Deep Dive into Android IPC/Binder Framework at Android Builders Summit 2013

Aleksandar (Saša) Gargenta, Marakana Inc.

Last Updated: 2013-02-19

Why are you here?

- You want to better understand how Android works
  - Intents, ContentProviders, Messenger
  - Access to system services
  - Life-cycle call-backs
  - Security
- You want to modularize your own business logic across application boundaries via a highly efficient and low-latency IPC framework
- You want to add new system services and would like to learn how to best expose them to your developers
- You just care about IPC and Binder seems unique and interesting
- You don't have anything better to do?

Objectives

- Binder Overview
- IPC
- Advantages of Binder
- Binder vs Intent/ContentProvider/Messenger-based IPC
- Binder Terminology
- Binder Communication and Discovery
- AIDL
- Binder Object Reference Mapping
- Binder by Example
- Async Binder
- Memory Sharing
- Binder Limitations
- Security

Slides and screencast from this class will be posted to: http://mrkn.co/bgnhg

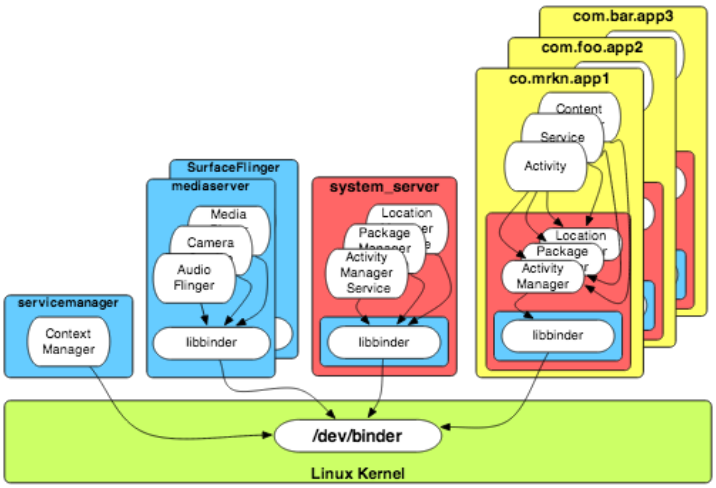
Who am I?

Aleksandar Gargenta

- Developer and instructor of Android Internals and Security training at Marakana
- Founder and co-organizer of San Francisco Android User Group (sfandroid.org)
- Founder and co-organizer of San Francisco Java User Group (sfjava.org)
- Co-founder and co-organizer of San Francisco HTML5 User Group (sfhtml5.org)
- Speaker at AnDevCon, AndroidOpen, Android Builders Summit, etc.
- Server-side Java and Linux, since 1997
- Android/embedded Java and Linux, since 2009
- Worked on SMS, WAP Push, MMS, OTA provisioning in previous life
- Follow
  - @agargenta
  - +Aleksandar Gargenta
  - http://marakana.com/s/author/1/aleksandar_gargenta

What is Binder?

- An IPC/component system for developing object-oriented OS services
  - Not yet another *object-oriented kernel*
  - Instead *an object-oriented operating system environment* that works on traditional kernels, like Linux!



- Essential to Android!
- Comes from OpenBinder
  - Started at Be, Inc. as a key part of the "next generation BeOS" (~ 2001)
  - Acquired by PalmSource
  - First implementation used in Palm Cobalt (micro-kernel based OS)
  - Palm switched to Linux, so Binder ported to Linux, open-sourced (~ 2005)
  - Google hired Dianne Hackborn, a key OpenBinder engineer, to join the Android team
  - Used as-is for the initial bring-up of Android, but then completely rewritten (~ 2008)
  - OpenBinder no longer maintained - long live Binder!

- Focused on scalability, stability, flexibility, low-latency/overhead, easy programming model

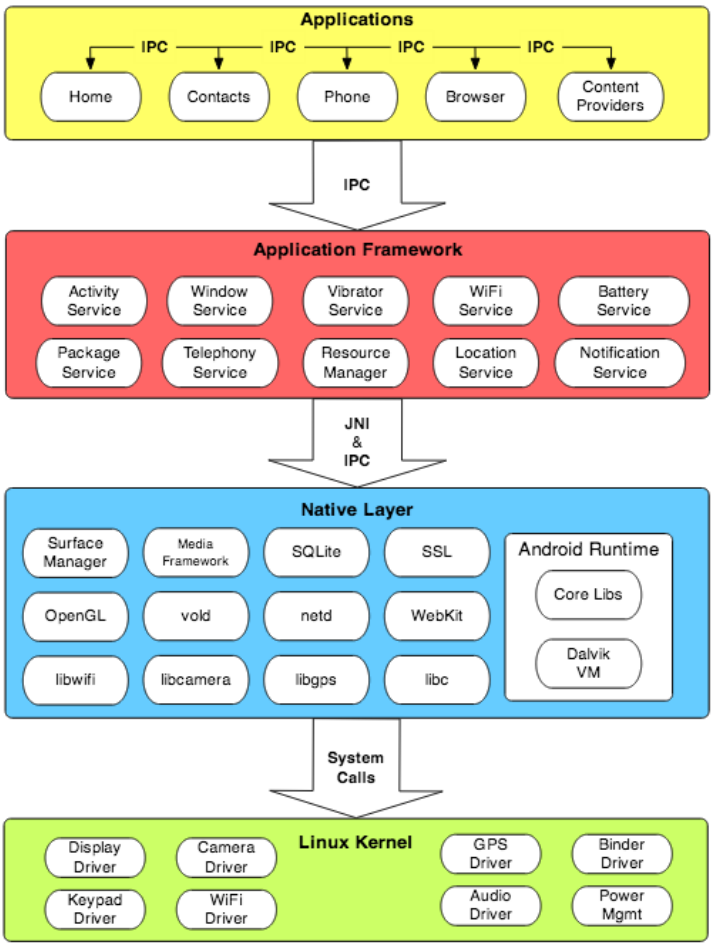
IPC

- Inter-process communication (IPC) is a framework for the exchange of signals and data across multiple processes
- Used for message passing, synchronization, shared memory, and remote procedure calls (RPC)
- Enables **information sharing**, computational speedup, **modularity**, convenience, **privilege separation**, **data isolation**, stability
  - Each process has its own (sandboxed) address space, typically running under a unique system ID

- Many IPC options
  - Files (including memory mapped)
  - Signals
  - Sockets (UNIX domain, TCP/IP)
  - Pipes (including named pipes)
  - Semaphores
  - Shared memory
  - Message passing (including queues, message bus)
  - Intents, ContentProviders, Messenger
  - Binder!

Why Binder?

- Android apps and system services run **in separate processes** for security, stability, and memory management reasons, but they need to communicate and share data!
  - Security: each process is sandboxed and run under a distinct system identity
  - Stability: if a process misbehaves (e.g. crashes), it does not affect any other processes
  - Memory management: "unneeded" processes are removed to free resources (mainly memory) for new ones
  - In fact, a single Android app can have its components run in separate processes



- IPC to the rescue
  - But we need to avoid overhead of traditional IPC and avoid denial of service issues

- Android's libc (a.k.a. bionic) does not support System V IPCs,
  - No SysV semaphores, shared memory segments, message queues, etc.
  - System V IPC is prone to kernel resource leakage, when a process "forgets" to release shared IPC resources upon termination
  - Buggy, malicious code, or a well-behaved app that is low-memory `SIGKILL`'ed

- Binder to the rescue!
  - Its built-in reference-counting of "object" references plus death-notification mechanism make it suitable for "hostile" environments (where lowmemorykiller roams)
  - When a binder service is no longer referenced by any clients, its owner is automatically notified that it can dispose of it

- Many other features:
  - "Thread migration" - like programming model:
    - Automatic management of thread-pools
    - Methods on remote objects can be invoked as if they were local - the thread appears to

"jump" to the other process
        - Synchronous and asynchronous (`oneway`) invocation model

    - Identifying senders to receivers (via UID/PID) - important for security reasons
    - Unique object-mapping across process boundaries
        - A reference to a remote object can be passed to yet another process and can be used as an identifying token

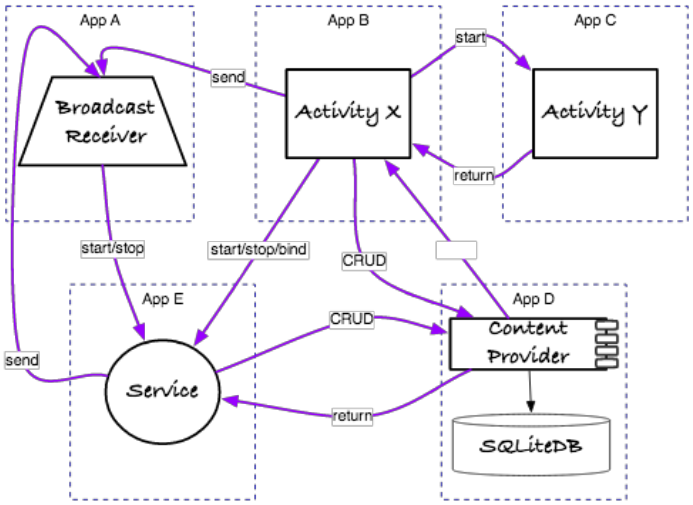
    - Ability to send file descriptors across process boundaries
    - Simple Android Interface Definition Language (AIDL)
    - Built-in support for marshalling many common data-types
    - Simplified transaction invocation model via auto-generated proxies and stubs (Java-only)
    - Recursion across processes - i.e. behaves the same as recursion semantics when calling methods on local objects
    - Local execution mode (no IPC/data marshalling) if the client and the service happen to be in the same process

- But:
    - No support for RPC (local-only)
    - Client-service message-based communication - not well-suited for streaming
    - Not defined by POSIX or any other standard

- Most apps and core system services depend on Binder
    - Most app component life-cycle call-backs (e.g. `onResume()`, `onDestory()`, etc.) are invoked by `ActivityManagerService` via binder
    - Turn off binder, and the entire system grinds to a halt (no display, no audio, no input, no sensors, ...)
    - Unix domain sockets used in some cases (e.g. RILD)

IPC with `Intents` and `ContentProviders`?

- Android supports a simple form of IPC via intents and content providers
- Intent messaging is a framework for asynchronous communication among Android components
  - Those components may run in the same or across different apps (i.e. processes)
  - Enables both point-to-point as well as publish-subscribe messaging domains
  - The intent itself represents a message containing the description of the operation to be performed as well as data to be passed to the recipient(s)
  - Implicit intents enable loosely-coupled APIs



- ContentResolvers communicate synchronously with ContentProviders (typically running in separate apps) via a fixed (CRUD) API
- All android component can act as a senders, and most as receivers
- All communication happens on the Looper (a.k.a. *main*) thread (by default)
- But:
  - Not really OOP
  - Asynchronous-only model for intent-based communication
  - Not well-suited for low-latency
  - Since the APIs are loosely-defined, prone to run-time errors
  - All underlying communication is *based on Binder*!
  - In fact, Intents and ContentProvider are just a higher-level abstraction of Binder
  - Facilitated via system services: `ActivityManagerService` and `PackageManagerService`

