Android NDK 程式 (.so 檔) 逆向與防逆向

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Outline

- Android NDK 程式簡介
- Hello World NDK
- 基本逆向分析與反逆向措施
- 進階逆向分析與反逆向措施
- 總結

Android NDK 程式簡介





Android NDK

- NDK = **Native Development Kit**，原生開發套件
- 在 Android 平台進行 **C** 和 **C++** 程式開發的工具
- 編譯後會產出副檔名為 **so** 的檔案，如 libndk.so
- 無法單獨執行，需透過 Java 程式碼 **System.loadLibrary("ndk");** 載入
- 執行速度**快**，常用於需大量運算的功能，如 3D 繪圖、美肌、修圖等
- 逆向難度較**高**，需熟悉基本 ARM 或 X86 組合語言指令集

Hello World NDK

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Hello World NDK

MainActivity.java

```java
public class MainActivity extends AppCompatActivity
{
    public native String stringFromJNI();
    static
    {
        System.loadLibrary( libname: "ndk");
    }
    @Override
    protected void onCreate(Bundle savedInstanceState)
    {
        super.onCreate(savedInstanceState);
        com.fourdesire.ndk.databinding.ActivityMainBinding
        setContentView(binding.getRoot());

        TextView tv = binding.sampleText;
        tv.setText(stringFromJNI());
    }
}
```

native-lib.cpp

```cpp
extern "C" JNIEXPORT jstring JNICALL
Java_com_fourdesire_ndk_MainActivity_stringFromJNI(
        JNIEnv *env,
        jobject MainActivity /* this */
)
{
    std::string hello = "Hello from C++";
    return env->NewStringUTF(hello.c_str());
}
```

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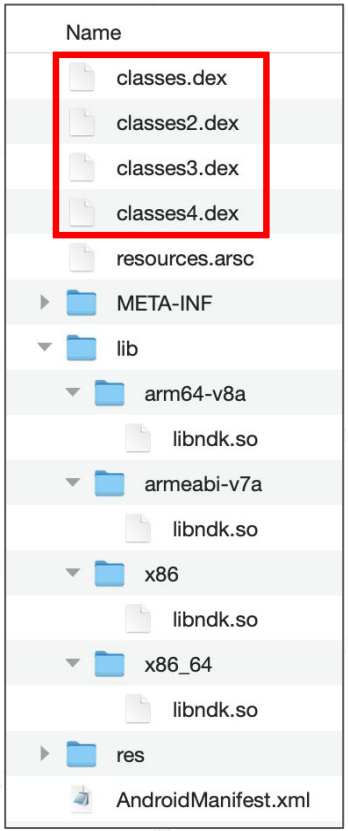
基本逆向分析與反逆向措施

逆向分析 - Hello World Java 層



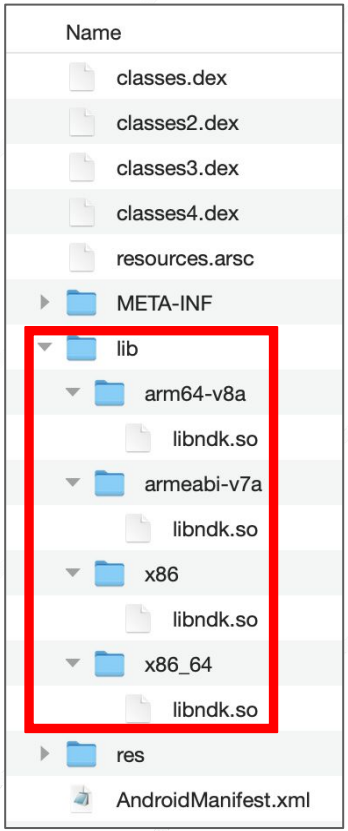

```
11  public class MainActivity extends AppCompatActivity {
        public native String stringFromJNI();

        static {
13          System.loadLibrary("ndk");
        }

        /* access modifiers changed from: protected */
        @Override // android.support.v7.app.AppCompatActivity
17      public void onCreate(Bundle savedInstanceState) {
18          super.onCreate(savedInstanceState);
19          ActivityMainBinding binding = ActivityMainBinding
20          setContentView(binding.getRoot());
23          binding.sampleText.setText(stringFromJNI());
        }
    }
```

https://github.com/skylot/jadx

逆向分析 - Hello World Native 層




```
1  __int64 __fastcall Java_com_fourdesire_ndk_MainActivity_stringFromJNI(_JNIEnv *a1)
2  {
3    __int64 v1; // ST30_8
4    __int64 result; // x0
5    __int64 v3; // [xsp+10h] [xbp-120h]
6    const char *v4; // [xsp+18h] [xbp-118h]
7    _JNIEnv *v5; // [xsp+80h] [xbp-B0h]
8    const char *v6; // [xsp+F0h] [xbp-40h]
9    const char *v7; // [xsp+F8h] [xbp-38h]
10   char v8; // [xsp+100h] [xbp-30h]
11   __int64 v9; // [xsp+118h] [xbp-18h]
12
13   v9 = *(_QWORD *)(_ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2)) + 40);
14   v5 = a1;
15   std::__ndk1::__compressed_pair_elem<std::__ndk1::basic_string<char,std::__ndk1::char_traits<char>,std::__ndk1::all
16   std::__ndk1::__compressed_pair_elem<std::__ndk1::allocator<char>,1,true>::__compressed_pair_elem(&v8);
17   v1 = std::__ndk1::char_traits<char>::length("Hello from C++");
18   std::__ndk1::basic_string<char,std::__ndk1::char_traits<char>,std::__ndk1::allocator<char>>::__init(
19     &v8,
20     "Hello from C++",
21     v1);
22   if ( *(_BYTE *)std::__ndk1::__compressed_pair_elem<std::__ndk1::basic_string<char,std::__ndk1::char_traits<char>,s
23   {
24     v4 = *(const char **)(std::__ndk1::__compressed_pair_elem<std::__ndk1::basic_string<char,std::__ndk1::char_traits
25                           + 16);
26   }
27   else
28   {
29     v6 = (const char *)(std::__ndk1::__compressed_pair_elem<std::__ndk1::basic_string<char,std::__ndk1::char_traits<
30                         + 1);
31     v4 = v6;
32   }
33   v7 = v4;
34   v3 = _JNIEnv::NewStringUTF(v5, v4);
35   std::__ndk1::basic_string<char,std::__ndk1::char_traits<char>,std::__ndk1::allocator<char>>::~basic_string(&v8);
36   result = *(_QWORD *)(_ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2)) + 40);
37   if ( result == v9 )
38     result = v3;
39   return result;
40 }
```

```
5  Java_com_fourdesire_ndk_MainActivity_stringFromJNI(
6          JNIEnv *env,
7          jobject MainActivity /* this */
8  )
9  {
10     std::string hello = "Hello from C++";
11     return env->NewStringUTF(hello.c_str());
12 }
```

