Sandboxing an Android application through system call interposition

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Ransomware

- Malicious piece of software that extorts a payment
- Blocks access to the user’s data and blackmails the user to pay a ransom
- Encrypting and non-encrypting variants of ransomware
- Ransomware on mobile phones is not particularly new (research papers from 2015 and earlier)
- The research field in cryptovirology is far broader
- Attacks are no longer theory but have been carried out in practice (and caused real damage)

Sandbox

- Isolate a process from the host machine
- Run unverified or untrusted application without risking harm to the operating system
- Provide a restricted operating system environment
- Various moulding of sandboxes
- Restrict access to system calls
- Rule based access control

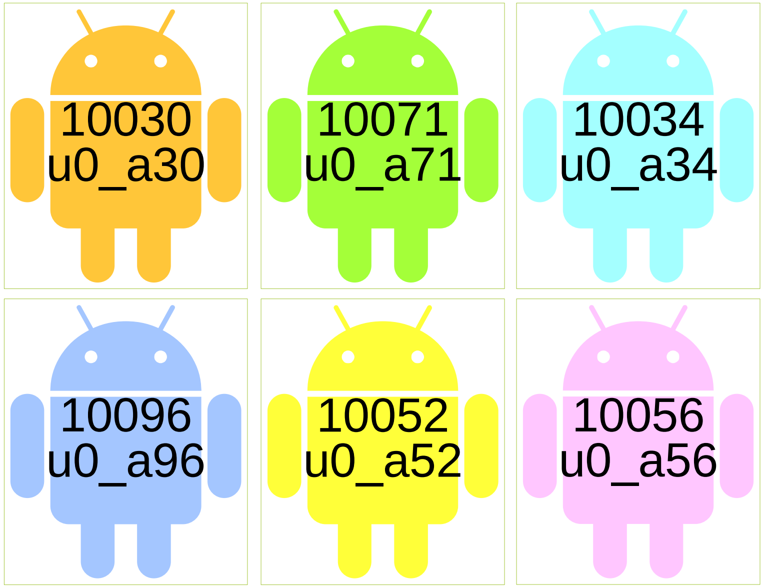
Sandbox

- Usable for legitimate software that runs in a risky environment (DNS server, browser)
- Record and analyse the tasks of the unknown application
- Monitoring the activities may yield insights into the unknown application

- When is a set of operations considered legitimate / suspicious / disruptive / ... ?
- Endless possibilities to
  - deceive user
  - cloak intents
  - ...

Privilege separation

- Unique user ID for each application
- Interactions only through interprocess communication
- Group assignment based on the permissions declared in the manifest file




```
<uses-permission
android:name="android.permission.WRITE_EXTERNAL_STORAGE"/>

<uses-permission
android:name="android.permission.READ_EXTERNAL_STORAGE"/>
```

Zygote

- Eukaryotic cell formed by a fertilization event between two gametes
- In Android: System service that is the parent of all Android application processes