- For example:
  `src/com/marakana/shopping/UpcLookupActivity.java`

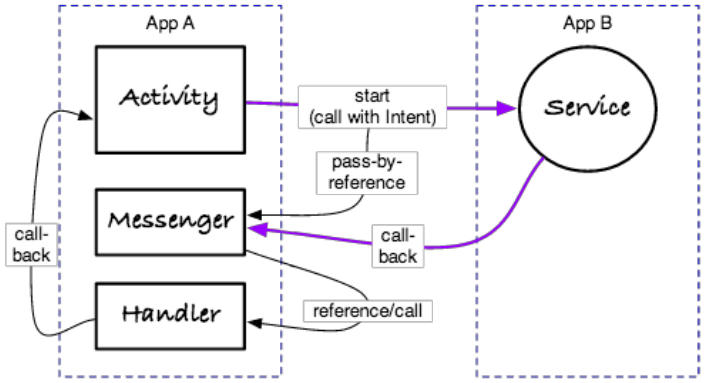
```
…
public class ProductLookupActivity extends Activity {
  private static final int SCAN_REQ = 0;
  …
  public void onClick(View view) {
    Intent intent = new Intent("com.google.zxing.client.android.SCAN");           //❶
    intent.setPackage("com.google.zxing.client.android");                         //❶
    intent.putExtra("SCAN_MODE", "PRODUCT_MODE");                                 //❷
    super.startActivityForResult(intent, SCAN_REQ);                               //❸
  }

  @Override
  protected void onActivityResult(int requestCode, int resultCode, Intent data) { //❹
    if (requestCode == SCAN_REQ && resultCode == RESULT_OK) {                     //❺
      String barcode = data.getStringExtra("SCAN_RESULT");                        //❻
      String format = data.getStringExtra("SCAN_RESULT_FORMAT");                  //❻
      …
      super.startActivity(
        new Intent(Intent.ACTION_VIEW,
          Uri.parse("http://www.upcdatabase.com/item/" + barcode)));              //❼
    }
    …
  }
}
```

src/com/google/zxing/client/android/CaptureActivity.java:

```
…
public class CaptureActivity extends Activity {
  …
  private void handleDecodeExternally(Result rawResult, …) {
    Intent intent = new Intent(getIntent().getAction());
    intent.addFlags(Intent.FLAG_ACTIVITY_CLEAR_WHEN_TASK_RESET);
    intent.putExtra(Intents.Scan.RESULT, rawResult.toString());                   //❽
    intent.putExtra(Intents.Scan.RESULT_FORMAT,
      rawResult.getBarcodeFormat().toString());
    …
    super.setResult(Activity.RESULT_OK, intent);
    super.finish();                                                               //❾
  }
}
```

❶ Specify who we want to call
❷ Specify the input parameter for our call
❸ Initiate the call asynchronously
❹ Receive the response via a call-back
❺ Verify that this is the response we we expecting
❻ Get the response
❼ Initiate another IPC request, but don't expect a result
❽ On the service side, put the result into a new intent
❾ Send the result back (asynchronously)

`Messenger` IPC



- Android's `Messenger` represents a reference to a `Handler` that can be sent to a remote process via an `Intent`
- A reference to the `Messenger` can be sent via an `Intent` using the previously mentioned IPC mechanism
- `Message`s sent by the remote process via the messenger are delivered to the local handler
- `Message`s are like `Intent`s, in that they can designate the "operation" (`aMessage.what`) and data (`aMessage.getData()`)
- Still asynchronous, but lower latency/overhead
- Great for efficient call-backs from the service to the client
- Messages are by default handled on the Looper thread
- All underlying communication is still *based on Binder*!
- For example, this is how we could write a client: ***`src/com/marakana/android/download/client/DownloadClientActivity.java`***:

```
…
public class DownloadClientActivity extends Activity {
  private static final int CALLBACK_MSG = 0;
  …
  @Override
  public void onClick(View view) {
    Intent intent = new Intent(
      "com.marakana.android.download.service.SERVICE");                    //❶
    ArrayList<Uri> uris = …
    intent.putExtra("uris", uris);                                         //❷
    Messenger messenger = new Messenger(new ClientHandler(this));          //❸
    intent.putExtra("callback-messenger", messenger);                      //❹
    super.startService(intent);                                            //❺
  }

  private static class ClientHandler extends Handler {
    private final WeakReference<DownloadClientActivity> clientRef;         //❻

    public ClientHandler(DownloadClientActivity client) {
      this.clientRef = new WeakReference<DownloadClientActivity>(client);
    }

    @Override
    public void handleMessage(Message msg) {                               //❼
      Bundle data = msg.getData();
      DownloadClientActivity client = clientRef.get();
      if (client != null && msg.what == CALLBACK_MSG && data != null) {
        Uri completedUri = data.getString("completed-uri");                //❽
        // client now knows that completedUri is done
        …
      }
    }
  }
}
```

❶ Specify who we want to call (back to using Intents!)
❷ Specify the input parameter for our call
❸ Create a messenger over our handler
❹ Pass the messenger also as an input parameter
❺ Initiate the call asynchronously
❻ Our handler remembers a reference to the client
❼ Receive responses via a call-back on the handler
❽ Get the response data

- And our service could look as follows:
  src/com/marakana/android/download/service/DownloadService.java:

```
…
public class MessengerDemoService extends IntentService {
  private static final int CALLBACK_MSG = 0;
  …
  @Override
  protected void onHandleIntent(Intent intent) {                          //❶
    ArrayList<Uri> uris = intent.getParcelableArrayListExtra("uris");     //❷
    Messenger messenger = intent.getParcelableExtra("callback-messenger"); //❸
    for (Uri uri : uris) {
      // download the uri
      …
      if (messenger != null) {
        Message message = Message.obtain();                               //❹
        message.what = CALLBACK_MSG;
        Bundle data = new Bundle(1);
        data.putParcelable("completed-uri", uri);                         //❺
        message.setData(data);                                            //❹
        try {
          messenger.send(message);                                        //❻
        } catch (RemoteException e) {
          …
        } finally {
          message.recycle();                                              //❹
        }
      }
    }
  }
}
```

❶ Handle the request from our client (which could be local or remote)
❷ Get the request data
❸ Get the reference to the messenger
❹ Use `Message` as a generic envelope for our data
❺ Set our reply
❻ Send our reply

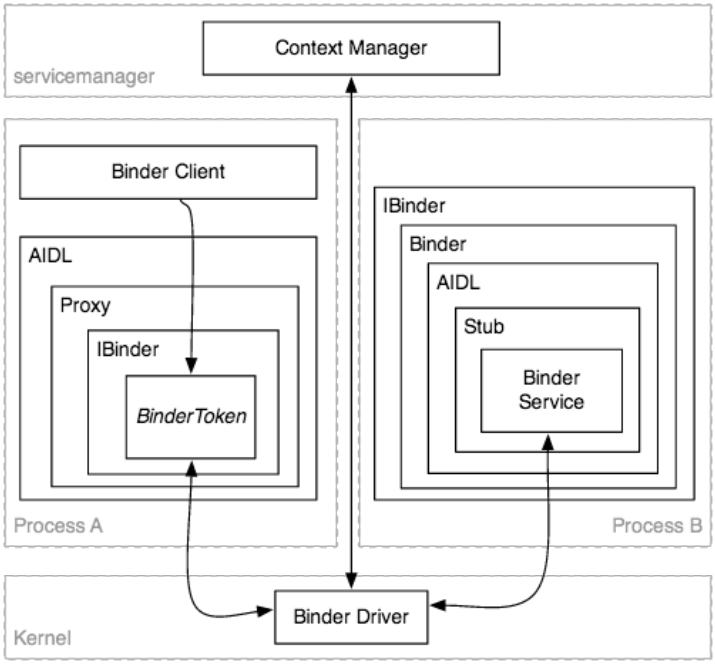
Binder Terminology

Binder (Framework)
The overall IPC architecture

Binder Driver
The kernel-level driver that fascinates the communication across process boundaries

Binder Protocol
Low-level protocol (`ioctl`-based) used to communicate with the Binder driver

IBinder Interface
A well-defined behavior (i.e. methods) that Binder Objects must implement



AIDL
Android Interface Definition Language used to describe business operations on an IBinder Interface

Binder (Object)
A generic implementation of the `IBinder` interface

Binder Token
An abstract 32-bit integer value that uniquely identifies a Binder object across all processes on the system

Binder Service
An actual implementation of the Binder (Object) that implements the business operations

Binder Client
An object wanting to make use of the behavior offered by a binder service

Binder Transaction
An act of invoking an operation (i.e. a method) on a remote Binder object, which may involve sending/receiving data, over the Binder Protocol

Parcel
"Container for a message (data and object references) that can be sent through an IBinder." A unit of transactional data - one for the outbound request, and another for the inbound reply

Marshalling
A procedure for converting higher level applications data structures (i.e. request/response parameters) into parcels for the purposes of embedding them into Binder transactions

Unmarshalling

A procedure for reconstructing higher-level application data-structures (i.e. request/response parameters) from parcels received through Binder transactions

Proxy

An implementation of the AIDL interface that un/marshals data and maps method calls to transactions submitted via a wrapped IBinder reference to the Binder object

Stub

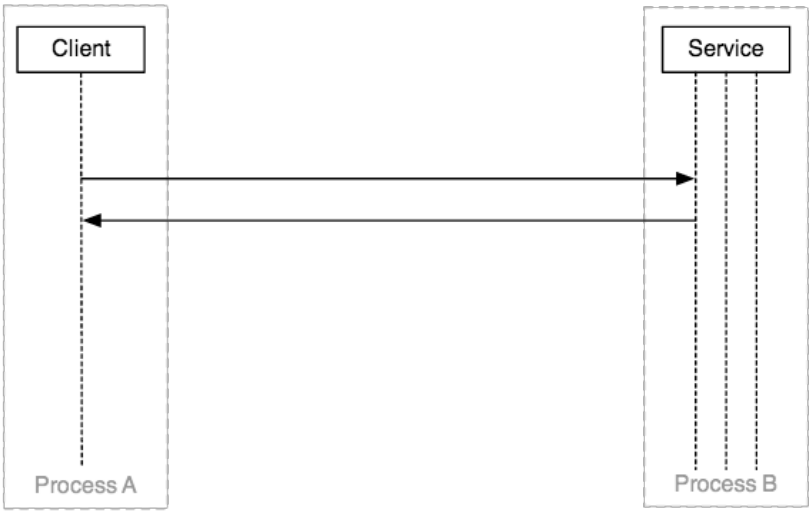
A partial implementation of the AIDL interface that maps transactions to Binder Service method calls while un/marshalling data

Context Manager (a.k.a. `servicemanager`)

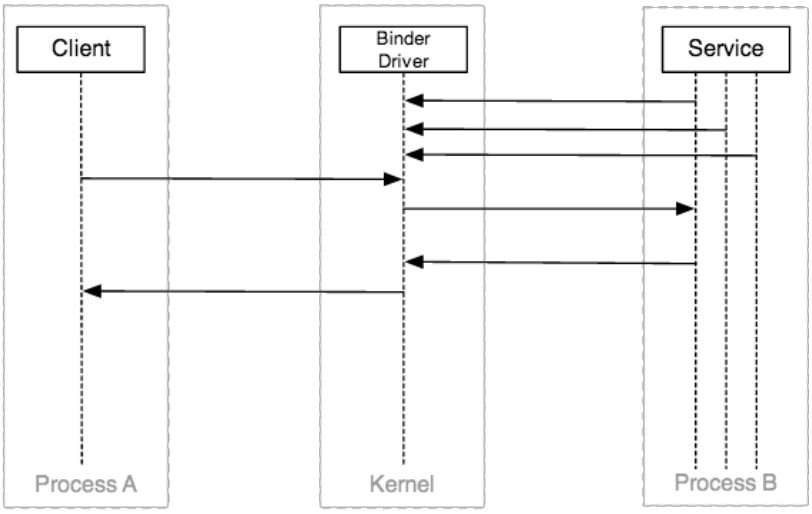
A special Binder Object with a known handle (registered as handle `0`) that is used as a registry/lookup service for other Binder Objects (*name* → *handle* mapping)

Binder Communication and Discovery

- As far as the client is concerned, it just wants to *use* the service:



- While processes cannot directly invoke operations (or read/write data) on other processes, the kernel can, so they make use of the Binder driver:




Since the service may get concurrent requests from multiple clients, it needs to protect (synchronize access to) its mutable state.

