https://www.ua.pt/static/css/bundle.24c9cca8.css HTTP/2.0
    <- 304 [no content] 277ms
GET https://www.ua.pt/static/js/bundle.24c9cca8.js HTTP/2.0
    <- 304 [no content] 350ms
GET https://www.ua.pt/styles/bootstrap-grid.min.css HTTP/2.0
    <- 304 [no content] 270ms
GET https://www.ua.pt/fontawesome/css/all.css HTTP/2.0
    <- 304 [no content] 303ms
GET https://www.ua.pt/styles/entypo.css HTTP/2.0
    <- 304 [no content] 364ms
GET https://www.ua.pt/styles/slick.min.css HTTP/2.0
    <- 304 [no content] 403ms
GET https://www.ua.pt/styles/slick-theme.min.css HTTP/2.0
    <- 304 [no content] 392ms
GET https://www.ua.pt/styles/system-bar.css HTTP/2.0
    <- 304 [no content] 381ms
GET https://www.ua.pt/fontawesome/webfonts/fa-light-300.woff2 HTTP/2.0
[1/33]                                                              [*:9090]
```



Network MITM - Limitations

- Packet dumps are limited to unprotected text and metadata
  - Again… it is still relevant as it may produce a valid indicator

- Traffic flow analysis is limited to devices where a CA can be injected
  - And where the APP will not use custom CA Certificates
  - And where the APP will not use Certificate Pinning

Certificate Pinning

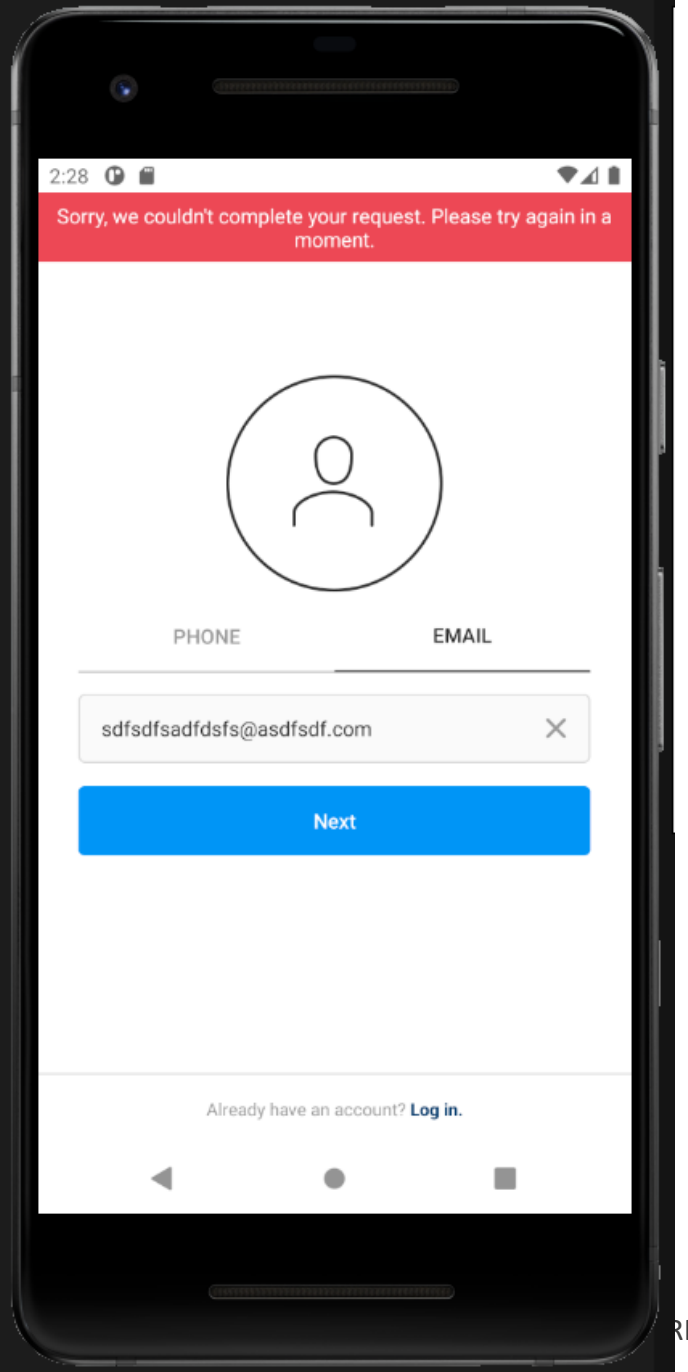
- **Applications put constraints on the certificates used for verification (Trusted Roots)**
  - They fix (Pin) a certificate/pub key/hash to a hostname
  - Validation of the host authenticity (in TLS) will also include this additional constraints

- **Impact**
  - A Trusted Root can be injected but it will be ignored
    - Application will simply not use it
    - Or the application will have additional checks with detect the injection

Certificate Pinning - Approaches

- Applications extend the X509TrustManager, overriding the checkServerTrusted method, with custom checks
  - E.g. the Certificate/Public Key/hash is hard coded, and this value is used to validate the certificate
- Using a KeyStore with a predefined list of certificates, ignoring other sources
