Systems and Internet Infrastructure Security

Network and Security Research Center
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Understanding Android's Security Framework

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Tutorial

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Telecommunications Nets.

- The telecommunications industry is in a period of transition to open handsets, open/augmented services and high-speed data.
  - Openmoko
  - LiMo
  - Android

- *Idea*: open platform to application developer ingenuity, will lead to new market drivers and differentiators.

This tutorial

- *We are here to describe the security available in Android*.
- Goals
  - Broadly catalog Android's application architecture
  - Describe how security policy is defined within Android
  - Describe the interfaces used to define policy
  - Best practices for using those interfaces
  - Show some pitfalls leading to insecure applications

- We *not* here to teach you to build Android apps ...
- Follow along at http://siis.cse.psu.edu/android_sec_tutorial.html

What is Android?

- One of the most anticipated smartphone operating systems -- led by Google
  - Complete software stack
  - Open source (Apache v2 license) ... mostly

- Open Handset Alliance
  ... 30+ industrial partners
  - Google, T-Mobile, Sprint, HTC, LG, Motorola, Samsung, Broadcom, Intent, NVIDIA, Qualcomm, and many more.

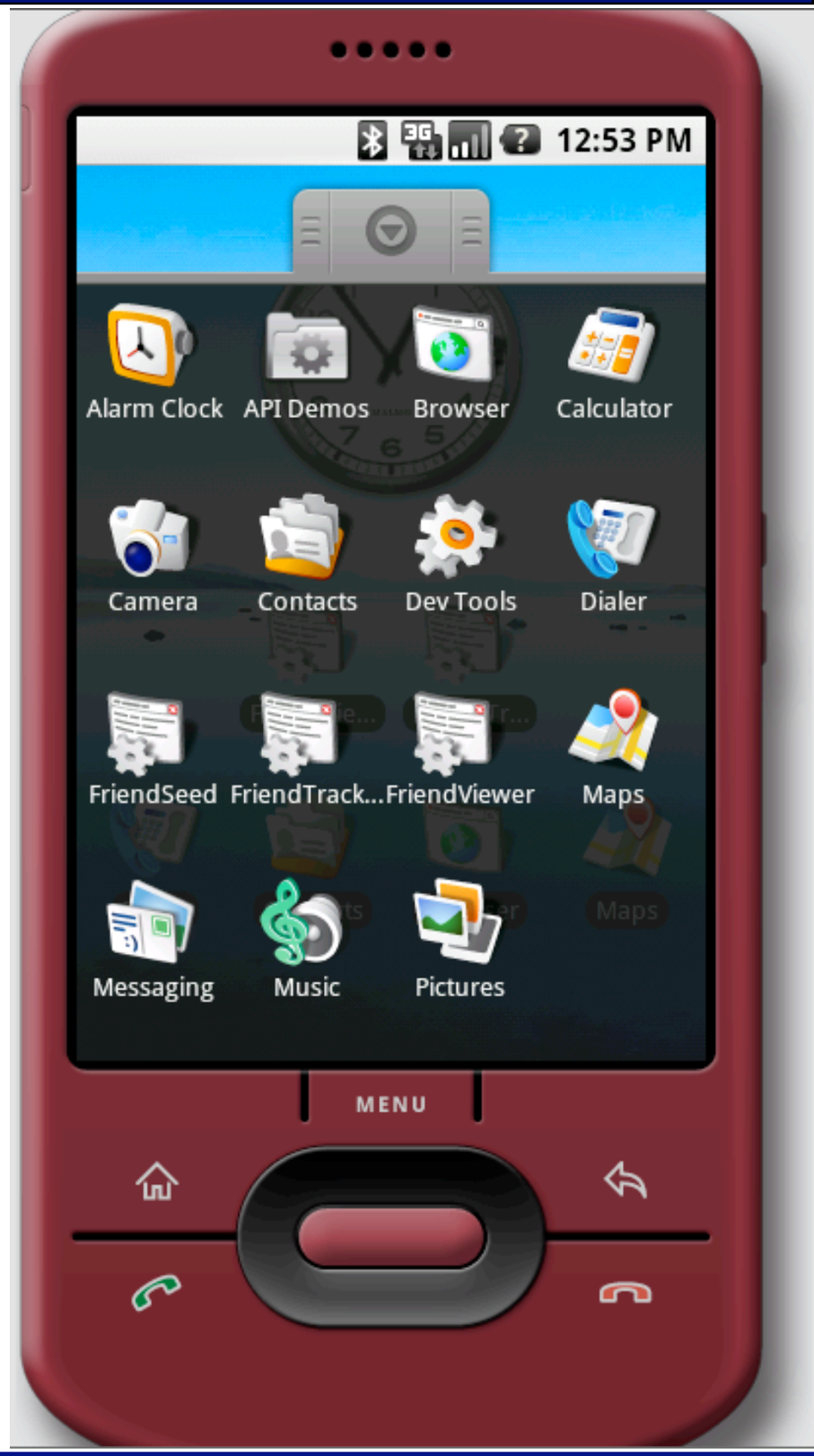
History of Android

- The Open Handset Alliance Vision (from their website)
  - Open interfaces (dialer, SMS, ...)
  - All applications are created equal
  - Breaking down application boundaries
  - Fast & easy application development

- The "Google Phone" rumors go back to at least 2006
  - Google acquired Android, Inc. in July 2005
  - Nov. 2007 - initial SDK release (multiple revs: M3, M5, 0.9, 1.0)
  - Sep. 2008 - T-Mobile announces G1 (available Oct. 2008)
  - Oct. 2008 - Source code released (some Google apps omitted)

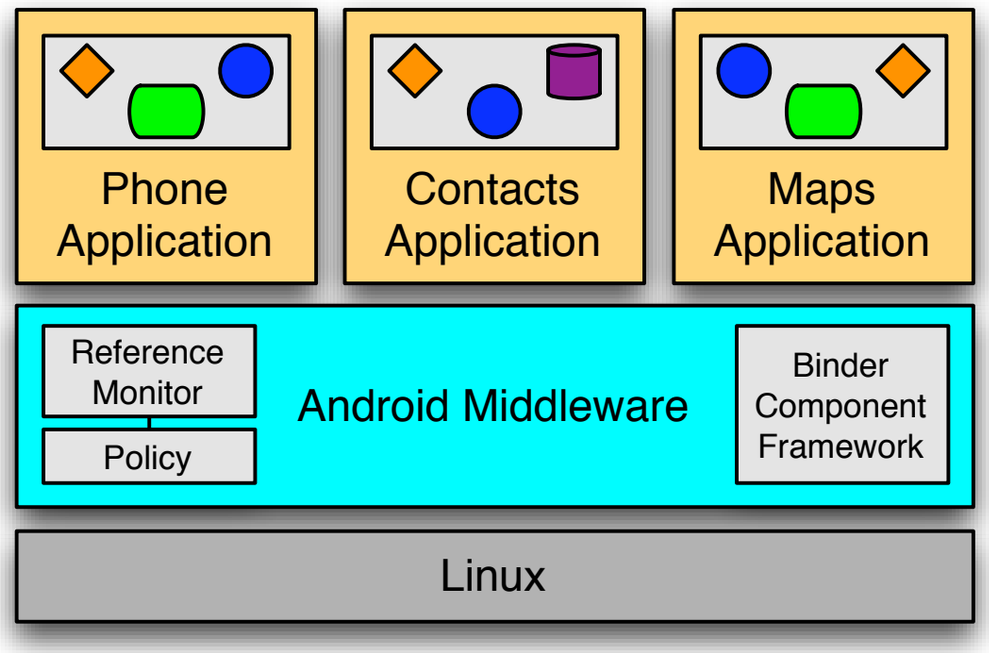
Android Phones

- An Android contains a number of "*applications*"
  - Android comes installed with a number of basic systems tools, e.g., dialer, address book, etc.
  - Developers use the Android API to construct applications.
    - All apps are written in *Java* and executed within a custom Java virtual machine.
  - Each application *package* is contained in a jar file (.apk)
- Applications are *installed* by the user
  - No "app store" required, just build and go.
  - Open access to data and voice services



