Android cross-platform support study

Name: Xinwen Li

About this study

Android has been most popular developing platform provide usuful services and fearures in recent years. Android apps run within the Dalvik Virtual Machine which is similar to Java VM optimized for devices with limited memory and processing capacity. Android app with Java source code are complied into the Java byte code using the Java complier. However, this approch introduces difficulties for developers farmiliar with other languages rather than Java. Then people dive into a solution build runtime library support developing language other than Java. This solution allow developers develop application use same source code for different platforms. For example, Xamarin allow developers develop application for Android, IOS, and OS X using C# and the .NET framwork.

While it brings benificial allow developers use same source code for different platforms, it also introduces difficulties reverse engineering the application with third-party language support runtime libraries. This study focus on third-party runtime libraries on Android platform.

Cross-platform fundamentals

Pros and cons of cross-platform support

Pros:
•Allow developers leverage exsiting language skills.
•Code re-use.

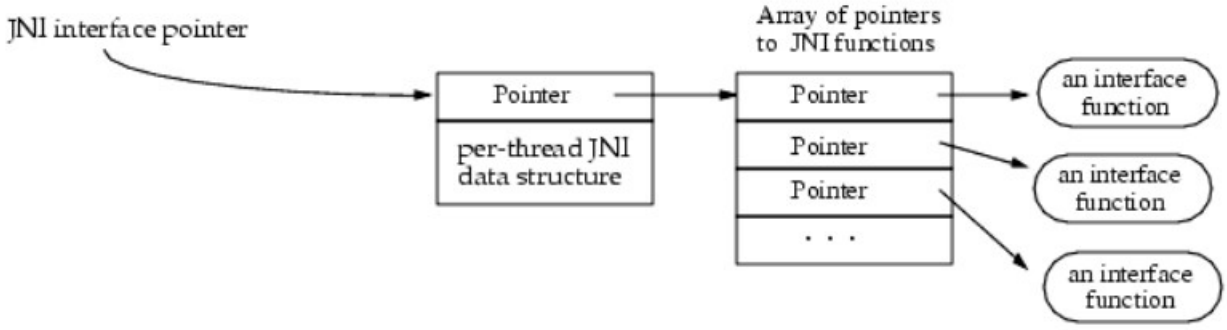
Cons:
•Third-party architecture lincensing requirement.
•Update delay.
•Performance and bugs.
•Understnad memory manage and API calling.
•Extra runtime libraries stored.

How does cross-platform work?

The trick is utilize Java Native Interface (JNI). JNI is a framwork that allows non-Java code to be called by a Java code running in side a JVM.

JNI Interface Functions and Pointers

Native code access Java VM features by calling JNI functions. Functions are pointed by an array of pointers pointed by JNI interface pointer. See figure below:



Native methods receive JNI interface pointer as an argument. For the same Java thread, multiple native method calls are guranteed to get the same interface pointer. For different different Java threads, it's possible to get different JNI interface pointers.

Compling, Loading and linking Native Methods

Since the Java VM is multithreaded, native libraries should also be complied and linked with multithread aware native compliers. e.g -D_REENTRANT flag for gcc complier.

Native methods are loaded with System.loadLibrary method. The system will follows a standard convert library name to a native dynamic linking library name. For example, Solaris system converts libXXX to libXXX.so and Win32 system converts libXXX to LibXXX.dll.

If operating system does not support dynamic linking, the VM completes the System.loadLibrary call to prelink the native methods with VM.

Native Method Arguments

JNI interpace pointer is the first argument of type JNIEnv. The second argument depends on method type. If native method is static. the second argument refers to its Java Class. If the method is nonstatic, the second argument refers to the object. The possible remaining arguments depends on the native method arguments.

Referencing Java Objects

Primitive types such as int, char are copied between Java and native code. Arbitrary Java objects are passed by reference. The VM keep track of all objects that have been passed to native code. The native code must inform VM the objects is no longer needed.

Accessing Java Objects, Primitive Arrays, Fields and Methods

- Java Objects
  Java VM creats a registry for each transition of control from Java to a native method to implement reference. JNI provides a set of accessor functions on references.

- Primitive Arrarys
  JNI provide a set tof functions copy primitive array elements between a segment of a Java array and a native memory buffer.

