Dynamic User Defined Permissions for Android Devices

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thank you; now let's go enjoy married life.

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Abstract

Mobile computing devices have become an essential part of everyday life and are becoming the primary means for collecting and storing sensitive personal and corporate data. Android is, by far, the dominant mobile platform, which makes its permissions model responsible for securing the vast majority of this sensitive data.

The current model falls well short of actual user needs, as permission assignments are made statically at installation time. Therefore, it is impossible to implement dynamic security policies that could be applied selectively depending on context. Users are forced to unconditionally trust installed apps without means to isolate them from sensitive data.

We describe a new approach, *app sanitization*, which automatically instruments apps at installation time, such that users can dynamically grant and revoke individual permissions. The main advantage of our technique is that it runs in userspace and utilizes standard aspect-oriented methods to incorporate custom security controls into the app.

Keywords: *android; security; privacy; permissions; instrumentation; aspect oriented programming; appsanitizer*

1. Introduction

The introduction of the first iPhone in 2007 marked the transition of mobile devices, such as cell phones, from specialized platforms into general purpose computers whose functionality can be extended by installing third-party applications (a.k.a. *apps*). Over time, the Android platform became the dominant standard with over a billion devices currently in active use and over a million applications are available from the Google Play app store [18]. Installing any of these applications requires a certain level of trust on part of the user, as most apps are given access to sensitive user information.

The user is given some control over the process as apps need explicit permission to access various data and hardware resources on the device, such as contact information, GPS location, microphone, camera, etc. Unfortunately, the Android permissions model does not provide users with enough control over the installed apps, which can easily result in loss of privacy, and has potentially serious security implications in corporate environments.

Android Permissions Framework

With few exceptions, Android applications are written in Java and executed by a special *virtual machine* (VM) known as Dalvik. The Dalvik VM consumes bytecode that is in a proprietary format; however, it can also be translated to and from standard Java bytecode format.

For an application to gain access to protected data or resources on a device, a *permission* must be obtained from the system [23]. Each application uses its *manifest* file to declare at installation time the permissions it needs; during the installation process, the user is given the choice of agreeing to the requested permissions on an all-or-nothing basis. That is, either the application is installed with the full complement of permissions it requested, or not at all. Once permissions are granted, the application has them for life and the user is never consulted again. The only way to revoke a permission is to uninstall the application altogether.

A permission can be defined by individual developers, but normally exists in a set contained within the stock Android operating system. If these are not included in the metadata, but the application attempts to use a resource under their jurisdiction anyway, a security exception is thrown and access is denied. Once agreed, the application can use the set of application programming interfaces (APIs) within the Android OS to access protected resources. At access time, the *Package Manager* is utilized by the API to perform application authentication for the specified resource. It is notable that no check is necessary on the developer's part—Android automatically handles the permission enforcement on every access.

Problems with Android Permissions Framework

There are several problems with the described permissions model; all stem from the overall focus on ease of use and the shortsighted view of the resulting weaknesses with respect to security and privacy. To understand these problems, we consider several representative use cases and show the resulting problems.

Over-provisioned applications

In our first case, Alice (who is an average user) wants to install a simple flashlight app. She would likely start by going to the *Play Store* and search for "flashlight"—hundreds of results will follow, and for such a simple application she is likely to pick a free one. Additionally, she is conscious of picking a well-respected application, so she always checks for a high rating in the 5-star system. The number one result (*Super-Bright LED Flashlight*) is free and ranks over a 4.75 out of 5 (stars) based on about 560,000 reviews. Absent any technical expertise, picking that app is a perfectly rationale choice, as illustrated by the more than 10 million installations, with the store advertisement show in Figure 1-1.

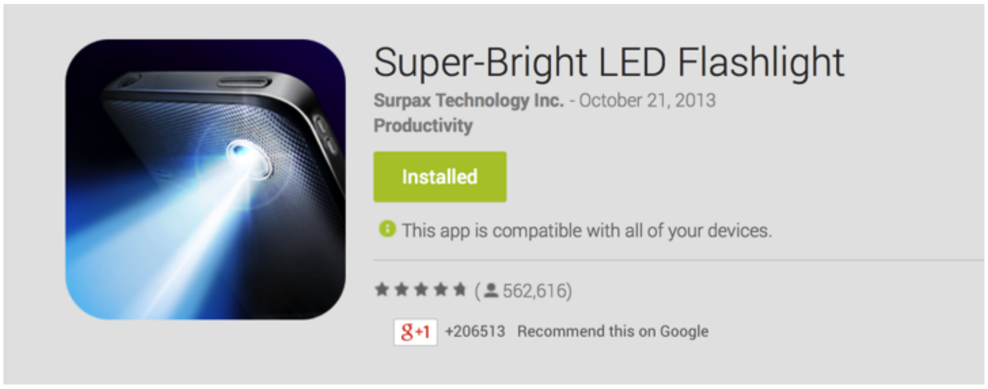
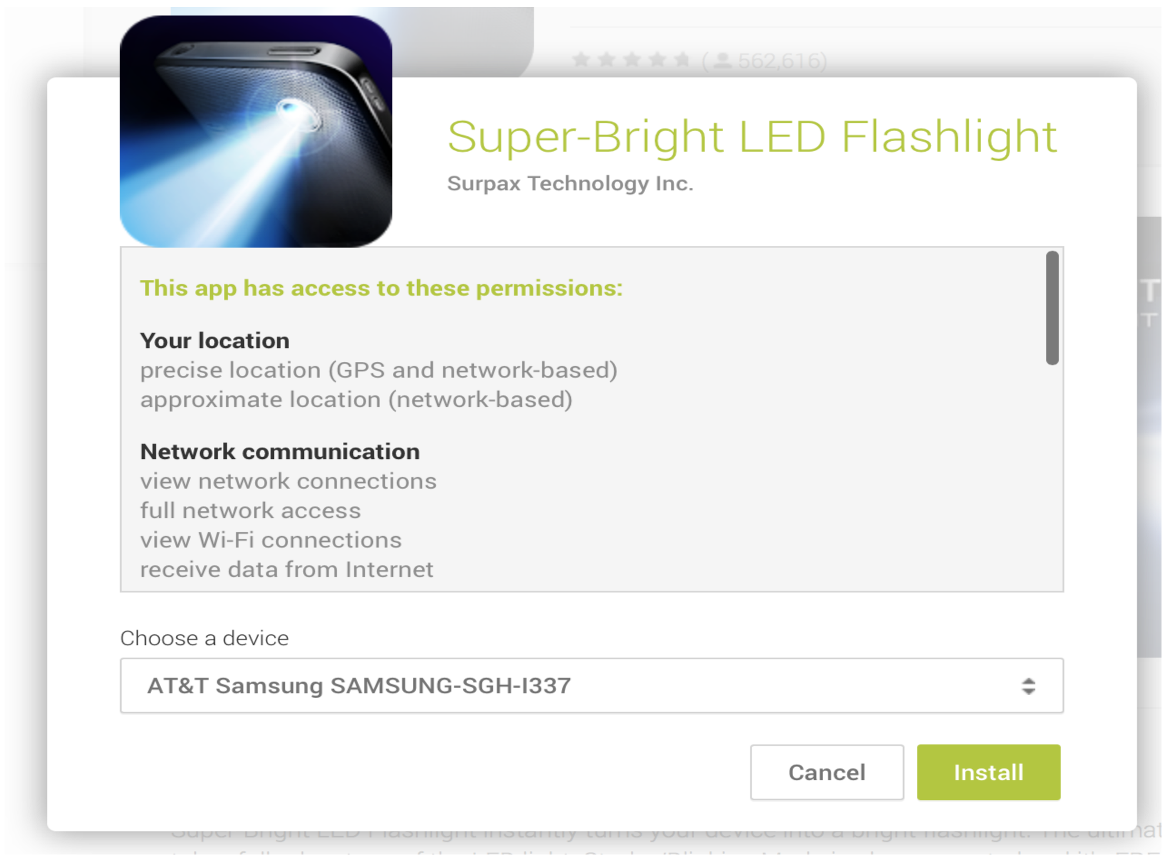

Super-Bright LED Flashlight
Surpax Technology Inc. - October 21, 2013
Productivity
Installed
This app is compatible with all of your devices.
★★★★★ (562,616)
g+1 +206513 Recommend this on Google

Figure 1-1 Simple Flashlight App

At the installation step, Alice is presented with the permissions request shown in Figure 1-2:


Super-Bright LED Flashlight
Surpax Technology Inc.

This app has access to these permissions:

Your location
precise location (GPS and network-based)
approximate location (network-based)

Network communication
view network connections
full network access
view Wi-Fi connections
receive data from Internet

Choose a device
AT&T Samsung SAMSUNG-SGH-I337

Figure 1-2 Permissions Requred (Partial Listing)

At this point, our average user is more than likely to grant the permissions requested as she probably does not fully understand the egregious nature of the requested permissions grab. The only criterion she can rely on is reputation, which in the absence of technical expertise gets substituted for trustworthiness.

From a technical perspective, the app is over-provisioned as the only permission required for the *stated* purpose of the application is 'control flashlight'; whatever other functionality is built into the app has a different purpose that users are ill-equipped to judge. We can surmise that most of it is tied to identifying and tracking the device, and to presumably serve targeted ads—the source of income for the developer.

Over-provisioning is rooted amongst several possible causes. From the app developer's perspective, there are monetary incentives to ask for everything they can get their hands on; advertisers live and die on the ability to deliver ads the user will pay attention to, and any information attainable that might aid that purpose. Additionally, user's lack of recourse empowers developers' mindsets when asking for permissions.

Unfortunately, Google—the owner of Android—has no incentive to minimize advertiser influence as the company is driven on an advertisement business model. It is not surprising, then, to learn that 70% of all apps collect data irrelevant to the main function of the application [17]; one advertisement library alone is installed on over 350,000 unique applications [10]. While no law governs the disclosure of a user's personal information in this manner, most users do not understand the amount of data that apps collect on them.

Even supposing it is the case that users and developers fully understand and accept this permissions framework (along with its implications), malicious applications take advantage of this state of affairs. These second order consequences are serious threats, as demonstrated with malware designed to hijack an application and redelegate their access to a different, arbitrary application [14]. This type of attack is able to utilize the inter-application communications infrastructure to perform a privileged task without the attacking application having such privileges.

The net effect of over-provisioned apps is twofold: an increased attack surface, and an increased exposure of personal information. These problems are exacerbated both by the user's lack of recourse and the static way in which permission policies are implemented.

