Why can’t my app open that file?

A deep dive into the Android app sandbox

Chris Simmonds

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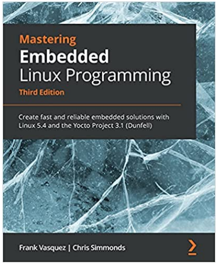
About Chris Simmonds



Mastering
Embedded
Linux Programming
Third Edition

Create fast and reliable embedded solutions with
Linux 5.4 and the Yocto Project 3.1 (Dunfell)

Frank Vasquez | Chris Simmonds

- Freelance consultant
- Author of *Mastering Embedded Linux Programming*
- Working with embedded Linux since 1999
- Android since 2009
- Speaker at many conferences and workshops
- Organiser of the AOSP and AAOS Meetup

"Looking after the Inner Penguin" blog at `https://2net.co.uk/`

Mastodon: @csimmonds@fosstodon.org `https://fosstodon.org/@csimmonds`

`https://uk.linkedin.com/in/chrisdsimmonds/`

Objectives of this talk

- Describe the Android application sandbox: why and how
- Give some insight into the internal workings of Android
- Show how platform apps can bypass (some of) these restrictions

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- ... and that's it

Anything else will result in a FileNotFoundException

Good or bad?

Good, because

- improves system and user security: I can be sure that no other app can read my bank account details

Bad, because

- makes it harder to share data between apps
- prevents apps from accessing useful system files
    - a problem when designing dedicated embedded Android devices

The Android application sandbox

- The sandbox was part of the original design of Android, right from day 1
- Isolates applications from each other and from the operating system
  - each application can access its own memory and files, and no others(*)
- The sandbox uses Linux kernel features for
  - memory isolation, based on Linux processes virtual memory
  - file isolation, based on Linux User IDs (UID), Group IDs (GID), and file mode

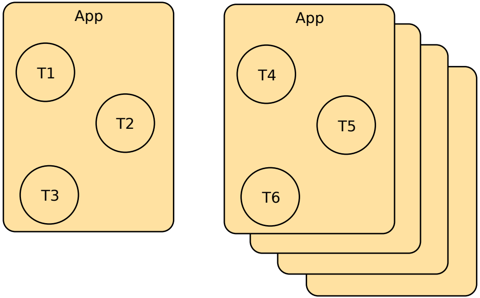
(*) in theory. There have been various loopholes, some of which get closed with each release

Linux processes

- A **Linux process** consists of
  - an area of virtual memory that contains the code, data, stack and heap
  - a Process Identifier (**PID**) that is allocated when the process is created
  - one or more threads, each identified by a Thread Identifier (**TID**)
  - an owner, indicated by a User Identifier (**UID**)
  - a group owner, indicated by a Group Identifier (**GID**)
  - zero or more supplementary GIDs
- The threads in a process share the address space, and so can share memory, but they cannot access any memory outside the process

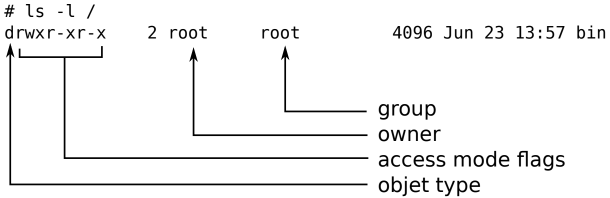
Sandbox: memory isolation

- Each Android app runs in a separate Linux process
  - therefore, threads in one app cannot read or write memory from another app



Linux file permissions and DAC

Each file has an owner (**UID**), a group (**GID**), and a set of permission flags, called the **mode**



```
# ls -l /
drwxr-xr-x    2 root     root         4096 Jun 23 13:57 bin
```

File mode flags

400	`r--------`	Owner permissions
200	`-w-------`	
100	`--x------`	
040	`---r-----`	Group permissions
020	`----w----`	
010	`-----x---`	
004	`------r--`	World permissions
002	`-------w-`	
001	`--------x`	

To read, write or execute a file, a process must match the mode flags

- if the UID of the process and file match, the first 3 flags ("owner")
- if the GID of the process and file match, the middle 3 flags ("group")
- otherwise, the last 3 flags ("world")