- Fields and Methods
  JNI identify methods and fields by their symbolic names and type signatures. For example: to call method f in class cls, the native code dirst obtain a method ID:
  jmethodID method_id = env->GetMethodID(cls, "f", "(ILjava/lang/String;)D");
  The native code can then use the method ID repeatedly:
  jdouble result = env->CallDoubleMethod(obj, method_id, 10, str);

For more JNI information

Please refer: https://docs.oracle.com/javase/7/docs/technotes/guides/jni/spec/jniTOC.html

APK decode and native library identify

What is inside an APK file?

An Apk file are a zip file containing resources and assembled java code. If we use apktool decode APK file, we usually get following part:

- AndroidManifest.xml
  Every app project must have one at the root of the project source set describing important information of the app. The information includes: app package name, components of the app, the permission the app needs, features app requires.

- smali
  Contains Kotlin/Java code that disassembles from APK's DEX files. Each .smali file corresponds to a Kotlin/Java class.

- res
  Resources are the additional files and static content the app code uses, such as layout, bitmaps.

- lib
  If app includes native code, this directory contains APK's native libraries (.so files).

How to identify native library exsist and in use?

- Native libraries exsist
  If we decode/unzip APK file, we can find .so file.

- Native libraries in use
  According to JNI working flow, Native methods are loaded with System.loadLibrary method. So if native libraries is in use, System.loadLibrary method must be called either from code or JVM.

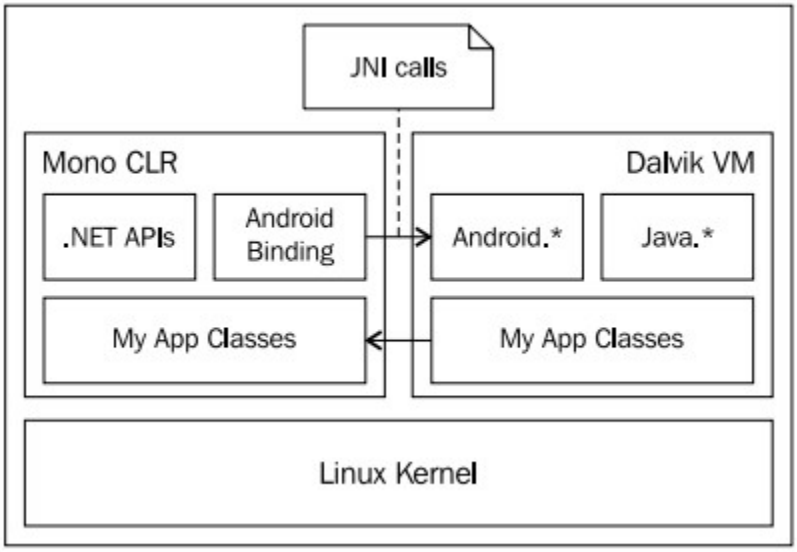
Native library identify implementation

Please see native_lib_identify.py

Current popular cross-platform framwork for Android

Xamarin.Android Architecture and Mono

Xmarin.Android is a product application provides software developing enviroment leverage Mono allow developers develop applications for Android, IOS and OS X using C# and .Net framework. Mono is one of cross-platform implementation support C# language. Mono is open source, includes C# complier, and a Common Language Runtime (CLR) that is binary compatible with Microsoft .NET. These Mono execution enviroment and Android Runtime (ART) virtual machine are running side-by-side. See below figure:



Both ART and Mono Runtime runn on top of the Linux kernel and expose APIs to the user code. Developer access the uderlying system using these API with their code. For example, within Mono Runtime, developers can use System.IO, System.Net in .NET class libraries to access underlying Linux system facilities. Within ART, most of system facilities such as Graphics, Andio, are not directly available to native applications. Developer using Java.* or Android.* namespaces to access the system facilities.

Managed Callable Warppers

Managed Callable Warppers (MCW) are a JNI bridge used any time the Android runtime needs to invoke managed code. MCW represents how Java Interfaces (The entire Android.* and related namespace) can be implemented and how virtual methods are overrided. MCW is responsible converting between managed classes, Android types and ART methods via JNI. Each MCW holds a Java global reference accessible threough Android.Runtime.IJavaObject.Handle property. This reference provides a mapping between Java instance and managed instance.

Java Activation

Whenever a Java object is exposed to managed code and a MCW needs to be constructed to manage the JNI handle, usually the constructor is invoked automatically. There are scenarios constructor must be manually provided but we do not expand here.