Architecture

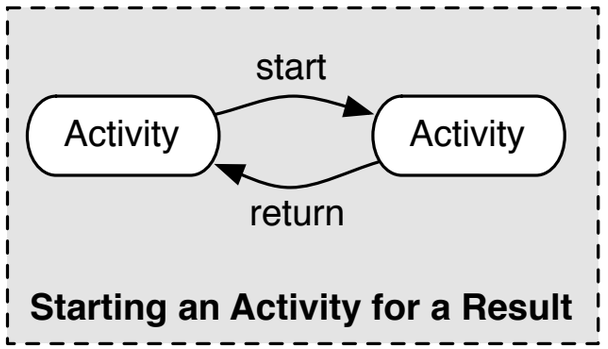
- The Android smartphone operating system is built upon Linux and includes many libraries and a core set of applications.
- The middleware makes it interesting
  - Not focused on UNIX processes
  - Uses the Binder component framework
    - Originally part of BeOS, then enhanced by Palm, now used in Android
  - Applications consist of many *components* of different types
  - Applications interact via components

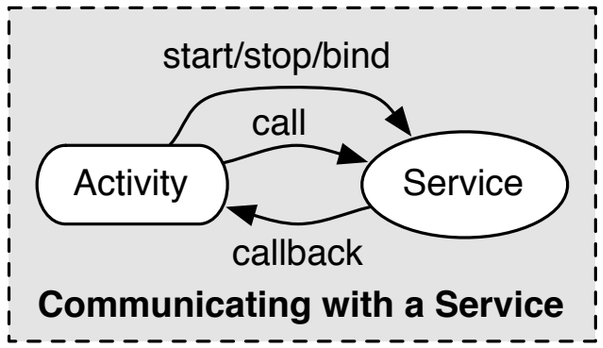


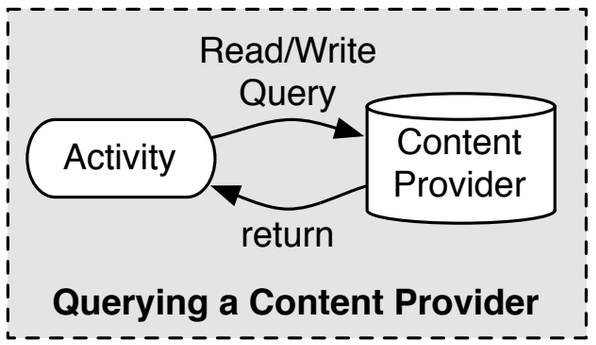
- We focus on security with respect to the component API

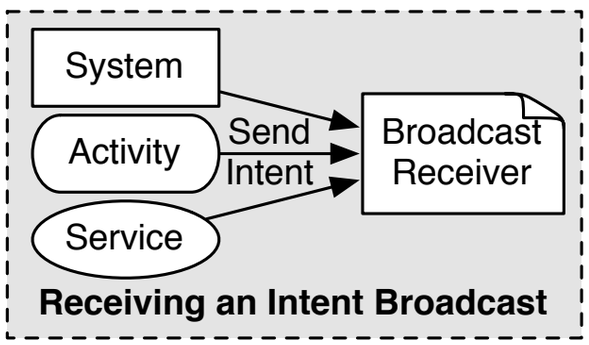
Component Model

- While each application runs as its own UNIX uid, sharing can occur through *application-level* interactions
  - Interactions based on components
  - Different component types
    - Activity
    - Service
    - Content Provider
    - Broadcast Receiver
  - Target component in the same or different application
  - *but first …*