Static policy assignment

Consider Bob, who, working as a manager, has access to important company information; additionally, he uses his mobile phone to conduct everyday business actions. If Bob were to install an application that had access to the camera and/or microphone, as well as network access, that application could surreptitiously record audio and/or take pictures and send them to unknown parties. Since Bob works with company trade secrets, this scenario is especially serious as anything within line of sight to the phone can be captured and important conversation could be eavesdropped upon.

This proof of concept attack has been successfully demonstrated on Android devices [15]. Any application (including completely legal and well-respected apps) asking for camera rights could carry out this attack. The attack vector involves taking pictures of the user's surroundings, without his knowledge, and sending the images to the remote attacker; in turn, the images are combined into a visual 3D model of his environment.

Other sophisticated attacks utilize the device's built-in accelerometers to capture keystrokes when the phone is placed near a keyboard. Furthermore, and as discussed earlier, applications are vulnerable to permission redelegation, further increasing the attack surface.

The cause of these problems is not that the application has been over-provisioned; instead the simple fact is that permissions are being abused. The inability for users to do anything about this is because of the *static* manner in which these permissions have been assigned.

A *static permissions* model means that once an application has been given a permission, it cannot be modified. That is, once a user agrees an application can use the microphone, it can access the microphone at any time it chooses and in whatever manner the application chooses. This is exacerbated by the fact that a user has only one choice when installing an application – either to grant the application *everything* it asks for, or to not install the application.

Alternatively, *dynamic permissions* would allow the users to enable or disable permissions on a per application basis. Using our process, users must initially accept everything the application asks for. However, they can then turn on/off individual permissions for individual applications through an easy to understand user interface. In addition, information resources (such as contacts) can be faked, which will allow the application to function as normal but with completely false data.

Confusing and coarsely-grained permissions

Users are presented with a synopsis of needed permissions when installing an app. Presupposing that users take the time to read the explanation for each permission, it is doubtful whether they understand the implications behind each one. Specifically, users exhibit problems caused by confusing category headings, disparities between permissions and risk, inability to reason about the absence of permissions, and warning fatigue [19].

Confusing Category Headings Overly broad category headings manifest themselves in many cases. In particular, the READ_PHONE_STATE permission, under the heading "Phone Calls", leads some users to believe companies have permission to market their number to telemarketers. The READ_CONTACTS permission under "Personal Information" leads other users to believe that the application would have access to their stored passwords. Asked whether or not a given application had permissions to read their text messages, users are able to accurately answer only 38% of the time.

Unclear Risks of making Resources Available Connecting warnings to risk is troublesome for users as well, even if the terms of the warnings in the permission are understood. For example, the warning that an application can have "full Internet access" leaves much to the imagination – the user must draw their own conclusions as to the risks involved with accepting that statement.

Absence of Permissions Because of the over 100 default permissions possible for the application to ask for, users lose track of or even forget permissions exist. Thus, when one is missing, they are not likely to notice. This leads to assessing a similar permission, which *is* asked for, as overly broad in scope.

Warning Fatigue Warning fatigue is unavoidable and contributes to the challenge of securing personal data. Instead of meeting this challenge with improved warnings or reducing low-risk warnings, it is better to change the model altogether by offering the user the option to give or take permissions individually. The user should be presented with a list of permissions the application asks for, with a checkbox (defaulted to 'unchecked') for each one, indicating if the application should have access to that particular resource. This way, the user is forced to think about what she is giving up instead of blankly accepting a risk she is tired of thinking about.

With a dynamic permissions model these issues would be circumvented if not rendered invalid. Additionally, we can specify our own permissions in as fine grain a manner as we wish and have them individually granted or revoked. In this fashion, security conscious users would have no qualms about what a particular application is asking for.

2. Prior Solutions

Previous solutions have been presented which implement additional protection, giving users control of protected resources. There are three general approaches when implementing additional resource protections: 1) return the resource unaltered, 2) deny any access to the resource, and 3) return fictitious or masked versions of the resource. Trusted apps can be given access to personal information, while untrusted apps can be fed fictitious data. The ability to return fictitious data is important as applications are expecting to have access to resources for which they were originally designed to use; with a denial of access, the app may behave erratically.

These solutions all wrest control from the application at various points in the control flow in order to implement additional security measures.

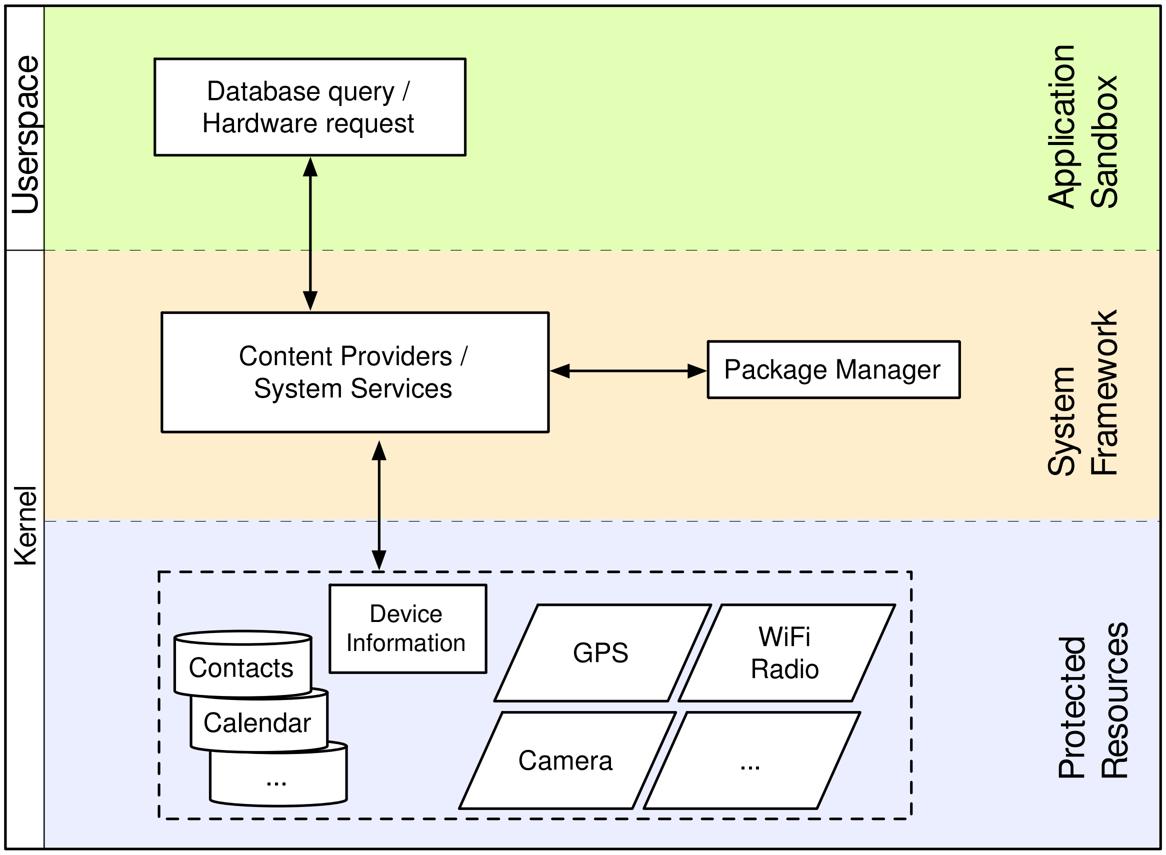


Figure 2-1 Android Architecture

In this representation of Android's architecture (Figure 2-1), there are several modules involved in executing an application's call for data. Each one of them is a control point that can be used to incorporate a custom security mechanism. Figure 2-2 lists the control points used by previous solutions:

Control point	Solution
Content Providers/System Services	MockDroid, TISSA
Android's Package Manager	FlaskDroid
Application layer (user-space)	Dr. Android & Mr. Hide

Figure 2-2 Prior Solutions

MockDroid

MockDroid intercepts the control flow at the System Framework level, within the kernel. Developed by Beresford et al. [1], it provides false information to apps if the user declares them untrusted. For example, they are able to return a constant, 'false', device id when an untrusted application attempts to read the device id.

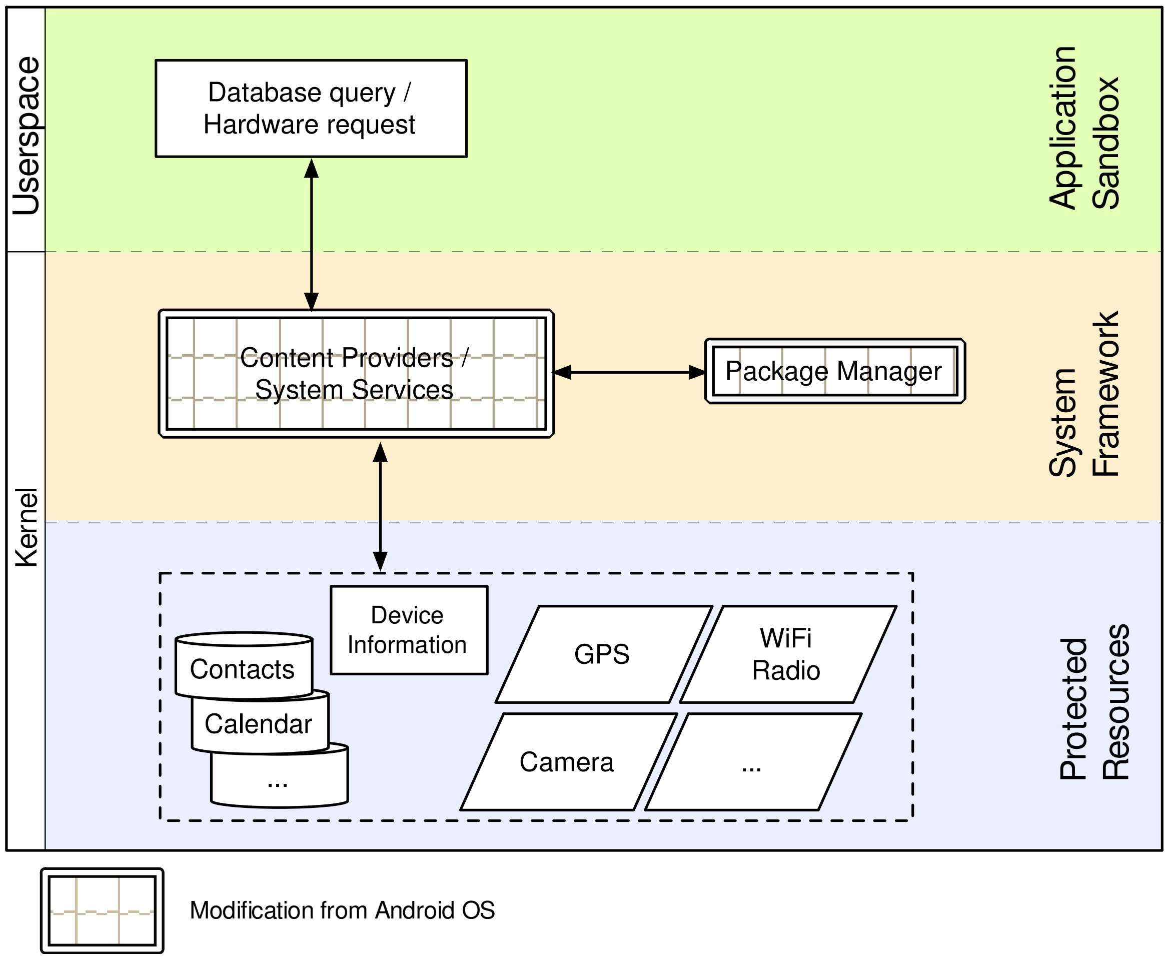


Figure 2-3 MockDroid

This approach relies on modifying both the security checks as well as the content provider libraries. The package manager service is the central node for Android security. Because every API interfacing sensitive data accesses the package manager, this is a perfect opportunity to intercept control flow.