Application Startup

When an activity, service, etc is lauched, android will first check to see if therer is already a process running to host the activity/service/etc. If no such process, then a new process will be created reading AndroidManifest.xml and the type specified in the /manifest/application/@android:name attribute is loaded and instantiated. Once instantiated, ContentProvider.AttachInfo(Context, ProviderInfo) method will be incoked. Xamarin.Android hooks into this by adding a mono.MonoRuntimeProvider ContentProvider to AndroidManifest.xml during the build process. The mono.MonoRuntimeProvider.attachInfo() method is responsible for loading the Mono runtime into the process. Any attempts to use Mono prior to this point will fail.

For more Xamarin.Android Architecture information

For more detailed information, please see https://docs.microsoft.com/en-us/xamarin/android/internals/architecture

How to identify Mono App

- Native library name
  This approach is based on assumption the universal libraries for mono will remain still. This approach is vulnerable if library name get updated in future. Until June 2020, we find below typical mono library names:
  - libmono-btls-shared.so
  - libmono-native.so
  - libmono-profiler-log.so
  - libmonodroid.so
  - libxamarin-app.so
  - libxamarin-debug-app-helper.so
- AndroidManifest.xml provider check
  This is a recommanded and easy way to classify Mono application. For example, in our test application, we see below provider statement:

<provider android:authorities="com.companyname.test_app.mono.MonoRuntimeProvider.__mono_init__" android:exported="false" android:initOrder="1999999999" android:name="mono.MonoRuntimeProvider"/>

- mono.MonoRuntimeProvider.attachInfo() method calling scan
  While we can check the runtime provider provides the method, If we want to ensure the app process loads the runtime, we can scan this method calling in the code.

- Class name check
  This approach is based on assumption the universal mono package name will remain still. This approach is vulnerable if class name get updated in future. Until June 2020, we find mono class name includes:

  – mono.MonoPackageManager_Resources
  – mono.MonoPackageManager
  – mono.MonoRuntimeProvider
  – mono.android.*
  – mono.java.*
  – mono.javax.*

React and React Native

React

React is a JavaScript framwork developed by Facebook designed for solving the problem with complex user interfaces which had data that changed over time. React serves as the “view” framework part of the development paradigm model-view-controller (MVC).

Virtual DOM

Once a web page is loaded into a web browser, a Document Object Model (DOM) is created containing that web page. A DOM is of tree structure represent the structure of the current web page and its HTML elements. When action is performed on the web page, usually a new page is created or doing corresponding JavaScript code action. When the DOM is manipulated by JavaScript, this is done using a single page application (SPA). However, DOM manipulattion is expensive when mutations are slow. Poeple dive into a solution called two-way data binding. This binding help receive the sychronisation between the application UI state and the data model’s state. This solution is achieved by using key-value observing used by Knockout.js. In IOS, this is achieved by checking which the framework Angular by Google. This would require a linking function to look at what data has changed and imperatively make change to the DOM to keep it updated.

React uses a concept called the Virtual DOM instead of two-way data binding. The Virtual DOM selectively renders subtrees of the node in the DOM based on the current state, resulting in a minimal amount of manipulattion to keep the page updated. The Virtual DOM is a representation of the actual DOM and is an abstraction which grants the ability to treat the the JavaScript and the DOM as if they ware reactive. React will store the state of the application internally and only perform the DOM manipulattion when the state has changed. When the state of data model has changes, the virtual DOM and React will re-render the user interface to identify the difference and what should be manipulated. Then the differences are updated into the real DOM.

React Native

React Native is a JavaScript framwork implementation on IOS and android based on React. React Native is not open-sourced yet and runs in an embedded instance of JavaScriptCore (IOS) or V8 (android) inside the application and render to higher-level platform-specifc components.

The core of React Native

React Native is able to render the React Native component to real native Views for Android or UI Views for IOS. This is achieved by the abstraction layer known as the "bridge" which enables React Native to invoke the rendering APIs in Java for android or Objective-C for IOS.

How to identify React App

- Native library name
  This approach is based on assumption the universal libraries for React will remain still. This approach is vulnerable if library name get updated in future. Until June 2020, we find below typical react library names:
  - libreactnativeblob.so
  - libreactnativejni.so
- Class name check
  This approach is based on assumption the universal React package name will remain still. This approach is vulnerable if class name get updated in future. Until June 2020, we find typical react class name includes:
  - com.facebook.react.ReactActivity*
  - com.facebook.react.ReactApplication
  - com.facebook.react.ReactDelegate
  - com.facebook.react.ReactFragment*
  - com.facebook.react.ReactInstanceManager*
  - com.facebook.react.ReactPackage*
  - com.facebook.react.*

Flutter

About Flutter

Flutter is an open-sourced app SDK developed by Google for building cross-platform application support Dart language. Application made in Flutter are build from a single codebase, are compiled to native ARM code.