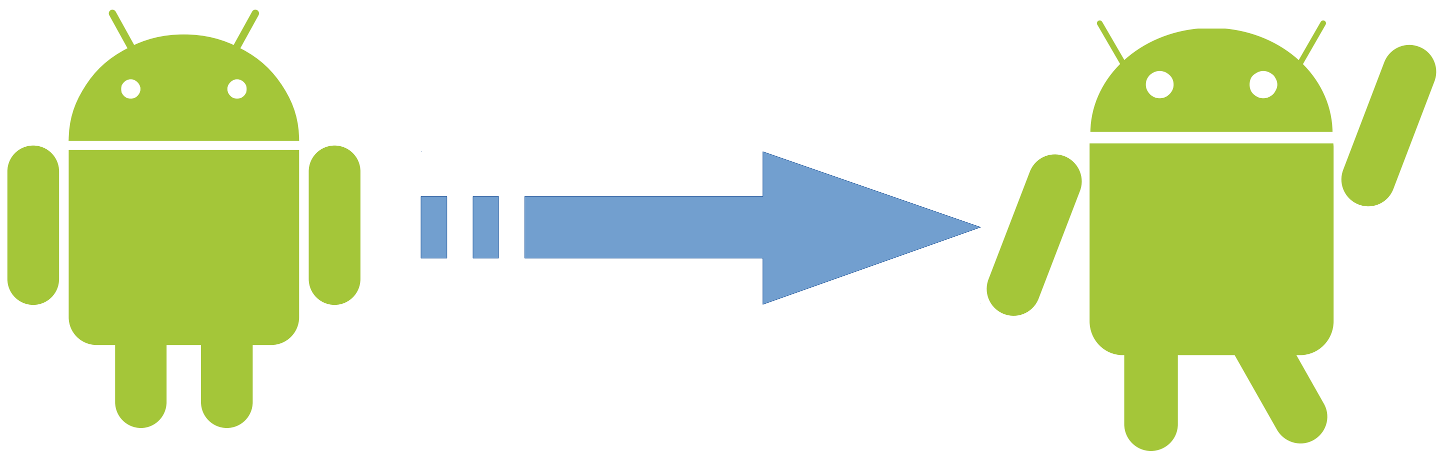
  Comparable to `init`

- User starts new application
- `Process` class calls the Zygote process
- Zygote creates a copy of itself using `fork()`
- Zygote returns a new process ID
- The `Process` class starts the new process through its `run()` method
- The `run()` method calls `startViaZygote()`
- Newly spawned process triggers the loading of the Dalvik virtual machine
- Now there are two Dalvik virtual machines

Trace an application

Root the device

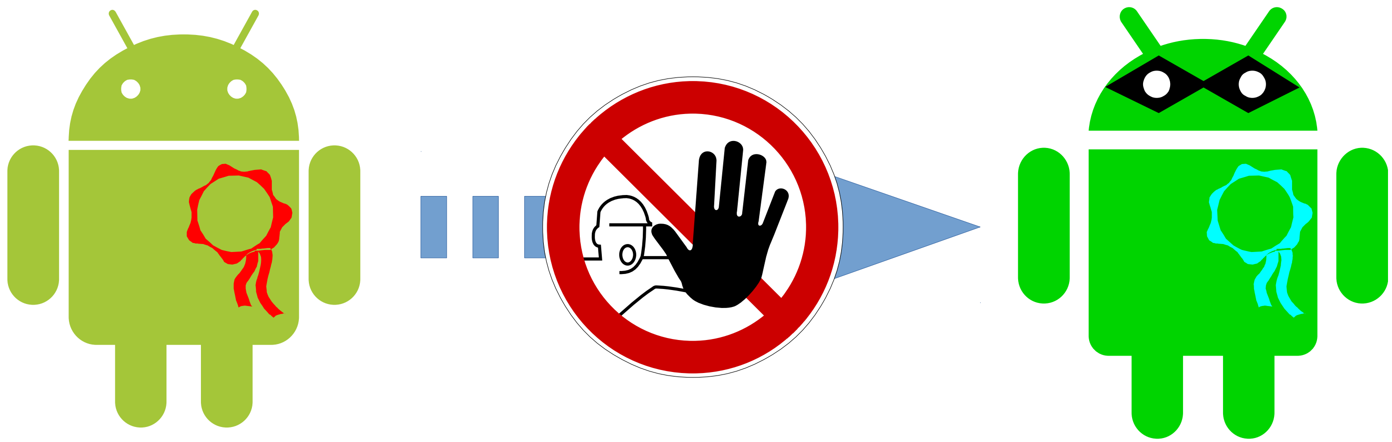
- Modify the kernel and all bets are off
- You do not want do demand the users to root their device
  - Technical knowledge required
  - Easily rip open security holes
  - Sometimes voids the warranty of the device



Trace an application

Share the user ID

- Run in the same user context
- Only possible if the applications
  - are signed with the same developer certificate
  - explicitly specify a common value for the shared UID in their manifest file



Trace an application

Use system call interposition

- The magic of peeking into another program
- Control the execution flow of the traced application

`long` **`ptrace`**`(enum __ptrace_request request, pid_t pid, void *addr, void *data);`

- Abbreviation of "process trace"
- One process can control another
- Controller can inspect and manipulate the internal state of its target
  - Used by debuggers and other code-analysis tools
- Here: Usage as a sandbox, run-time environment simulator

- Powerful ability → Attaching is limited to processes that the owner can send signals to (typically only their own processes)
  - CAP_SYS_PTRACE capability limitation
  - YAMA Linux Security Module
  - FreeBSD: jails and Mandatory Access Control policies.