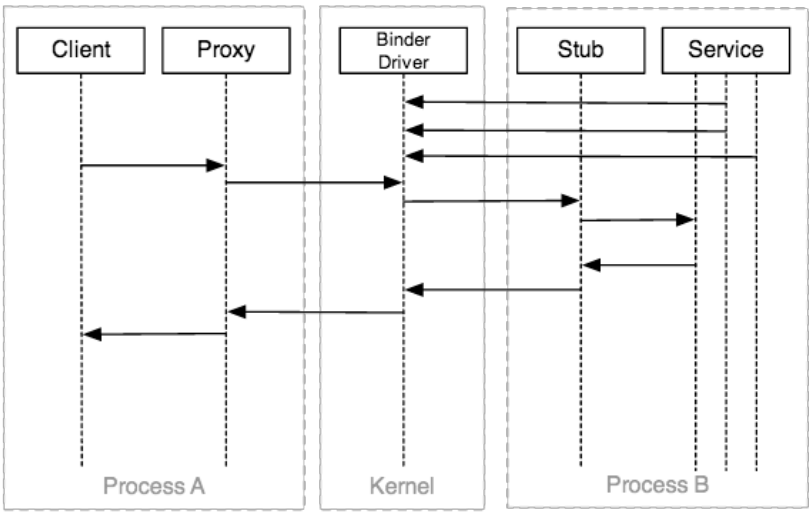
- Binder driver is exposed via `/dev/binder` and offers a relatively simple API based on `open`, `release`, `poll`, `mmap`, `flush`, and `ioctl` operations.
- In fact most communication happens via `ioctl(binderFd, BINDER_WRITE_READ, &bwd)`, where `bwd` is defined as:

```
struct binder_write_read {
  signed long write_size; /* bytes to write */
  signed long write_consumed; /* bytes consumed by driver */
  unsigned long write_buffer;
  signed long read_size;  /* bytes to read */
  signed long read_consumed;  /* bytes consumed by driver */
  unsigned long read_buffer;
};
```

- The **`write_buffer`** contains a series of commands for the driver to perform
  - Book-keeping commands, e.g. inc/decrement binder object references, request/clear death notification, etc.
  - A command requiring a response, like **`BC_TRANSACTION`**

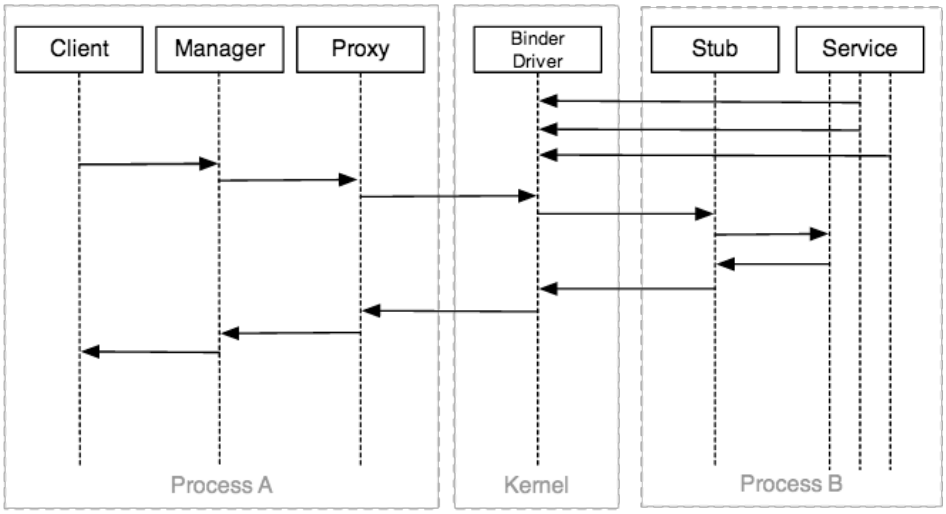
- Upon returning, the **`read_buffer`** will contain commands for the user-space to perform
  - Same book-keeping commands
  - A command requesting processing of the response (i.e. **`BC_REPLY`**) or a request to perform a nested (recursive) operation

- Clients communicate with services via transactions, which contain a binder token, code of the method to execute, raw data buffer, and sender PID/UID (added by the driver)
- Most-low-level operations and data structures (i.e. **`Parcel`**) are abstracted by **`libbinder`** (at the native level), which is what the clients and services use.
- Except that clients and services don't want to know anything about the Binder protocol and **`libbinder`**, so they make use of proxies and stubs:



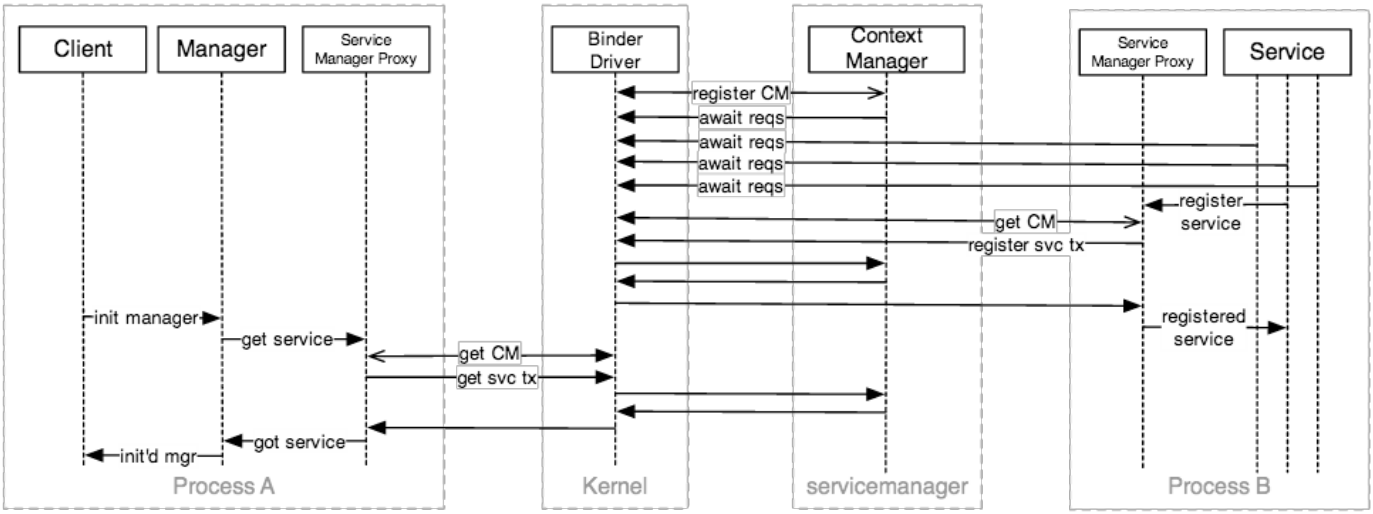

Java-based proxies and stubs can be automatically generated by **`aidl`** tool for services described with AIDL.

- In fact, most clients don't even want to know that they are using IPC, never mind Binder, or proxies, so they count on *managers* to abstract all of that complexity for them:



This is in particular true for system services, which typically expose only a subset of their APIs to the clients via their managers.

- But how does the client get a handle to the service it wants to talk to? Just ask the **`servicemanager`** (Binder's **`CONTEXT_MGR`**), and hope that the service has already registered with it:

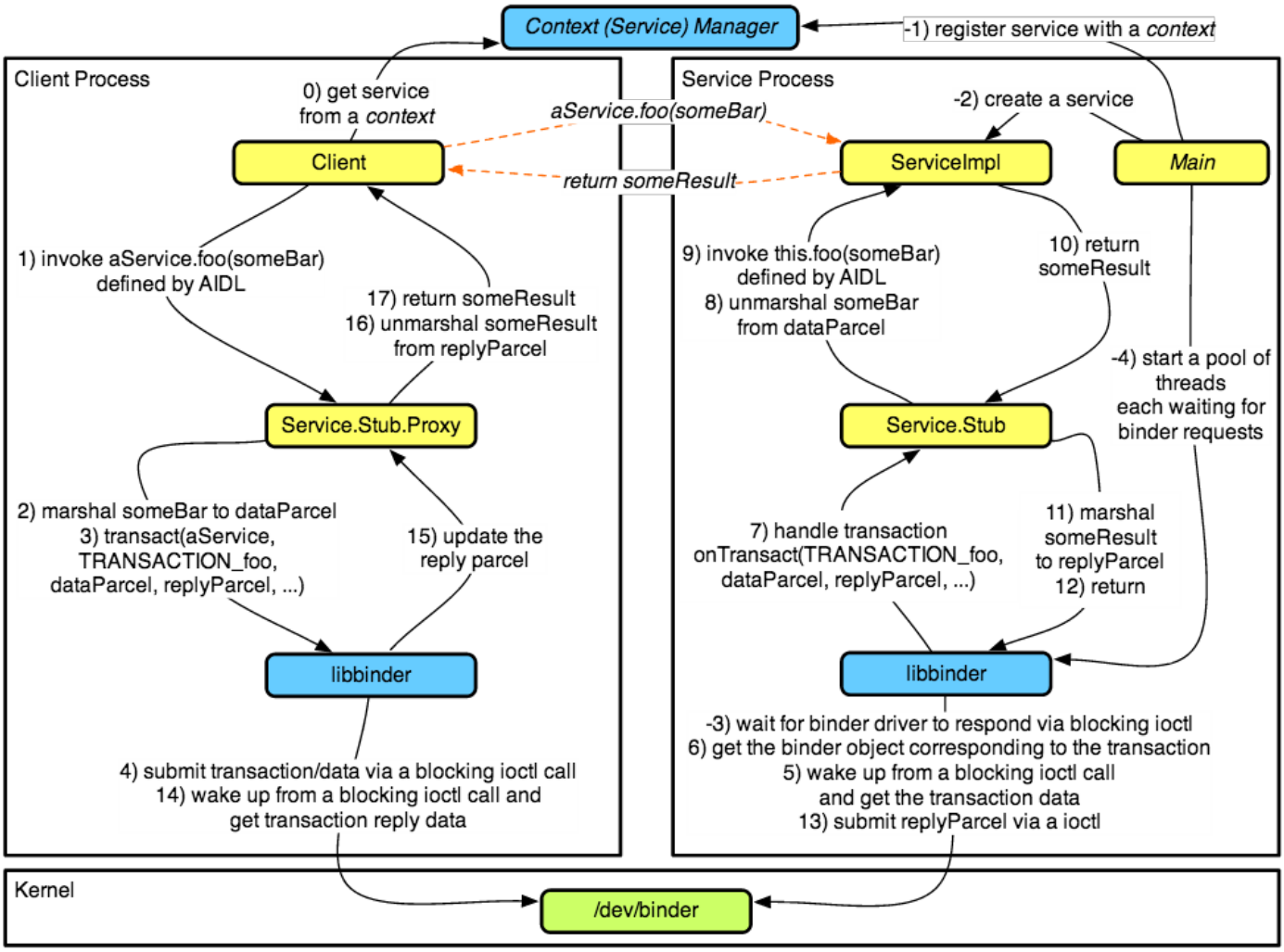


For security/sanity reasons, the binder driver will only accept a single/one-time **`CONTEXT_MGR`** registration, which is why **`servicemanager`** is among the first services to start on Android.

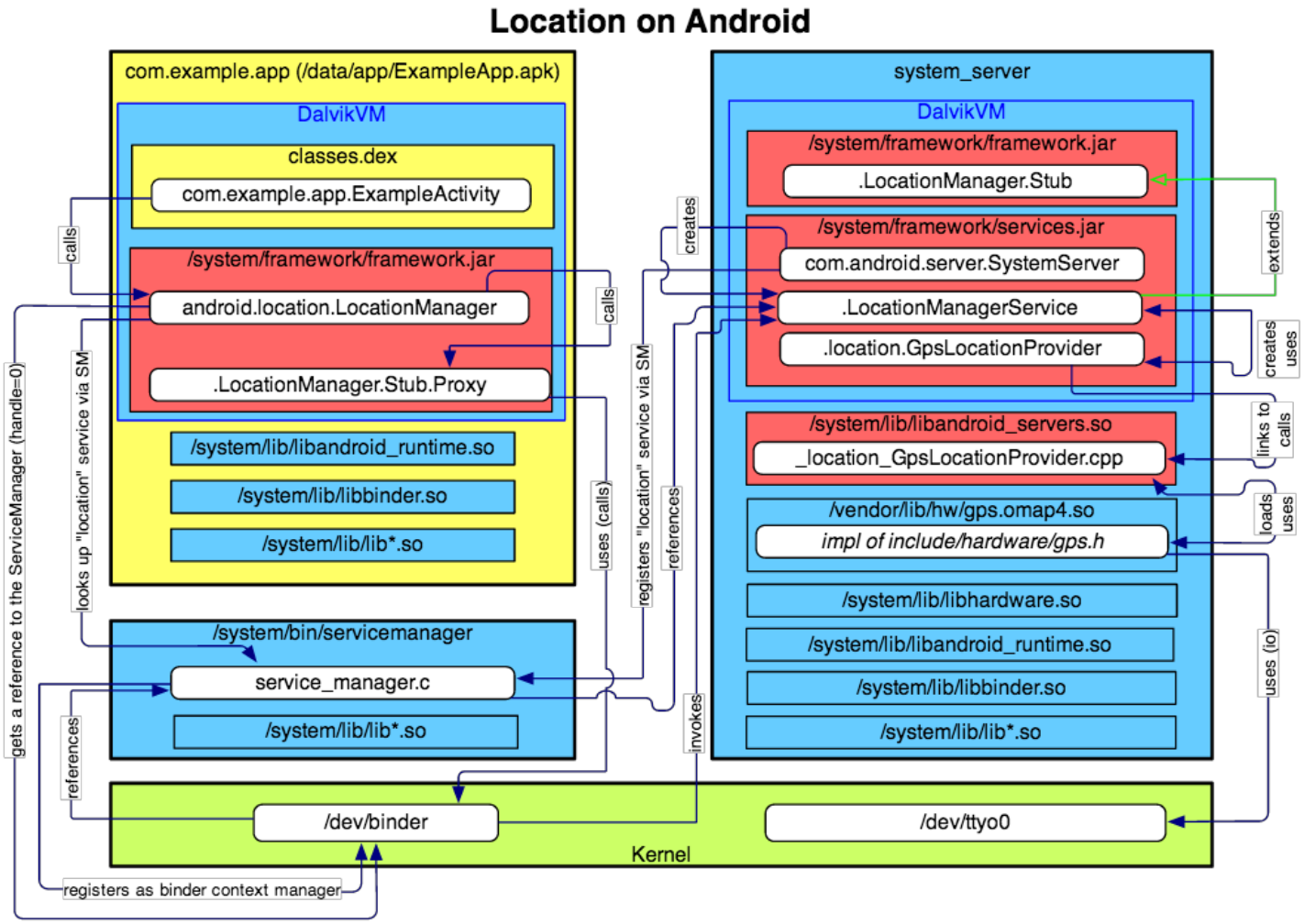
To get a list of services currently registered with **`servicemanager`**, run:

```
$ adb shell service list
Found 71 services:
0 sip: [android.net.sip.ISipService]
1 phone: [com.android.internal.telephony.ITelephony]
…
20  location: [android.location.ILocationManager]
…
55  activity: [android.app.IActivityManager]
56  package: [android.content.pm.IPackageManager]
…
67  SurfaceFlinger: [android.ui.ISurfaceComposer]
68  media.camera: [android.hardware.ICameraService]
69  media.player: [android.media.IMediaPlayerService]
70  media.audio_flinger: [android.media.IAudioFlinger]
```