About DART

Google created Dart and uses it internally with some of its big projects such as Google AdWords. Dart is used to build mobile, web and server applications fast, portable and reactive. There are some benificial using Dart:

- Just in time
  Dart is just in time (JIT) compiled. When developer debugging application, the JIT compilation also happends.

- Fast
  Flutter rendering runs at 60 frames per second(fps) and 120fps for capable devices of 120HZ. The more fps, the smoother the app.

How to identify Flutter App

- Native library name
  This approach is based on assumption the universal libraries for Flutter will remain still. This approach is vulnerable if library name get updated in future. Until June 2020, we find below typical react library names:

  - libflutter.so

- Class name check
  This approach is based on assumption the universal Flutter package name will remain still. This approach is vulnerable if class name get updated in future. Until June 2020, we find typical react class name includes:

  - io.flutter.app
  - io.flutter.embedding
  - io.flutter.plugin*
  - io.flutter.view
  - io.flutter.util
  - io.flutter.*

PhoneGap and Apache Cordova

PhoneGap

PhoneGap is an application cross-platform framework that enables developers build native applications using HTML and JavaScript.

PhoneGap and Apache Cordova

PhoneGap was originally developed by Nitobi, a company acquired by Adobe. After this company was acquired, Nitobi donated the PhoneGap code base to Apache Software Foundation (ASF) under the project name Cordova.
PhoneGap is a free and open licensed distributin of Apache Cordova.

How Cordova access to Native APIs

When people begin to require cross-platform solution. The most simple cross-platform solution for mobile devices was using HTML as a webapp. However, for mobile developers, many mobile applications need to do more than HTML and web browser can support. For example, building a web application that interactied with the mobile camera. To get around this, Cordova implements a suite of APIs that extend native device capabilities to a web application. Cordova provide a suit of Java APIs that a developer

can leverage to allow a web application running with the Cordova container to access device capabilities outside of the web xontext. Essentially these APIs are implemented in two parts: a JavaScript library that expose to the native capabilities to the web application and the corresponding native code running in the container that implements the native part of the API. JavaScript access to native APIs made available through the JavaScript to native bridge into the Cordova container.

When a developer implements a feature in an application that uses one of the Cordova APIs, the application calls the API using JavaScript, and then a special layer within the Cordova translates the Cordova API call into the appropriate native API for the particular features.

How to identify Cordova App

- Class name check
  This approach is based on assumption the universal Cordova package name will remain still. This approach is vulnerable if class name get updated in future. Until June 2020, we find typical react class name includes:
  - org.apache.cordova.engine
  - org.apache.cordova.whitelist
  - org.apache.cordova.*
- JavaScript lib support check
  From Apktool decoding, we find one extra directory called "assets" inside Cordova app. This directory include JavaScript source code, HTML file and native API translation providers.
  The name of the directory include:
  - \assets\www\cordova-js-src\
  - \assets\www\css\
  - \assets\www\img\
  - \assets\www\js\
  - \assets\www\cordova_plugin.js
  - \assets\www\cordova.js
  - \assets\www\index.html

Capacitor

About Capacitor

Capacitor is a cross-platform app runtime that makes it easy to build web apps that run natively on iOS, Android, and the web. Capacitor provides a consistent, web-focused set of APIs that enable an app to stay as close to web-standards as possible, while accessing rich native device features on platforms that support them. Adding native functionality is easy with a simple Plugin API for Swift on iOS, Java on Android, and JavaScript for the web.

Capacitor has compatible support for many existing Cordova libraries.

How to identify Capacitor App

- Class name check
  This approach is based on assumption the universal Capacitor package name will remain still. This approach is vulnerable if class name get updated in future. Until June 2020, we find typical react class name includes:
  - com.getcapacitor.android.android
  - com.getcapacitor.android.cordova
  - com.getcapacitor.android.plugin
  - com.getcapacitor.android.ui
  - com.getcapacitor.android.util
  - com.getcapacitor.android.*
  - capacitor.android.plugins.*
- JavaScript lib support check
  From Apktool decoding, we find one extra directory called "assets" inside Capacitor app. This directory include JavaScript source code, HTML file and native API translation providers.
  The name of the directory include:
  - \assets\public\
  - \assets\capacitor.config.json

Will library obfuscation technology effect our platform detection result?