This mechanism is known as Discretionary Access Control, **DAC**

Sandbox: file isolation

- Android apps have Linux User IDs!
- Each app is assigned a unique Linux UID by Package Manager when installed
  - i.e. Android uses a Linux UID to identify an application (known as an appId in 14+)
  - App UIDs are in the range 10,000 to 99,999 (so, a maximum of 89,999 apps installed at once?); UIDs 0 to 9,999 are reserved for the system
- Each app has a place to put private files, e.g. `/data/data/<package name>`
- Linux DAC ensures that no other app can access those files

Note: since DAC is enforced by the kernel, NDK libraries have exactly the same restrictions as byte code

Digression: AOSP build types

For some of the examples, I am using a **userdebug** build so that I can use a root shell to show things that are not normally visible

The Android platform is built from the Android Open Source Project (AOSP)

AOSP allows three build types:

- **user**: locked-down, production build
- **userdebug**: includes `su` command for root-access, good for debugging
- **eng**: similar to userdebug, but root access is the default

$ prompt = normal shell

prompt = root shell

DAC in action

The user ID is recorded by Package Manager when the app was installed:

```
$ dumpsys package packages
[...]
  Package [com.example.filedemo] (878585b):
    appId=10089
[...]
```

At run-time the app has UID 10089

```
$ ps -An | grep filedemo
USER           PID  PPID        VSZ    RSS WCHAN            ADDR S NAME
10089         2592   330   13817352 130652 0                   0 S com.example.filedemo
```

The internal storage for the app has UID 10089 and GID 10089 for persistent files, and 20089 for cached files

```
# ls -ln /data/data/com.example.filedemo/
total 24
drwxrws--x 3 10089 20089 4096 2023-10-25 09:54 cache
drwxrws--x 2 10089 20089 4096 2023-10-24 19:49 code_cache
drwxrwx--x 2 10089 10089 4096 2023-10-25 09:54 files
```

supplementary groups

Find the PID of the app:

```
$ ps -A | grep filedemo
u0_a116       2071   357 13672104 117356 0                  0 S com.example.filedemo
```

Look at the supplementary groups:

```
emulator64_x86_64:/ $ grep Groups /proc/2071/status
Groups: 9997 20116 50116
```

Meaning:

```
9997     shared between all apps in the same profile
20116    cached data
50116    apps in each user to share
```

What about Android Users?

- Jelly Bean 4.2 introduced multi-user Android on tablets; later releases extended support to other devices including phones and cars
- With the multi-user UI enabled, each user identifies themselves when they authenticate with the device (PIN, fingerprint, ...)
- But Linux UIDs are used already as appId, so how are real users accommodated?

Android user ID?

- Android maps ranges of 100,000 Linux UIDs onto each Android user ID (AUID)
  - but note that AUID 1 to 9 are missing(*)
- UID = AUID*100000 + appId
- For example, the filedemo app running with AUID 10 and appId 10089:

```
$ ps -An | grep filedemo
USER           PID  PPID      VSZ    RSS WCHAN            ADDR S NAME
1010089       3194   354 13725488 102688 0                   0 S com.example.filedemo
```

Or, without the n option, ps shows PID symbolically as u0_a89

```
u0_a89        3194   354 13725488 102688 0                   0 S com.example.filedemo
```

(*) I don't know why

File isolation for multi-user

- We need to isolate different users of the same app from each other
- For each user (AUID) there is a separate private data storage area in `/data/user/`
- For example,

```
/data/user/0/com.example.filedemo/files/myfile.txt
/data/user/10/com.example.filedemo/files/myfile.txt
```

- `/data/user/0` is a link to `/data/data` for backwards compatibility

```
 # ls -ln /data/user/0/com.example.filedemo/files/myfile.txt
-rw-rw---- 1 10116 10116 13 2023-10-26 16:26 /data/user/0/com.example.filedemo/files/myfile.txt
# ls -ln /data/user/10/com.example.filedemo/files/myfile.txt
-rw-rw---- 1 1010116 1010116 13 2023-10-26 16:32 /data/user/10/com.example.filedemo/files/myfile.txt
```

SELinux enters the picture

- Basic DAC permissions leave some loopholes
- So, we need a layer of Mandatory Access Control (**MAC**)
- Linux supports several MAC implementations: Android uses **SELinux**
  - SELinux = Security Enhanced Linux, written by the NSA
  - deployed in full enforcing mode since Android 5
- Note that DAC and MAC work together: a process has to pass both layers of security before it can access a file or other resource

