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Android Application Security II

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Android App Development

- Logic implemented in Java / Kotlin / C / C++
  - “Contract between app and OS”: AndroidManifest.xml

- Apps are embedded in and driven by the platform framework
  - Many different entry points
  - Lots of callbacks

- Java APIs for basic functionality
  - Data Types, File System APIs, Networking, Crypto, …

- Android APIs for OS integration
  - IPC, HW access

Android API Architecture

- Many APIs are Stubs for RPC interfaces to system services
  - Run inside the system_server process (runs as system user)

- For example:
  `LocationManager` is the RPC interface for `LocationManagerService`

- Example call flow:
  1. Call `LocationManager.getLastKnownLocation()`
  2. Binder is used to forward call to system_server process
  3. LocationManagerService ensures that caller holds LOCATION permission
  4. Result is returned through Binder

Demo: https://cs.android.com

Inter-Process Communication

- At the lowest (kernel) level, IPC is implemented through **Binder**
- Arguments need to be serialised for passing them to other processes
  - Affected classes need to implement Parcelable interface

```java
public class MyParcelable implements Parcelable {
    private int mData;

    public int describeContents() { return 0; }

    public void writeToParcel(Parcel out, int flags) { out.writeInt(mData); }

    public static final Parcelable.Creator<MyParcelable> CREATOR = new Parcelable.Creator<MyParcelable>() {
        public MyParcelable createFromParcel(Parcel in) { return new MyParcelable(in); }

        public MyParcelable[] newArray(int size) { return new MyParcelable[size]; }
    };

    private MyParcelable(Parcel in) { mData = in.readInt(); }
}
```

Android Versions / API Levels

- The Android application framework evolved over time
  - New APIs, deprecated APIs, changed permissions, policies, UI design, …
  - Fragmentation: Backwards compatibility is important

- New Android version: New API (=SDK) Level
  - Accessible through Build.VERSION_CODE

- Every app references 3 different API versions:
  - Minimum SDK Version: App requires at least this API version
  - Target SDK Version: App operates as if it was running on this Android version
  - Compile SDK Version: All classes/methods known in this version may be used

Target SDK Level

- Apps can set Target SDK Level to bypass API policies introduced in later version

Example:

- Runtime permissions were added in Android 6.0 (SDK/API Level 23)
- Only affected applications targetting API Level 23!
- Apps could set lower targetSdkVersion to bypass user prompts

- **Google Play** only allows upload of apps targetting most recent SDK Level!
  - **New:** Starting in ***August 2023!***
  - Used to be ~2 releases behind the most recent SDK Level

Key Framework Components

Intent

- In many IPC transactions, an Intent carries arguments
  - Specifying the **component** that should be launched
    - Explicitly (package and class name)
    - Implicitly (action that should be supported)
  - **Data:** A URI or file path to a remote or local file
  - **Extras:** Key-Value pairs of arbitrary data

- The system is responsible for
  - Resolving the Intent: What component should be used
  - Instantiating and starting the target component