What can obfuscation tool do?

Code obfuscation is commemly used to hide code information from reverse engineering. Typical code obfuscation tools include ProGuard from Android Studio and DashO from PreEmptive. These tools support obfuscation features such as identifier renaming, method renaming, class renaming, Code removal/addition, String encrytion, etc.

Determine if current class must be predictable

While code obfuscation brings benificial hide information from reverse engineering, as obfuscation renames different part of the code, tasks, in some cases, when those part must be kept as a entry points to build the code, those part must be kept.

Platform classes under obfuscation tool

Mono

Mono Platform classes are one of the examples must remain static as code entry point. Xmarin.Android platform will automatically generate a ProGuard rule file proguard_xamarin.cfg to keep the necessary names. A typical proguard_xamarin.cfg looks like below:

The following example illustrates a typical generated **proguard_xamarin.cfg** file:

cfg

```
# This is Xamarin-specific (and enhanced) configuration.

-dontobfuscate

-keep class mono.MonoRuntimeProvider { *; <init>(...); }
-keep class mono.MonoPackageManager { *; <init>(...); }
-keep class mono.MonoPackageManager_Resources { *; <init>(...); }
-keep class mono.android.** { *; <init>(...); }
-keep class mono.java.** { *; <init>(...); }
-keep class mono.javax.** { *; <init>(...); }
-keep class opentk.platform.android.AndroidGameView { *; <init>(...); }
-keep class opentk.GameViewBase { *; <init>(...); }
-keep class opentk_1_0.platform.android.AndroidGameView { *; <init>(...); }
-keep class opentk_1_0.GameViewBase { *; <init>(...); }

-keep class android.runtime.** { <init>(***); }
-keep class assembly_mono_android.android.runtime.** { <init>(***); }
# hash for android.runtime and assembly_mono_android.android.runtime.
-keep class md52ce486a14f4bcd95899665e9d932190b.** { *; <init>(...); }
-keepclassmembers class md52ce486a14f4bcd95899665e9d932190b.** { *; <init>(...); }

# Android's template misses fluent setters...
-keepclassmembers class * extends android.view.View {
   *** set*(***);
}

# also misses those inflated custom layout stuff from xml...
-keepclassmembers class * extends android.view.View {
   <init>(android.content.Context,android.util.AttributeSet);
   <init>(android.content.Context,android.util.AttributeSet,int);
}
```

For more information, please refer: https://docs.microsoft.com/en-us/xamarin/android/deploy-test/release-prep/proguard?tabs=windows

Flutter

There are no documentation says Flutter project should keep the name when working with ProGuard. However, according to our test result, Flutter classes must also remain still as code entry point. Otherwise the APK cannot successfully built.

We tested below ProGuard rule as example to see what is the behavior building APK with and without these rules:

```
-dontwarn android.**
#Flutter Wrapper
-keep class io.flutter.app.** { *; }
-keep class io.flutter.plugin.**  { *; }
-keep class io.flutter.util.**  { *; }
-keep class io.flutter.view.**  { *; }
-keep class io.flutter.**  { *; }
-keep class io.flutter.plugins.**  { *; }
-keep class io.flutter.embedding.**  { *; }
```

When we build the APK without these rules, we get compiling errors as below:

```
Warning: io.flutter.embedding.android.FlutterView: can't find referenced method 'android.graphics.Inse
Warning: io.flutter.embedding.android.FlutterView: can't find referenced class android.graphics.Insets
Warning: io.flutter.embedding.android.FlutterView: can't find referenced class android.graphics.Insets
Warning: io.flutter.embedding.android.FlutterView: can't find referenced class android.graphics.Insets
Warning: io.flutter.embedding.android.FlutterView: can't find referenced class android.graphics.Insets
Warning: io.flutter.embedding.android.FlutterView: can't find referenced class android.graphics.Insets
Warning: io.flutter.embedding.android.FlutterView: can't find referenced class android.graphics.Insets
```

Apearently, when class names or method names are obfuscated, we cannot find the necessary entry point to compile the code. After we add the rules to keep both class names and method names, the compiling process finished with no errors.