https://hex-rays.com/ida-pro/

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逆向分析 - 總結

- Java 層反編譯非常容易，原始碼還原度高
- Native 層反編譯後原始碼還原度低，但仍有弱點：

  ➔ **函數名稱未隱藏**：可透過函數名稱猜出函數功能

  ➔ **字串內容明碼顯示**：可透過字串內容猜出程式功能

反逆向措施 1 - 隱藏函數名稱

```
extern "C" JNIEXPORT jstring JNICALL
Java_com_fourdesire_ndk_MainActivity_stringFromJNI(
        JNIEnv *env,
        jobject MainActivity
)
{
    std::string hello = "Hello from C++";
    return env->NewStringUTF(hello.c_str());
}
```

```
static
jstring nativeStringFromJNI(
        JNIEnv *env,
        jobject
)
{
    std::string hello = "Hello from C++";
    return env->NewStringUTF(hello.c_str());
}

JNIEXPORT jint JNI_OnLoad(JavaVM *vm, void *reserved)
{
    JNIEnv *env;
    if (vm->GetEnv(reinterpret_cast<void **>(&env), JNI_VERSION_1_6) != JNI_OK) return JNI_ERR;

    jclass c = env->FindClass( name: "com/fourdesire/ndk/MainActivity");
    if (c == nullptr) return JNI_ERR;

    static const JNINativeMethod methods[] = {
            { .name: "stringFromJNI", .signature: "()Ljava/lang/String;", (void *) nativeStringFromJNI
    };
    int rc = env->RegisterNatives(c, methods, nMethods: sizeof(methods) / sizeof(JNINativeMethod));
    if (rc != JNI_OK) return rc;

    return JNI_VERSION_1_6;
}
```

1. 函數宣告使用 **static** 關鍵字
2. 新增 **JNI_OnLoad** 函數
3. 在 JNI_OnLoad 函數內使用 **RegisterNatives** 動態註冊函數

參考資料

:https://developer.android.com/training/articles/perf-jni#native-libraries

反逆向措施 1 - 隱藏函數名稱效果

```
static
jstring nativeStringFromJNI(
        JNIEnv *env,
        jobject
)
{
    std::string hello = "Hello from C++";
    return env->NewStringUTF(hello.c_str());
}
```

```
__int64 __fastcall sub_92CC(_JNIEnv *a1)
{
  __int64 v1; // ST30_8
  __int64 result; // x0
  __int64 v3; // [xsp+10h] [xbp-120h]
  const char *v4; // [xsp+18h] [xbp-118h]
  _JNIEnv *v5; // [xsp+80h] [xbp-B0h]
  const char *v6; // [xsp+F0h] [xbp-40h]
  const char *v7; // [xsp+F8h] [xbp-38h]
  char v8; // [xsp+100h] [xbp-30h]
  __int64 v9; // [xsp+118h] [xbp-18h]

  v9 = *(_QWORD *)(_ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2)) + 40);
  v5 = a1;
  std::__ndk1::__compressed_pair_elem<std::__ndk1::basic_string<char,std::__ndk1::char_traits<char>,std::
  std::__ndk1::__compressed_pair_elem<std::__ndk1::allocator<char>,1,true>::__compressed_pair_elem(&v8);
  v1 = std::__ndk1::char_traits<char>::length("Hello from C++");
```

- 函數名稱 nativeStringFromJNI → 檔案位址 sub_92CC

反逆向措施 2 - 字串加密

1. 使用 **C++ 巨集**加密字串 : https://github.com/adamyaxley/Obfuscate
2. 複製 obfuscate.h 到原始碼專案內, **#include "obfuscate.h"** 宣告該標頭檔
3. 替換要加密的字串 : "My String" → **AY_OBFUSCATE("My String")**

```
static
jstring nativeStringFromJNI(
        JNIEnv *env,
        jobject
)
{
    std::string hello = "Hello from C++";
    return env->NewStringUTF(hello.c_str());
}

JNIEXPORT jint JNI_OnLoad(JavaVM *vm, void *reserved)
{
    JNIEnv *env;
    if (vm->GetEnv(reinterpret_cast<void **>(&env), JNI_VERSION_1_6) != JNI_OK) return JNI_ERR;

    jclass c = env->FindClass( name: "com/fourdesire/ndk/MainActivity");
    if (c == nullptr) return JNI_ERR;

    static const JNINativeMethod methods[] = {
            { .name: "stringFromJNI", .signature: "()Ljava/lang/String;", (void *) nativeStringFromJNI}
    };
    int rc = env->RegisterNatives(c, methods, nMethods: sizeof(methods) / sizeof(JNINativeMethod));
    if (rc != JNI_OK) return rc;

    return JNI_VERSION_1_6;
}
```

```
static
jstring nativeStringFromJNI(
        JNIEnv *env,
        jobject
)
{
    return env->NewStringUTF( bytes: AY_OBFUSCATE( data: "Hello from C++"));
}

JNIEXPORT jint JNI_OnLoad(JavaVM *vm, void *reserved)
{
    JNIEnv *env;
    if (vm->GetEnv(reinterpret_cast<void **>(&env), JNI_VERSION_1_6) != JNI_OK) return JNI_ERR;

    jclass c = env->FindClass( name: AY_OBFUSCATE( data: "com/fourdesire/ndk/MainActivity"));
    if (c == nullptr) return JNI_ERR;

    static const JNINativeMethod methods[] = {
            { .name: AY_OBFUSCATE( data: "stringFromJNI"), .signature: AY_OBFUSCATE( data: "()Ljava/lang/String;")
    };
    int rc = env->RegisterNatives(c, methods, nMethods: sizeof(methods) / sizeof(JNINativeMethod));
    if (rc != JNI_OK) return rc;

    return JNI_VERSION_1_6;
}
```

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反逆向措施 2 - 字串加密效果

```
static
jstring nativeStringFromJNI(
        JNIEnv *env,
        jobject
)
{
    return env->NewStringUTF( bytes: AY_OBFUSCATE( data: "Hello from C++"));
}
```

- 明碼字串已不再出現
- 所有字串皆使用 XOR 運算加密
- 每個字串使用的加密金鑰皆不同
- 逆向難度大幅上升

```
v1 = _ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2));
v11 = *(_QWORD *)(v1 + 40);
v2 = a1;
v3 = v1;
v4 = sub_89C8(&v10);
v8 = (const char *)ay::obfuscated_data<15ull,417139055448629745 9ull>::operator char *(v4, v5, v6, v7);
result = JNIEnv::NewStringUTF(v2, v8);
*(_QWORD *)(v3 + 40);
return result;
```

```
ay *__fastcall ay::obfuscated_data<15ull,417139055448629745 9ull>::decrypt(ay *result,
{
  ay *v4; // [xsp+8h] [xbp-18h]

  v4 = result;
  if ( *((_BYTE *)result + 15) & 1 )
  {
    result = (ay *)ay::cipher(result, &byte_9[6], 0x39E3C19BBB935373uLL);
    *((_BYTE *)v4 + 15) = 0;
  }
  return result;
}
```

```
__int64 __fastcall ay::cipher(__int64 result, char *a2, unsigned __int64 a3)
{
  unsigned __int64 i; // [xsp+0h] [xbp-20h]

  for ( i = 0LL; i < (unsigned __int64)a2; ++i )
    *(_BYTE *)(result + i) ^= a3 >> 8 * (unsigned __int8)(i % 8);
  return result;
}
```

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反逆向措施 - 總結

- 函數名稱未隱藏
  - ➔ 將函數宣告為 static 類型
  - ➔ 使用 RegisterNatives 動態註冊 JNI 函數
- 字串內容明碼顯示
  - ➔ 使用 C++ 巨集加密字串內容