Picture: developer.android.com / Apache 2.0

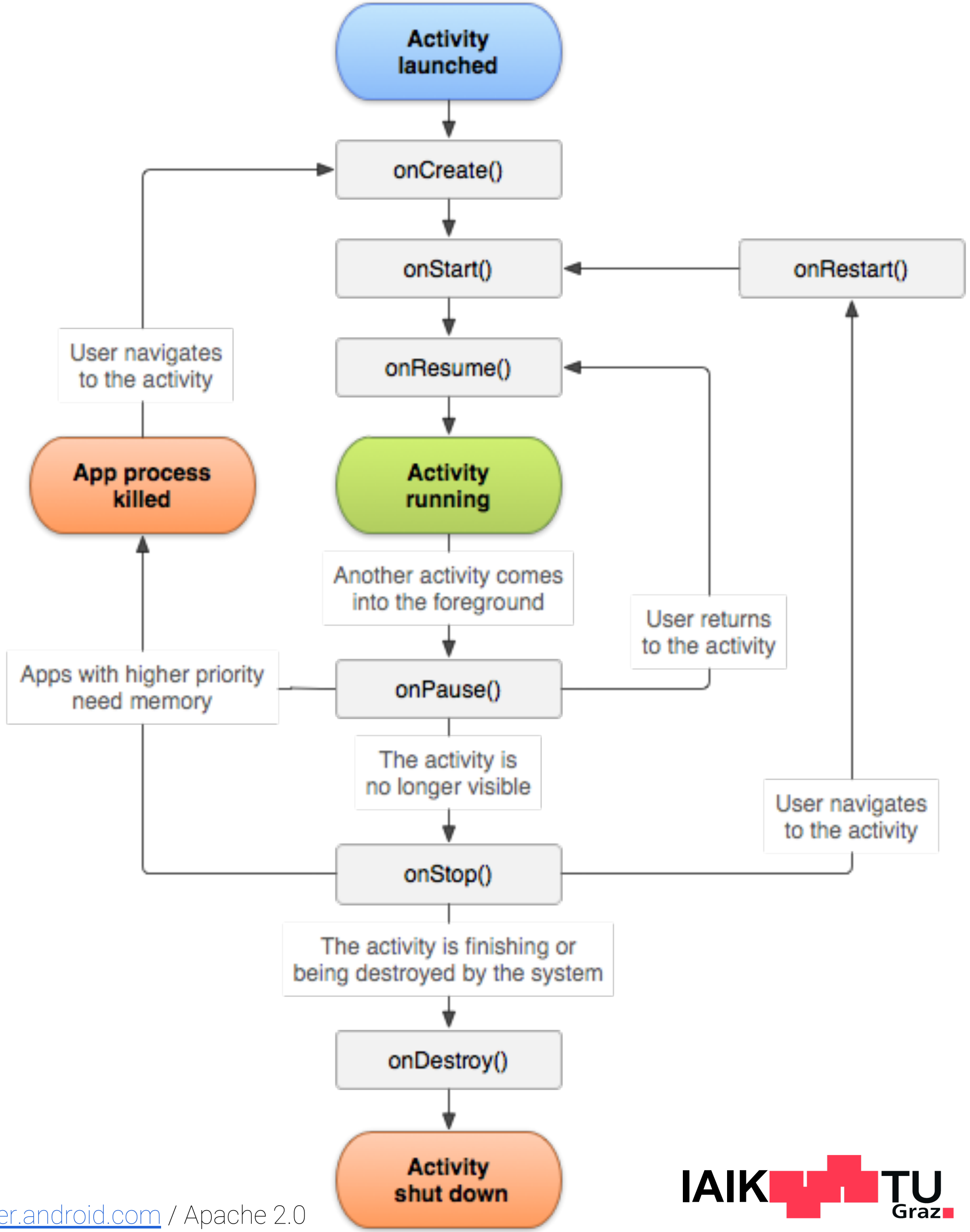
Context

- The base class for most Android app components

- Offers helper functions for
  - Reading app resources and assets
    - `Context.getResource()`, `Context.openAssetStream()`
  - Obtaining IPC handles for system services
    - `Context.getSystemService()`
  - Accessing the app-private folder
    - `Context.getFilesDir()`
  - Launching or registering app components
    - `Context.startService()`, `Context.registerReceiver()`
  - …

Activity

- ~"A UI screen and its logic controller"
- All (visible) apps have a Main Activity
  - May be started from the app launcher
- Launched through `Context.startActivity()`
  - Intent specifies target activity & arguments
- Must be declared in AndroidManifest.xml



Activity launched
onCreate()
onStart()
onRestart()
User navigates to the activity
onResume()
App process killed
Activity running
Another activity comes into the foreground
User returns to the activity
Apps with higher priority need memory
onPause()
The activity is no longer visible
User navigates to the activity
onStop()
The activity is finishing or being destroyed by the system
onDestroy()
Activity shut down

Picture: developer.android.com / Apache 2.0

Intent Filters

- If Activity should be launchable **by other apps**:
  - Mark as exported in AndroidManifest.xml

Explicity set exported=false otherwise!