Intents

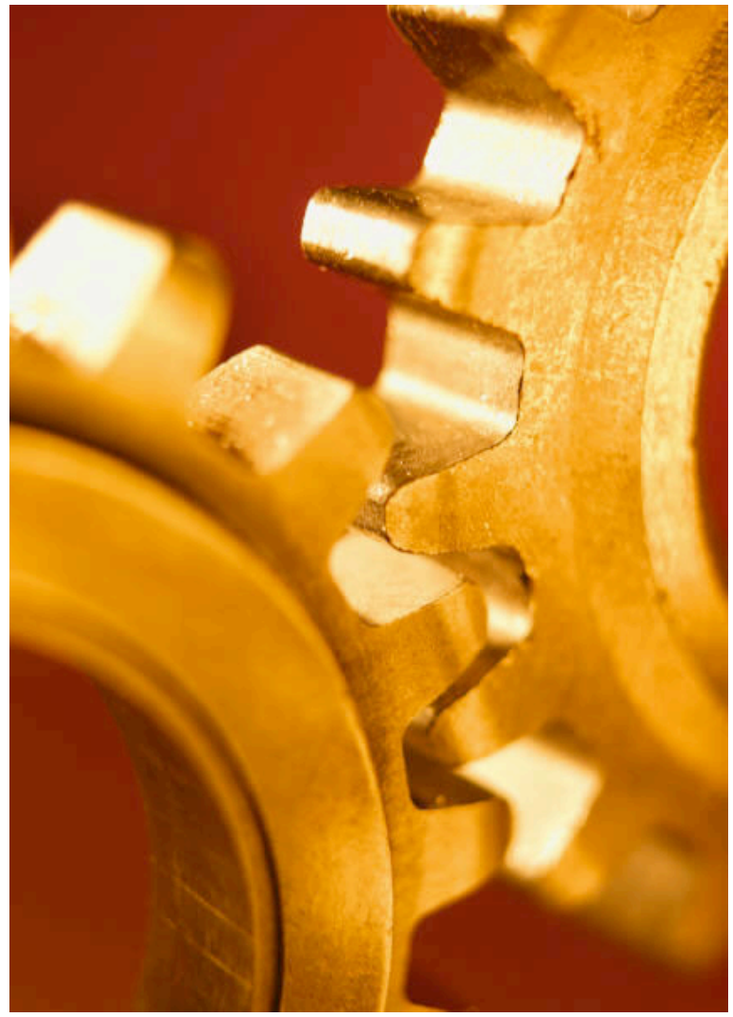
- Intents are objects used as inter-component signaling
  - Starting the user interface for an application
  - Sending a message between components
  - Starting a background service

Activity Component

- The user interface consists of a series of *Activity* components.
- Each Activity is a "screen".
- User actions tell an Activity to *start* another Activity, possibly with the expectation of a *result*.
- The target Activity is not necessarily in the same application.
- Directly or via Intent "action strings".
- Processing stops when another Activity is "on top".

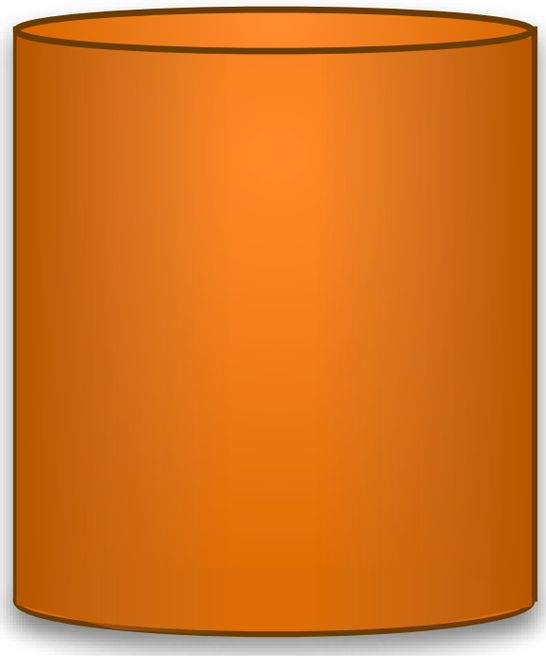
Service Component

- Background processing occurs in *Service* components.
  - Downloading a file, playing music, tracking location, polling, etc.
  - Local vs. Remote Services (process-level distinction)
- Also provides a "service" interface between applications
  - Arbitrary interfaces for data transfer
    - Android Interface Definition Language (AIDL)
  - Register callback methods
  - Core functionality often implemented as Service components
    - e.g., Location API, Alarm service
- Multiple interfaces
  - Control: start, stop
  - Method invocation: bind