SELinux context

- SELinux contexts are of the form **user:role:type:sensitivity[:category]**
- Each process has an SELinux context, shown with `ps -Z`:

```
$ ps -AZ
LABEL                              USER       PID  PPID  S NAME
u:r:platform_app:s0:c512,c768      u0_a98     753   373  S com.android.systemui
u:r:priv_app:s0:c512,c768          u0_a91    1090   373  S com.android.launcher3
u:r:system_app:s0                  system    1890   373  S com.android.localtransport
u:r:untrusted_app_25:s0:c512,c768  u0_a86    2282   373  S com.android.deskclock
```

- Each file also has an SELinux context `ls -Z`:

```
# ls -Z1 /data/user/0/com.example.filedemo/
u:object_r:app_data_file:s0:c116,c256,c512,c768 cache
u:object_r:app_data_file:s0:c116,c256,c512,c768 code_cache
u:object_r:app_data_file:s0:c116,c256,c512,c768 files
```

SELinux policy

- (Most) Android apps belong to one of these SELinux types
  - `untrusted_app`: a regular app, including all user-installed apps
  - `platform_app`: a pre-installed app, signed with the platform keys
  - `system_app`: a pre-installed app with UID = 1000 (system)
  - `priv_app`: a pre-installed app which can be granted permissions with protection level `signature|privileged`

SELinux policy

- SELinux policy is coded in AOSP: you can't change it at runtime
- The policy for each type is in a type enforcement (.te) file

Here is an example of the policy for an untrusted_app in `untrusted_app.te`

```
# Some apps ship with shared libraries and binaries that they write out
# to their sandbox directory and then execute.
allow untrusted_app_all privapp_data_file:file { r_file_perms execute };
allow untrusted_app_all app_data_file:file     { r_file_perms execute };
```

SELinux policy for untrusted_app

- For `untrusted_app`, the policy depends on the targetSdkVersion:

Policy file	**targetSdkVersion range**
`untrusted_app.te`	34 and later
`untrusted_app_32.te`	from 32 to 33
`untrusted_app_30.te`	from 30 to 31
`untrusted_app_29.te`	29 only
`untrusted_app_27.te`	from 26 to 27
`untrusted_app_25.te`	25 and earlier

Changes over the years

- API level 19 and higher: app doesn't need to request any storage-related permissions to access app-specific directories within external storage. The files stored in these directories are removed when your app is uninstalled
- API level 28 or lowerr: your app can access the app-specific files that belong to other apps, provided that your app has the appropriate storage permissions
- API level 29 and higher: apps are given scoped access into external storage, or scoped storage, by default. When scoped storage is enabled, apps cannot access the app-specific directories that belong to other apps
- API level 30 and higher: apps cannot create their own app-specific directory on external storage

`https://developer.android.com/training/data-storage/app-specific`

Breaking the rules: platform apps

- You can break the rules if you are the platform developer
- Usecases
  - (mass market) platform developer/integrator for phone/TV/Automotive OEM
  - (specialized hardware) embedded Android devices - smart white boards, room access/booking systems, test and measurement, PoS, Advertising

Platform apps

- Platform key is the key used to sign `/system/framework/framework-res.apk`
- Any app signed with the same key becomes a **platform_app**
- Platform apps can use low-level platform APIs by adding `platform_apis: true`, and removing `sdk_version`

```
android_app {
[...]
    certificate: "platform",
    platform_apis: true,
}
```

System apps

- A system app is a platform app with UID system (1000)
- Just add `android:sharedUserId="android.uid.system"` to `AndroidManifest.xml`
- SELinux domain `system_app`
- Can access files and resources with UID and GID system

Privileged apps

- A privileged app is a platform app with the privileged flag set in `Android.bp`

```
privileged: true,
```

- SELinux domain is `priv_app`
- Privileged apps can be granted permissions with protection level `"signature|privileged"`

Persistent apps

- A platform app can be made a persistent app by adding `android:persistent="true"` to `AndroidManifest.xml`
- Persistent apps are started early: before the HOME activity is started, and way before `BOOT_COMPLETED`
- Persistent apps are restarted if they crash
- Examples: SystemUI, phone

The AOSP and AAOS Meetup

If you are interested in these low-level details of Android then you might be interested in this meetup group

On-line meetup up every 2 months - next is Wednesday 15th November

Sign up: `https://www.meetup.com/the-aosp-and-aaos-meetup/`

Details of past meetups, including slides and videos: `https://aospandaaos.github.io/`

Questions?

Slides: `https://2net.co.uk/slides/sandbox-csimmonds-droidcon-london-2023.pdf`

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