- If Activity should support launching through **implicit** Intent:
  - Mark with intent-filter in AndroidManifest.xml

```
<activity android:name=".MainActivity” android:exported="true">
   <intent-filter>
      <action android:name="android.intent.action.MAIN" />
      <category android:name="android.intent.category.LAUNCHER" />
   </intent-filter>
   <intent-filter>
      <action android:name="android.intent.action.SEND"/>
      <category android:name="android.intent.category.DEFAULT"/>
      <data android:mimeType="text/plain"/>
   </intent-filter>
</activity>
```

BroadcastReceiver

- ~"Subscribe to system-wide events"

- Broadcasts are Intents published through `Context.sendBroadcast()`
  - Sent by system components or apps to communicate certain events
  - Their *action* carries information about the specific event

- BroadcastReceivers allow subscribing to specific events
  - IntentFilter specifies desired action

- Broadcast senders or receivers may be protected using a permission
  - Sender may restrict receivers to only those holding given permission
  - Receiver may only accept broadcasts send by apps holding given permission

BroadcastReceiver

- May be registered at runtime or statically through AndroidManifest.xml
  - Statically registered: Don’t receive implicit broadcasts
  - Dynamically registered: Only works while app is running

```
<receiver android:name=".MyBroadcastReceiver" android:exported="false">
    <intent-filter>
        <action android:name="android.intent.action.AIRPLANE_MODE" />
    </intent-filter>
</receiver>
```

```
BroadcastReceiver receiver = new MyBroadcastReceiver();
IntentFilter filter = new IntentFilter("android.intent.action.AIRPLANE_MODE");
ContextCompat.registerReceiver(context, receiver, filter, ContextCompat.RECEIVER_EXPORTED);
```

Don’t export BroadcastReceivers for app-internal broadcasts!

Service

- ~"Keep app running while no Activity is shown"

- Foreground Service: Visible to user through notification
- Background Service: Almost impossible nowadays
  - Battery drain and security issues

- Must be declared in AndroidManifest.xml
  - Binding to it (attaching to IPC interface) may be restricted using permission
  - If bindable or launchable from other apps: Set exported=true

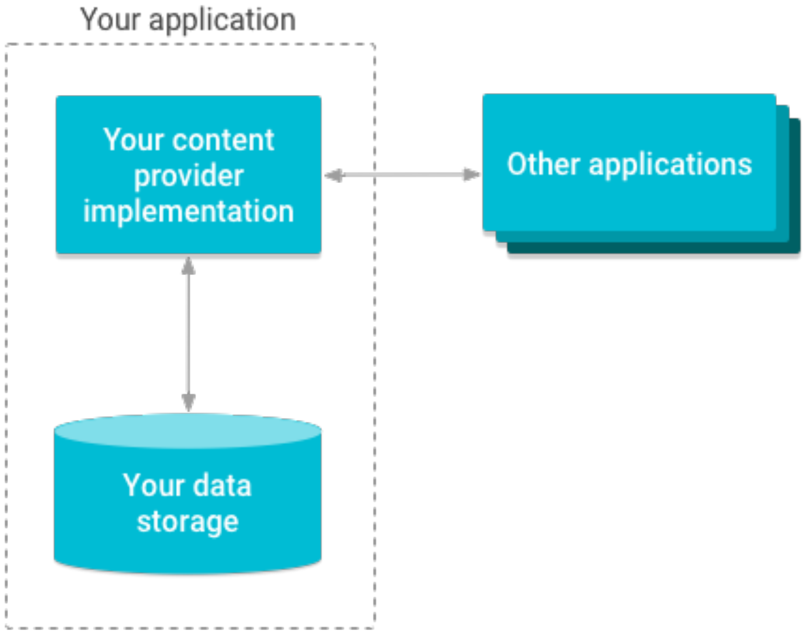
- Started using `Context.startForegroundService()`

Services and IPC

- Services may offer functionality for call by other processes
  - RPC implemented through Binder
- Interface defined in Android Interface Definition Language (AIDL)
  - Proxy (hiding away low-level marshaling and RPC) auto-generated
- Apps may calls Context.bindService() to obtain service’s Binder handle
  - Allows invoking functions of the service’s RPC interface