進階逆向分析與反逆向措施

逆向神器 - Unicorn (unicorn-engine.org)

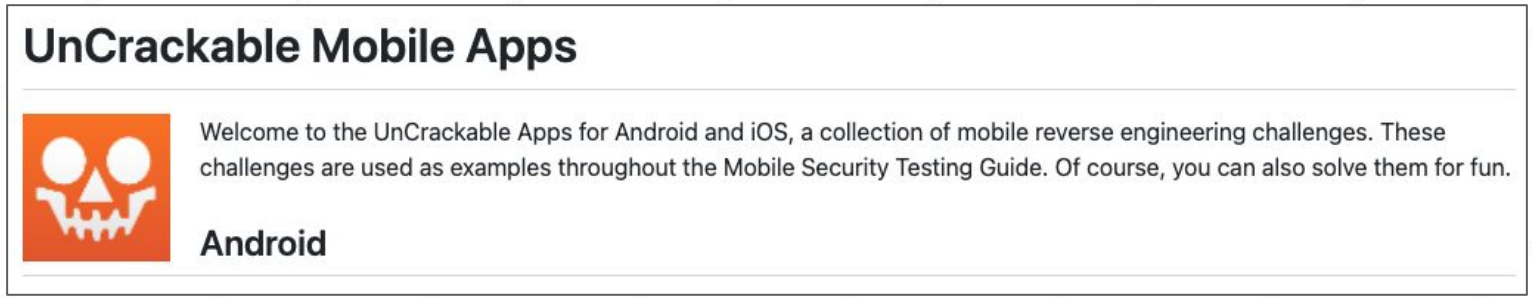
- 輕量化、多架構的 CPU 模擬器引擎
- 可模擬 ARM、ARM64、x86、x86_64 等指令集 CPU
- 已有許多使用該引擎的逆向工具，主要用於各平台 Binary 的逆向分析
- Android NDK 程式逆向分析工具，可模擬 ARM CPU 執行 so 檔的函數

  ➔ **unidbg** (https://github.com/zhkl0228/unidbg)

  ➔ **AndroidNativeEmu** (https://github.com/AeonLucid/AndroidNativeEmu)

OWASP - MSTG Crackmes

- 用於練習逆向的 App
- 由 OWASP 旗下的 MSTG (Mobile Security Testing Guide) 所提供
- Android 平台難度由簡單到困難分為 Level 1 ~ 4
- https://github.com/OWASP/owasp-mstg/tree/master/Crackmes



UnCrackable App for Android Level 2

- 目標：找出隱藏在 App 裡的密碼字串
- 提示：此 App 有 Root 及 Debugger 偵測機制

UnCrackable App for Android Level 2

This app holds a secret inside. May include traces of native code.

- Objective: A secret string is hidden somewhere in this app. Find a way to extract it.
- Author: Bernhard Mueller.
- Special thanks to Michael Helwig for finding and fixing an oversight in the anti-tampering mechanism.
- Maintained by the OWASP MSTG leaders.

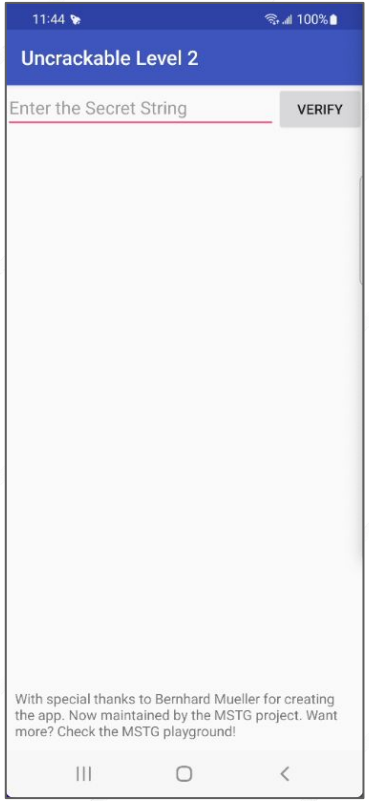
Installation

This app is compatible with Android 4.4 and up.

```
$ adb install UnCrackable-Level2.apk
```

Solutions

- Solution using Frida and radare2 by c0dmtr1x.
- Solution using Frida by Eduardo Novella.
- Solution using patches by sh3llc0d3r.
- Solution using RMS by @mobilesecurity_ (video).
- Solution using static analysis and Ghidra by Eduardo Vasconcelos.
- Solution using Ghidra and Frida by Davide Cioccia



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逆向分析 - Java 層

```
40    private native void init();
41
42    /* access modifiers changed from: protected */
43    @Override // android.support.v4.app.h, android.support.v4.app.z, andro
44    public void onCreate(Bundle bundle) {
45        init();
46        if (b.a() || b.b() || b.c()) {
47            a("Root detected!");
48        }
49        if (a.a(getApplicationContext())) {
50            a("App is debuggable!");
51        }
52        new AsyncTask<Void, String, String>() {
53            /* class sg.vantagepoint.uncrackable2.MainActivity.AnonymousCl
54
55            /* access modifiers changed from: protected */
56            /* renamed from: a */
57            public String doInBackground(Void... voidArr) {
58                while (!Debug.isDebuggerConnected()) {
59                    SystemClock.sleep(100);
60                }
61                return null;
62            }
63
64            /* access modifiers changed from: protected */
65            /* renamed from: a */
66            public void onPostExecute(String str) {
67                MainActivity.this.a((MainActivity) "Debugger detected!");
68            }
69        }.execute(null, null, null);
70        this.m = new CodeCheck();
71        super.onCreate(bundle);
72        setContentView(R.layout.activity_main);
73    }
```

App開啟：OnCreate() → **init()**

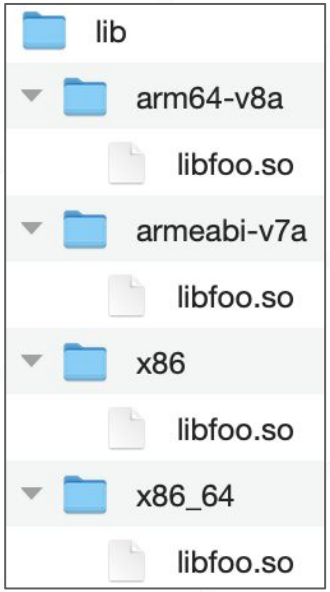
```
<?xml version="1.0" encoding="utf-8"?>
1  <LinearLayout xmlns:android="http://schemas.android.com/apk/res/android" android:orientation="vertical" android:layout_width="match_parent" android:layou
6      <LinearLayout android:orientation="horizontal" android:layout_width="match_parent" android:layout_height="wrap_content">
11         <EditText android:id="@+id/edit_text" android:layout_width="0dp" android:layout_height="wrap_content" android:hint="@string/edit_text" android:la
18         <Button android:layout_width="wrap_content" android:layout_height="wrap_content" android:text="@string/button_verify" android:onClick="verify"/>
6      </LinearLayout>
25     <RelativeLayout android:padding="10dp" android:layout_width="match_parent" android:layout_height="match_parent">
30         <TextView android:layout_width="match_parent" android:layout_height="wrap_content" android:text="@string/thanks" android:layout_alignParentBottom
25     </RelativeLayout>
1  </LinearLayout>
```

```
75    public void verify(View view) {
76        String str;
77        String obj = ((EditText) findViewById(R.id.edit_text)).getText().toString();
78        AlertDialog create = new AlertDialog.Builder(this).create();
79        if (this.m.a(obj)) {
80            create.setTitle("Success!");
81            str = "This is the correct secret.";
82        } else {
83            create.setTitle("Nope...");
84            str = "That's not it. Try again.";
85        }
86        create.setMessage(str);
87        create.setButton(-3, "OK", new DialogInterface.OnClickListener() {
88            /* class sg.vantagepoint.uncrackable2.MainActivity.AnonymousClass3 */
89
90            public void onClick(DialogInterface dialogInterface, int i) {
91                dialogInterface.dismiss();
92            }
93        });
94        create.show();
95    }
```

```
3  public class CodeCheck {
4      private native boolean bar(byte[] bArr);
5
6      public boolean a(String str) {
7          return bar(str.getBytes());
8      }
9  }
```