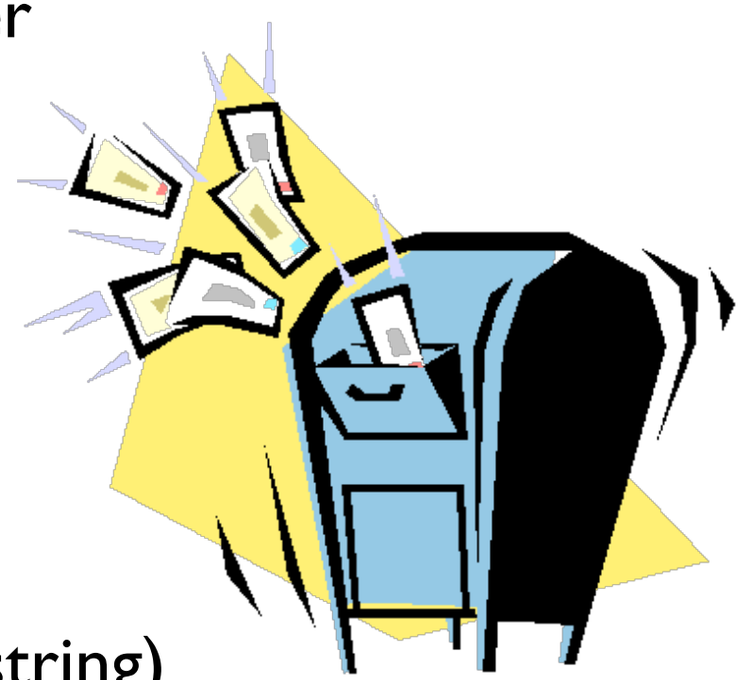
Content Provider Component

- *Content Provider* components provide a standardized interface for sharing data, i.e., content (between applications).
- Models content in a relational DB
  - Users of Content Providers can perform queries equivalent to SELECT, UPDATE, INSERT, DELETE
  - Works well when content is tabular
  - Also works as means of addressing "files"
- URI addressing scheme
  - `content://<authority>/<table>/[<id>]`
  - `content://contacts/people/10`



Broadcast Receiver Component

- *Broadcast Receiver* components act as specialized event *Intent* handlers (also think of as a message mailbox).
- Broadcast Receiver components "*subscribe*" to specific action strings (possibly multiple)
  - action strings are defined by the system or developer
  - component is automatically called by the system
- Recall that Android provides automatic Activity resolution using "action strings".
  - The action string was assigned to an *Intent* object
  - Sender can specify component recipient (no action string)



The Android Manifest

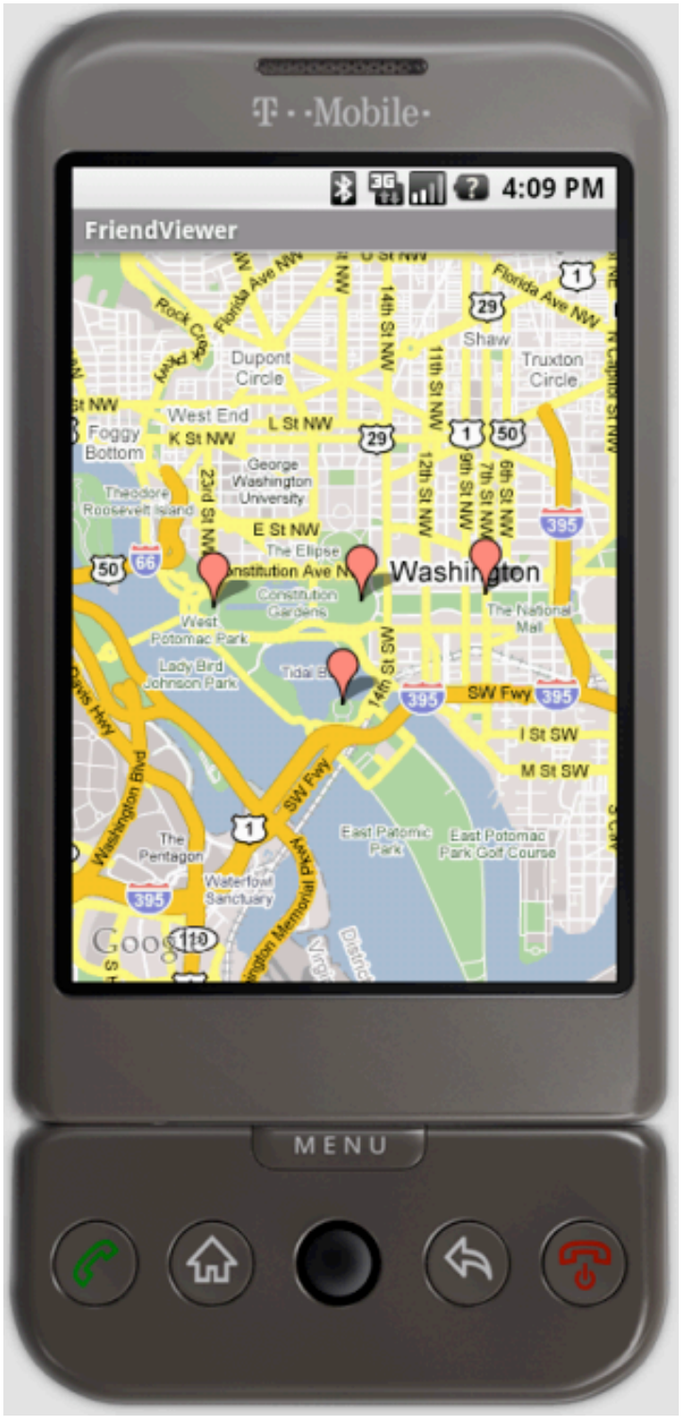
- Manifest files are the technique for describing the contents of an application *package* (i.e., resource file)
- Each Android application has a special `AndroidManifest.xml` file (included in the .apk package)
  - describes the contained components
    - components cannot execute unless they are listed
  - specifies rules for "auto-resolution"
  - specifies access rules
  - describes runtime dependencies
  - optional runtime libraries
  - required system permissions