  - Pins the host certificate
  - Pins an intermediate Certification Authority
  - Pins a Root Certification Authority
- Pinning may create issues for developers as changes to certificates or PKI must be reflected to the applications
  - Soft Fail: just let the application work, even if with limited functionality
  - Hard Fail: an update is forced for the application to work

Flows



Applications using Pinning will not communicate through a proxy

Certificate Pinning - Circumvention

- **If restricted KeyStores are used:** use an emulator or rooted device
  - Enables free manipulation of the keystores, injecting custom certificates
  - Inject certificates to the system keystores

- **If Pinned with hard coded information:** modify the application
  - Unpack the application
  - Edit the code, changing the Pin or removing it
    - `smali` may be enough and full decompilation to java is not required
  - Repack and install the application

Dynamic Code Instrumentation

- Applications are implemented with functions
  - Functions have addresses that may be determined
    - Or subverted
  - Java uses further abstractions when using native code
    - Creating strict interaction points towards which is possible to access the external world

- This enables the possibility of manipulating symbols/addresses to instrumentalize code
  - Observe internal structure of the program flow
  - Inject new code by replacing the implementation of a function represented by a symbol

Dynamic Binary Instrumentation - Why

- Requests to APIs are further encrypted, signed or MITM is not available
  - MITM and packet sniffers are useless
- Application has obfuscated values in RAM, created dynamically, received from the network
  - Static analysis and Decompilation is useless
- Code is loaded dynamically with objects received
  - Static analysis and Decompilation will have no code to analyze
- Many values are hard coded (keys, urls…)
  - Patching takes too long and becomes expensive

Custom Signatures are used