按下確認按鈕：verify(View) → a(String) → **bar(byte[])**

逆向分析 - Native 層



- 字串長度為 23
- strncmp() 的第二參數即為答案

Java_sg_vantagepoint_uncrackable2_MainActivity_init .text

Java_sg_vantagepoint_uncrackable2_CodeCheck_bar .text

```
bool __fastcall Java_sg_vantagepoint_uncrackable2_CodeCheck_bar(JNIEnv *a1, __int64 a2, __int64 a3)
{
  __int64 v3; // x19
  JNIEnv *v4; // x20
  _BOOL8 result; // x0
  __int64 v6; // x21
  __int128 v7; // [xsp+0h] [xbp-40h]
  __int64 v8; // [xsp+10h] [xbp-30h]
  __int64 v9; // [xsp+18h] [xbp-28h]

  v3 = a3;
  v4 = a1;
  result = 0LL;
  v9 = *( QWORD *)( ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2)) + 40);
  if ( byte_1300C == 1 )
  {
    v8 = 0LL;
    v7 = xmmword_EA0;
    LODWORD(v8) = 1713399144;
    WORD2(v8) = 29545;
    BYTE6(v8) = 104;
    v6 = ((__int64 (__fastcall *)(JNIEnv *, __int64, _QWORD))(*v4)->GetByteArrayElements)(v4, a3, 0LL);
    result = ((unsigned int (__fastcall *)(JNIEnv *, __int64))(*v4)->GetArrayLength)(v4, v3) == 23
          && !(unsigned int)strncmp(v6, &v7, 23LL);
  }
  return result;
}
```

```
__int64 Java_sg_vantagepoint_uncrackable2_MainActivity_init()
{
  __int64 result; // x0

  result = sub_918();
  byte_1300C = 1;
  return result;
}
```

模擬執行 - unidbg

```
emulator.attach().addBreakPoint(module, offset: 0x820, (emulator, address) -> {
        RegisterContext context = emulator.getContext();
        String s1 = context.getPointerArg( index: 0).getString( offset: 0);
        String s2 = context.getPointerArg( index: 1).getString( offset: 0);
        int n = context.getIntArg( index: 2);
        System.out.printf("UnCrackable2: strncmp() before, s1=\"%s\", s2=\"%s\", n=%d\n", s1, s2, n);
        emulator.attach().addBreakPoint(context.getLRPointer().peer, (emulator, address) -> {
                RegisterContext context = emulator.getContext();
                System.out.printf("UnCrackable2: strncmp() after, return=0x%08x\n", context.getIntArg( index: 0));
                return true;
        });
        return true;
});
```

Hook strncmp()

```
Pointer jniEnv = vm.getJNIEnv();
DvmObject<?> thiz = vm.resolveClass( className: "owasp.mstg.uncrackable2.MainActivity").newObject( value: null);
List<Object> args = new ArrayList<>();
args.add(jniEnv);
args.add(vm.addLocalObject(thiz));
module.callFunction(emulator, symbolName: "Java_sg_vantagepoint_uncrackable2_MainActivity_init", args.toArray());
```

模擬呼叫 init()

```
System.out.println("UnCrackable2: bar() before");
thiz = vm.resolveClass( className: "owasp.mstg.uncrackable2.CodeCheck").newObject( value: null);
args = new ArrayList<>();
args.add(jniEnv);
args.add(vm.addLocalObject(thiz));
String inputSecretString = "1234567890123456789123";
ByteArray byteArray = new ByteArray(vm, inputSecretString.getBytes());
args.add(vm.addLocalObject(byteArray));
int result = module.callFunction(emulator, symbolName: "Java_sg_vantagepoint_uncrackable2_CodeCheck_bar", args.toArray())[0].intValue();
System.out.println("UnCrackable2: bar() after, return=" + result);
```

傳入長度為 23 的任意字串，模擬呼叫 bar(byte[])

```
UnCrackable2: bar() before
JNIEnv->GetArrayLength([B@3ada9e37 => 23) was called from RX@0x40000e48[libfoo.so]0xe48
UnCrackable2: strncmp() before, s1="1234567890123456789123", s2="Thanks for all the fish", n=23
UnCrackable2: strncmp() after, return=0xffffffba
UnCrackable2: bar() after, return=0
```

查看模擬結果，strncmp 參數 2 即為正確密碼

模擬執行 - AndroidNativeEmu

```python
strncmp_symbol = 0
for module in emulator.modules:
    if 'libc.so' in module.filename:
        strncmp_symbol = module.find_symbol('strncmp')

try:
    function_hooker = FuncHooker(emulator)
    function_hooker.fun_hook(strncmp_symbol, 3, strncmp_before, strncmp_after)

    emulator.call_symbol(lib_module, 'Java_sg_vantagepoint_uncrackable2_MainActivity_init', emulator.java_vm.jni_env.address_ptr, 0x00)

    print("UnCrackable2: bar() before")
    input_secret_string = b'1234567890123456789O123'
    java_byte_array = Array(bytearray(input_secret_string))
    result = emulator.call_symbol(lib_module, 'Java_sg_vantagepoint_uncrackable2_CodeCheck_bar', emulator.java_vm.jni_env.address_ptr, 0x00, java_byte_array)
    print("UnCrackable2: bar() after, return=%d\n" % result)
except UcError as e:
    print("UnCrackable2: Exit at %x" % emulator.mu.reg_read(UC_ARM_REG_PC))
    raise
```

Hook strncmp()

模擬呼叫 init()

傳入長度為 23 的任意字串，模擬呼叫 bar(byte[])

```
UnCrackable2: bar() before
DEBUG:androidemu.java.jni_env:JNIEnv->GetByteArrayElements(bytearray(b'1234567890123456789O123')(1), 0) was called
DEBUG:androidemu.java.jni_env:JNIEnv->GetArrayLength(1) was called, return value = 23
DEBUG:root:trigger hook on 0xCBC45B1C
UnCrackable2: strncmp() before, s1="1234567890123456789O123", s2="Thanks for all the fish", n=23
UnCrackable2: strncmp() after, return=0xFFFFFFFFFFFFFFDD
UnCrackable2: bar() after, return=0
```

查看模擬結果，strncmp 參數 2 即為正確密碼

UnCrackable App for Android Level 3

- 目標：找出隱藏在App 裡的密碼字串
- 提示：此 App 有 Root、Debugger 偵測及完整性檢查機制

UnCrackable App for Android Level 3

The crackme from hell!