MockDroid implements application access verification within Android's package manager class. If the decision is made to 'mock the data', the customized package manager returns control to the content providers, indicating the user's decision.

When a content provider receives a request from an application for which the user declares untrusted, an empty data set will be returned. If, on the other hand, the user has only allowed the application to have 'mocked' data, "plausible but incorrect" results, such as a falsified last names, are returned to the application.

This approach implements dynamic permissions; however, it involves low level modification within the kernel. Rewriting part of an operating system, although providing a robust solution, is not without drawbacks, and we revisit the issue later in this chapter. Furthermore, MockDroid was not demonstrated to be effective for several types of sensors and data; only one or two types of data are protected with this system.

FlaskDroid

At the 2013 USENIX Security Symposium, a group of researchers presented their work on an improved Android security architecture. This work was realized as a framework dubbed *FlaskDroid* [5].

FlaskDroid is an implementation of the Flask architecture [21], with heavy inspiration from SELinux (or, in this case, SE Android). Flask is a Linux operating system implementing flexible security policies, and is now incorporated into SELinux (a popular security conscious distribution).

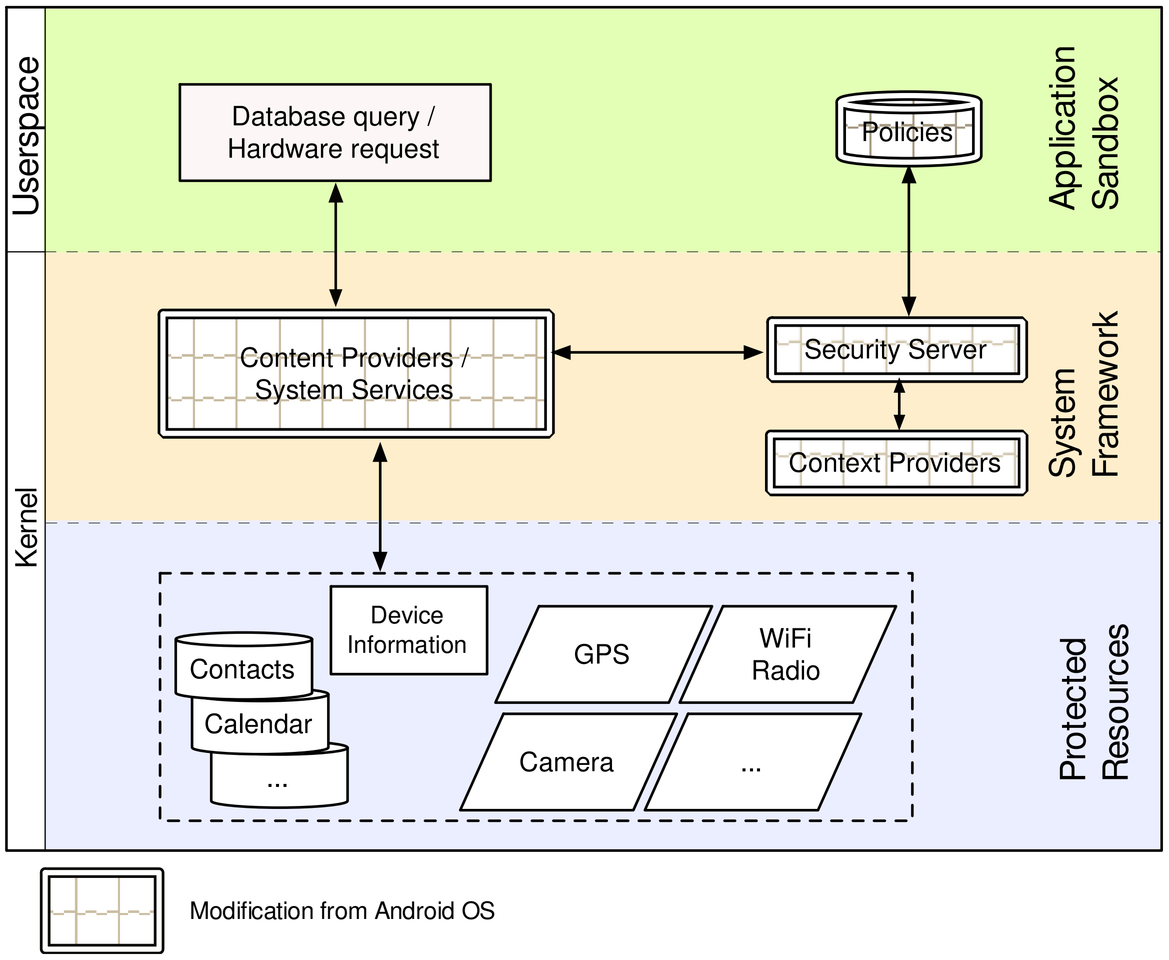


Figure 2-4 FlaskDroid

In this architecture, the major change is the way in which access policies are implemented. There are three central components that constrict application access to a minimum: Context Providers, a Security Server, and a Policy Database. These are in addition to modifications to kernel components such as content providers.

When a system library such as a content provider queries for data, it first reaches the newly implemented user-space security server. This server implements policy decisions based on input previously received from the user. Depending on the outcome of that verification, the calling app is allowed access to the data.

In addition to the standard resource APIs, this approach also takes into consideration a malicious application that has gained root access. To protect against such a threat, policy checks are enforced at the syscall level. This means that were a malicious application to attempt a MAC level query, FlaskDroid would be able to intercept the call and respond appropriately.

The vetted nature of the Flask operating system, and by extension the FlaskDroid operating system, provides for a sound approach to policy management. In addition, FlaskDroid protects from malware with root access.

The major drawback this approach exhibits is consistent with other work – extensive modification of the operating system is required.

Dr. Android and Mr. Hide

Dr. Android and Mr. Hide are two processes that work together to intercept control flow of the app within the Application layer and execute entirely in user space [16].

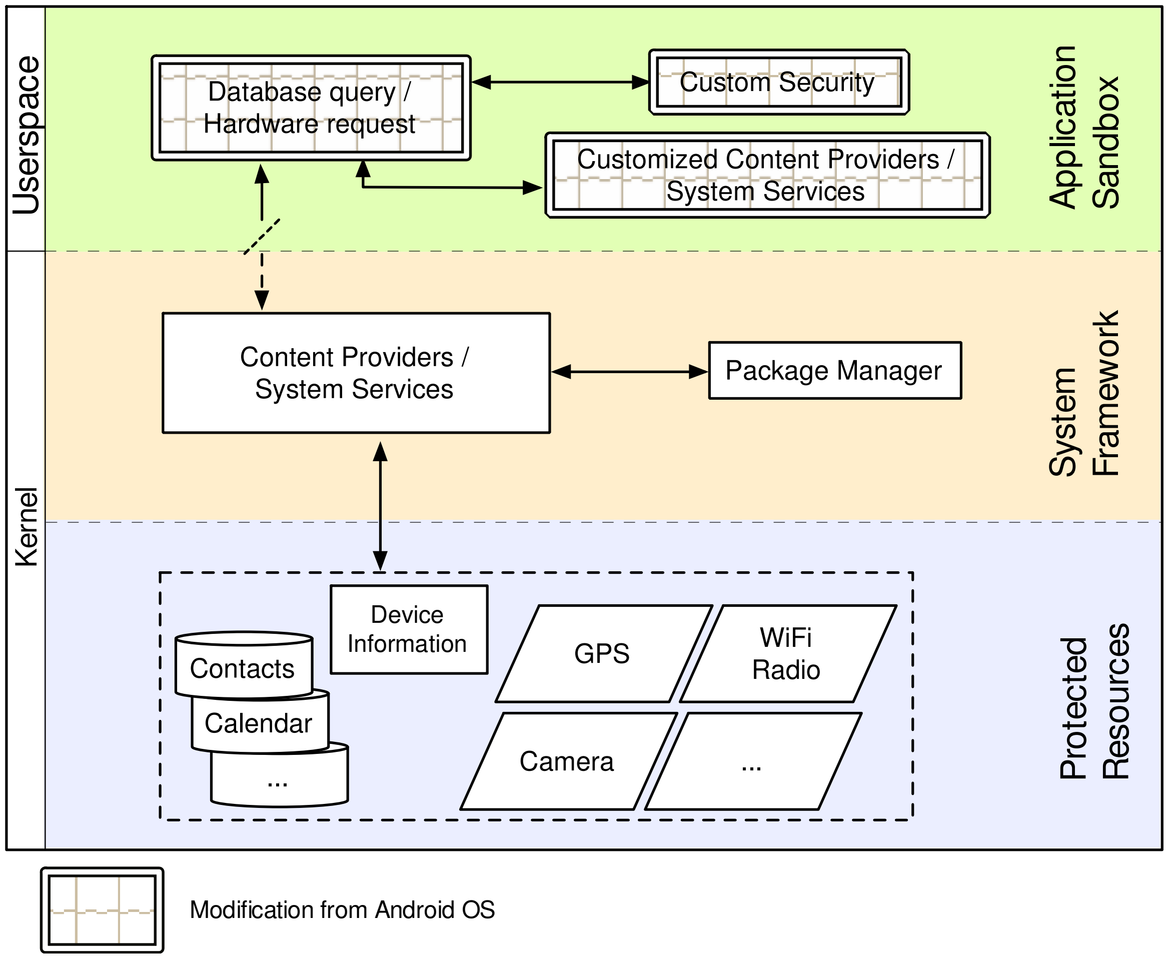


Figure 2-5 Dr. Android Mr. Hide

Dr. Android and Mr. Hide *instrument* target applications. Instrumentation is the act of modifying a program's bytecode representation *without* having access to the source code. This is possible because strongly-typed interpreted languages use an intermediate representation, known as bytecode, which retains all necessary symbolic information, allowing additional code to be spliced in.