ContentProvider

- ~"Selectively grant other apps access to database or files"
- Every data item is addressed through a `content://` URI
- Some implemented by the system
  - Others by third-party applications
- Optionally protected by permissions
  - Separate permissions for read/write



Picture: developer.android.com / Apache 2.0

Source: developer.android.com

Data Storage

Data Storage on Android

File Scopes

App-Specific Files

- Private to the application
- Sharing must be initiated by the app

Public Files

- Not linked to a particular app
- Media, Documents, Downloads, …

File Locations

Internal Storage

- Always available
- Very limited capacity

External Storage

- Might be removable (SD, USB)

Data Storage

On the first versions of Android, apps had

- Private folder(s) they could access without permissions
- Option to access (almost) full public file system by requesting permission
  - Simply use Java File APIs

Today:

- Private folder(s) mostly staid the same
  - Though additionally encrypted on Android 10+
- Full public file system access no longer possible
- All public file access routed through system `ContentProviders`
  - Fine-grained per-path access control

ContentProviders for Data Storage

- **App-Specific Files**
  - **FileProvider:** Implemented by apps to expose their files to other apps

- **Media**: Pictures, Audio, Videos
  - **MediaStore:** Local centralised store, modifiable by apps
  - **CloudMediaProvider:** Read-only media from cloud (Android 13)

- **Documents**: Editable files (+ anything that's not media)
  - **DocumentProviders:** Central component of the **Storage Access Framework**
  - May be organised in a nested hierarchy

Sources: developer.android.com, medium.com/androiddevelopers

Storage Access Framework

Android 4.4+

An abstraction layer for file systems implemented on top of ContentProviders

- Several DocumentsProviders implement different data sources
  - Have a concept of nested document trees (~ folders)
  - External Storage
  - Media Store (videos, photos, audio)
  - Cloud Providers (Dropbox, Google Drive, …)

- Data source transparent to consuming applications

- User grants access to individual document or document trees

Source: developer.android.com

Scoped Storage

In Android 11, SAF was made **mandatory for accessing public files**

- Apps may write to MediaStore without requiring extra permission
- Permission still needed to access items created by other apps

- File API is transparently rerouted to MediaStore provider

- Exemption: *All files access* permission
  - Requires special approval for distribution through Google Play

Sources: developer.android.com, support.google.com

Application Security

Android Cryptography APIs

Java Cryptography Architecture: Consumer abstracted from Implementor

- Cipher: Encryption and Decryption
- SecureRandom: Random Number Generation
- MessageDigest: Calculating hash values
- SecretKeyFactory: Deriving keys from passwords
- …

Java Secure Socket Extension:

- SSLSocket: Provides TLS and SSL communication

HTTPS on Android

- Use Android's `HttpsURLConnection` class
  - By default: Secure `TrustManager` and `HostnameVerifier` (Details depend on Android version)
  - Possibility to use custom `TrustManager` and `HostnameVerifier`

- Use a third-party library such as OkHttp (built on top of `SSLSocket`)
  - Usually secure custom `TrustManager` and `HostnameVerifier`
  - Support self-signed certificates, certificate pinning, …

- Implement a custom HTTP stack on top of `SSLSocket`
  - Secure system-default `TrustManager`
  - HostnameVerifier up to developer!

Network Security Configuration (Android 7)

- XML-based system for configuring self-signed certificates and pinning
- These use cases no longer require custom validation code
- Default NSC: Don’t trust user-installed CA certificates

However

- Even the NSC can be misconfigured
  - Trust user-installed CAs
- Some applications still use custom `TrustManagers` or `HostnameVerifiers`
  - Overrides the NSC system altogether
- NSC only works on Android 7 or later
  - Silently ignored when app is run on older OS

Source: developer.android.com

Avoiding Crypto API misuse

- Use **trusted** high-level **libraries** instead of re-inventing the wheel
  - Crypto: Google Tink
  - HTTPS: OkHttp

- Follow **best practices** from official developer documentation

- Do not trust random code snippets from StackOverflow!