- Objective: A secret string is hidden somewhere in this app. Find a way to extract it.
- Author: Bernhard Mueller.
- Special thanks to Eduardo Novella for testing, feedback and pointing out flaws in the initial build(s).
- Maintained by the OWASP MSTG leaders.

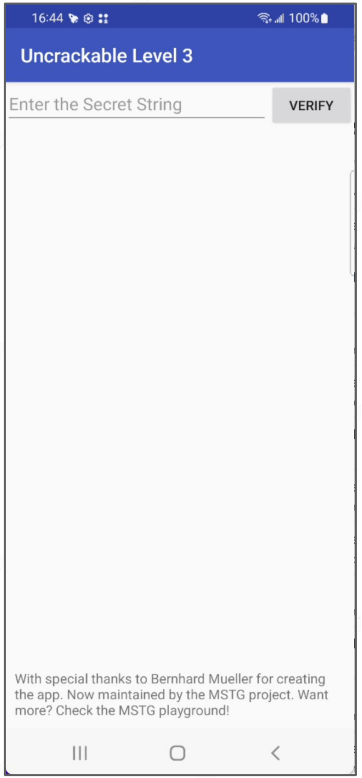
Installation

This app is compatible with Android 4.4 and up.

```
$ adb install UnCrackable-Level3.apk
```

Solutions

- Solution using Frida by Eduardo Novella.
- Solution using patches by sh3llc0d3r.
- Solution using Ghidra and Frida by Davide Cioccia



逆向分析 - Java 層

App開啟：OnCreate() → **init(byte[])**

```
103     public void onCreate(Bundle bundle) {
104         verifyLibs();
106         init(xorkey.getBytes());
124         new AsyncTask<Void, String, String>() {
                /* class sg.vantagepoint.uncrackable3.MainActivity.AnonymousClass2 */

                /* access modifiers changed from: protected */
112             public String doInBackground(Void... voidArr) {
113                 while (!Debug.isDebuggerConnected()) {
114                     SystemClock.sleep(100);
                    }
114                 return null;
                }

                /* access modifiers changed from: protected */
120             public void onPostExecute(String str) {
121                 MainActivity.this.showDialog("Debugger detected!");
122                 System.exit(0);
                }
            }.execute(null, null, null);
126         if (RootDetection.checkRoot1() || RootDetection.checkRoot2() || RootDetection.checkRoot3() || IntegrityCheck.isDebuggable(getApplicationContext()) || tampered != 0) {
127             showDialog("Rooting or tampering detected.");
            }
130         this.check = new CodeCheck();
132         super.onCreate(bundle);
133         setContentView(R.layout.activity_main);
        }
```

```
36  public class MainActivity extends AppCompatActivity {
        private static final String TAG = "UnCrackable3";
        static int tampered = 0;
        private static final String xorkey = "pizzapizzapizzapizzapizz";
        private CodeCheck check;
        Map<String, Long> crc;

        private native long baz();

        private native void init(byte[] bArr);
```

按下確認按鈕：verify(View) → check_code(String) → **bar(byte[])**

```
137     public void verify(View view) {
138         String obj = ((EditText) findViewById(R.id.edit_text)).getText().toString();
139         AlertDialog create = new AlertDialog.Builder(this).create();
141         if (this.check.check_code(obj)) {
142             create.setTitle("Success!");
143             create.setMessage("This is the correct secret.");
            } else {
145             create.setTitle("Nope...");
146             create.setMessage("That's not it. Try again.");
            }
```

```
3   public class CodeCheck {
4       private static final String TAG = "CodeCheck";
5
6       private native boolean bar(byte[] bArr);
7
8       public boolean check_code(String str) {
9           return bar(str.getBytes());
10      }
11  }
```

逆向分析 - Native 層

Java_sg_vantagepoint_uncrackable3_MainActivity_init	.text
Java_sg_vantagepoint_uncrackable3_MainActivity_baz	.text
Java_sg_vantagepoint_uncrackable3_CodeCheck_bar	.text

```
__int64 __fastcall Java_sg_vantagepoint_uncrackable3_MainActivity_init(JNIEnv *env, __int64 a2, __int64 xorkey)
{
  __int64 v3; // x19
  JNIEnv *v4; // x20
  __int64 v5; // x21
  __int64 result; // x0

  v3 = xorkey;
  v4 = env;
  sub_323C();
  v5 = ((__int64 (__fastcall *)(JNIEnv *, __int64, _QWORD))(*v4)->GetByteArrayElements)(v4, v3, 0LL);
  strncpy(&qword_15038, v5, 24LL);
  result = ((__int64 (__fastcall *)(JNIEnv *, __int64, __int64, signed __int64))(*v4)->ReleaseByteArrayElements)(
             v4,
             v3,
             v5,
             2LL);
  ++dword_15054;
  return result;
}
```

- 字串長度為 24
- 輸入字元：*((uint8 *)(v7+v8)) → byte [X21+X8] → W12
- 密碼字元：*((uint8 *)(&v9+v8)) XOR qword_15038[v8]
  → byte [X9+X8] XOR byte [X23+X8]
  → W11 XOR W10 → W10
- v8 → X8 → 0,1,2,3…23
- 關鍵點為 0x3450：CMP W12, W10，密碼字元在 W10

```
signed __int64 __fastcall Java_sg_vantagepoint_uncrackable3_CodeCheck_bar(JNIEnv *env, __int64 a2, __int64 a3)
{
  unsigned __int64 v3; // x22
  __int64 v4; // x19
  JNIEnv *v5; // x20
  signed __int64 result; // x0
  __int64 v7; // x21
  __int64 v8; // x8
  __int64 v9; // [xsp+8h] [xbp-58h]
  __int64 v10; // [xsp+10h] [xbp-50h]
  __int64 v11; // [xsp+18h] [xbp-48h]
  char v12; // [xsp+20h] [xbp-40h]
  __int64 v13; // [xsp+28h] [xbp-38h]

  v3 = _ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2));
  v4 = a3;
  v5 = env;
  result = 0LL;
  v13 = *(_QWORD *)(v3 + 40);
  v9 = 0LL;
  v10 = 0LL;
  v12 = 0;
  v11 = 0LL;
  if ( dword_15054 == 2 )
  {
    sub_10E0(&v9);
    v7 = ((__int64 (__fastcall *)(JNIEnv *, __int64, _QWORD))(*v5)->GetByteArrayElements)(v5, v4, 0LL);
    if ( ((unsigned int (__fastcall *)(JNIEnv *, __int64))(*v5)->GetArrayLength)(v5, v4) == 24 )
    {
      v8 = 0LL;
      while ( *(unsigned __int8 *)(v7 + v8) == (qword_15038[v8] ^ *((unsigned __int8 *)&v9 + v8)) )
      {
        if ( (unsigned __int64)++v8 >= 24 )
        {
          if ( (_DWORD)v8 != 24 )
            break;
          result = 1LL;
          goto LABEL_9;
        }
      }
    }
    result = 0LL;
  }
LABEL_9:
  *(_QWORD *)(v3 + 40);
  return result;
}
```

```
33F4                ADD             X23, SP, #0x60+var_58
33F8                BL              sub_10E0
33FC                LDR             X8, [X20]
3400                MOV             X0, X20
3404                MOV             X1, X19
3408                MOV             X2, X2R
340C                LDR             X8, [X8,#0x5C0]
3410                BLR             X8
3414                LDR             X8, [X20]
3418                MOV             X21, X0
341C                MOV             X0, X20
3420                MOV             X1, X19
3424                LDR             X8, [X8,#0x558]
3428                BLR             X8
342C                CMP             W0, #0x18
3430                B.NE            loc_3474
3434                ADRP            X9, #qword_15038@PAGE
3438                MOV             X8, X2R
343C                ADD             X9, X9, #qword_15038@PAGEOFF
3440
3440 loc_3440                                   ; CODE XREF: Java_sg_
3440                LDRB            W10, [X23,X8]
3444                LDRB            W11, [X9,X8]
3448                LDRB            W12, [X21,X8]
344C                EOR             W10, W11, W10
3450                CMP             W12, W10
```