```
POST /login HTTP/1.1
Host: social.io
Proxy-Connection: keep-alive
Content-Length: X
Accept: text/html, application/xhtml-
xml,application/xml;q=0.9,image/webp,*/*,q=0.8
Origin: http://social.io
Content-Type: application/x-www-form-urlencoded
Cookie: SessionId=O+qxnaYZLjpnLwHBcKmRcTexTWk=

username=john&password=xpto&signature=2rf+roJPEdCOSL0XXusHBcA0BGk=
```

Data is encrypted

```
POST /login HTTP/1.1
Host: social.io
Proxy-Connection: keep-alive
Content-Length: X
Accept: text/html, application/xhtml-
xml,application/xml;q=0.9,image/webp,*/*,q=0.8
Origin: http://social.io
Content-Type: application/x-www-form-urlencoded
Cookie: SessionId=O+qxnaYZLjpnLwHBcKmRcTexTWk=

authData=3NH71S+7P8YeafgnBvXzJ1RzJdXm51VNPQYMWFiIMl8ZNr7+vGDNTcms8LHDUaC/lK2xRF/L
bPMwQ0pB+ZyB6PfYNaf5fIh/IGdlQZJrgXXgDDT7Mn2d259vzcdmBA3pJ04cLxGNnLSvdorYF+mLN7yik
zEagUWGfQe1nYzu3OT3947kqSORQuc4PTzuFKUXlolCcuVYvr5gt6ykfk9ACGVwyywGBG3OeFxNKi0kme
iBYxB8EJlmCF/xojM59gcGDv61ytidhVs=
```

Many others

- Retrieving a call flow
  - Map which methods are used, and what is the actual code execution flow
- Identify arguments of Android API methods
  - Log traffic and calls
  - Allows intercepting data even with encrypted connections
    - Interception happens before data is encrypted
- Modify arguments of Android API methods
  - Fuzzing
  - Filter/modify data to trigger additional behavior
  - Trigger custom events
- Circumvent protections to enable further analysis
- Application is obfuscated and it is difficult to obtain the actual algorithm