More Interesting APIs

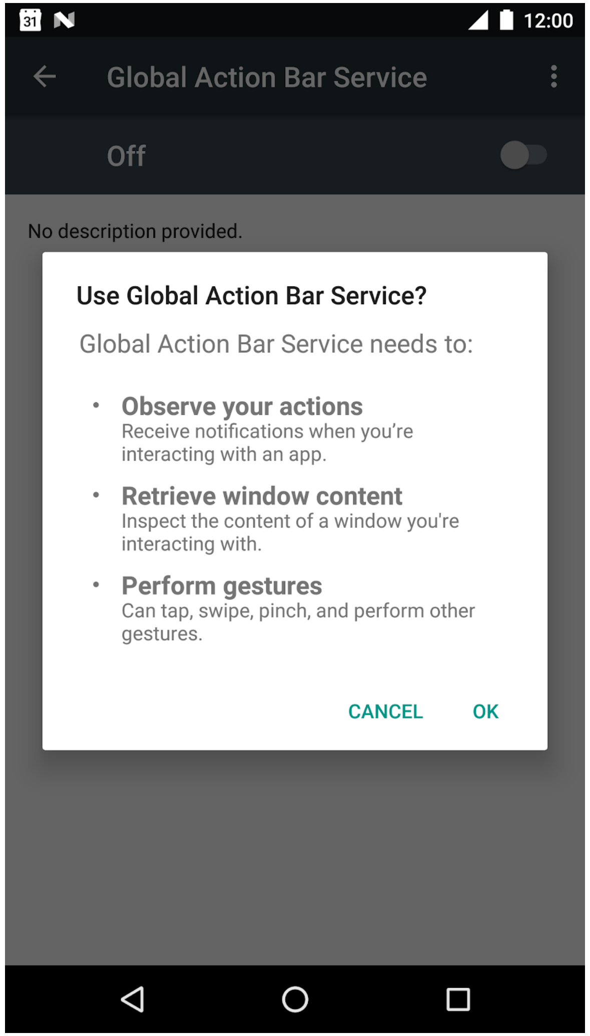
Reflection

- Android apps may use Java reflection
  - Accessing classes, methods or fields through their names
- This sometimes allowed or facilitated apps to bypass API restrictions
  - E.g. On early Android versions, Wifi AP could be started despite no official API
- Starting with Android 9: Restrictions on non-SDK interfaces
  - Sine then: More and more APIs hidden away from apps
- There still are ways for bypassing these restrictions!
  - Android 9 & 10: Use Double-Reflection / Meta-Reflection
  - All versions: E.g. use JNI / Java Unsafe API to manipulate ART runtime structs

AccessibilityService

~"Service for helping impaired users navigate their device"
  – Screen readers, Voice control, …

- Must be explicitly enabled by the user
  – Multiple services may be enabled in parallel
- Can access UI of other apps and inject input events
  – Very powerful role on the device!
- Google Play is very strict on which apps allowed to use AccessibilityService API
  – If not for accessibility: Disclose exact use, manual review



No description provided.

Use Global Action Bar Service?

Global Action Bar Service needs to:

- **Observe your actions**
  Receive notifications when you're interacting with an app.
- **Retrieve window content**
  Inspect the content of a window you're interacting with.
- **Perform gestures**
  Can tap, swipe, pinch, and perform other gestures.

VpnService

~”Service for rerouting device’s Internet traffic”

- Receives IP packets of all other processes

- Must be explicitly allowed by the user
  - Indicator in status bar, only one active VpnService allowed

- May collect information about user
  - HTTPS: Accessed hosts
  - HTTP: Full request + response

- Google Play is tying down on VpnServices
  - Similar process as for AccessibilityService

Device Administration API

- DeviceAdmin Apps: May enforce security policies on device
  - E.g. password strength, disable camera, remote wipe / lock

- Must be explicitly enabled by user
  - Once enabled: Must be disabled before app can be uninstalled

- Even more powerful role: DeviceOwner
  - Must be explicitly enabled through ADB or Android Enterprise
  - Can only disable (and therefore uninstall) itself
  - May
    - Install apps without user consent
    - Reboot the device
    - Install trusted CA certificates
    - …

Vulnerabilities and Attacks

Side Channels

Malicious apps may extract sensitive information using seemingly harmless permissions