The instrumented version of the app is almost exact replica of the original application, except that calls using privacy-related APIs are replaced with calls to a modified implementation of the API. This duplicate API, loaded into userspace, will cause the application to exhibit a new behavior when utilizing methods within it. For example, the duplicated API might block network access if the request is to a known malicious URI.

Written in OCaml, the instrumentation mechanisms are non-trivial to use for the average Java developer. Additionally, this approach relies on up-to-date Android APIs, which are continuously updated over time. Finally, this method does not provide dynamic control of permission revocation.

Drawbacks

These methods presented have achieved securing sensitive data and resources on the Android platform. However, to implement these features in most of the methods above, a modification of Android source code is required. The fallout from this simple fact is far reaching. Some of these disadvantages include:

- Recompilation of the Android operating system is necessary
- Custom ROM is needed to install the new version of the operating system
- Future updates released for the Android operating system are not likely to be folded into the custom operating system
  - Future updates released for the Android operating system could break the way these modifications work
- Technical knowledge is needed to flash ROMs and reinstall operating systems on mobile devices

Since Android is open source, developers can easily change source code and recompile the system. However, the sheer size and complexity behind operating systems can inhibit kernel hackers from doing this in a robust manner. Modifications to such complex systems are likely to have unintended, unsafe, and insecure consequences. For this reason, warranties on mobile devices are generally voided upon installation of such changes.

These devices are, by design, resistant to installation of unverified software; a user must first overwrite such built-in security mechanisms. This process includes flashing new Read Only Memory (ROM) to the device, which in turn disables verification of the update being pushed. If the user then trusts the source of the new operating system, he will be able to install the operating system. Should any step in this dubious process fail, it is possible for the device to become 'bricked', effectively rendering the device useless. In these situations, and if it is possible in the given situation, the user usually resorts to restoring the device to the as-purchased state. The majority of Android users cannot be expected to exhibit this level of technical knowledge.

Another drawback of using a custom operating system is that updates to the original operating system are not necessarily going to be installed on the device. This fact alone should discourage installation of unsupported constructs. Should the custom operating system implement updates from Android, it is possible that updates to any part of the kernel interfere with the customizations made, making the device more unstable if usable at all.

Despite the number of drawbacks, there are some important advantages to a kernel space solution, the largest of which is that it provides a higher level of assurance by ensuring that protection is not circumvented. In particular, if malware were to gain root access on the device, it is still possible to protect the resources. Separately, apps can be run as-is with no need for modification.

Dr. Android and Mr. Hide, while providing the advantage of making all modifications solely in userspace, does not allow for a dynamic permissions model. In addition, it must continuously update its libraries to match that of the current API release. Finally, the instrumentation must be written in OCaml, which would have a relatively steep learning curve.

To eliminate the largest of these drawbacks, while still achieving the same goals, we developed a method that allows any application to be automatically instrumented with our sanitization process, thereby giving us control at important junctions in the flow of the program. Based on that, we implement a dynamic, user-defined permissions model that effectively supersedes the default one.

3. New Approach: Aspect-Oriented Programming

We have developed a methodology to transform applications such that users can control how these applications access protected resources. The idea is similar to the one proposed by Jeon et al. [16], in that it uses bytecode instrumentation as a means to intercept the control flow of the application within user space. However, instead of using a custom bytecode instrumentation tool (written in OCaml), we utilize an *aspect-oriented programming* (AOP) approach, which allows us to write the control code in Java, and splice it into the original application using the de facto standard Java AOP implementation, *AspectJ* [8]. The benefits of the approach are threefold: a) developers of the access control enforcement point can utilize the Android environment; b) our implementation does not require the tracking and replication of the rapidly evolving Android SDK capabilities; and c) it reduces access-control-induced latency by performing the checks *inside* the application's process.

Bytecode instrumentation with AspectJ

As discussed earlier, Android applications are compiled into a series of instructions prior to execution. These instructions – the *bytecode* – are then interpreted by the Dalvik virtual machine. Instrumentation is the act of modifying these instructions. For instance, we can modify every instruction accessing personal data to instead return an empty data set. Aspect oriented programming gives us the ability to find every set of such instructions.

Suppose we wish to modify a query into the contacts database. The normal call is of the form:

```
query
public final Cursor query(Uri uri,
                          String[] projection,
                          String selection,
                          String[] selectionArgs,
                          String sortOrder)
```

Query the given URI, returning a Cursor over the result set.

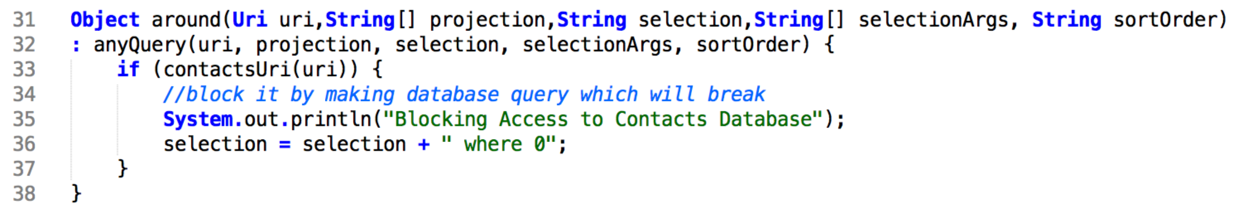
Parameters:

- ***uri*** - The URI, using the content:// scheme, for the content to retrieve.
- ***projection*** - A list of which columns to return.
- ***selection*** - A filter declaring which rows to return.
- ***selectionArgs*** - The values will be bound as Strings.
- ***sortOrder*** - How to order the rows

Returns:

A *Cursor* object, which is positioned before the first entry, or null

AspectJ can modify the query prior to execution yet after arguments have been assigned values. We will selectively modify the query to return an empty cursor by changing the query's selection criteria.



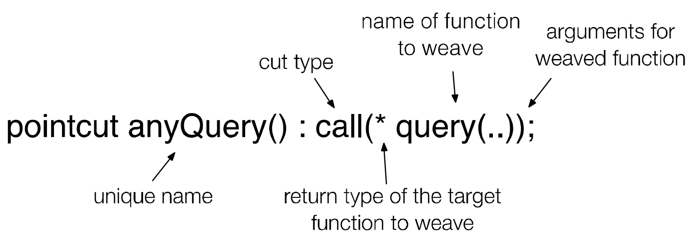
```
31  Object around(Uri uri,String[] projection,String selection,String[] selectionArgs, String sortOrder)
32  : anyQuery(uri, projection, selection, selectionArgs, sortOrder) {
33      if (contactsUri(uri)) {
34          //block it by making database query which will break
35          System.out.println("Blocking Access to Contacts Database");
36          selection = selection + " where 0";
37      }
38  }
```

Figure 3-1 Code to implement when accessing contacts

The code shown in Figure 3-1 will, conditionally, shut off access to a database. If it passes a conditional branch, line 33, it will append a false condition, "`where 0`", line 36, to the query's criteria. When the program executes the query to get a cursor to the contacts database, it will necessarily find nothing – a cursor pointing to an empty dataset. The `proceed` function is how an aspect hands control back to the application in order for control flow to resume as normal; in this case, the query will execute and return its result to the application.

Now that we have the code we want to run, we find all points in the application that access the contacts database. Aspect oriented programming is the ideal paradigm to follow in this case. With it, we are able to crosscut the entire application, applying *advice* (additional or modified behavior) at all *join points* (specified locations within the application code) we specify.

Our join point for contacts looks like the following:



```
pointcut anyQuery() : call(* query(..));
```

cut type
name of function to weave
arguments for weaved function
unique name
return type of the target function to weave

Figure 3-2 Pointcut Breakdown

The name of the pointcut is used when defining the advice type later in the aspect. The cut type 'call' is used to weave when the function is called within the original program. The return type can be used to more exactly filter what methods we want to weave throughout the target program. With the wildcard '*', it will match any return type. Next is the name of the function, here 'query. This specifies the name of the function(s) we want to weave. While this supports wildcards, as well as classpath filtering, we limit our weave points to the function name. The last part of the pointcut to define is the argument specification. In our example, we allow any number of arguments.

The final step remaining combines the code we want to execute at the pointcuts we specify within a single object. This object is known as an *aspect*.

```
1. public aspect aspect24adba4 {
2.        pointcut anyQuery (Uri uri,String[] projection,String selection,String[] selec
      tionArgs, String sortOrder)
3.      : call(* query(..))
4.          && args(uri, projection, selection, selectionArgs, sortOrder)
5.          && within (  (com.google.ads.u) || .... );
6.
7.      Object around(Uri uri,String[] projection,String selection,String[] selectionArg
      s, String sortOrder)
8.      : anyQuery(uri, projection, selection, selectionArgs, sortOrder) {
9.          try {
10.             if (accessingContactsDatabase()) {
11.                 if (blockContacts == false){
12.                     //do nothing
13.                     System.out.println("[!]Allowing access to contacts");
14.                 } else {
15.                     //block access
16.                     System.out.println("[!]Blocking access to contacts");
17.                     selection = selection + " where 1 > 2 ";
18.                }
19.            }
20.         } catch (Exception e) {
21.             System.out.println(e);
22.         }
23.     return proceed(uri, projection, selection, selectionArgs, sortOrder);
24.     }
```

Figure 3-3 Contact Blocking Aspect

This aspect, show in Figure 3-3, will utilize a pointcut to capture all calls within the application's code matching the function name "query" (line 3). Additional requirements are imposed on the pointcut, assuring that any matched functions both have specified arguments and exist within a specified classpath. These additional restrictions allow us to specify what classes we weave into; without8 them, we could potentially instrument more bytecode than we wish to. Lines 7 and 8 declare that the following code should be applied *around* all found pointcuts matching the criteria. The 'around' advice is used when we want to modify the functionality at weaving point; alternative types of advice can modify control flow either before or after the weaving point.

A graphical representation of this flow is represented with Figure 3-4.