Manifest Specification

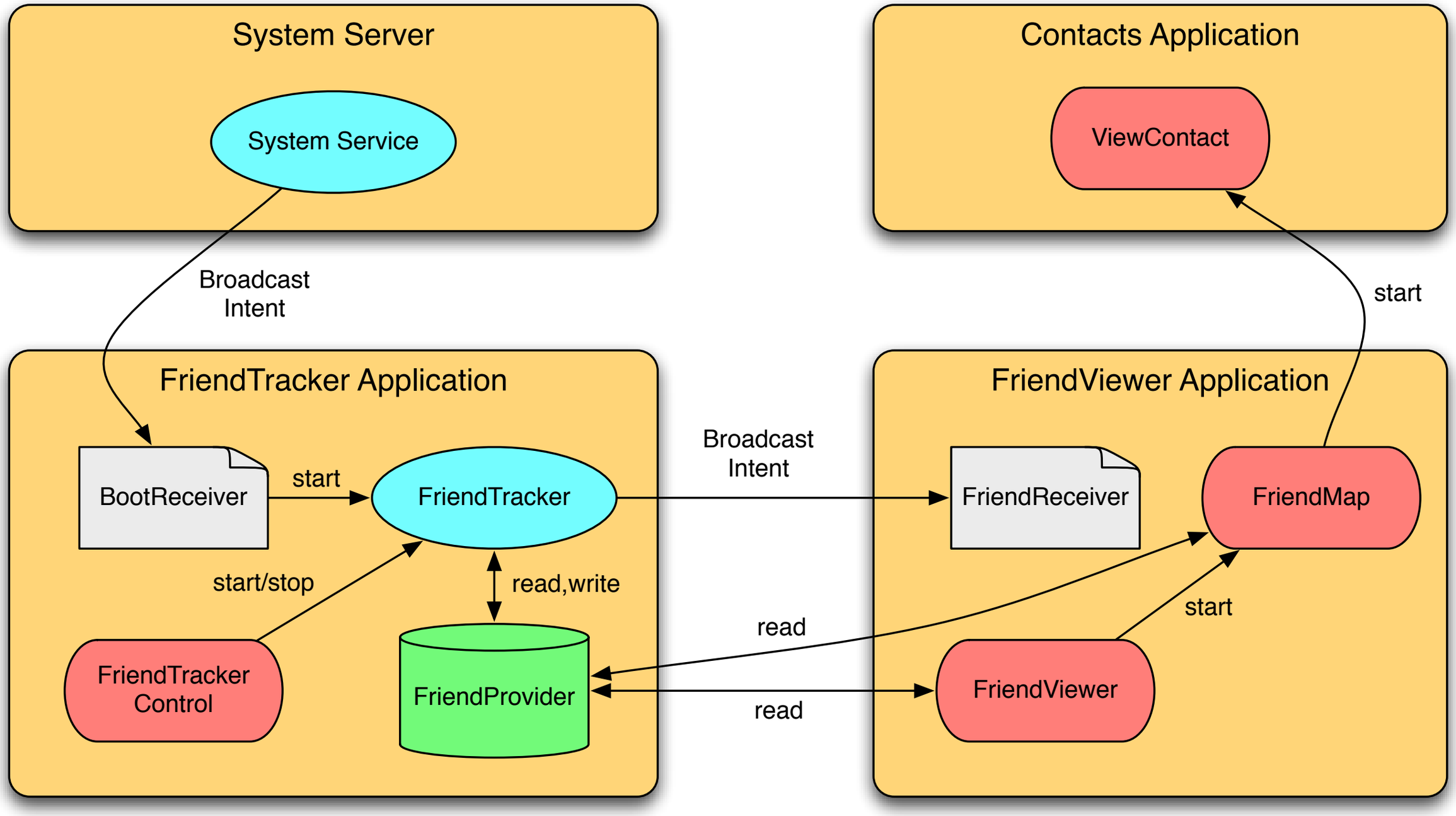
```xml
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
      package="org.siislab.tutorial.friendtracker"
      android:versionCode="1"
      android:versionName="1.0.0">
    <application android:icon="@drawable/icon" android:label="@string/app_name">
        <activity android:name=".FriendTrackerControl"
                  android:label="@string/app_name">
            <intent-filter>
                <action android:name="android.intent.action.MAIN" />
                <category android:name="android.intent.category.LAUNCHER" />
            </intent-filter>
        </activity>
        <provider android:authorities="friends"
              android:name="FriendProvider"
              android:writePermission="org.siislab.tutorial.permission.WRITE_FRIENDS"
              android:readPermission="org.siislab.tutorial.permission.READ_FRIENDS">
        </provider>
        <service android:name="FriendTracker" android:process=":remote"
              android:permission="org.siislab.tutorial.permission.FRIEND_SERVICE">
        </service>
        <receiver android:name="BootReceiver">
            <intent-filter>
                <action android:name="android.intent.action.BOOT_COMPLETED"></action>
            </intent-filter>
        </receiver>
    </application>

    <!--  Define Permissions -->
    <permission android:name="org.siislab.tutorial.permission.READ_FRIENDS"></permission>