模擬執行 - unidbg

```
emulator.attach().addBreakPoint(module,  offset: 0x3450, (emulator, address) -> {
        RegisterContext context = emulator.getContext();
        int w10 = context.getIntByReg(Arm64Const.UC_ARM64_REG_W10);
        int w12 = context.getIntByReg(Arm64Const.UC_ARM64_REG_W12);
        System.out.printf("UnCrackable3: w10=0x%X(\"%s\"), w12=0x%X(\"%s\")\n", w10, (char) w10, w12, (char) w12)
        emulator.getBackend().reg_write(Arm64Const.UC_ARM64_REG_W12, w10);
        return true;
});
```

指令級 Hook，顯示密碼字元 W10 並修改 W12 為 W10，讓字元比對能繼續下去

```
Pointer jniEnv = vm.getJNIEnv();
DvmObject<?> thiz = vm.resolveClass( className: "owasp.mstg.uncrackable3.MainActivity").newObject( value: null);
List<Object> args = new ArrayList<>();
args.add(jniEnv);
args.add(vm.addLocalObject(thiz));
String xorkey = "pizzapizzapizzapizzapizz";
args.add(vm.addLocalObject(new ByteArray(vm, xorkey.getBytes())));
module.callFunction(emulator,  symbolName: "Java_sg_vantagepoint_uncrackable3_MainActivity_init", args.toArray());
```

模擬呼叫 init(byte[])

```
System.out.println("UnCrackable3: bar() before");
thiz = vm.resolveClass( className: "owasp.mstg.uncrackable3.CodeCheck").newObject( value: null);
args = new ArrayList<>();
args.add(jniEnv);
args.add(vm.addLocalObject(thiz));
String inputSecret = "123456789012345678901234";
args.add(vm.addLocalObject(new ByteArray(vm, inputSecret.getBytes())));
int result = module.callFunction(emulator,  symbolName: "Java_sg_vantagepoint_uncrackable3_CodeCheck_bar", args.toArray())[0].intValue();
System.out.printf("UnCrackable3: bar() after, return=%d\n", result);
```

傳入長度為 24 的任意字串，模擬呼叫 bar(byte[])

```
UnCrackable3: w10=0x6D("m"), w12=0x31("1")
UnCrackable3: w10=0x61("a"), w12=0x32("2")
UnCrackable3: w10=0x6B("k"), w12=0x33("3")
UnCrackable3: w10=0x69("i"), w12=0x34("4")
UnCrackable3: w10=0x6E("n"), w12=0x35("5")
UnCrackable3: w10=0x67("g"), w12=0x36("6")
UnCrackable3: w10=0x20(" "), w12=0x37("7")
UnCrackable3: w10=0x6F("o"), w12=0x38("8")
UnCrackable3: w10=0x77("w"), w12=0x39("9")
UnCrackable3: w10=0x61("a"), w12=0x30("0")
UnCrackable3: w10=0x73("s"), w12=0x31("1")
UnCrackable3: w10=0x70("p"), w12=0x32("2")
UnCrackable3: w10=0x20(" "), w12=0x33("3")
UnCrackable3: w10=0x67("g"), w12=0x34("4")
UnCrackable3: w10=0x72("r"), w12=0x35("5")
UnCrackable3: w10=0x65("e"), w12=0x36("6")
UnCrackable3: w10=0x61("a"), w12=0x37("7")
UnCrackable3: w10=0x74("t"), w12=0x38("8")
UnCrackable3: w10=0x20(" "), w12=0x39("9")
UnCrackable3: w10=0x61("a"), w12=0x30("0")
UnCrackable3: w10=0x67("g"), w12=0x31("1")
UnCrackable3: w10=0x61("a"), w12=0x32("2")
UnCrackable3: w10=0x69("i"), w12=0x33("3")
UnCrackable3: w10=0x6E("n"), w12=0x34("4")
```

查看模擬結果，W10為正確的字元，正確的密碼字串為 “**making owasp great again**”

模擬執行 - AndroidNativeEmu

```python
def hook_code(uc_engine, address, size, user_data):
    if address in instructions_list:
        w10 = uc_engine.reg_read(UC_ARM64_REG_W10)
        w12 = uc_engine.reg_read(UC_ARM64_REG_W12)
        print('UnCrackable3: w10=0x%X("%s"), w12=0x%X("%s")' % (w10, chr(w10), w12, chr(w12)))
        uc_engine.reg_write(UC_ARM64_REG_W12, w10)


emulator = Emulator(vfs_root=posixpath.join(posixpath.dirname(__file__), "vfs"), arch=emu_const.ARCH_ARM64)
libfoo3_module = emulator.load_library("tests/bin64/libfoo3.so")
instructions_list = [libfoo3_module.base + 0x3450]
emulator.mu.hook_add(UC_HOOK_CODE, hook_code, emulator, libfoo3_module.base, libfoo3_module.base + libfoo3_module.size)

try:
    xorkey = b'pizzapizzapizzapizzapizz'
    emulator.call_symbol(libfoo3_module, 'Java_sg_vantagepoint_uncrackable3_MainActivity_init', emulator.java_vm.jni_env.address_ptr, 0x00, Array(bytearray(xorkey)))

    print("UnCrackable3: bar() before")
    input_secret = b'12345678901234567890123'
    result = emulator.call_symbol(libfoo3_module, 'Java_sg_vantagepoint_uncrackable3_CodeCheck_bar', emulator.java_vm.jni_env.address_ptr, 0x00, Array(bytearray(input_secret)))
    print("UnCrackable3: bar() after, return=%d" % result)
except UcError as e:
    print("UnCrackable3: Exit at %x" % emulator.mu.reg_read(UC_ARM64_REG_PC))
    raise
```

指令級 Hook，顯示密碼字元 W10 並修改 W12 為 W10，讓字元比對能繼續下去

模擬呼叫 init(byte[])