- Another way to look at it:



Location Service: An Example



AIDL

- Android Interface Definition Language is a Android-specific language for defining Binder-based service interfaces
- AIDL follows Java-like interface syntax and allows us to declare our "business" methods
- Each Binder-based service is defined in a separate **`.aidl`** file, typically named **`IFooService.aidl`**, and saved in the **`src/`** directory
  `src/com/example/app/IFooService.aidl`

```
package com.example.app;
import com.example.app.Bar;
interface IFooService {
  void save(inout Bar bar);
  Bar getById(int id);
  void delete(in Bar bar);
  List<Bar> getAll();
}
```

- The **`aidl`** build tool (part of Android SDK) is used to extract a real Java interface (along with a **`Stub`** providing Android's **`android.os.IBinder`**) from each **`.aidl`** file and place it into our **`gen/`** directory
  `gen/com/example/app/IFooService.java`

```
package com.example.app;
public interface IFooService extends android.os.IInterface
{
  public static abstract class Stub extends android.os.Binder
    implements com.example.app.IFooService {
    …
    public static com.example.app.IFooService asInterface(
      android.os.IBinder obj) {
      …
      return new com.example.app.IFooService.Stub.Proxy(obj);
    }
    …
    public boolean onTransact(int code, android.os.Parcel data, android.os.Parcel reply, int
flags) throws android.os.RemoteException {
      switch (code) {
        …
        case TRANSACTION_save: {
          …
          com.example.app.Bar _arg0;
          …
          _arg0 = com.example.app.Bar.CREATOR.createFromParcel(data);
          this.save(_arg0);
          …
        }
        …
      }
      …
    }
    …
    private static class Proxy implements com.example.app.IFooService {
      private android.os.IBinder mRemote;
      …
      public void save(com.example.app.Bar bar) throws android.os.RemoteException {
        …
        android.os.Parcel _data = android.os.Parcel.obtain();
        …
        bar.writeToParcel(_data, 0);
        …
        mRemote.transact(Stub.TRANSACTION_save, _data, _reply, 0);
        …
      }
    }
  }
  void save(com.example.app.Bar bar) throws android.os.RemoteException;
  com.example.app.Bar getById(int id) throws android.os.RemoteException;
  void delete(com.example.app.Bar bar) throws android.os.RemoteException;
  java.util.List<Bar> getAll() throws android.os.RemoteException;
}
```


Eclipse ADT automatically calls `aidl` for each `.aidl` file that it finds in our `src/` directory

- AIDL supports the following types:
  - `null`
  - `boolean`, `boolean[]`, `byte`, `byte[]`, `char[]`, `int`, `int[]`, `long`, `long[]`, `float`, `float[]`, `double`, `double[]`
  - `java.lang.CharSequence`, `java.lang.String` (sent as UTF-16)

- **`java.io.FileDescriptor`** - transferred as a dup of the original file descriptor (points to the same underlying stream and position)
- **`java.io.Serializable`** - not efficient (too verbose)
- **`java.util.Map<String, Object>`** - of supported types (always reconstructed as **`java.util.HashMap`**)
- **`android.os.Bundle`** - a specialized Map-wrapper that only accepts AIDL-supported data types
- **`java.util.List`** - of supported types (always reconstructed as **`java.util.ArrayList`**)
- **`java.lang.Object[]`** - of supported types (including primitive wrappers)
- **`android.util.SparseArray`**, **`android.util.SparseBooleanArray`**
- **`android.os.IBinder`**, **`android.os.IInterface`** - transferred *by (globally unique) reference* (as a "strong binder", a.k.a. handle) that can be used to call-back into the sender
- **`android.os.Parcelable`** - allowing for custom types:
  src/com/example/app/Bar.java

```
package com.example.app;

import android.os.Parcel;
import android.os.Parcelable;

public class Bar implements Parcelable {
  private int id;
  private String data;

  public Bar(int id, String data) {
    this.id = id;
    this.data = data;
  }

  // getters and setters omitted
  …
  public int describeContents() {
    return 0;
  }

  public void writeToParcel(Parcel parcel, int flags) {
    parcel.writeInt(this.id);
    parcel.writeString(this.data);
  }

  public void readFromParcel(Parcel parcel) {
    this.id = parcel.readInt();
    this.data = parcel.readString();
  }

  public static final Parcelable.Creator<Bar> CREATOR = new Parcelable.Creator<Bar>() {
    public Bar createFromParcel(Parcel parcel) {
      return new Bar(parcel.readInt(), parcel.readString());
    }
    public Bar[] newArray(int size) {
      return new Bar[size];
    }
  };
}
```

Here, the `public void readFromParcel(Parcel)` method is *not* defined by the `Parcelable` interface. Instead, it would be required here because `Bar` is considered mutable - i.e. we expect the remote side to be able to change it in `void save(inout Bar bar)` method.

Similarly, `public static final Parcelable.Creator<Bar> CREATOR` field is also *not* defined by the `Parcelable` interface (obviously). It reconstructs `Bar` from `_data` parcel in `save` transaction, and from `_reply` parcel in `getById` operation.

- These custom classes have to be declared in their own (simplified) `.aidl` files
  src/com/example/app/Bar.aidl

```
package com.example.app;
parcelable Bar;
```

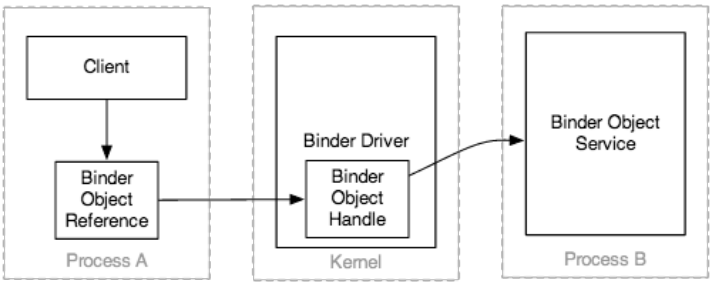
AIDL-interfaces have to `import` parcelable custom classes even if they are in the same package. In the case of the previous example, `src/com/example/app/IFooService.aidl` would have to `import com.example.app.Bar;` if it makes any references to `com.example.app.Bar` even though they are in the same package.

- AIDL-defined methods can take zero or more parameters, and must return a value or `void`
- All non-primitive parameters require a *directional tag* indicating which way the data goes: one of: `in`, `out`, or `inout`
  - Direction for primitives is always `in` (can be omitted)
  - The direction tag tells binder when to marshal the data, so its use has direct consequences on performance

- All `.aidl` comments are copied over to the generated Java interface (except for comments before the import and package statements).
- Only the following exceptions are implicitly supported: `SecurityException`, `BadParcelableException`, `IllegalArgumentException`, `NullPointerException`, and `IllegalStateException`
- Static fields are not supported in `.aidl` files

Binder Object Reference Mapping Across Process Boundaries

- A binder object reference is one of the following
  - An actual virtual *memory address* to a binder object in the *same process*
  - An abstract 32-bit *handle* to a binder object in *another process*

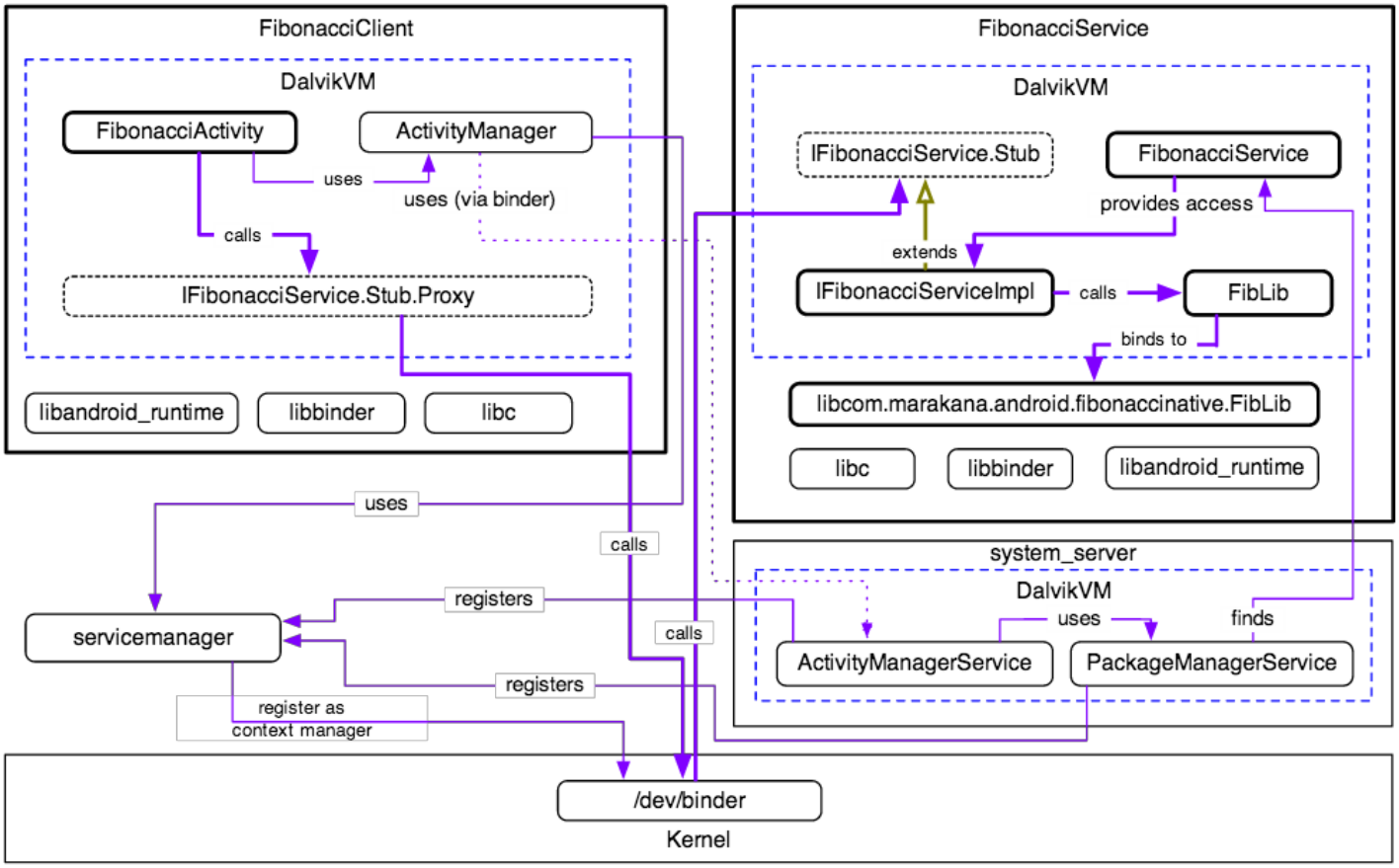


- On every transaction, the binder driver automatically maps local addresses to remote binder handles and remote binder handles to local addresses
- This mapping is done on:
  - Targets of binder transactions
  - `IBinder` object references shared across process boundaries as a parameter or a return value (embedded in transaction data)