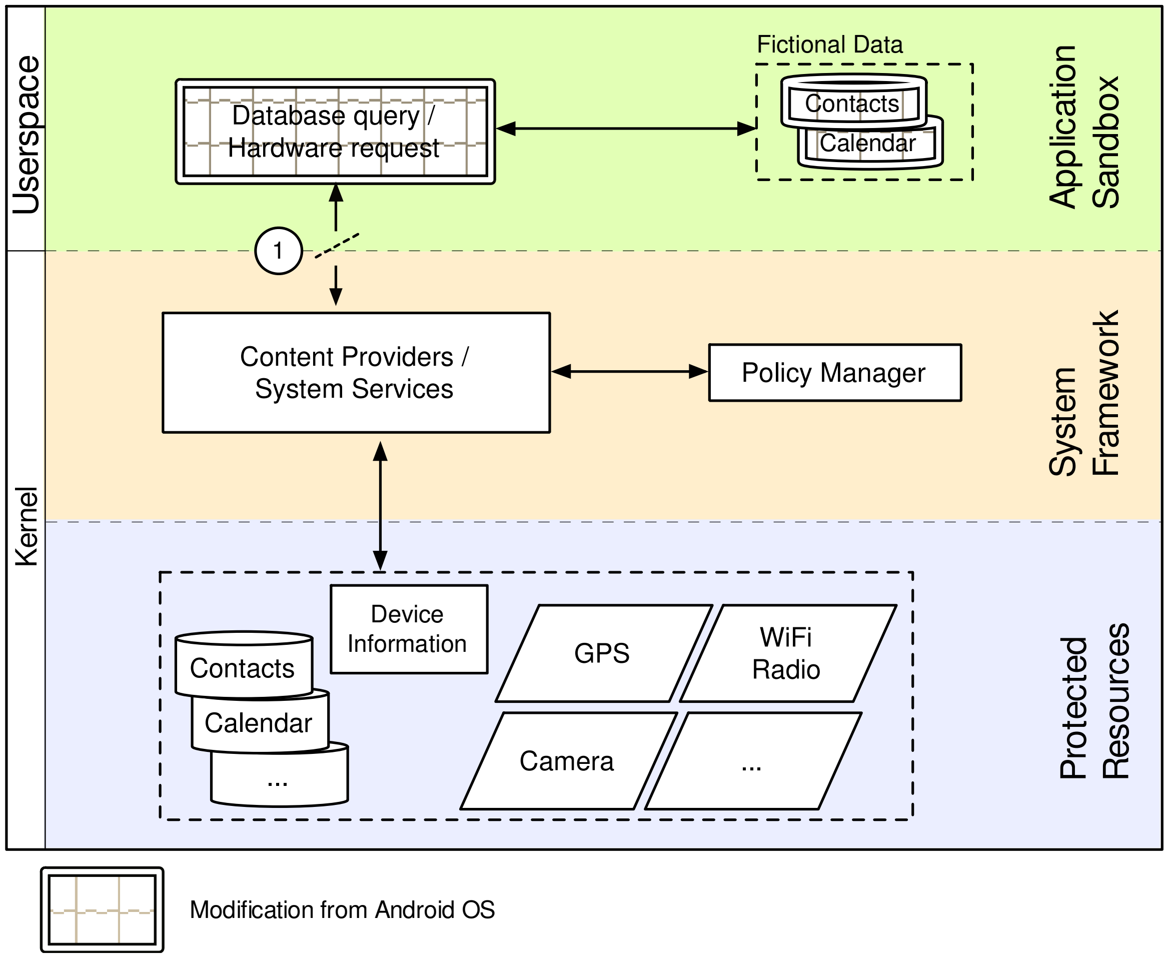


Figure 3-4 AppSanitizer

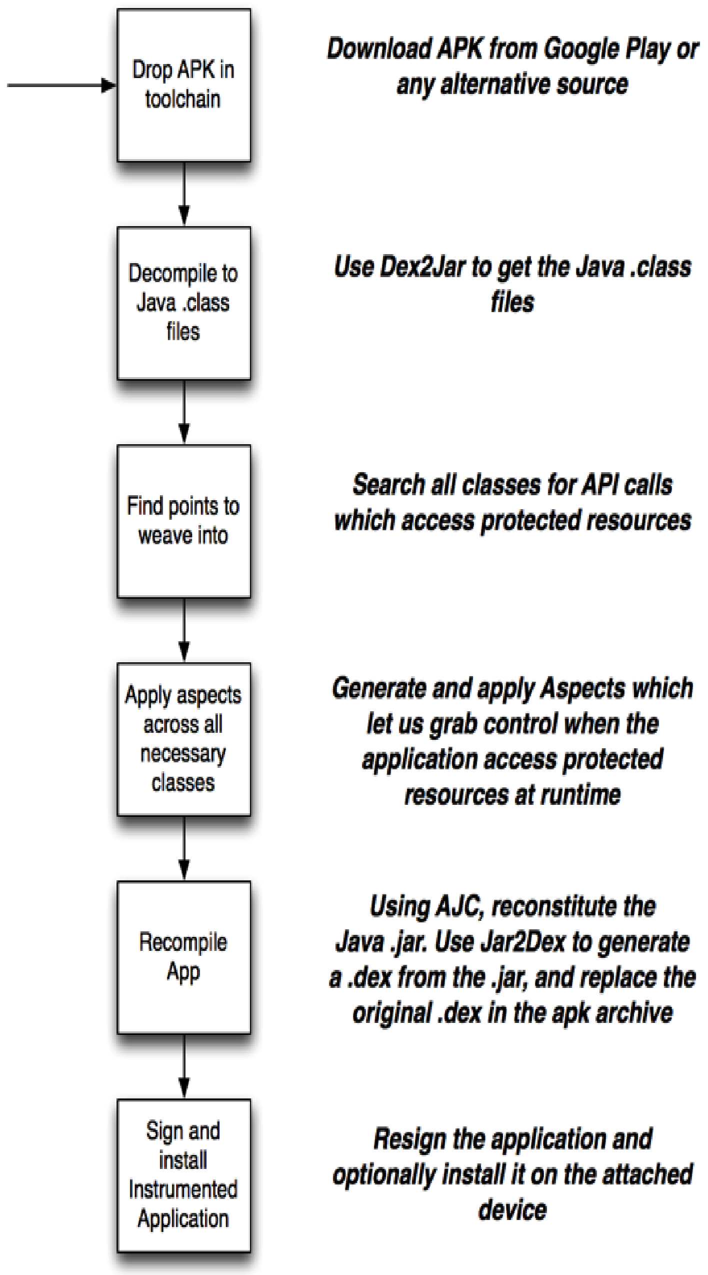
After applying aspects to the application, the requests going to the system framework (denoted with the '1' and intercepted control line), have been weaved based on our advice. Instrumenting bytecode in this fashion leaves both the application and operating system agnostic to the fact that we've gained control.

Automation

We have built a process to automatically perform bytecode instrumentation.

The first step in the process is attaining the target application file. While the routine method involves visiting Google's Play Store, .apks can be installed from any source. For our purposes, we utilized open source libraries that crawl the Play Store, downloading apps as if it were an Android device. This was successful in downloading about 100 applications before being blocked by Google's servers. A more effective method, although not autonomous, involves a third party extension for Google Chrome, ApkDownloader.

Once the .apk has been downloaded, we begin the process of implementing additional security measures. The format of an .apk archive allows us to unzip the file and gain access to the bytecode. This code is in an Android specific format, Dalvik bytecode. In order to utilize well-established tools, we convert the Dalvik bytecode back to Java bytecode thereby granting use of tools made specifically to study, modify, and rebuild Java bytecode (such as AspectJ). This conversion process is performed with the Dex2Jar suite of tools, and the output is in Java's *.class* format.



Drop APK in toolchain
Download APK from Google Play or any alternative source
Decompile to Java .class files
Use Dex2Jar to get the Java .class files
Find points to weave into
Search all classes for API calls which access protected resources
Apply aspects across all necessary classes
Generate and apply Aspects which let us grab control when the application access protected resources at runtime
Recompile App
Using AJC, reconstitute the Java .jar. Use Jar2Dex to generate a .dex from the .jar, and replace the original .dex in the apk archive
Sign and install Instrumented Application
Resign the application and optionally install it on the attached device

Figure 3-5 Sanitation Pipeline

We could immediately begin applying aspects to Java's bytecode, however, to minimize the amount of work done when recompiling the instrumented bytecode, we first want to get a list of all classes we want to weave into. Bash level tools can be utilized for finding all classes that contain a particular function call. Obfuscation would normally present a barrier to this method, however since we are only weaving calls to the Android API we can be sure the function definitions remain unchanged. We add all found classes that make these targeted API calls as additional criteria when applying our aspects.

The aspects are then ready to be applied. The AspectJ tool suite includes a special compiler, AspectJ compiler, or *ajc*. We provide ajc with the aspects we've defined as well as all .class files derived from the original Android application. Ajc will apply the aspects to the bytecode and output a new .jar archive. Still in the Java format, we use another tool in the Dex2Jar toolchain, jar2dex, to get back to our desired Android format, Dalvik bytecode. This bytecode, output as a .dex file, replaces the .dex file within the original application's archive. With the new bytecode inside its archive, the .apk is ready to be resigned and reinstalled.

Instrumentation for Dynamic Permissions

In the Android API, there are only a few ways to utilize or access protected resources, and we have broken these down by what archetype of resource they are most closely related to. We focus on *Sensors*, which includes the camera, network radio, and GPS radio, as well as *Databases*, which include contact information, calendar, and account information. While the functions of resources within these archetypes are not necessarily similar, the methods to access them through the API are exactly the same; we take advantage of this fact when applying aspects.

Databases

Databases are used to store many kinds of information within the device. Of paramount importance to privacy is the contacts database, which stores names, phone numbers, addresses, photos, and other information. To intercept requests for this data, we configure our aspects to match the method within the Android API matching '*cursor query(Uri uri, String[] projection, String selection….)*'. The first argument in this method defines what database to pull from by use of a URI. Contact information, for example, is accessed with the URI "android.provider.ContactsContract.Contacts.CONTENT_URI". Remaining arguments are used for further defining the query, such as the columns to select from and the criteria the results must match. When weaving, we only apply additional security measures to target URIs.

Databases also offer a unique opportunity in that we can provide the calling application with fake information. We achieve this by copying a database to the device's storage that, while identical in schema, has falsified information in it. Within the aspect, we instead generate a *cursor*, the Android handler for queries, to the falsified database. When the cursor is returned to the application, it would have no knowledge it is instead looking at false information.