    <permission android:name="org.siislab.tutorial.permission.WRITE_FRIENDS"></permission>
    <permission android:name="org.siislab.tutorial.permission.FRIEND_SERVICE"></permission>

    <!--  Uses Permissions -->
    <uses-permission android:name="org.siislab.tutorial.permission.READ_FRIENDS"></uses-permission>
    <uses-permission android:name="org.siislab.tutorial.permission.WRITE_FRIENDS"></uses-permission>
    <uses-permission android:name="org.siislab.tutorial.permission.FRIEND_SERVICE"></uses-permission>

    <uses-permission android:name="android.permission.RECEIVE_BOOT_COMPLETED"></uses-permission>
    <uses-permission android:name="android.permission.READ_CONTACTS"></uses-permission>
    <uses-permission android:name="android.permission.ACCESS_FINE_LOCATION"></uses-permission>
</manifest>
```

Example Applications

- FriendTracker Application
  - *FriendTracker* Service to poll for friend locations
    - Broadcasts an Intent when near a friend
  - *FriendProvider* Content Provider to store location of friends
    - Cross references friends with system Contacts Provider
  - *FriendTrackerControl* Activity to start and stop the Service
  - *BootReceiver* Broadcast Receiver to start the service on boot
- FriendViewer Application
  - *FriendViewer* Activity to display list of friend locations
  - *FriendMap* Activity to show friends on a map (on right)
  - *FriendReceiver* Broadcast Receiver to display when near
- Available from http://siis.cse.psu.edu/android_sec_tutorial.html