- For this to work
  - The driver maintains mappings of local addresses and remote handles between processes (as a binary-tree per process) so that it can perform this translation
  - References embedded in transaction data are discovered based on offsets that the client provides when it submits its transaction and then rewritten in-place

- The binder driver does not know anything about binder objects that have never been shared with a remote process
  - Once a new binder object reference is found in a transaction, it is remembered by binder
  - Any time that reference is shared with another process, its reference count is incremented
  - Reference count is decremented either explicitly or automatically, when the process dies
  - When a reference is no longer needed, its owner is notified that it can be released, and binder removes its mapping

Building a Binder-based Service and Client by Example

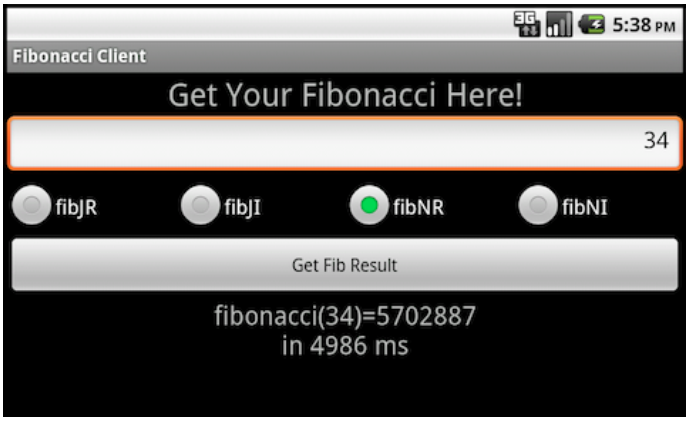


- To demonstrate a Binder-based service and client (based on Fibonacci), we'll create three separate projects:
  1. `FibonacciCommon` library project - to define our AIDL interface as well as custom types for parameters and return values
  2. `FibonacciService` project - where we implement our AIDL interface and expose it to the clients
  3. `FibonacciClient` project - where we connect to our AIDL-defined service and use it

- The code is available

- As a ZIP archive: https://github.com/marakana/FibonacciBinderDemo/zipball/master
- By Git: `git clone https://github.com/marakana/FibonacciBinderDemo.git`

- The UI will roughly look like this when done:



`FibonacciCommon` - Define AIDL Interface and Custom Types

- We start by creating a new Android (library) project, which will host the common API files (an AIDL interface as well as custom types for parameters and return values) shared by the service and its clients
  - Project Name: **`FibonacciCommon`**
  - Build Target: Android 2.2 (API 8) or later
  - Package Name: **`com.marakana.android.fibonaccicommon`**
  - Min SDK Version: 8 or higher
  - No need to specify Application name or an activity

- To turn this into a *library project* we need to access project properties → **`Android`** → **`Library`** and check **`Is Library`**
  - We could also manually add **`android.library=true`** to **`FibonacciCommon/default.properties`** and refresh the project

- Since library projects are never turned into actual applications (APKs)
  - We can simplify our manifest file:
    `FibonacciCommon/AndroidManifest.xml`
    ```
    <?xml version="1.0" encoding="utf-8"?>
    <manifest xmlns:android="http://schemas.android.com/apk/res/android"
      package="com.marakana.android.fibonaccicommon" android:versionCode="1"
      android:versionName="1.0">
    </manifest>
    ```
  - And we can remove everything from **`FibonacciCommon/res/`** directory (e.g. **`rm -fr FibonacciCommon/res/*`**)

- We are now ready to create our AIDL interface
  `FibonacciCommon/src/com/marakana/android/fibonaccicommon/IFibonacciService.aidl`
  ```
  package com.marakana.android.fibonaccicommon;

  import com.marakana.android.fibonaccicommon.FibonacciRequest;
  import com.marakana.android.fibonaccicommon.FibonacciResponse;

  interface IFibonacciService {
      long fibJR(in long n);
      long fibJI(in long n);
      long fibNR(in long n);
      long fibNI(in long n);
      FibonacciResponse fib(in FibonacciRequest request);
  }
  ```

- Our interface clearly depends on two custom Java types, which we have to not only implement in Java, but define in their own `.aidl` files

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciRequest.java

```
package com.marakana.android.fibonaccicommon;

import android.os.Parcel;
import android.os.Parcelable;

public class FibonacciRequest implements Parcelable {

  public static enum Type {
    RECURSIVE_JAVA, ITERATIVE_JAVA, RECURSIVE_NATIVE, ITERATIVE_NATIVE
  }

  private final long n;

  private final Type type;

  public FibonacciRequest(long n, Type type) {
    this.n = n;
    if (type == null) {
      throw new NullPointerException("Type must not be null");
    }
    this.type = type;
  }

  public long getN() {
    return n;
  }

  public Type getType() {
    return type;
  }

  public int describeContents() {
    return 0;
  }

  public void writeToParcel(Parcel parcel, int flags) {
    parcel.writeLong(this.n);
    parcel.writeInt(this.type.ordinal());
  }

  public static final Parcelable.Creator<FibonacciRequest> CREATOR = new
Parcelable.Creator<FibonacciRequest>() {
    public FibonacciRequest createFromParcel(Parcel in) {
      long n = in.readLong();
      Type type = Type.values()[in.readInt()];
      return new FibonacciRequest(n, type);
    }

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

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciRequest.aidl

```
package com.marakana.android.fibonaccicommon;

parcelable FibonacciRequest;
```

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciResponse.java

```
package com.marakana.android.fibonaccicommon;

import android.os.Parcel;
import android.os.Parcelable;

public class FibonacciResponse implements Parcelable {

  private final long result;

  private final long timeInMillis;

  public FibonacciResponse(long result, long timeInMillis) {
    this.result = result;
    this.timeInMillis = timeInMillis;
  }

  public long getResult() {
    return result;
  }

  public long getTimeInMillis() {
    return timeInMillis;
  }

  public int describeContents() {
    return 0;
  }

  public void writeToParcel(Parcel parcel, int flags) {
    parcel.writeLong(this.result);
    parcel.writeLong(this.timeInMillis);
  }

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

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

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciResponse.aidl

```
package com.marakana.android.fibonaccicommon;

parcelable FibonacciResponse;
```

- Finally we are now ready to take a look at our generated Java interface ***FibonacciCommon/gen/com/marakana/android/fibonaccicommon/IFibonacciService.java***

```
package com.marakana.android.fibonaccicommon;
public interface IFibonacciService extends android.os.IInterface
{
    public static abstract class Stub extends android.os.Binder
        implements com.marakana.android.fibonacci.IFibonacciService {
        …
        public static com.marakana.android.fibonacci.IFibonacciService asInterface(
            android.os.IBinder obj) {
            …
        }
        public android.os.IBinder asBinder() {
            return this;
        }
        …
    }

    public long fibJR(long n) throws android.os.RemoteException;
    public long fibJI(long n) throws android.os.RemoteException;
    public long fibNR(long n) throws android.os.RemoteException;
    public long fibNI(long n) throws android.os.RemoteException;
    public com.marakana.android.fibonaccicommon.FibonacciResponse fib(
        com.marakana.android.fibonaccicommon.FibonacciRequest request)
        throws android.os.RemoteException;
}
```

`FibonacciService` - Implement AIDL Interface and Expose It To Our Clients

- We start by creating a new Android project, which will host the our AIDL Service implementation as well as provide a mechanism to access (i.e. bind to) our service implementation
  - Project Name: **`FibonacciService`**
  - Build Target: Android 2.2 (API 8) or later
  - Package Name: **`com.marakana.android.fibonacciservice`**
  - Application name: Fibonacci Service
  - Min SDK Version: 8 or higher
  - No need to specify an Android activity

- We need to link this project to the **`FibonacciCommon`** in order to be able to access the common APIs: project properties → **`Android`** → **`Library`** → **`Add...`** → **`FibonacciCommon`**
  - As the result, **`FibonacciService/default.properties`** now has **`android.library.reference.1=../FibonacciCommon`** and **`FibonacciService/.classpath`** and **`FibonacciService/.project`** also link to **`FibonacciCommon`**

- Our service will make use of the **`com.marakana.android.fibonaccinative.FibLib`**, which provides the actual implementation of the Fibonacci algorithms
- We copy (or move) this Java class (as well as the **`jni/`** implementation) from the **`FibonacciNative`** project
  - Don't forget to run **`ndk-build`** under **`FibonacciService/`** in order to generate the required native library

- We are now ready to implement our AIDL-defined interface by extending from the auto-generated **`com.marakana.android.fibonaccicommon.IFibonacciService.Stub`** (which in turn extends from **`android.os.Binder`**)
  `FibonacciService/src/com/marakana/android/fibonacciservice/IFibonacciServiceImpl.java`

```
package com.marakana.android.fibonacciservice;

import android.os.SystemClock;
import android.util.Log;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;
import com.marakana.android.fibonaccinative.FibLib;

public class IFibonacciServiceImpl extends IFibonacciService.Stub {
  private static final String TAG = "IFibonacciServiceImpl";

  public long fibJI(long n) {
    Log.d(TAG, String.format("fibJI(%d)", n));
    return FibLib.fibJI(n);
  }

  public long fibJR(long n) {
    Log.d(TAG, String.format("fibJR(%d)", n));
    return FibLib.fibJR(n);
  }

  public long fibNI(long n) {
    Log.d(TAG, String.format("fibNI(%d)", n));
    return FibLib.fibNI(n);
  }

  public long fibNR(long n) {
    Log.d(TAG, String.format("fibNR(%d)", n));
    return FibLib.fibNR(n);
  }

  public FibonacciResponse fib(FibonacciRequest request) {
    Log.d(TAG,
        String.format("fib(%d, %s)", request.getN(), request.getType()));
    long timeInMillis = SystemClock.uptimeMillis();
    long result;
    switch (request.getType()) {
    case ITERATIVE_JAVA:
      result = this.fibJI(request.getN());
      break;
    case RECURSIVE_JAVA:
      result = this.fibJR(request.getN());
      break;
    case ITERATIVE_NATIVE:
      result = this.fibNI(request.getN());
      break;
    case RECURSIVE_NATIVE:
      result = this.fibNR(request.getN());
      break;
    default:
      return null;
    }
    timeInMillis = SystemClock.uptimeMillis() - timeInMillis;
    return new FibonacciResponse(result, timeInMillis);
  }
}
```

Expose our AIDL-defined Service Implementation to Clients

- In order for clients (callers) to use our service, they first need to bind to it.
- But in order for them to *bind* to it, we first need to expose it via our own `android.app.Service`'s `onBind(Intent)` implementation

FibonacciService/src/com/marakana/android/fibonacciservice/FibonacciService.java

```
package com.marakana.android.fibonacciservice;

import android.app.Service;
import android.content.Intent;
import android.os.IBinder;
import android.util.Log;

public class FibonacciService extends Service { // ❶

  private static final String TAG = "FibonacciService";

  private IFibonacciServiceImpl service; // ❷

  @Override
  public void onCreate() {
    super.onCreate();
    this.service = new IFibonacciServiceImpl(); // ❸
    Log.d(TAG, "onCreate()'ed"); // ❺
  }

  @Override
  public IBinder onBind(Intent intent) {
    Log.d(TAG, "onBind()'ed"); // ❺
    return this.service; // ❹
  }

  @Override
  public boolean onUnbind(Intent intent) {
    Log.d(TAG, "onUnbind()'ed"); // ❺
    return super.onUnbind(intent);
  }

  @Override
  public void onDestroy() {
    Log.d(TAG, "onDestroy()'ed");
    this.service = null;
    super.onDestroy();
  }
}
```

❶ We create yet another "service" object by extending from `android.app.Service`. The purpose of `FibonacciService` object is to provide access to our Binder-based `IFibonacciServiceImpl` object.