- **Motion**: Extract passwords from device movements (Cai et al, 2011)
- **Sound:** Use speaker and microphone as sonar, infer unlock patterns (Cheng et al., 2019)
- **Power:** Fingerprint websites from device's power consumption (Quin et al, 2018)
- **Time:** Detect installed applications by timing API calls (Palfinger et al., 2020)
- **Data:** Fingerprint accessed websites from network traffic statistics (Spreitzer et al, 2018)
- **Electromagnetic emissions**: Extract screen content via SDR receiver (Liu et al, 2021)

Component Hijacking

- Benign applications may leak permissions to malicious apps
  - E.g. due to exporting components designed for app-internal use
- Example:

Victim App A (holds `android.permission.CALL_PHONE`)

```java
public class VictimActivity extends Activity {
    @Override
    protected void onCreate(@Nullable Bundle savedState) {
        Intent intent = new Intent(Intent.ACTION_CALL,
                                   getIntent().getData());
        startActivity(intent);
    }
}
```

VulnerableActivity.java

```xml
<manifest package=”at.victim">
    <uses-permission android:name="android.permission.CALL_PHONE" />
    <application>
        <activity
            android:name=".VictimActivity"
            android:exported="true”/>
    </application>
</manifest>
```

AndroidManifest.xml

Attacker App B (holds no permission)

```java
public class AttackerActivity extends Activity {
    @Override
    protected void onCreate(@Nullable Bundle savedState) {
        Intent intent = new Intent();
        intent.setComponent(new ComponentName(”at.victim",
                                              ".VActivity"));
        intent.setData(Uri.parse("tel://0800 123123"));
        startActivity(intent);
    }
}
```

➔ Attacker can initiate phone calls without holding the corresponding permission

Source: Zhang et al.: AppSealer: Automatic Generation of Vulnerability-Specific Patches for Preventing Component Hijacking Attacks in Android Applications

Crypto Misuse on Android

Apps commonly make mistakes in their use of cryptographic primitives

- **Cipher**: Using ECB mode, Re-using IV and key combination
- **SecureRandom**: Re-using seed value
- **MessageDigest**: Using MD5 algorithm
- **SecretKeyFactory**: Too low iteration count, salt re-use
- **SSLSocket**: Insecure TrustManager

2020 study found that > 99% of apps using crypto APIs make some mistake

Source: Piccolboni et al: CRYLOGGER: Detecting Crypto Misuses Dynamically

Containerization

- Android apps may dynamically load code from external files
- It is possible to execute complete APKs in the context of another app

- Malicious app may pretend to be legitimate app
  - By executing the original legitimate app in a malicious container
  - Can intercept and extract all user data

- Malicious apps can evade detection by Play Store analysis
  - Loading malicious components as plugins at runtime

Sources: Shi et al: „VAHunt: Warding Off New Repackaged Android Malware in App-Virtualization's Clothing".
Luo et al: "Anti-Plugin: Don't let your app play as an Android plugin" , blog.avast.com

UI Deception

- Android allows apps to display overlays on top of system UI
  - Requires special permission (increasingly harder to obtain on modern Android)
- Accessibility Service apps can explore app UIs and inject input events

This enabled

- Context-aware clickjacking
  - Overlay system UI to trick user e.g. into granting specific permission
- Inferring on-screen keyboard input
  - Through ingenious side-channel that exploits the mitigation against clickjacking

No longer possible on modern Android versions (overlays restricted)!

Source: Fratantonio et al.: Cloak and Dagger: From Two Permissions to Complete Control of the UI Feedback Loop

Google Play Core Library Vulnerability

- Registered an unprotected BroadcastReceiver
  - Data parsed from received Intents: Data URI for download, Split ID
- Loaded data from URI and put into
  - `/data/data/com.app.abc/unverified-splits/{split_id}`
- Unverified splits are verified and moved to verified-splits folder
- Files from verified-splits folder loaded into classpath

Problem: split_id not validated!