FRIDA – How?

- Set of tools (framework) for Dynamic Code Instrumentation
  - Instruments the Application Code with hooks
  - Not specific for Android, and may be used on other applications and Operating Systems

- Allows:
  - Tracing network communications at the method level
  - Understand how the application behaves
  - Manipulate the methods called, arguments and return codes
  - …

FRIDA – How?

- Frida-core injecting a Google V8 JS Engine into the App scope
  - Frida-core Written in C
  - GumJS (the JS part) is packed as a shared library and loaded into the app
- GumJS has access to the application memory
  - Can be hooked to methods and intercept calls, even native APIs
- GumJS API allow interaction with GumJS from an external client
  - Because GumJS resides the application address space, it has full access to its structures

FRIDA – mode Embedded

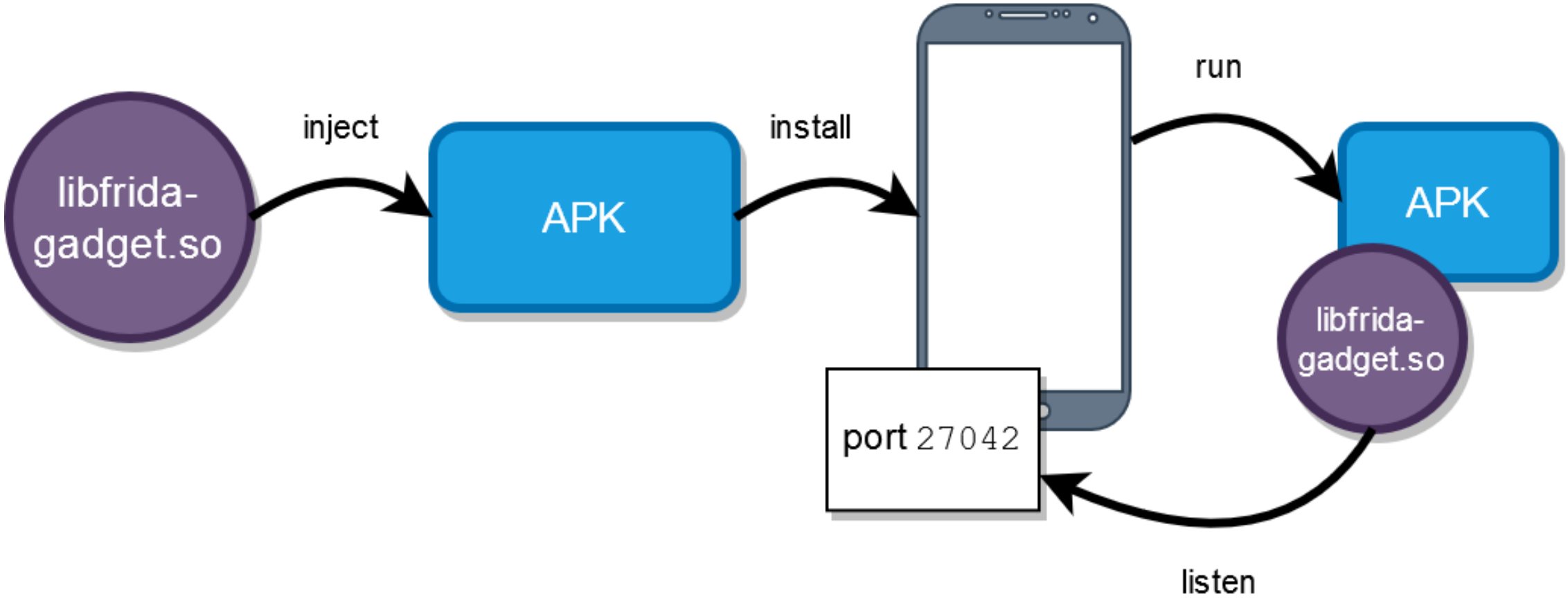
- Frida agent is embedded as a dependency of an existing application library
  - Requires the application to have an .so
  - `libfrida-gadget.so` is injected into the existing library and loaded at the same time

- Alternative: existing library is modified in order to load the additional library
  - Requires patching the code in a function will be called (e.g. `JNI_OnLoad`)

- Alternative: patching the `smali` code to load the library
  - Obtain APK
  - Extract smali
  - Change smali
  - Pack it and install

- Method implies that the application is repacked/resigned

FRIDA – mode Embedded



FRIDA – mode Embedded – How?