❷ Here we simply declare a local reference to `IFibonacciServiceImpl`, which will act as a singleton (i.e. all clients will share a single instance). Since our `IFibonacciServiceImpl` does

not require any special initialization, we could instantiate it at this point, but we choose to delay this until the `onCreate()` method.

❸ Now we instantiate our `IFibonacciServiceImpl` that we'll be providing to our clients (in the `onBind(Intent)` method). If our `IFibonacciServiceImpl` required access to the `Context` (which it doesn't) we could pass a reference to `this` (i.e. `android.app.Service`, which implements `android.content.Context`) at this point. Many Binder-based services use `Context` in order to access other platform functionality.

❹ This is where we provide access to our `IFibonacciServiceImpl` object to our clients. By design, we chose to have only one instance of `IFibonacciServiceImpl` (so all clients share it) but we could also provide each client with their own instance of `IFibonacciServiceImpl`.

❺ We just add some logging calls to make it easy to track the life-cycle of our service.

- Finally, we register our `FibonacciService` in our `AndroidManifest.xml`, so that clients can find it

FibonacciService/AndroidManifest.xml

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
  package="com.marakana.android.fibonacciservice" android:versionCode="1"
  android:versionName="1.0">
  <uses-sdk android:minSdkVersion="8" />
  <application android:icon="@drawable/icon" android:label="@string/app_name">
    <service android:name=".FibonacciService">
      <intent-filter>
        <action android:name="com.marakana.android.fibonaccicommon.IFibonacciService" /> <!--
❶  -->
      </intent-filter>
    </service>
  </application>
</manifest>
```

❶ The name of this action is arbitrary, but it is a common convention to use the fully-qualified name of our AIDL-derived interface.

`FibonacciClient` - Using AIDL-defined Binder-based Services

- We start by creating a new Android project, which will server as the client of the AIDL Service we previously implemented
  - Project Name: **`FibonacciClient`**
  - Build Target: Android 2.2 (API 8) or later
  - Package Name: **`com.marakana.android.fibonacciclient`**
  - Application name: Fibonacci Client
  - Create activity: **`FibonacciActivity`**
    - We'll repurpose most of this activity's code from **`FibonacciNative`**
  - Min SDK Version: 8 or higher
- We need to link this project to the **`FibonacciCommon`** in order to be able to access the common APIs: project properties → **`Android`** → **`Library`** → **`Add…`** → **`FibonacciCommon`**
  - As the result, **`FibonacciClient/default.properties`** now has **`android.library.reference.1=../FibonacciCommon`** and **`FibonacciClient/.classpath`** and **`FibonacciClient/.project`** also link to **`FibonacciCommon`**
  - As an alternative, we could've avoided creating **`FibonacciCommon`** in the first place
    - **`FibonacciService`** and **`FibonacciClient`** could have each had a copy of: **`IFibonacciService.aidl`**, FibonacciRequest.aidl, FibonacciResponse.aidl, FibonacciResult.java, **`and`** FibonacciResponse.java++
    - But we don't like duplicating source code (even though the binaries do get duplicated at runtime)
- Our client will make use of the string resources and layout definition from **`FibonacciNative`** application
  `FibonacciClient/res/values/strings.xml`

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
  <string name="hello">Get Your Fibonacci Here!</string>
  <string name="app_name">Fibonacci Client</string>
  <string name="input_hint">Enter N</string>
  <string name="input_error">Numbers only!</string>
  <string name="button_text">Get Fib Result</string>
  <string name="progress_text">Calculating...</string>
  <string name="fib_error">Failed to get Fibonacci result</string>
  <string name="type_fib_jr">fibJR</string>
  <string name="type_fib_ji">fibJI</string>
  <string name="type_fib_nr">fibNR</string>
  <string name="type_fib_ni">fibNI</string>
</resources>
```

FibonacciClient/res/layout/main.xml

```
<?xml version="1.0" encoding="utf-8"?>
<LinearLayout xmlns:android="http://schemas.android.com/apk/res/android"
  android:orientation="vertical" android:layout_width="fill_parent"
  android:layout_height="fill_parent">
  <TextView android:text="@string/hello" android:layout_height="wrap_content"
    android:layout_width="fill_parent" android:textSize="25sp" android:gravity="center"/>
  <EditText android:layout_height="wrap_content"
    android:layout_width="match_parent" android:id="@+id/input"
    android:hint="@string/input_hint" android:inputType="number"
    android:gravity="right" />
  <RadioGroup android:orientation="horizontal"
    android:layout_width="match_parent" android:id="@+id/type"
    android:layout_height="wrap_content">
    <RadioButton android:layout_height="wrap_content"
      android:checked="true" android:id="@+id/type_fib_jr" android:text="@string/type_fib_jr"
      android:layout_width="match_parent" android:layout_weight="1" />
    <RadioButton android:layout_height="wrap_content"
      android:id="@+id/type_fib_ji" android:text="@string/type_fib_ji"
      android:layout_width="match_parent" android:layout_weight="1" />
    <RadioButton android:layout_height="wrap_content"
      android:id="@+id/type_fib_nr" android:text="@string/type_fib_nr"
      android:layout_width="match_parent" android:layout_weight="1" />
    <RadioButton android:layout_height="wrap_content"
      android:id="@+id/type_fib_ni" android:text="@string/type_fib_ni"
      android:layout_width="match_parent" android:layout_weight="1" />
  </RadioGroup>
  <Button android:text="@string/button_text" android:id="@+id/button"
    android:layout_width="match_parent" android:layout_height="wrap_content" />
  <TextView android:id="@+id/output" android:layout_width="match_parent"
    android:layout_height="match_parent" android:textSize="20sp"
android:gravity="center|top"/>
</LinearLayout>
```

- We are now ready to implement our client

FibonacciClient/src/com/marakana/android/fibonacciclient/FibonacciActivity.java

```
package com.marakana.android.fibonacciclient;

import android.app.Activity;
import android.app.ProgressDialog;
import android.content.ComponentName;
import android.content.Intent;
import android.content.ServiceConnection;
import android.os.AsyncTask;
```

```
import android.os.Bundle;
import android.os.IBinder;
import android.os.RemoteException;
import android.os.SystemClock;
import android.text.TextUtils;
import android.util.Log;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.Button;
import android.widget.EditText;
import android.widget.RadioGroup;
import android.widget.TextView;
import android.widget.Toast;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;

public class FibonacciActivity extends Activity implements OnClickListener,
    ServiceConnection {

  private static final String TAG = "FibonacciActivity";

  private EditText input; // our input n

  private Button button; // trigger for fibonacci calcualtion

  private RadioGroup type; // fibonacci implementation type

  private TextView output; // destination for fibonacci result

  private IFibonacciService service; // reference to our service

  @Override
  public void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    super.setContentView(R.layout.main);
    // connect to our UI elements
    this.input = (EditText) super.findViewById(R.id.input);
    this.button = (Button) super.findViewById(R.id.button);
    this.type = (RadioGroup) super.findViewById(R.id.type);
    this.output = (TextView) super.findViewById(R.id.output);
    // request button click call-backs via onClick(View) method
    this.button.setOnClickListener(this);
    // the button will be enabled once we connect to the service
    this.button.setEnabled(false);
  }

  @Override
  protected void onResume() {
    Log.d(TAG, "onResume()'ed");
    super.onResume();
    // Bind to our FibonacciService service, by looking it up by its name
    // and passing ourselves as the ServiceConnection object
    // We'll get the actual IFibonacciService via a callback to
    // onServiceConnected() below
    if (!super.bindService(new Intent(IFibonacciService.class.getName()),
        this, BIND_AUTO_CREATE)) {
      Log.w(TAG, "Failed to bind to service");
    }
  }
```

```
@Override
protected void onPause() {
  Log.d(TAG, "onPause()'ed");
  super.onPause();
  // No need to keep the service bound (and alive) any longer than
  // necessary
  super.unbindService(this);
}

public void onServiceConnected(ComponentName name, IBinder service) {
  Log.d(TAG, "onServiceConnected()'ed to " + name);
  // finally we can get to our IFibonacciService
  this.service = IFibonacciService.Stub.asInterface(service);
  // enable the button, because the IFibonacciService is initialized
  this.button.setEnabled(true);
}

public void onServiceDisconnected(ComponentName name) {
  Log.d(TAG, "onServiceDisconnected()'ed to " + name);
  // our IFibonacciService service is no longer connected
  this.service = null;
  // disabled the button, since we cannot use IFibonacciService
  this.button.setEnabled(false);
}

// handle button clicks
public void onClick(View view) {
  // parse n from input (or report errors)
  final long n;
  String s = this.input.getText().toString();
  if (TextUtils.isEmpty(s)) {
    return;
  }
  try {
    n = Long.parseLong(s);
  } catch (NumberFormatException e) {
    this.input.setError(super.getText(R.string.input_error));
    return;
  }

  // build the request object
  final FibonacciRequest.Type type;
  switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
  case R.id.type_fib_jr:
    type = FibonacciRequest.Type.RECURSIVE_JAVA;
    break;
  case R.id.type_fib_ji:
    type = FibonacciRequest.Type.ITERATIVE_JAVA;
    break;
  case R.id.type_fib_nr:
    type = FibonacciRequest.Type.RECURSIVE_NATIVE;
    break;
  case R.id.type_fib_ni:
    type = FibonacciRequest.Type.ITERATIVE_NATIVE;
    break;
  default:
    return;
  }
  final FibonacciRequest request = new FibonacciRequest(n, type);

  // showing the user that the calculation is in progress
  final ProgressDialog dialog = ProgressDialog.show(this, "",
```

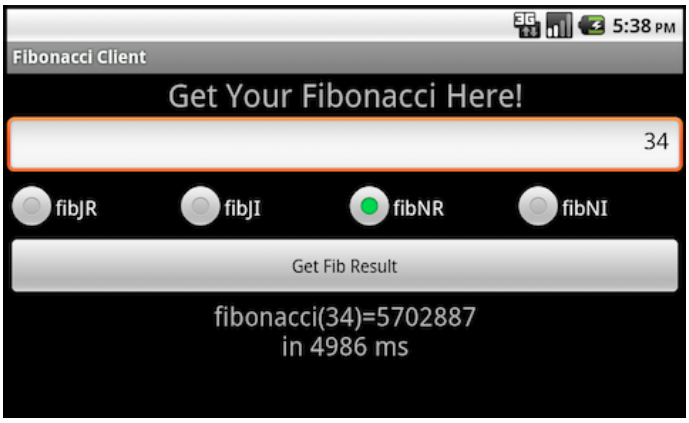
```
        super.getText(R.string.progress_text), true);
    // since the calculation can take a long time, we do it in a separate
    // thread to avoid blocking the UI
    new AsyncTask<Void, Void, String>() {
      @Override
      protected String doInBackground(Void... params) {
        // this method runs in a background thread
        try {
          long totalTime = SystemClock.uptimeMillis();
          FibonacciResponse response = FibonacciActivity.this.service
              .fib(request);
          totalTime = SystemClock.uptimeMillis() - totalTime;
          // generate the result
          return String.format(
              "fibonacci(%d)=%d\nin %d ms\n(+ %d ms)", n,
              response.getResult(), response.getTimeInMillis(),
              totalTime - response.getTimeInMillis());
        } catch (RemoteException e) {
          Log.wtf(TAG, "Failed to communicate with the service", e);
          return null;
        }
      }

      @Override
      protected void onPostExecute(String result) {
        // get rid of the dialog
        dialog.dismiss();
        if (result == null) {
          // handle error
          Toast.makeText(FibonacciActivity.this, R.string.fib_error,
              Toast.LENGTH_SHORT).show();
        } else {
          // show the result to the user
          FibonacciActivity.this.output.setText(result);
        }
      }
    }.execute(); // run our AsyncTask
  }
}
```


We should avoid having an implicit (but strong) reference from our `AsyncTask` to our activity. Here we took a shortcut for brevity reasons.