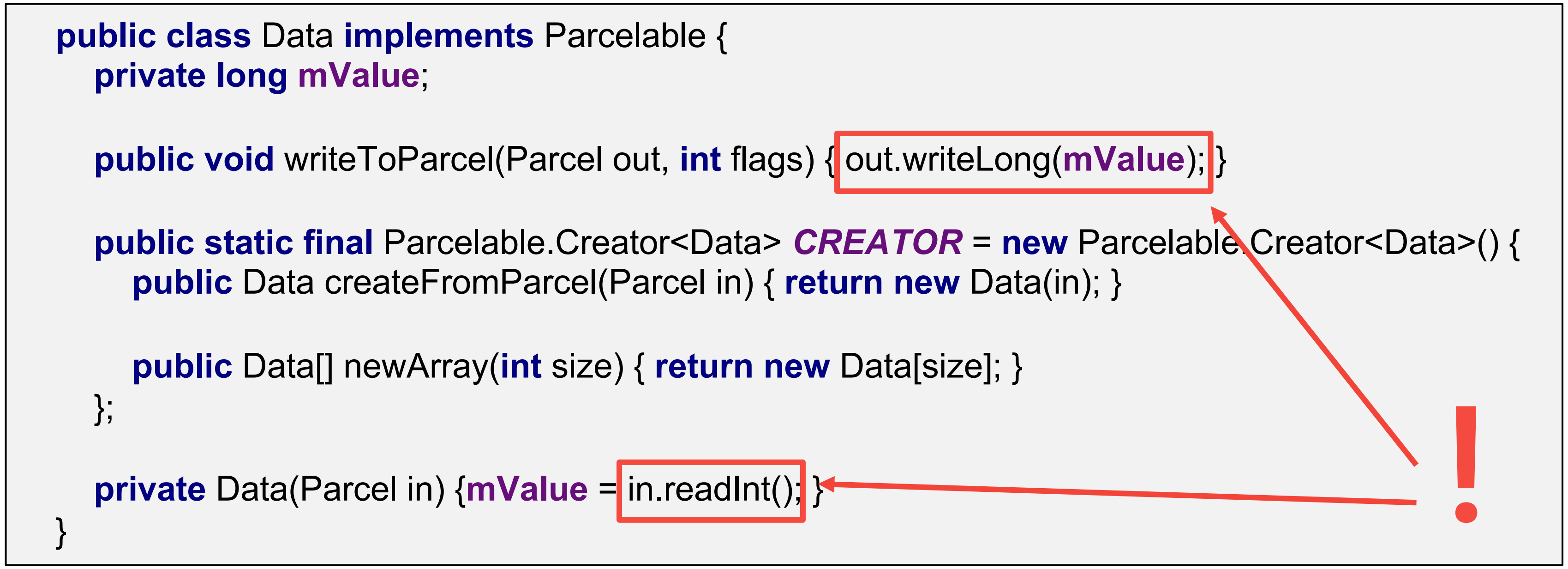
- Path traversal: Set split_id to “`../verified_splits/config.test`”
- Allows code execution in the context of victim app!

Source: oversecured.com

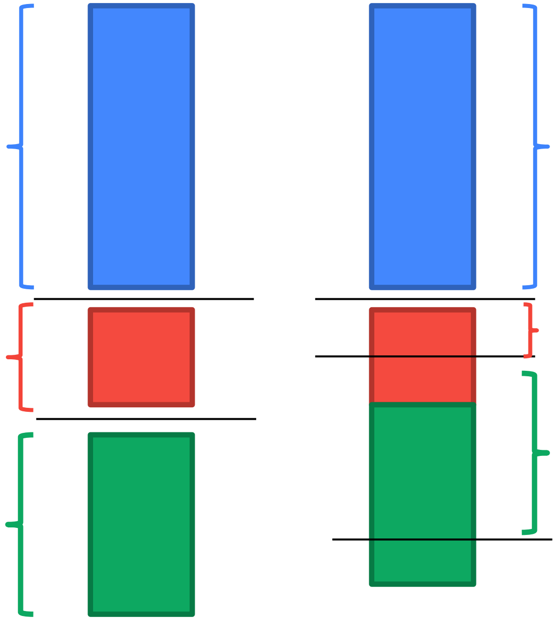
Parcelable Mismatch

- For every IPC transaction (through Binder), arguments have to be serialised
  - Arguments need to implement Parcelable interface from earlier today

- What if parsing the serialised Parcelable does not yield the original instance?
  - i.e. `!new Data(writeToParcel(myData, 0)).equals(myData)`
  - Data misalignment, subsequent data will be read from wrong offset!