An aspect applying this style of advice is the following:

```
public aspect aspectba818d3 {
    private final String NoChange = "0";
    private final String Block = "1";
    private final String FakeIt = "2";
    SanitizedAppData sad = new SanitizedAppData();

    pointcut anyQuery (Uri uri,String[] projection,String selection,String[] selectionArgs, String sortOrder)
    : call(* query(..))
        && args(uri, projection, selection, selectionArgs, sortOrder);

         Object around(Uri uri,String[] projection,String selection,String[] selectionArgs, String sortOrder)
         : anyQuery(uri, projection, selection, selectionArgs, sortOrder) {
             System.out.println(" -- Sanitizer has reached our Weaved Code --");
             sad.initialize();

             try {
                 if (uriHelper.contactsUri()) {
                     System.out.println(" -- Sanitizer has matched the target URI --");
                     System.out.println(" -- 'SAD' setting: " + sad.contactsSetting());
                     if (sad.contactsSetting().equals(NoChange)){
                         //do nothing
                         System.out.println("Allowing access to Contacts");
                     } else if (sad.contactsSetting().equals(Block)) {
                         //block it by making database query which will break
                         System.out.println("Blocking Access to Contacts Database");
                         selection = selection + " and 1 > 2";
                     } else {
                         System.out.println(" -- Attempting to get into the second database.. --");
                         Cursor myCursor = fakeContactData(uri, projection, selection, selectionArgs, sortOrder);
                         return myCursor;
                     }
                 }
             } catch (Exception e) {
                 System.out.println(" -- Sanitizer has reached our Weaved Code, but failed to successfully interrupt the system call --");
                 System.out.println(e);
                 proceed(uri, projection, selection, selectionArgs, sortOrder);
             }
             return proceed(uri, projection, selection, selectionArgs, sortOrder);
         }

         public Cursor fakeContactData(Uri uri,String[] projection,String selection,String[] selectionArgs, String sortOrder) {
             System.out.println("-- Opening Database to /sdcard/contacts2.db --");
             SQLiteDatabase myDB = SQLiteDatabase.openOrCreateDatabase("/sdcard/contacts2.db", null);
             return myDB.query("view_contacts", projection, selection, selectionArgs, null, null, null, null);
      }
     }
```

Figure 3-6 Contacts Aspect

Figure 3-6 contains an entire aspect. Combining both the pointcut, lines 7 through 9, and the advice, lines 11 through 49. The net effect of this aspect is to splice into the application at any point a ‘query’ function is called with the following logic: a) if the target database is the contacts database, then b) proceed by following user’s selection by allowing access to the database, denying access to the database, or returning a cursor to the alternative database with fake information, and finally c) return the cursor to application, thereby conceding control back to its original state.

Sensors

The GPS radio is a sensor attached to Android devices. This peripheral is one of the most unnecessarily requested by applications; ad supported apps generally require it. In order to activate the radio within code, developers use the high-level procedure *getSystemService(String name)*, where *name* is, in this instance, “location”. The returned object is a LocationManager, which has callback functions for when it is updated. Crafting a malformed LocationManager, and returning that in place of what the application is expecting, prevents the application from receiving any kind of update.

An HTTP Download service is built into the API for managing downloads from the internet. To utilize this method, developers use the same *getSystemService(String name)* method, but provide “download” to the procedure. The resulting returned object is of type DownloadManager. Weaving into this point, we can similarly craft a response preventing the DownloadManager from completing its download.

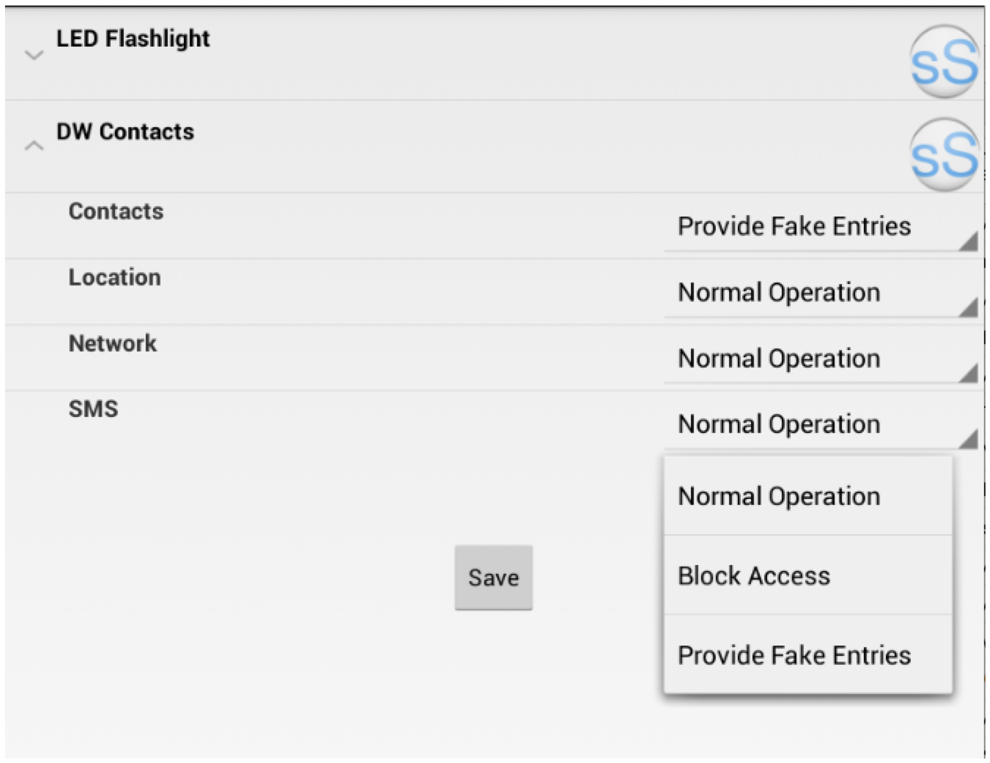
```java
public aspect aspect262fac6 {
  pointcut systemServiceCut(String theString)
  : call(* getSystemService(..))
    && args(theString)
    && within(com.QrBarcodeScanner.Encode.*);

  Object around(String theString)
  : systemServiceCut(theString) {
    System.out.println(" -- Sanitizer has reached our Weaved Code --");
      if (theString.equalsIgnoreCase("download")) {
        if (sad.httpDownload().equals(NoChange)){
          //do nothing
          System.out.println("Allowing access to HTTP Download");
        } else if (sad.httpDownload().equals(Block)) {
          //block it by returning a bad service
          System.out.println(" -- Blocking Download --");
          return proceed(" ");
        }
      }
      return proceed(theString);
    }
  }
```

Figure 3-7 System Service Aspect

In order to grant the user the ability to dynamically choose what action to take - to allow access, to deny access, or in some cases provide fake information – we install an application on the device to write user decisions to the SD card. Acting as a shared resource, the SD card is an easy way to share information between the settings application and the instrumented application. Alternatively, broadcasts and intents could be used, however this method requires the settings application to be constantly running in the background as a service. While providing the advantage of no read/write operations to the SD card, the drawbacks include that Android can kill background =services when running low on memory.

To make these decisions, we provide the user a simple GUI.



Contacts	Provide Fake Entries
Location	Normal Operation
Network	Normal Operation
SMS	Normal Operation

Figure 3-8 Dynamic Permission Setting

Using the application demonstrated in Figure 3-8, the user can grant and revoke permissions on a per-application basis.

Location Based Permissions

In addition to allowing the user to selectively grant and revoke access to individual permissions, a location based access policy is useful. Within sensitive government installations, for instance, no pictures should be taken by any applications. Likewise, employees in corporate environments will have a smartphone on or near them; were a device to be infected with malware, attackers could gain access to valuable company trade-secrets. To this end, aspects can be configured to detect whether or not the device is within a certain distance from a given location. If so, information can be hidden from instrumented applications, and sensor access can be revoked.

4. Results

To study the effectiveness of our process, we built a proof of concept process named 'AppSanitizer', and conducted several case studies.

General Usage

Assuming that we have attained a copy of the apk we wish to 'sanitize', we begin the process by dropping the file into our pipeline.

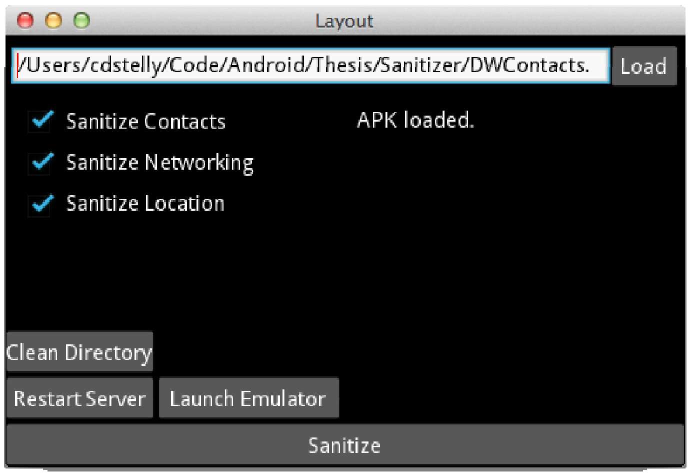


Figure 4-1 Sanitizer GUI

There are several options for sanitization. While the default is to cut across the entire application, we provide the option to reduce the amount of instrumentation done to the source application. Upon sanitization, we see output similar to the following:

```
58:Sanitizer cdstelly$ SanitizeAPK.py -c true -a DWApp.apk
[*] Beginning Sanitization
[-] Cleaning the working directory
[-] Decompiling the APK
       dex2jar DWApp.apk -> outJar.jar
[-] Generating random class name
[-] Aspect Name: aspectd138229
[-] Finding the classes which call: "query"
[-] Preparing the environment...
[-] Weaving aspect from just .class files..:
[-] 8 warnings
[-] Now we have the jar.. let's generate a dex!
[-] jar2dex ./target/classes/post-compile-time/output.jar -> classes.dex
[-] call com.android.dx.command.Main.main[--dex, --no-strict, --
output=/Users/cdstelly/Code/Android/Thesis/Sanitizer/classes.dex,
/Users/cdstelly/Code/Android/Thesis/Sanitizer/target/classes/post-compile-
time/output.jar]
[-] updating: classes.dex
[-]    zip warning: Local Entry CRC does not match CD: classes.dex
       (deflated 60%)
[-] Signing the apk
[-] sign DWApp.apk -> DWApp-signed.apk
[-] Removing the currently installed application..
[-] * daemon not running. starting it now on port 5037 *
[-] * daemon started successfully *
[-] Success
[-] Installing the modified version..
2151 KB/s (3255732 bytes in 1.477s)
       pkg: /data/local/tmp/DWApp-signed.apk
[-] Success
```

Figure 4-2 Sample Sanitization

Case Studies

DW Contacts

DW Contacts is a free application aimed at enhancing or replacing the standard phone application packaged within Android [22]. Most features advertised relate to accessing and communicating contacts quickly and efficiently, whether via SMS, MMS, email, or a normal phone conversation.