- Our activity should already be registered in our `AndroidManifest.xml` file
  FibonacciClient/AndroidManifest.xml

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
  android:versionCode="1" android:versionName="1.0"
  package="com.marakana.android.fibonacciclient">
  <uses-sdk android:minSdkVersion="8" />
  <application android:icon="@drawable/icon" android:label="@string/app_name">
    <activity android:name="com.marakana.android.fibonacciclient.FibonacciActivity"
      android:label="@string/app_name">
      <intent-filter>
        <action android:name="android.intent.action.MAIN" />
        <category android:name="android.intent.category.LAUNCHER" />
      </intent-filter>
    </activity>
  </application>
</manifest>
```

- And the result should look like



Async Binder IPC (by Example)

- Binder allows for the asynchronous communication between the client and its service via the `oneway` declaration on the AIDL interface
- Of course, we still care about the result, so generally async calls are used with call-backs - typically through listeners
- When clients provide a reference to themselves as call-back listeners, then the roles reverse at the time the listeners are called: clients' listeners become the services, and services become the clients to those listeners
- This is best explained via an example (based on Fibonacci)
- The code is available
  - As a ZIP archive: https://github.com/marakana/FibonacciAsyncBinderDemo/zipball/master
  - By Git: `git clone https://github.com/marakana/FibonacciAsyncBinderDemo.git`

`FibonacciCommon` - Defining a `oneway` AIDL Service

- First, we need a listener, which itself is a `oneway` AIDL-defined "service":
  FibonacciCommon/src/com/marakana/android/fibonaccicommon/IFibonacciServiceResponseListener.aidl:

```
package com.marakana.android.fibonaccicommon;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;

oneway interface IFibonacciServiceResponseListener {
    void onResponse(in FibonacciResponse response);
}
```

- Now we can create a our `oneway` (i.e. asynchronous) interface:
  FibonacciCommon/src/com/marakana/android/fibonaccicommon/IFibonacciService.aidl:

```
package com.marakana.android.fibonaccicommon;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciServiceResponseListener;

oneway interface IFibonacciService {
    void fib(in FibonacciRequest request, in IFibonacciServiceResponseListener listener);
}
```

`FibonacciService` - Implementing our async AIDL service

- The implementation of our service invokes the listener, as opposed to returning a result:
  FibonacciService/src/com/marakana/android/fibonacciservice/IFibonacciServiceImpl.java:

```
package com.marakana.android.fibonacciservice;

import android.os.RemoteException;
import android.os.SystemClock;
import android.util.Log;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;
import com.marakana.android.fibonaccicommon.IFibonacciServiceResponseListener;
import com.marakana.android.fibonaccinative.FibLib;

public class IFibonacciServiceImpl extends IFibonacciService.Stub {
  private static final String TAG = "IFibonacciServiceImpl";

  @Override
  public void fib(FibonacciRequest request,
      IFibonacciServiceResponseListener listener) throws RemoteException {
    long n = request.getN();
    Log.d(TAG, "fib(" + n + ")");
    long timeInMillis = SystemClock.uptimeMillis();
    long result;
    switch (request.getType()) {
    case ITERATIVE_JAVA:
      result = FibLib.fibJI(n);
      break;
    case RECURSIVE_JAVA:
      result = FibLib.fibJR(n);
      break;
    case ITERATIVE_NATIVE:
      result = FibLib.fibNI(n);
      break;
    case RECURSIVE_NATIVE:
      result = FibLib.fibNR(n);
      break;
    default:
      result = 0;
    }
    timeInMillis = SystemClock.uptimeMillis() - timeInMillis;
    Log.d(TAG, String.format("Got fib(%d) = %d in %d ms", n, result,
        timeInMillis));
    listener.onResponse(new FibonacciResponse(result, timeInMillis));
  }
}
```


The service will not block waiting for the listener to return, because the listener itself is also **oneway**.

`FibonacciClient` - Implementing our async AIDL client

- Finally, we implement our client, which itself has to also implement a listener as a Binder service:
`FibonacciClient/src/com/marakana/android/fibonacciclient/FibonacciActivity.java`:

```
package com.marakana.android.fibonacciclient;

import android.app.Activity;
import android.app.Dialog;
import android.app.ProgressDialog;
import android.content.ComponentName;
import android.content.Intent;
import android.content.ServiceConnection;
import android.os.Bundle;
import android.os.Handler;
import android.os.IBinder;
import android.os.Message;
import android.os.RemoteException;
import android.os.SystemClock;
import android.text.TextUtils;
import android.util.Log;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.Button;
import android.widget.EditText;
import android.widget.RadioGroup;
import android.widget.TextView;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;
import com.marakana.android.fibonaccicommon.IFibonacciServiceResponseListener;

public class FibonacciActivity extends Activity implements OnClickListener,
    ServiceConnection {

  private static final String TAG = "FibonacciActivity";

  // the id of a message to our response handler
  private static final int RESPONSE_MESSAGE_ID = 1;

  // the id of a progress dialog that we'll be creating
  private static final int PROGRESS_DIALOG_ID = 1;

  private EditText input; // our input n

  private Button button; // trigger for fibonacci calcualtion

  private RadioGroup type; // fibonacci implementation type

  private TextView output; // destination for fibonacci result

  private IFibonacciService service; // reference to our service

  // the responsibility of the responseHandler is to take messages
```

```
  // from the responseListener (defined below) and display their content
  // in the UI thread
  private final Handler responseHandler = new Handler() {
    @Override
    public void handleMessage(Message message) {
      switch (message.what) {
      case RESPONSE_MESSAGE_ID:
        Log.d(TAG, "Handling response");
        FibonacciActivity.this.output.setText((String) message.obj);
        FibonacciActivity.this.removeDialog(PROGRESS_DIALOG_ID);
        break;
      }
    }
  };

  // the responsibility of the responseListener is to receive call-backs
  // from the service when our FibonacciResponse is available
  private final IFibonacciServiceResponseListener responseListener = new
IFibonacciServiceResponseListener.Stub() {

    // this method is executed on one of the pooled binder threads
    @Override
    public void onResponse(FibonacciResponse response)
        throws RemoteException {
      String result = String.format("%d in %d ms", response.getResult(),
          response.getTimeInMillis());
      Log.d(TAG, "Got response: " + result);
      // since we cannot update the UI from a non-UI thread,
      // we'll send the result to the responseHandler (defined above)
      Message message = FibonacciActivity.this.responseHandler
          .obtainMessage(RESPONSE_MESSAGE_ID, result);
      FibonacciActivity.this.responseHandler.sendMessage(message);
    }
  };

  @Override
  public void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    super.setContentView(R.layout.main);
    // connect to our UI elements
    this.input = (EditText) super.findViewById(R.id.input);
    this.button = (Button) super.findViewById(R.id.button);
    this.type = (RadioGroup) super.findViewById(R.id.type);
    this.output = (TextView) super.findViewById(R.id.output);
    // request button click call-backs via onClick(View) method
    this.button.setOnClickListener(this);
    // the button will be enabled once we connect to the service
    this.button.setEnabled(false);
  }

  @Override
  protected void onStart() {
    Log.d(TAG, "onStart()'ed");
    super.onStart();
    // Bind to our FibonacciService service, by looking it up by its name
    // and passing ourselves as the ServiceConnection object
    // We'll get the actual IFibonacciService via a callback to
    // onServiceConnected() below
    if (!super.bindService(new Intent(IFibonacciService.class.getName()),
        this, BIND_AUTO_CREATE)) {
      Log.w(TAG, "Failed to bind to service");
    }
```

```
}

@Override
protected void onStop() {
  Log.d(TAG, "onStop()'ed");
  super.onStop();
  // No need to keep the service bound (and alive) any longer than
  // necessary
  super.unbindService(this);
}

public void onServiceConnected(ComponentName name, IBinder service) {
  Log.d(TAG, "onServiceConnected()'ed to " + name);
  // finally we can get to our IFibonacciService
  this.service = IFibonacciService.Stub.asInterface(service);
  // enable the button, because the IFibonacciService is initialized
  this.button.setEnabled(true);
}

public void onServiceDisconnected(ComponentName name) {
  Log.d(TAG, "onServiceDisconnected()'ed to " + name);
  // our IFibonacciService service is no longer connected
  this.service = null;
  // disabled the button, since we cannot use IFibonacciService
  this.button.setEnabled(false);
}

@Override
protected Dialog onCreateDialog(int id) {
  switch (id) {
  case PROGRESS_DIALOG_ID:
    // this dialog will be opened in onClick(...) and
    // dismissed/removed by responseHandler.handleMessage(...)
    ProgressDialog dialog = new ProgressDialog(this);
    dialog.setMessage(super.getText(R.string.progress_text));
    dialog.setIndeterminate(true);
    return dialog;
  default:
    return super.onCreateDialog(id);
  }
}

// handle button clicks
public void onClick(View view) {
  // parse n from input (or report errors)
  final long n;
  String s = this.input.getText().toString();
  if (TextUtils.isEmpty(s)) {
    return;
  }
  try {
    n = Long.parseLong(s);
  } catch (NumberFormatException e) {
    this.input.setError(super.getText(R.string.input_error));
    return;
  }

  // build the request object
  final FibonacciRequest.Type type;
  switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
  case R.id.type_fib_jr:
    type = FibonacciRequest.Type.RECURSIVE_JAVA;
```

```
      break;
    case R.id.type_fib_ji:
      type = FibonacciRequest.Type.ITERATIVE_JAVA;
      break;
    case R.id.type_fib_nr:
      type = FibonacciRequest.Type.RECURSIVE_NATIVE;
      break;
    case R.id.type_fib_ni:
      type = FibonacciRequest.Type.ITERATIVE_NATIVE;
      break;
    default:
      return;
    }

    final FibonacciRequest request = new FibonacciRequest(n, type);
    try {
      Log.d(TAG, "Submitting request...");
      long time = SystemClock.uptimeMillis();
      // submit the request; the response will come to responseListener
      this.service.fib(request, this.responseListener);
      time = SystemClock.uptimeMillis() - time;
      Log.d(TAG, "Submited request in " + time + " ms");
      // this dialog will be dismissed/removed by responseHandler
      super.showDialog(PROGRESS_DIALOG_ID);
    } catch (RemoteException e) {
      Log.wtf(TAG, "Failed to communicate with the service", e);
    }
  }
}
```

Our listener should not retain a strong reference to the activity (and it does since it's an anonymous inner class), but in this case we skip on the correctness for the sake of brevity.

Sharing Memory via Binder

- Binder transactional data is copied among parties communicating - not ideal if we have a lot of data to send
  - In fact, binder imposes limits on how much data we can send via transactions

- If the data we want to share comes from a file, then we should just send the file descriptor instead
  - This is how we ask the media player to play an audio/video file for us - we just send it the FD

- If the data we want to send is located in memory, rather than trying to send all of it at once, we could send multiple but smaller chunks instead
  - Complicates our design

- Alternatively, we could take advantage of Android's **`ashmem`** (Anonymous Shared Memory) facilities
  - Its Java wrapper **`android.os.MemoryFile`** is not meant for memory sharing from 3rd party apps
  - Drop to native (via JNI) and use ashmem directly?

- Native memory sharing implemented via **`frameworks/base/libs/binder/Parcel.cpp`**'s:
  - **`void Parcel::writeBlob(size_t len, WritableBlob* outBlob)`**
  - **`status_t Parcel::readBlob(size_t len, ReadableBlob* outBlob)`**

- This is roughly implemented as follows:

Client

```
size_t len = 4096;
int fd = ashmem_create_region("Parcel Blob", len);
ashmem_set_prot_region(fd, PROT_READ | PROT_WRITE);
void* ptr = mmap(NULL, len, PROT_READ | PROT_WRITE, MAP_SHARED, fd, 0);
ashmem_set_prot_region(fd, PROT_READ);
writeFileDescriptor(fd, true);
// write into  ptr for len as desired
…
munmap(ptr, len);
close(fd);
```

Service

```
int fd = readFileDescriptor();
void* ptr = mmap(NULL, len, PROT_READ, MAP_SHARED, fd, 0);
// read from ptr up to len as desired
…
munmap(ptr, len);
```

Removed error handling for brevity. Also, **`writeFileDescriptor(…)`** and **`readFileDescriptor(…)`** are provided by **`libbinder`**.

Limitations of Binder

- Binder supports a maximum of 15 binder threads per process
  frameworks/base/libs/binder/ProcessState.cpp