```
$ apktool d app.apk
$ cp libfrida-gadget.so target/lib/arm
$ python3
>>> import lief
>>> native = lief.parse(“target/lib/arm/libsomething.so”)
>>> native.add_library(“libfrida-gadget.so”)
>>> native.write(“target/lib/arm/libsomething.so”)
>>> exit

$ apktool b target
… sign … install
```

FRIDA – mode Embedded – Smali - How

- Unpack the app using `apktool`
- Patch the `smali` with

```
const-string v0, "frida-gadget"
invoke-static {v0}, Ljava/lang/System;->loadLibrary(Ljava/lang/String;)V
```

- Where? In the main activity constructor
  - Even in as a static property of the class
- repack, sign, install

FRIDA – mode Embedded - Caveats

- Applications may search for the library name as an anti-debug technique
  - May need to change the library name
- Must use a version compatible with the target architecture
  - https://github.com/frida/frida/releases
- Agent may only be loaded after the JNI library is loaded or code is reached
  - After `System.loadLibrary("lib.so")`
- Agent may impose the need for permissions to access the INTERNET
  - Manifest may need to be updated

FRIDA – mode Injected

- Run a Frida Server which injects the agent into the target process
  - Server provides an API for remote use
  - Server injects the agents into applications

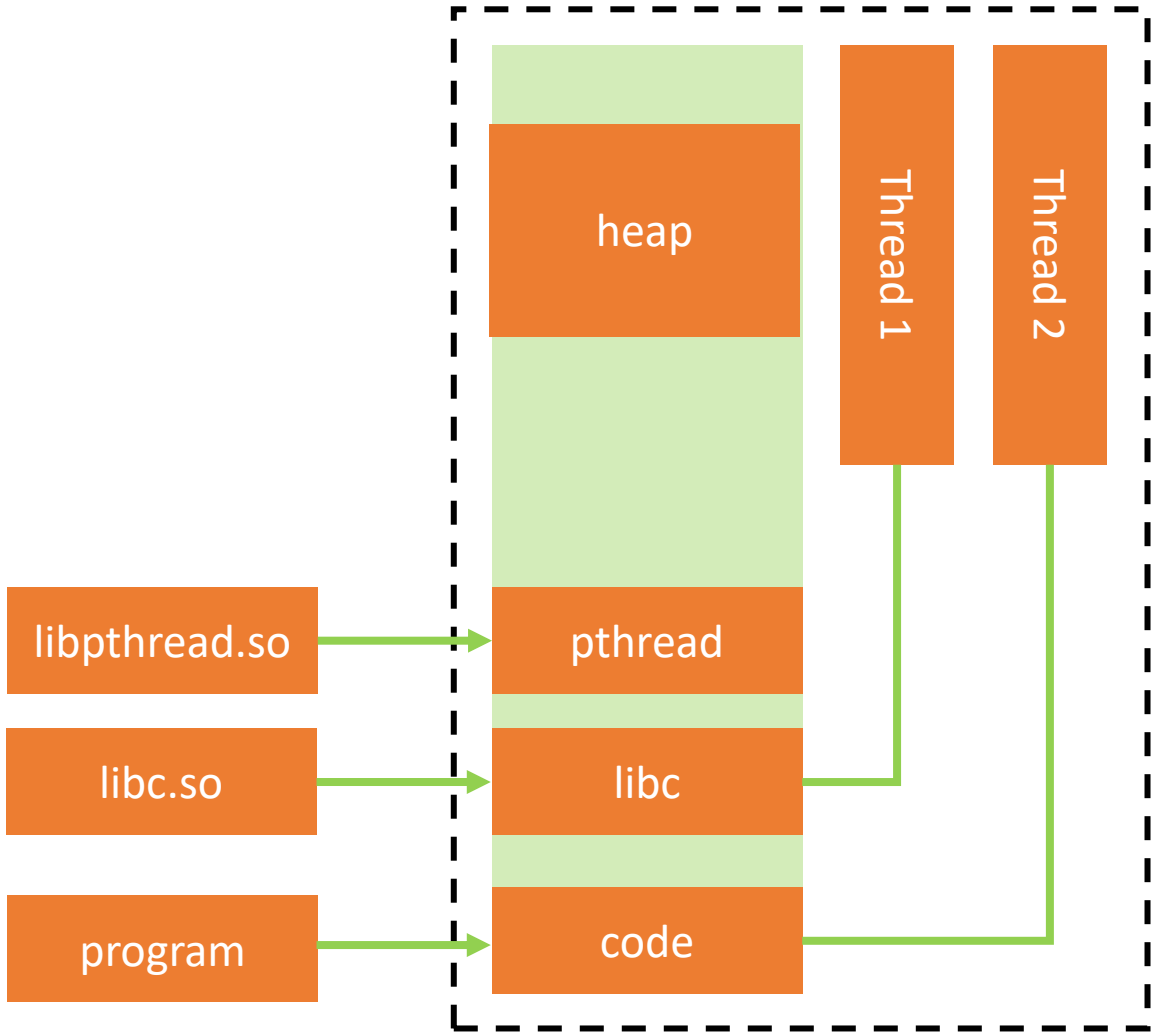
- Requires the smartphone to be rooted or to be an emulator
  - In order to run the server and inject applications

- Cannot be used in production builds, only development
  - When in an Emulator, use a base without WITHOUT “Google Services”

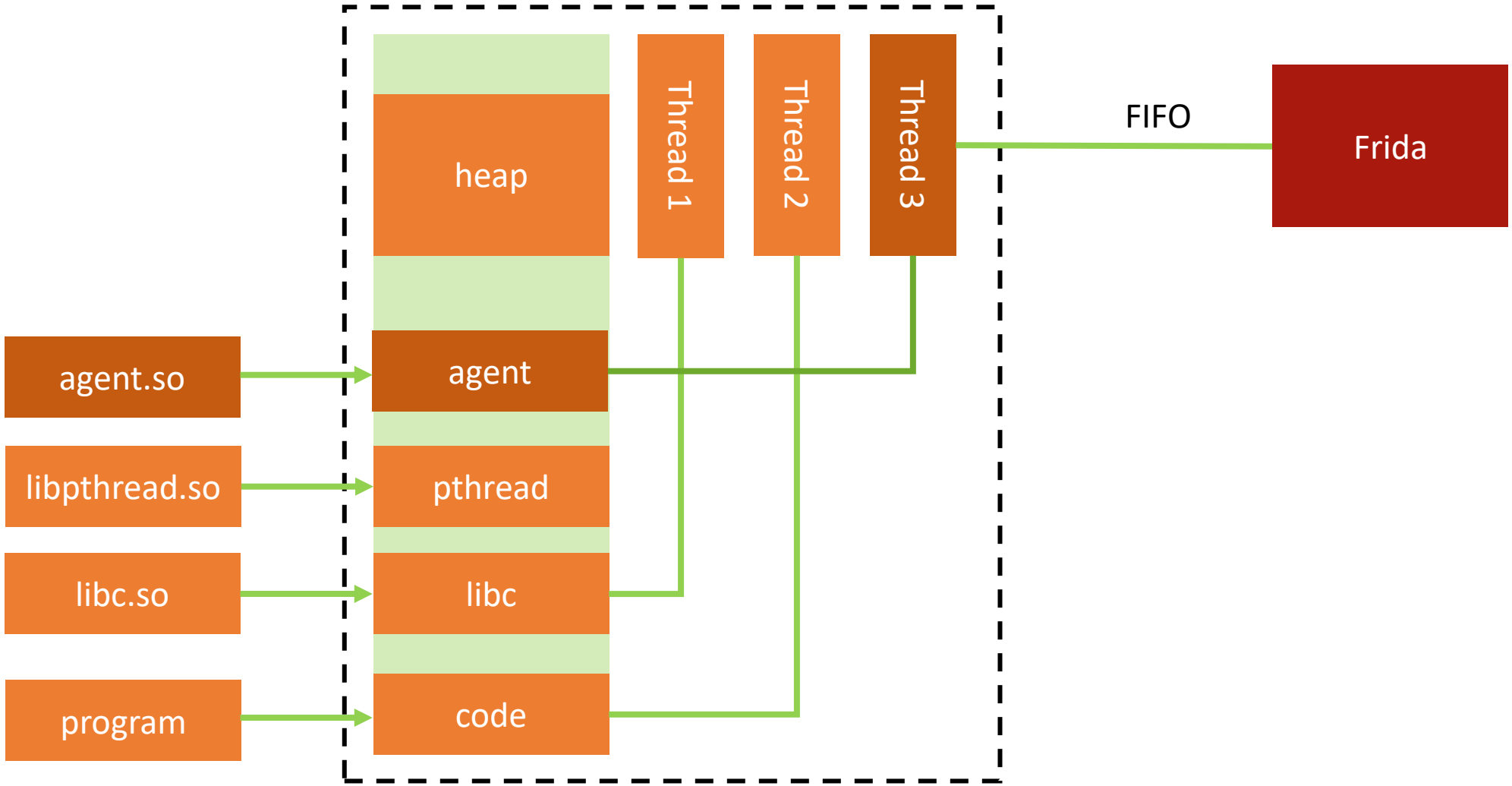
FRIDA – mode Injected – How it works?

- Create an Agent: it's an `.so` with some custom code
- Start a server that will be ready to attach to processes
- Injection:
  - Create thread in the remote process using `ptrace`
    - `PTRACE_ATTACH, PRACE_GETREGS`
  - Allocate memory for a bootstrapping code
    - Minimal amount of code required for pulling the agent
  - Write bootstrapper to memory
  - Execute bootstrapper in remote process
    - Open communication channel to server (FIFO)
    - Loads the agent from a shared library (.so)
    - Executes the agent
    - Closes communication channel (agent will expose an API)

FRIDA – mode Injected



FRIDA – mode Injected



FRIDA – mode Injected

- Required functionality:
- ptrace
  - Process tracing
- mmap
  - Map files to memory. In particular, the agent .so
- dlopen
  - Open the .so with the agent
- dlsym
  - Retrieves addresses of loaded symbols
- signal
  - To handle system signals

FRIDA – mode Injected - Howto