This application was chosen due to its large volume of downloads (up to 5 million) as well as an easy way to show the ability to provide fake information

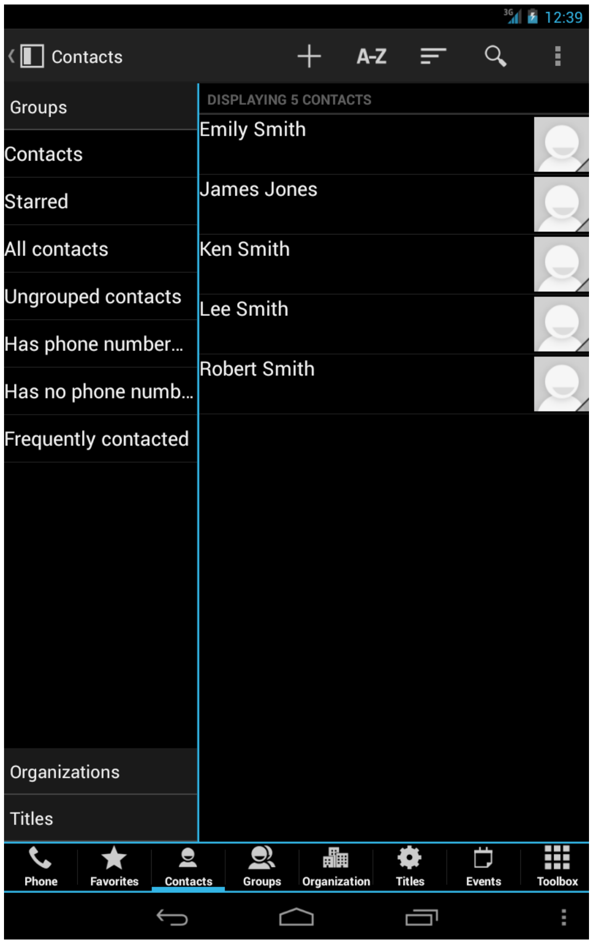


Figure 4-3 DW Contacts (Unmodified)

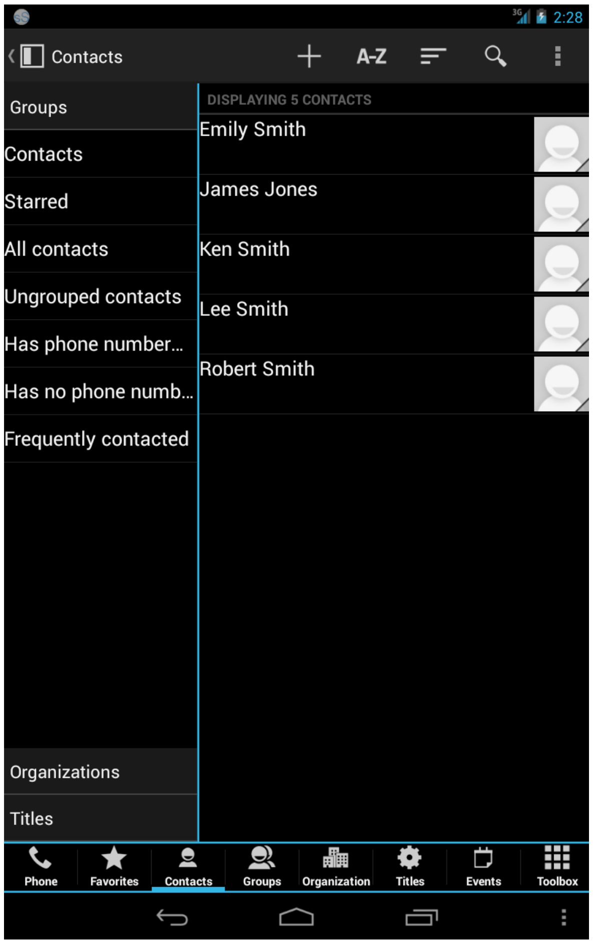


Figure 4-4 DW Contacts (Instrumented)

In Figure 4-3, we see normal operation of the application – loading of contact names. After instrumenting the application's bytecode, launching the application results in the screen presented in Figure 4-4. The user has been notified with the standard Android notification system; optionally, an alert is fired, and an icon appears in the top left of the status bar.

Upon inspection of the notification (i.e., pulling down the notification bar), the following selection is presented to the user (Figure 4-5).

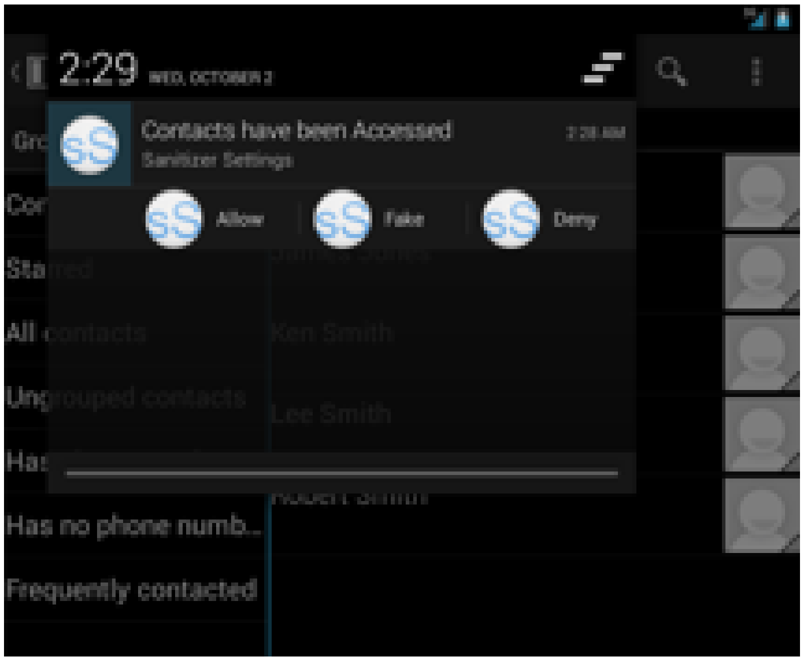


Figure 4-5 Notification contacts were accessed (Instrumented)

Three options are displayed: Allow, Fake, and Deny. Selecting the notification itself will take the user to the SanitizerSettings application, where he can select to allow, fake, or block data.

As show previously with Figure 3-3, the user is able to modify the privacy settings of any sanitized app he has installed. After saving, he should restart the app she is trying to modify the settings of. This is not strictly necessary, but should be done to clear anything the app has cached.

If she selected the option to fake all contact information for DW Contacts, the next time she runs the app he could expect to see the image in Figure 4-6.

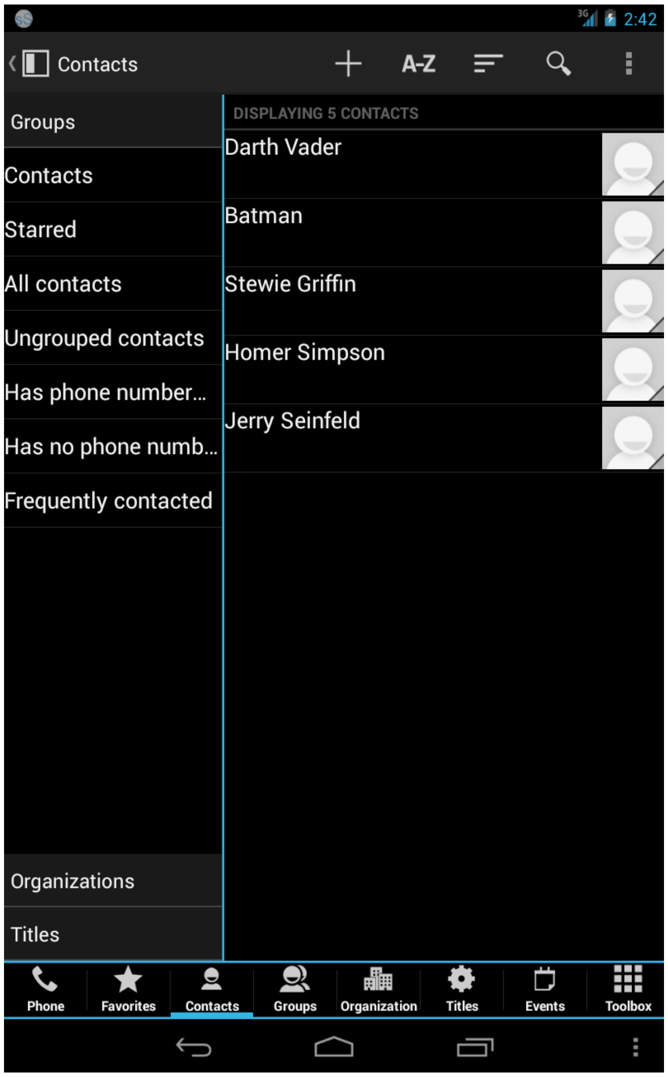


Figure 4-3 DW Contacts with fictitious contacts (instrumented)

Fictitious data has been given to the application. This will ensure that even though we are modifying the application to protect our privacy, the application will continue to behave as normal.

As the fictitious data resides in userspace, it could be modified at any time. Thus, it is possible to populate the database with 'masked' data, which could prove to be a useful middle ground between privacy and application usability. Masked data could take the form of contacts which last names were all replaced with a mask character, such as the letter 'x'.

Super-Bright LED Flashlight

In our case studies used to describe the permissions issue, we looked at the 'Super-Bright LED Flashlight' app [20]. Since it has been installed up to 500 million times, or one in five Android devices worldwide, it is worth a deeper look.