傳入長度為 24 的任意字串，模擬呼叫 bar(byte[])

```
UnCrackable3: w10=0x6D("m"), w12=0x31("1")  UnCrackable3: w10=0x77("w"), w12=0x39("9")  UnCrackable3: w10=0x61("a"), w12=0x37("7")
UnCrackable3: w10=0x61("a"), w12=0x32("2")  UnCrackable3: w10=0x61("a"), w12=0x30("0")  UnCrackable3: w10=0x74("t"), w12=0x38("8")
UnCrackable3: w10=0x6B("k"), w12=0x33("3")  UnCrackable3: w10=0x73("s"), w12=0x31("1")  UnCrackable3: w10=0x20(" "), w12=0x39("9")
UnCrackable3: w10=0x69("i"), w12=0x34("4")  UnCrackable3: w10=0x70("p"), w12=0x32("2")  UnCrackable3: w10=0x61("a"), w12=0x30("0")
UnCrackable3: w10=0x6E("n"), w12=0x35("5")  UnCrackable3: w10=0x20(" "), w12=0x33("3")  UnCrackable3: w10=0x67("g"), w12=0x31("1")
UnCrackable3: w10=0x67("g"), w12=0x36("6")  UnCrackable3: w10=0x67("g"), w12=0x34("4")  UnCrackable3: w10=0x61("a"), w12=0x32("2")
UnCrackable3: w10=0x20(" "), w12=0x37("7")  UnCrackable3: w10=0x72("r"), w12=0x35("5")  UnCrackable3: w10=0x69("i"), w12=0x33("3")
UnCrackable3: w10=0x6F("o"), w12=0x38("8")  UnCrackable3: w10=0x65("e"), w12=0x36("6")  UnCrackable3: w10=0x6E("n"), w12=0x34("4")
```

查看模擬結果，將 W10 的字元組合起來即為密碼字串

逆向分析 - 總結

- 善用模擬執行工具可事半功倍，無需手機或模擬器也能逆向分析
- 監控敏感函數的參數或回傳值可獲得許多有用資訊
  - ➔ 字串相關：strcmp()、strncmp()、strstr()、strlen()...
  - ➔ 檔案相關：open()、read()、write()、mmap()...
- 對於沒有呼叫敏感函數的程式，需要多點耐心去分析

反逆向措施 1 - 自行實作敏感函數

1. 自行實作 libc.so 常用的敏感函數並將函數宣告為 static
2. 將原先呼叫 libc.so 敏感函數的地方改為呼叫自行實作的函數，不再依賴 libc.so
3. 可避免逆向人員使用逆向工具對 libc.so 敏感函數進行 Hook，監控參數及回傳 值
4. 實作範例：https://github.com/darvincisec/DetectFrida/tree/master/app/src/main/c

strncmp() → my_strncmp()

```
static inline int
my_strncmp(const char *s1, const char *s2, size_t n)
{
    if (n == 0)
        return (0);
    do {
        if (*s1 != *s2++)
            return (*(unsigned char *)s1 - *(unsigned char *)--s2);
        if (*s1++ == 0)
            break;
    } while (--n != 0);
    return (0);
}
```

read() → my_read()

```
static inline ssize_t my_read(int __fd, void* __buf, size_t __count){
    return __syscall3(__NR_read, __fd, (long)__buf, (long)__count);
}
```

```
static inline long __syscall3(long n, long a, long b, long c)
{
        register long x8 __asm__("x8") = n;
        register long x0 __asm__("x0") = a;
        register long x1 __asm__("x1") = b;
        register long x2 __asm__("x2") = c;
        __asm_syscall("r"(x8), "0"(x0), "r"(x1), "r"(x2));
}
```

```
#define __asm_syscall(...) do { \
        __asm__ __volatile__ ( "svc 0" \
        : "=r"(x0) : __VA_ARGS__ : "memory", "cc"); \
        return x0; \
        } while (0)
```

反逆向措施 1 - 自行實作敏感函數效果

```
__int64 __fastcall sub_8B58(_JNIEnv *a1)
{
  unsigned __int64 v1; // x8
  _JNIEnv *v2; // ST58_8
  unsigned __int64 v3; // ST38_8
  __int64 v4; // x0
  __int64 v5; // ST48_8
  __int64 v6; // x0
  __int64 v7; // ST40_8
  __int64 v8; // x0
  __int64 v9; // ST30_8
  unsigned int v10; // w0
  __int64 result; // x0
  char v12; // [xsp+60h] [xbp-230h]
  char v13; // [xsp+68h] [xbp-228h]
  char v14; // [xsp+70h] [xbp-220h]
  char v15; // [xsp+78h] [xbp-218h]
  __int64 v16; // [xsp+278h] [xbp-18h]

  v1 = _ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2));
  v16 = *(_QWORD *)(v1 + 40);
  v2 = a1;
  v3 = v1;
  v4 = sub_8FB8(&v14);
  v5 = ay::obfuscated_data<15ull,8432754782978560477ull>::operator char *(v4);
  v6 = sub_90AC(&v13);
  v7 = ay::obfuscated_data<15ull,5164447508740687751ull>::operator char *(v6);
  v8 = sub_91A0(&v12);
  v9 = ay::obfuscated_data<27ull,7305246811387187981ull>::operator char *(v8);
  v10 = strncmp(v5, v7, 14LL);
  sprintf(&v15, v9, v10);
  result = _JNIEnv::NewStringUTF(v2, &v15);
  *(_QWORD *)(v3 + 40);
  return result;
}
```

```
__int64 __fastcall sub_8B18(_JNIEnv *a1)
{
  unsigned __int64 v1; // x8
  _JNIEnv *v2; // ST58_8
  unsigned __int64 v3; // ST38_8
  __int64 v4; // x0
  unsigned __int8 *v5; // ST48_8
  __int64 v6; // x0
  unsigned __int8 *v7; // ST40_8
  __int64 v8; // x0
  __int64 v9; // ST30_8
  unsigned int v10; // ST2C_4
  __int64 result; // x0
  char v12; // [xsp+60h] [xbp-230h]
  char v13; // [xsp+68h] [xbp-228h]
  char v14; // [xsp+70h] [xbp-220h]
  char v15; // [xsp+78h] [xbp-218h]
  __int64 v16; // [xsp+278h] [xbp-18h]

  v1 = _ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2));
  v16 = *(_QWORD *)(v1 + 40);
  v2 = a1;
  v3 = v1;
  v4 = sub_8F78(&v14);
  v5 = (unsigned __int8 *)ay::obfuscated_data<15ull,1122904582700332131 9ull>::operator char *(v4);
  v6 = sub_906C(&v13);
  v7 = (unsigned __int8 *)ay::obfuscated_data<15ull,4171390554486297459ull>::operator char *(v6);
  v8 = sub_9160(&v12);
  v9 = ay::obfuscated_data<27ull,1437533952960399144 9ull>::operator char *(v8);
  v10 = sub_9254(v5, v7, 14LL);
  sprintf(&v15, v9, v10);
  result = _JNIEnv::NewStringUTF(v2, &v15);
  *(_QWORD *)(v3 + 40);
  return result;
}
```

```
v8 = a1;
v7 = a2;
v6 = a3;
if ( a3 )
{
  do
  {
    v3 = v7++;
    if ( *v8 != *v3 )
      return *v8 - (unsigned int)*(v7 - 1);
    v4 = v8++;
    if ( !*v4 )
      break;
    --v6;
  }
  while ( v6 );
  v9 = 0;
}
else
{
  v9 = 0;
}
return v9;
```

- strncmp() → my_strncmp()
- 函數名稱 my_strncmp 被隱藏，變成檔案位址 sub_9254
- sub_9254 函數內容不易被辨識為 strncmp()