React Native

We find below tested ProGuard rule for React Native to avoid both compiling error and applicatin malfunctioned:

```
# React Native

# Keep our interfaces so they can be used by other ProGuard rules.
# See http://sourceforge.net/p/proguard/bugs/466/
-keep,allowobfuscation @interface com.facebook.proguard.annotations.DoNotStrip
-keep,allowobfuscation @interface com.facebook.proguard.annotations.KeepGettersAndSetters
-keep,allowobfuscation @interface com.facebook.common.internal.DoNotStrip
-keep,allowobfuscation @interface com.facebook.jni.annotations.DoNotStrip

# Do not strip any method/class that is annotated with @DoNotStrip
-keep @com.facebook.proguard.annotations.DoNotStrip class *
-keep @com.facebook.common.internal.DoNotStrip class *
-keep @com.facebook.jni.annotations.DoNotStrip class *
-keepclassmembers class * {
    @com.facebook.proguard.annotations.DoNotStrip *;
    @com.facebook.common.internal.DoNotStrip *;
    @com.facebook.jni.annotations.DoNotStrip *;
}

-keepclassmembers @com.facebook.proguard.annotations.KeepGettersAndSetters class * {
  void set*(***);
  *** get*();
}

-keep class * implements com.facebook.react.bridge.JavaScriptModule { *; }
-keep class * implements com.facebook.react.bridge.NativeModule { *; }
-keepclassmembers,includedescriptorclasses class * { native <methods>; }
-keepclassmembers class *  { @com.facebook.react.uimanager.annotations.ReactProp <methods>; }
-keepclassmembers class *  { @com.facebook.react.uimanager.annotations.ReactPropGroup <methods>; }

-dontwarn com.facebook.react.**
-keep,includedescriptorclasses class com.facebook.react.bridge.** { *; }
```

Phone Gap and Cordova

We find below tested ProGuard rule for Cordova to avoid both compiling error and applicatin malfunctioned:

```
-keep public class * extends org.apache.cordova.CordovaPlugin
-keep public class * extends com.phonegap.api.Plugin
-keep class org.apache.cordova.** { *; }
-dontwarn android.webkit.*
```

Capacitor

We find below tested ProGuard rule for Capacitor to avoid both compiling error and applicatin malfunctioned:

```
-keep,allowobfuscation @interface com.getcapacitor.NativePlugin,com.getcapacitor.PluginMethod
-keep @com.getcapacitor.NativePlugin class * { *; }
-keepclasseswithmembernames class * {
  @com.getcapacitor.PluginMethod public *;
}
```

About AndroidX

AndroidX is the package name of all libraries within Jetpack. Android Jetpack is a suite of libraries to helps developers follow best practices, reduce boilerplate code, and write code that works consistently across Android versions and devices so that developers can focus on the code they care about. Each AndroidX library ships separately from the Android OS and provides backwards-compatibility across Android release. In addition, other libraries have migrated use AndroidX namespace libraries including Google Play service, Firebase, Butterknife, Mockito 2, SQLDelight. AndroidX is a full replacement of the Support Library.

Example libraries in AndroidX

androidx.camera

This library is also called CameraX. CameraX is a Jetpack support library, built to help developers develop camera app easier. It also provides a consistent and easy to use API serface that works acoss most Android devices, with backward-compatibility to Android 5.0. This library is different from Android Camera2 API included in Andriod framwork. The android.hardware.camera2 package provides an interface to individual camera devices connected to an Android device. Individual CameraDevices provide a set of static property information that describes the hardware device and the available settings and output parameters for the device. CameraX is based on camera2, observes a lifecycle to determine when to open the camera, when to create a capture session, ans when to stop and shutdown. The API provide method calls and callbacks to monitor progress.

androidx.sqlite

This library contains abstract interface along with basic implementation which can be used to build developers' own libraries that access SQLite. In addition, developers might choose to use androidx.room library, which provides an abstraction layer over SQLite to allow for more robust database access. the old fasion work with SQLite database management classes is to work with android.database.sqlite classes.

Firebase

Firebase libraries gives developers functionality such as analytics, databases, messaging and crash reporting. For example, AdMob library included in Firebase offers advertisement support with different format.

Firebase are included in Jetpack meet following version requirement:
com.android.tools.build:gradle v3.2.1 or later
compileSdkVersion 28 or later

For more Jetpack libraries

Please refer: https://developer.android.com/jetpack/androidx/explorer