```
…
static int open_driver()
{
    int fd = open("/dev/binder", O_RDWR);
    if (fd >= 0) {
        …
        size_t maxThreads = 15;
        result = ioctl(fd, BINDER_SET_MAX_THREADS, &maxThreads);
        …
    } else {
        …
    }
    return fd;
}
…
```

  - Avoid blocking binder threads
  - If we need to perform a long-running task, it's better to spawn our own thread

- Binder limits its transactional buffer to **1Mb** per process across all concurrent transactions
  - If arguments/return values are too large to fit into this buffer, TransactionTooLargeException is thrown
  - Because this buffer is shared across all transactions in a given process, many moderately sized transactions could also exhaust its limit
  - When this exception is thrown, we don't know whether we failed to *send the request*, or failed to *receive the response*
  - Keep transaction data small or use shared memory (ashmem)

Binder - Security

- Binder does directly deal with "security" concerns, but it enables a "trusted" execution environment and DAC
- The binder driver allows only a single **`CONTEXT_MGR`** (i.e. **`servicemanager`**) to register:
  `drivers/staging/android/binder.c`:

```
…
static long binder_ioctl(struct file *filp, unsigned int cmd, unsigned long arg)
{
  …
  switch (cmd) {
  …
  case BINDER_SET_CONTEXT_MGR:
    if (binder_context_mgr_node != NULL) {
      printk(KERN_ERR "binder: BINDER_SET_CONTEXT_MGR already set\n");
      ret = -EBUSY;
      goto err;
    }
    …
    binder_context_mgr_node = binder_new_node(proc, NULL, NULL);
    …
  }
  …
…
```

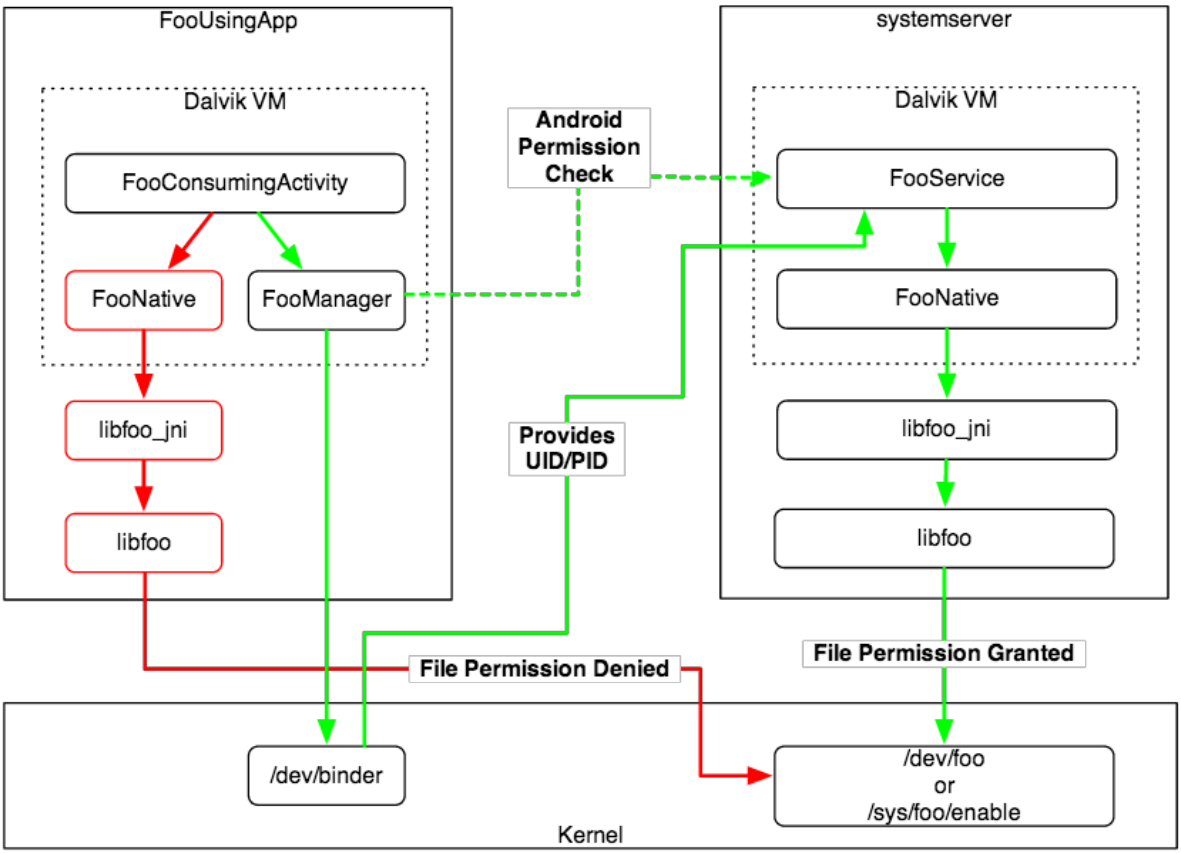
- The **`servicemanager`** in turn only allows registrations from trusted UIDs (like **`system`**, **`radio`**, **`media`**, etc.):
  `frameworks/base/cmds/servicemanager/service_manager.c`:

```
…
static struct {
    unsigned uid;
    const char *name;
} allowed[] = {
#ifdef LVMX
    { AID_MEDIA, "com.lifevibes.mx.ipc" },
#endif
    { AID_MEDIA, "media.audio_flinger" },
    { AID_MEDIA, "media.player" },
    { AID_MEDIA, "media.camera" },
    { AID_MEDIA, "media.audio_policy" },
    { AID_DRM,   "drm.drmManager" },
    { AID_NFC,   "nfc" },
    { AID_RADIO, "radio.phone" },
    { AID_RADIO, "radio.sms" },
    { AID_RADIO, "radio.phonesubinfo" },
    { AID_RADIO, "radio.simphonebook" },
/* TODO: remove after phone services are updated: */
    { AID_RADIO, "phone" },
    { AID_RADIO, "sip" },
    { AID_RADIO, "isms" },
    { AID_RADIO, "iphonesubinfo" },
    { AID_RADIO, "simphonebook" },
};
…
int svc_can_register(unsigned uid, uint16_t *name)
{
    unsigned n;

    if ((uid == 0) || (uid == AID_SYSTEM))
        return 1;

    for (n = 0; n < sizeof(allowed) / sizeof(allowed[0]); n++)
        if ((uid == allowed[n].uid) && str16eq(name, allowed[n].name))
            return 1;

    return 0;
}
…
int do_add_service(struct binder_state *bs,
                   uint16_t *s, unsigned len,
                   void *ptr, unsigned uid)
{
    …
    if (!svc_can_register(uid, s)) {
        LOGE("add_service('%s',%p) uid=%d - PERMISSION DENIED\n",
             str8(s), ptr, uid);
        return -1;
    }
    …
}
…
```

- Each binder transaction caries in it the UID and PID of the sender, which we can easily access:
  - **`android.os.Binder.getCallingPid()`**
  - **`android.os.Binder.getCallingUid()`**

- Once we have the knowledge of the calling UID, we can easily resolve it the calling app via **`PackageManager.getPackagesForUid(int uid)`**
- Once we have the knowledge of the calling app, we can easily check whether it holds a permission we want to enforce via **`PackageManager.getPackageInfo(String packageName, int flags)`** (with the **`PackageManager.GET_PERMISSIONS`** flag)
- But, much easier to do permission enforcement via:
  - **`Context.checkCallingOrSelfPermission(String permission)`**, which returns **`PackageManager.PERMISSION_GRANTED`** if the calling process has been granted the *permission* or **`PackageManager.PERMISSION_DENIED`** otherwise
  - **`Context.enforceCallingPermission(String permission, String message)`** - to automatically throw **`SecurityException`** if the caller does not have the requested permission

- This is how many of the application framework services enforce their permissions



- For example:
  `frameworks/base/services/java/com/android/server/VibratorService.java`:

```
package com.android.server;
…
public class VibratorService extends IVibratorService.Stub {
  …
  public void vibrate(long milliseconds, IBinder token) {
    if (mContext.checkCallingOrSelfPermission(android.Manifest.permission.VIBRATE)
      != PackageManager.PERMISSION_GRANTED) {
      throw new SecurityException("Requires VIBRATE permission");
    }
    …
  }
  …
}
```

frameworks/base/services/java/com/android/server/LocationManagerService.java:

```
package com.android.server;
…
public class LocationManagerService extends ILocationManager.Stub implements Runnable {
  …
  private static final String ACCESS_FINE_LOCATION =
      android.Manifest.permission.ACCESS_FINE_LOCATION;
  private static final String ACCESS_COARSE_LOCATION =
      android.Manifest.permission.ACCESS_COARSE_LOCATION;
  …
  private void checkPermissionsSafe(String provider) {
    if ((LocationManager.GPS_PROVIDER.equals(provider)
            || LocationManager.PASSIVE_PROVIDER.equals(provider))
        && (mContext.checkCallingOrSelfPermission(ACCESS_FINE_LOCATION)
            != PackageManager.PERMISSION_GRANTED)) {
        throw new SecurityException("Provider " + provider
                + " requires ACCESS_FINE_LOCATION permission");
    }
    if (LocationManager.NETWORK_PROVIDER.equals(provider)
        && (mContext.checkCallingOrSelfPermission(ACCESS_FINE_LOCATION)
            != PackageManager.PERMISSION_GRANTED)
        && (mContext.checkCallingOrSelfPermission(ACCESS_COARSE_LOCATION)
            != PackageManager.PERMISSION_GRANTED)) {
        throw new SecurityException("Provider " + provider
                + " requires ACCESS_FINE_LOCATION or ACCESS_COARSE_LOCATION permission");
    }
  }
  …
  private Location _getLastKnownLocationLocked(String provider) {
    checkPermissionsSafe(provider);
    …
  }
  …
  public Location getLastKnownLocation(String provider) {
    …
    _getLastKnownLocationLocked(provider);
    …
  }
}
```

Binder Death Notification

Given a reference to an **`IBinder`** object, we can:

- Ask whether the remote object is alive, via **`Binder.isBinderAlive()`** and **`Binder.pingBinder()`**
- Ask to be notified of its death, via **`Binder.linkToDeath(IBinder.DeathRecipient recipient, int flags)`**
  - This is useful if we want to clean up resources associated with a remote binder object (like a listener) that is no longer available
  - For example:
    `frameworks/base/services/java/com/android/server/LocationManagerService.java`:

```
public class LocationManagerService extends ILocationManager.Stub implements Runnable {
  …
  private Receiver getReceiver(ILocationListener listener) {
    IBinder binder = listener.asBinder();
    Receiver receiver = mReceivers.get(binder);
    if (receiver == null) {
      receiver = new Receiver(listener);
      …
      receiver.getListener().asBinder().linkToDeath(receiver, 0);
      …
    }
    return receiver;
  }

  private final class Receiver implements IBinder.DeathRecipient,
PendingIntent.OnFinished {
    final ILocationListener mListener;
    …
    Receiver(ILocationListener listener) {
      mListener = listener;
      …
    }
    …
    public void binderDied() {
      …
      removeUpdatesLocked(this);
    }
    …
  }
  …
}
```

Binder Reporting

Binder driver reports various stats on active/failed transactions via **`/proc/binder/`**

- **`/proc/binder/failed_transaction_log`**
- **`/proc/binder/state`**
- **`/proc/binder/stats`**
- **`/proc/binder/transaction_log`**
- **`/proc/binder/transactions`**
- **`/proc/binder/proc/<pid>`**

Replace **`/proc/binder`** with **`/sys/kernel/debug/binder`** on devices with **`debugfs`** enabled.

Additional Binder Resources

- *Android Binder* by Thorsten Schreiber from Ruhr-Universität Bochum
- Android Binder IPC Mechanism - 0xLab by Jim Huang (黃敬群) from 0xlab
- Android's Binder by Ken from Ken's Space
- Dianne Hackborn on Binder in Android on Linux Kernel Mailing List archive (LKML.ORG)
- Android Binder on elinux.org
- Share memory using ashmem and binder in the android framework
- Introduction to OpenBinder and Interview with Dianne Hackborn
- Open Binder Documentation
- Binder IPC - A walk-though native **`IAudioFlinger::setMode`** call

Summary

We learned about:

- Why Android needs IPC
- What is Binder and how it differs from other forms of IPC
- Binder vs Intent/ContentProvider/Messenger-based IPC
- Binder Terminology
- Binder Communication and Discovery Model
- AIDL
- Binder Object Reference Mapping
- Synchronous vs Async Binder Invocations
- Memory Sharing
- Binder Limitations
- Security Implications
- Death Notification
- Reporting

Questions?

Didn't we run out of time by now? :-)

Thank you for your patience!

Slides and screencast from this class will be posted to: http://mrkn.co/bgnhg

You can follow me here:

- @agargenta
- +Aleksandar Gargenta
- http://marakana.com/s/author/1/aleksandar_gargenta