反逆向措施 2 - 程式碼混淆

- 使用帶有混淆功能的 C/C++ 編譯器 O-LLVM 進行程式碼混淆：
  1. FLA：Control Flow Flattening，控制流程平坦化
  2. SUB：Instructions Substitution，指令替換
  3. BCF：Bogus Control Flow，虛假控制流程
- 在 CMakeLists.txt 裡面新增 O-LLVM 相關編譯設定即可 啟用
- O-LLVM：https://github.com/darvincisec/o-llvm-binary

```
set(OLLVM_PATH ${CMAKE_HOME_DIRECTORY}/../../../../../build/bin)
set(OLLVM_C_COMPILER ${OLLVM_PATH}/clang)
set(OLLVM_CXX_COMPILER ${OLLVM_PATH}/clang++)

set(OLLVM_C_FLAGS "-mllvm -fla -mllvm -sub -mllvm -bcf")

set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} ${OLLVM_C_FLAGS}")
set(CMAKE_CXX_FLAGS "${CMAKE_CXX_FLAGS} ${OLLVM_C_FLAGS}")
set(CMAKE_C_COMPILER ${OLLVM_C_COMPILER})
set(CMAKE_CXX_COMPILER ${OLLVM_CXX_COMPILER})
```

反逆向措施 2 - 程式碼混淆效果

原始碼

```
static size_t my_strlen(const char *s)
{
    size_t len = 0;
    while (*s++)
    {
        len++;
    }
    return len;
}
```

正常編譯後反編譯

```
__int64 __fastcall sub_9160(_BYTE *a1)
{
  _BYTE *v1; // x10
  __int64 i; // [xsp+0h] [xbp-10h]
  _BYTE *v4; // [xsp+8h] [xbp-8h]

  v4 = a1;
  for ( i = 0LL; ; ++i )
  {
    v1 = v4++;
    if ( !*v1 )
      break;
  }
  return i;
}
```

經 O-LLVM 編譯後反編譯

```
__int64 __fastcall sub_95DC(_BYTE *a1)
{
  _BYTE *v1; // x12
  signed int v2; // w8
  signed int v4; // [xsp+Ch] [xbp-14h]
  __int64 v5; // [xsp+10h] [xbp-10h]
  _BYTE *v6; // [xsp+18h] [xbp-8h]

  v6 = a1;
  v5 = 0LL;
  v4 = 1217852730;
  do
  {
    while ( 1 )
    {
      while ( v4 == 1217852730 )
      {
        v1 = v6++;
        if ( *v1 )
          v2 = 791389876;
        else
          v2 = 1334314678;
        v4 = v2;
      }
      if ( v4 != 791389876 )
        break;
      ++v5;
      v4 = 1217852730;
    }
  }
  while ( v4 != 1334314678 );
  return v5;
}
```

- 正常編譯後進行反編譯，結果與原始碼差異不大
- 經 O-LLVM 編譯後反編譯，出現許多 while 及 if else
- 混淆後逆向難度大幅上升

反逆向措施 - 總結

- 模擬執行工具可監控任意函數及指令執行時的 CPU 暫存器數值

  ➔ 使用 O-LLVM 進行程式碼混淆，避免監控點輕易被找到

- 外部敏感函數呼叫易被監控

  ➔ 自行實作敏感函數，不呼叫外部敏感函數

- 自行實作的敏感函數可搭配程式碼混淆，反逆向效果更佳

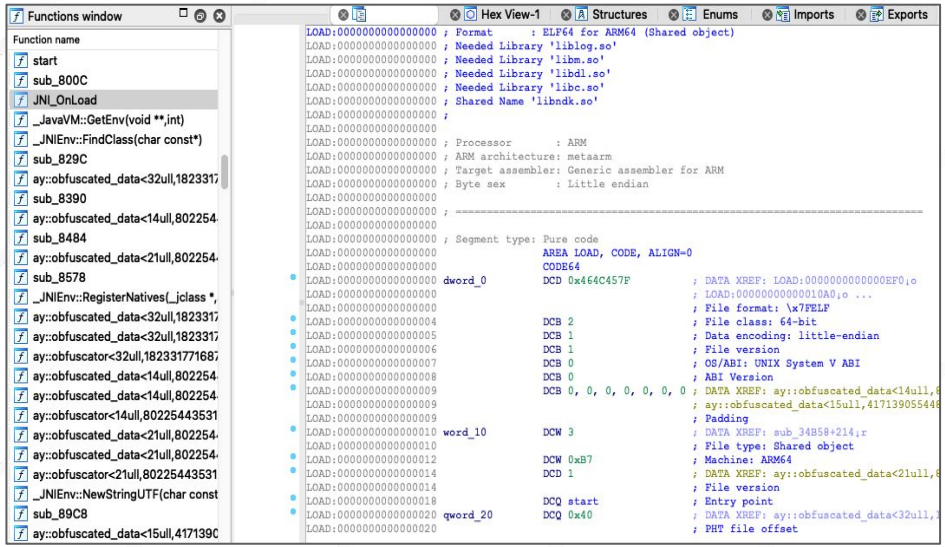
總結

如何增加 NDK 程式的逆向難度

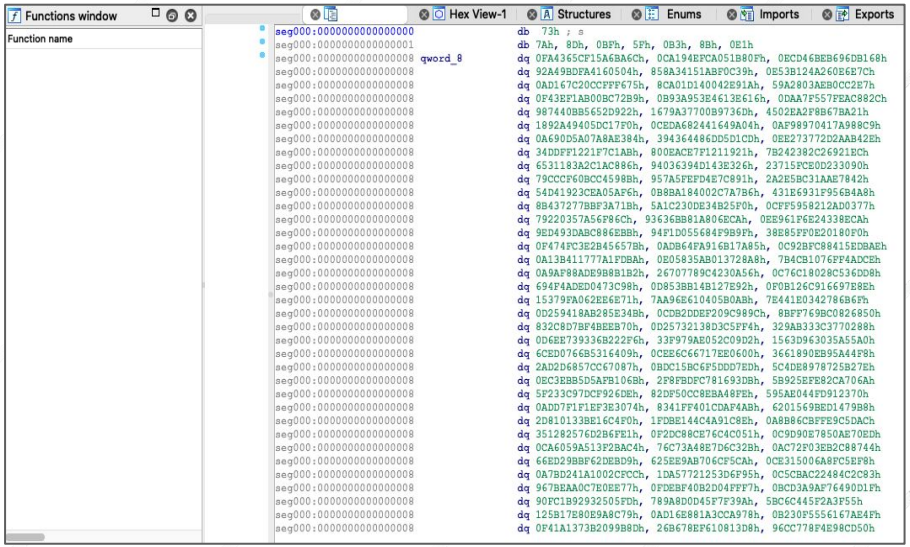
1. 將函數宣告為 static 類型，避免暴露函數名稱
2. JNI 函數使用 RegisterNatives 進行動態註冊
3. 所有字串使用字串加密巨集進行加密
4. 敏感函數自行實作，不呼叫系統函示庫的敏感函數
5. 所有程式碼使用 O-LLVM 進行混淆
6. **使用商用 App 安全防護產品加密整個 .so 檔**

反逆向措施 - 加密 .so 檔

加密前



加密後



有效的 .so 檔，可進行反組譯分析

無效的 .so 檔，都是亂碼無法分析

fourdesire

Thank you :)

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