```
### On the first PC terminal

# wget frida-server from github

adb push frida-server /data/local/tmp
adb shell
su
cd /data/local/tmp
chmod +x frida-server
./frida-server

### On the second PC terminal
# List processes
$ frida-ps -U
```

FRIDA – How to use

- Command line tools: frida, frida-trace, frida-ps, frida-discover..

- Python interface
  - Provides a more advanced, programmatic interface
  - Allows predictable and repeatable instrumentation

- How to instrument code: using JS that overload existing functions
  - Large repository at: Frida CodeShare

Example: com.re.lab1

- Application requires a pin to unlock the flag
  - Pin is created dynamically and stored to an encrypted database
  - Application cannot be tampered as it checks the signature
- Static analysis will yield little as the value is created on real time
- Approaches to dynamic analysis:
  - Insert a function to access the correct pin and log it to the terminal

com.re.lab1

Let’s break the check. Just to test.
Objective: make b.checkAppSignature return false

```
int d1 = b.checkAppSignature(this);
if(d1 < 1){
    Toast.makeText(context,"Application Tampered",Toast.LENGTH_LONG).show();
    this.finishAffinity();
}
try{
```

com.re.lab1 - Java.perform: executes the given payload

Snippet provides an alternative implementation of the method.

```
Java.perform(function(){
  Java.use("com.re.lab1.b").checkAppSignature.implementation = function(a) {
     console.log("Signature will fail");
     return 0;
  };
});
```

```
[jpbarraca@wintermute] frida -U -f com.re.lab1 -l signatureFail.js

     ____
    / _  |   Frida 14.2.13 - A world-class dynamic instrumentation toolkit
   | (_| |
    > _  |   Commands:
   /_/ |_|       help      -> Displays the help system
   . . . .       object?   -> Display information about 'object'
   . . . .       exit/quit -> Exit
   . . . .
   . . . .   More info at https://www.frida.re/docs/home/
Spawned `com.re.lab1`. Use %resume to let the main thread start executing!
[Android Emulator 5554::com.re.lab1]-> %resume
[Android Emulator 5554::com.re.lab1]-> Signature will fail
```

pp has the pin provided

Cursor has the value obtained form the DB

```
cursor = secureDB.rawQuery("SELECT * FROM a;",null);
cursor.moveToFirst();

if(pp.equalsIgnoreCase(cursor.getString(0))){
    Toast.makeText(MainActivity.this, "Right Pin, Congratulations", Toast.LENGTH_SHORT).show();
    pin1.removeAllViews();
    String xo = getResources().getString(R.string.google_api_key);
    a mo = new a();
    xo = mo.func1(xo,xo.substring(4));
    xo = a.func2(xo);
    xo = a.func3(xo.substring(1),xo);
    xo = a.func4(xo,xo,xo.substring(2));
    tv1.setText("Flag: "+xo);
}else{
    Toast.makeText(MainActivity.this, "Incorrect Pin, "+(max_tries+1-i)+" attempts remaining",
}
```

Objective: reimplement Java.lang.String.equalsIgnoreCase so that it return true, and prints the correct ping

```
Java.perform(function(){
  Java.use("java.lang.String").equalsIgnoreCase.implementation = function(a) {
      console.log("Real PIN: " + a);
      return true;
  };
});
```

```
[jpbarraca@wintermute] frida -U -f com.re.lab1 -l equalsIgnoreCase.js

    ____
   / _  |   Frida 14.2.13 - A world-class dynamic instrumentation toolkit
  | (_| |
   > _  |   Commands:
  /_/ |_|       help      -> Displays the help system
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  . . . .       exit/quit -> Exit
  . . . .
  . . . .   More info at https://www.frida.re/docs/home/
Spawned `com.re.lab1`. Use %resume to let the main thread start executing!
[Android Emulator 5554::com.re.lab1]-> %resume
[Android Emulator 5554::com.re.lab1]-> Real PIN: INSERT
Real PIN: INSERT
Real PIN: INSERT
Real PIN: INSERT
Real PIN: 4597
```

Other uses of the method

Finally, the PIN

Interceptors: Intercepts calls to a function

- Define two events where code can be executed
  - **OnEnter**: When the function is called
  - **OnLeave**: After the function returns

- Can be used as generic logger, or to trigger other actions
  - Can intercept calls on lower layers of the application stack
    - Data that is to be written, sql queries, etc…

```
function foo(){
    Interceptor.attach(Module.findExportByName("libc.so", "open"), {
    onEnter: function(args){
        console.log("Entering the function");
    },
    onLeave: function(args){
       console.log("Leaving the function");
   },
 });
}
```