- Higher level usage of `ptrace`: Userspace utility `strace`
- Projects move on extending strace instead of ptrace

Approximately 60 `ptrace` tags

PTRACE_ATTACH
PTRACE_CONT
PTRACE_DETACH
PTRACE_EVENT_CLONE
PTRACE_EVENT_EXEC
PTRACE_EVENT_EXIT
PTRACE_EVENT_FORK
PTRACE_EVENT_SECCOMP
PTRACE_EVENT_STOP
PTRACE_EVENT_VFORK
PTRACE_EVENT_VFORK_DONE
PTRACE_GETEVENTMSG
PTRACE_GETFPREGS
PTRACE_GETFPXREGS
PTRACE_GETREGS
PTRACE_GETREGSET
PTRACE_GETSIGINFO
PTRACE_GETSIGMASK
PTRACE_INTERRUPT
PTRACE_KILL
PTRACE_LISTEN
PTRACE_O_EXITKILL
PTRACE_O_MASK
PTRACE_O_SUSPEND_SECCOMP
PTRACE_O_TRACECLONE
PTRACE_O_TRACEEXEC
PTRACE_O_TRACEEXIT
PTRACE_O_TRACEFORK
PTRACE_O_TRACESECCOMP
PTRACE_O_TRACESYSGOOD
PTRACE_O_TRACEVFORK
PTRACE_O_TRACEVFORKDONE
PTRACE_PEEKDATA
PTRACE_PEEKSIGINFO
PTRACE_PEEKSIGINFO_SHARED
PTRACE_PEEKTEXT
PTRACE_PEEKUSER
PTRACE_PEEKUSR
PTRACE_POKEDATA
PTRACE_POKETEXT
PTRACE_POKEUSER
PTRACE_POKEUSR
PTRACE_SECCOMP_GET_FILTER
PTRACE_SEIZE
PTRACE_SEIZE_DEVEL
PTRACE_SETFPREGS
PTRACE_SETFPXREGS
PTRACE_SETOPTIONS
PTRACE_SETREGS
PTRACE_SETREGSET
PTRACE_SETSIGINFO
PTRACE_SETSIGMASK
PTRACE_SINGLESTEP
PTRACE_SYSCALL
PTRACE_SYSEMU
PTRACE_SYSEMU_SINGLESTEP
PTRACE_TRACEME

Some interesting `ptrace` arguments

- `PTRACE_TRACEME`
  - Program is conveying its readiness to get traced
- `WIFSTOPPED`
  - Status variable contains a bit pattern which indicates the fact that the child process has stopped
- `PTRACE_CONT`
  - Restart the child by invoking `ptrace` with the request
- `PTRACE_GETREGS`
  - Request results in the values of the CPU registers used by the stopped child
- `PTRACE_SETREGS`
  - Change the value of the registers
- `PTRACE_PEEKDATA`
  - Of the process being traced examine the content localised at the given address
- `PTRACE_POKEDATA`
  - Alter the contents of a memory location
- `PTRACE_SINGLESTEP`
  - Restart the stopped process, let it execute a single instruction and then stop it again
- `PTRACE_ATTACH`
  - Attach to the process specified by its process ID, making it a tracee of the calling process
- `PTRACE_SYSCALL`
  - Restart the child process (just like `PTRACE_CONT`) but arrange for it to stop at the next entry to or exit from a system call

Particular approach

- Load and execute the code of the original application in the context of the monitoring application
- Start the application we want to sandbox
- Generate a stub application, that loads the code and monitors its execution through system call interposition
- Patch the parameters of some system calls for e.g. file operations

- Limitations:
  - Any ptrace-based sandbox limited to register filtering
  - No filtering for arguments pointing to memory, e.g. file name provided to the `open()` system call
  - Seccomp (secure computing mode) unable to examine memory

Monitor

Stub

Orig

Follow-up techniques

- Superseded by access control security policies
- Enforce separation guarantees between applications

- First permissive release of Android 4.3 Jelly Bean (2012)
- Selective root daemon confinement, enforcement on a limited set of crucial domains (`installd`, `netd`, `vold` and `zygote`) in Android 4.4 KitKat (2013)
- Full confinement, Android Trusted Computing Base protection as well as full enforcement mode in Android 5.0 Lollipop (2014) and higher

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