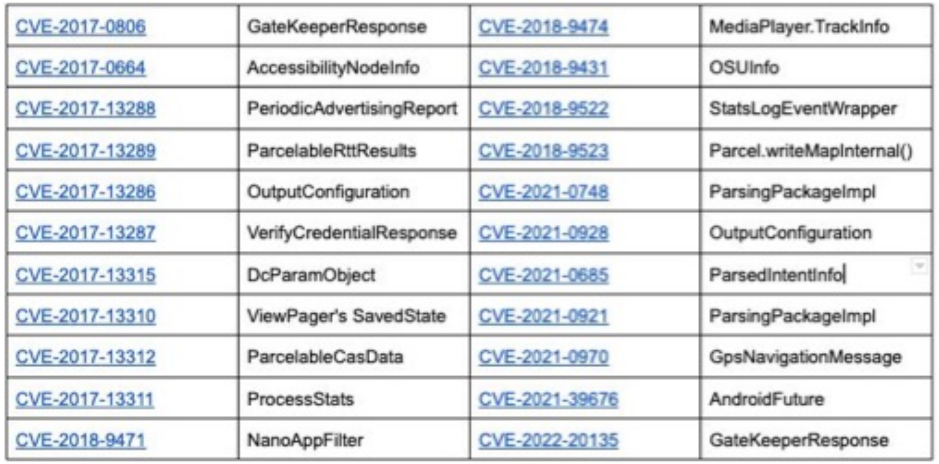


```
public class Data implements Parcelable {
   private long mValue;

   public void writeToParcel(Parcel out, int flags) { out.writeLong(mValue); }

   public static final Parcelable.Creator<Data> CREATOR = new Parcelable.Creator<Data>() {
      public Data createFromParcel(Parcel in) { return new Data(in); }

      public Data[] newArray(int size) { return new Data[size]; }
   };

   private Data(Parcel in) {mValue = in.readInt(); }
}
```



Parcelable Mismatch

- If transaction contains Parcelables originating from system & malicious app:
  - Data controlled by malicious app may spill into data originating from system
- E.g. Delivering broadcast to victim app
  - Attacker App ➔ System ➔ Victim App
  - Attacker App Parcelable: `Intent`
  - System Parcelable: `ActivityInfo`
  - May be exploited for code execution!



CVE-2017-0806	GateKeeperResponse	CVE-2018-9474	MediaPlayer.TrackInfo
CVE-2017-0664	AccessibilityNodeInfo	CVE-2018-9431	OSUInfo
CVE-2017-13288	PeriodicAdvertisingReport	CVE-2018-9522	StatsLogEventWrapper
CVE-2017-13289	ParcelableRttResults	CVE-2018-9523	Parcel.writeMapInternal()
CVE-2017-13286	OutputConfiguration	CVE-2021-0748	ParsingPackageImpl
CVE-2017-13287	VerifyCredentialResponse	CVE-2021-0928	OutputConfiguration
CVE-2017-13315	DcParamObject	CVE-2021-0685	ParsedIntentInfo
CVE-2017-13310	ViewPager's SavedState	CVE-2021-0921	ParsingPackageImpl
CVE-2017-13312	ParcelableCasData	CVE-2021-0970	GpsNavigationMessage
CVE-2017-13311	ProcessStats	CVE-2021-39676	AndroidFuture
CVE-2018-9471	NanoAppFilter	CVE-2022-20135	GateKeeperResponse

- Full writeup: https://github.com/michalbednarski/ReparcelBug2
- Parcelable was responsible for a series of critical Android vulnerabilities
  - Situation improved with systemic changes in Android 12

Picture Source: Ke et al.: Android parcels: the bad, the good, the better. BlackHat Europe 2022

Outlook

- 26.04.2024
  - iOS Platform Security

- 03.05.2024
  - iOS Application Security