Prior to download, the following permissions are required:

Your location
- precise location (GPS and network-based)
- approximate location (network-based)

Network communication
- view network connections
- full network access
- view Wi-Fi connections
- receive data from Internet

Phone calls
- read phone status and identity

Storage
- modify or delete the contents of your USB storage

Your applications information
- retrieve running apps

Camera
- take pictures and videos

Development tools
- change system display settings

System tools
- modify system settings
- test access to protected storage

Affects Battery
- control flashlight
- prevent device from sleeping

Figure 4-4 Permissions required for installation of "Super Bright LED Flashlight"

The number of permissions is too many – there is only one required for a flashlight app, and that is “control flashlight”. With network and camera access, this application has the facility to execute the PlaceRaider attacks as discussed earlier. The application is ad-supported, however, and as such can reasonably require network access. On the other hand, the application also has the ability to *upload* information with ‘full network access’. Clearly, this application is over-provisioned.

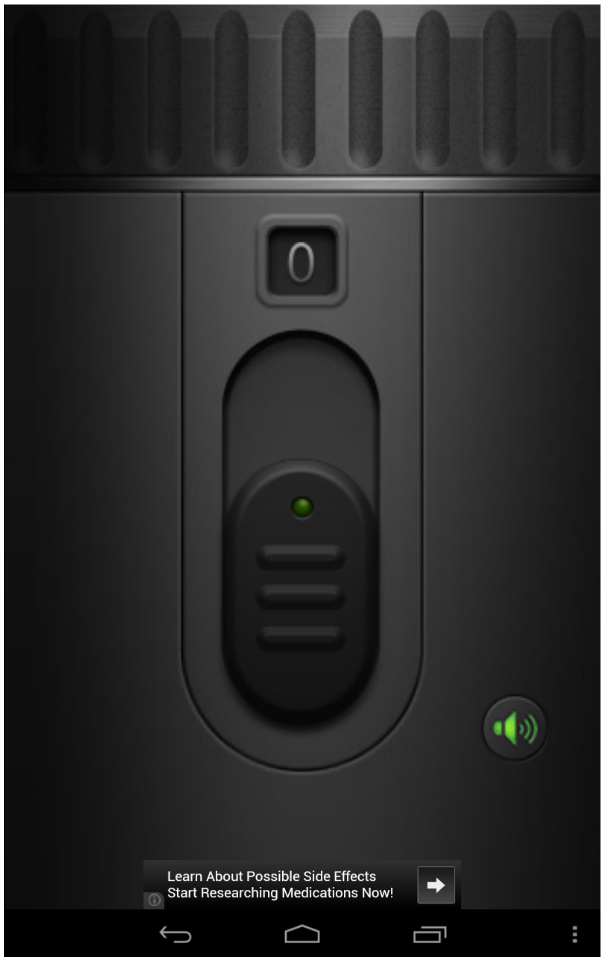
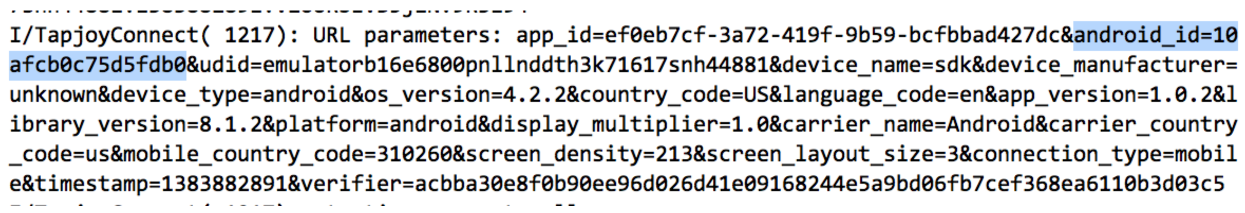

Learn About Possible Side Effects
Start Researching Medications Now!

Figure 4-5 Super-Bright LED Flashlight (Unmodified)

We immediately notice the ads at the bottom - this is the plausible cause for full Internet permissions. However, without doing anything remotely close to network traffic analysis, one can simply look at the standard debugging output of the application when running to see that it is sending off the device id and several kinds of private information off to an ad service.



```
I/TapjoyConnect( 1217): URL parameters: app_id=ef0eb7cf-3a72-419f-9b59-bcfbbad427dc&android_id=10
afcb0c75d5fdb0&udid=emulatorb16e6800pnllnddth3k71617snh44881&device_name=sdk&device_manufacturer=
unknown&device_type=android&os_version=4.2.2&country_code=US&language_code=en&app_version=1.0.2&l
ibrary_version=8.1.2&platform=android&display_multiplier=1.0&carrier_name=Android&carrier_country
_code=us&mobile_country_code=310260&screen_density=213&screen_layout_size=3&connection_type=mobil
e&timestamp=1383882891&verifier=acbba30e8f0b90ee96d026d41e09168244e5a9bd06fb7cef368ea6110b3d03c5
```

Figure 4-6 Logcat Output: Device ID being given to an ad service, along with other encrypted strings

This is in addition to several encrypted strings appearing in the standard output. We do know that the app requires exact GPS location permissions, so it is possible that it is encrypting your location (for use with the ads, hopefully).

Applying the same sanitization process to the flashlight apk, we were able to block all network access. The effects of this are at least twofold: 1) the application cannot upload any information about the device, and 2) ads are no longer displayed.

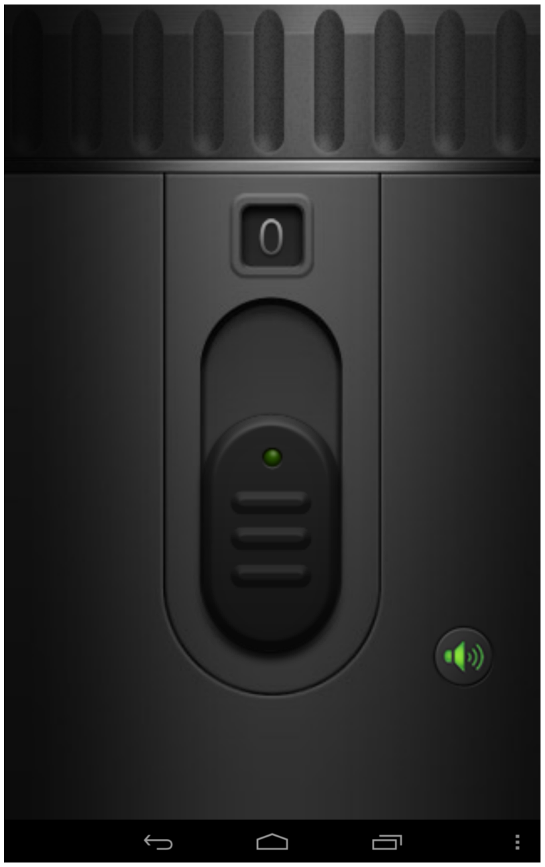


Figure 4-7 FlashlightApp (Instrumented)

This application is a prime example of why these kinds of apps should have a more versatile permissions model. When we trust an application with any combination of permissions including full network access, we must be wary of the possible consequences.

5. Critique of Methods

While we achieve the goal of implementing dynamic privacy controls, we have discovered drawbacks with our method. These include:

- Advanced obfuscation techniques inhibit ability to recompile some applications
- To install these apps, we must resign other people's work
- If the device's available memory runs low, the permission watching service could be killed and the user will not be notified until restarting the service or device
- When Android eventually implements required permissions to read/write the SD card, we will have to add that permission to the application's manifest
- Many apps are advertiser based; this method can prevent ads from running

Many developers obfuscate their application's code prior to release. This is an effective way to prevent reverse engineers from immediately realizing the purpose of a given method. Our design takes this into account as we consider the fact that Android API calls cannot be obfuscated – to utilize certain functionality, you must use the methods provided. What was unaccounted for, however, was the inability for our decompilation and recompilation tool (dex2jar) to handle obfuscation techniques. The dex2jar suite works well in most cases of obfuscation, but for some apps (such as Google Chrome), the recompilation process did not work as planned. Although the decompilation and weaving processes worked as intended, more research into this, or perhaps a future update of the dex2jar tool, are required to provide a completely robust solution.

One consideration our work brings to light is that in order to install the modified application, we must re-sign the original developer's work as any modifications break the original developer's signature. From a functional standpoint, this is no problem. However, original developers can be understandably displeased with such actions.

In order to utilize the run-time warnings that notify the user when a sensitive resource is active, we deploy a service that runs in the background processes of the device. Once the aspect is accessed, the warning comes from this service vice weaved code. As all devices are constantly trying to conserve battery, they periodically kill inactive services. While this behavior was not witnessed when testing, the shutdown of the service would prevent the user from being warned their information was being accessed. However, the aspects would continue to function as normal and would follow any settings already set in place.

Once side effect we introduce is that advertisements can be effectively disabled when we deny network access to an application. An issue worthy of a debate in itself, this can be seen as both a fantastic side effect for end users and as a negative consequence for developers who are financially supported by advertisements.

6. Conclusion

Mobile devices are increasingly trusted with information of both corporate and personal varieties. The largest platform by far, Android, has not even come close to implementing an exemplary security model with regards to protection of this information. Likewise, protection for hardware sensors on Android devices has fallen by the wayside. The lack of protection falls well short of user needs while simultaneously presents a serious security threat.

A variety of causes contribute to the lack of protection. Statically assigned permissions, which must be agreed upon prior to application installation, cannot be changed at any time. Rampant numbers of apps are over-provisioned, each asking for ludicrous access to personal information or completely unrelated hardware sensors.

This is a well-known set of problems, and prior solutions have approached it from the ground up; that is, they have focused on implementing reasonable security policies within Android's open source kernel. While these solutions have achieved the goals of improving Android with such security policies, they are severely hampered by the way in which they have implemented them; the re-writing of operating system source code is unnecessary and burdensome.

Alternatively, other prior work has implemented improvements to the security model at the application layer, within userspace, bypassing the excessive drawbacks caused by operating system modification. This prior work, however, could be improved upon by use of standard, well-understood technologies, as well as expansion of goals and implementation.

Our research, instantiated in the form of AppSanitizer, provides an ideal solution for implementation of reasonable security policies within Android. These policies revert the static nature of permission assignment, while simultaneously giving the user the power to grant and revoke individual permissions on a per-application basis. For permissions that access information, such as contacts, AppSanitizer can reliably return fictitious data. AppSanitizer is also automated, providing an additional advantage for this approach.

The main benefit of this work is the grant to a user the ability to control whether or not an application can access a protected resource, post-install time, without modifying the operating system.

Future Work

Future work could implement the sanitization process on the device itself, bypassing the need for ad-hoc installation and instrumentation. Because this solution likely requires root access of the device, an alternative may be to provide the sanitation of apps as a web service.

In a different light, the ability to easily instrument Android apps is not limited to improvement of security policies. This approach can be used in a variety of situations; almost any behavior can be implemented if an appropriate aspect is written.

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