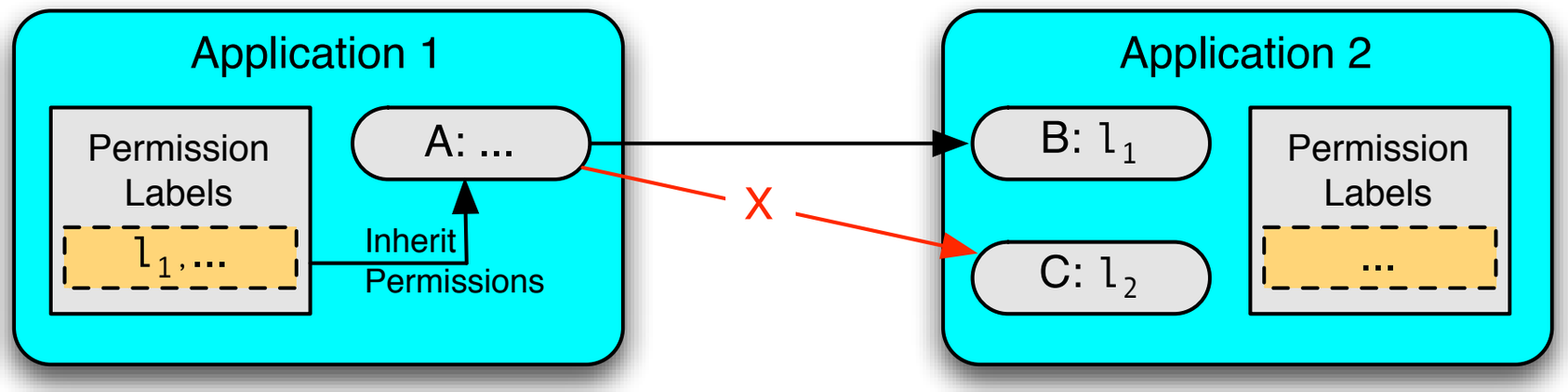
Component Interaction



Defining Security Policy

- Android focuses on *Inter Component Communication* (ICC)
- The Android manifest file allows developers to define an access control policy for access to components
  - Each component can be assigned an access *permission label*
  - Each application requests a list of permission labels (fixed at install)

- Android's security model boils down to the following:



- However, there are a number of exceptions ...

Public and Private Components

- *Exception: Components can be public or private.*
  - Default is dependent on "intent-filter" rules
  - The manifest schema defines an "*exported*" attribute
- *Why:* Protect internal components
  - Especially useful if a "sub-Activity" returns a result
  - e.g., FriendMap Activity in our example

```
<activity android:name="FriendMap" android:exported="false"></activity>
```

- *Implication:* Components may unknowingly be (or become) accessible to other applications.
- *Best Practice:* Always set the "exported" attribute.

Implicitly Open Components

- *Exception*: *If the manifest file does not specify an access permission on a public component, any component in any application can access it.*
- *Why*: Some components should provide "global" access
  - e.g., the main Activity for an Application
  - Permissions are assigned at install-time
- *Implication*: Unprivileged applications have access
  - e.g., FriendReceiver in our example (spoof notification)
- *Best Practice*: Components without access permissions should be exceptional cases, and inputs *must* be scrutinized (consider splitting components).

Implicitly Open Components

- *Excepti* ...ss *permiss* ...ny *applica*
- *Why*: S... ...cess
  - e.g., ...
  - Perm...

```
<activity android:name=".FriendViewer"
          android:label="@string/app_name">
    <intent-filter>
        <action android:name="android.intent.action.MAIN" />
        <category android:name="android.intent.category.LAUNCHER" />
    </intent-filter>
</activity>


<receiver android:name="FriendReceiver"
    android:permission="org.siislab.tutorial.permission.BROADCAST_FRIEND_NEAR">
    <intent-filter>
        <action android:name="org.siislab.tutorial.action.FRIEND_NEAR"></action>
    </intent-filter>
</receiver>
```

- *Implication*: Unprivileged applications have access
  - e.g., FriendReceiver in our example (spoof notification)
- *Best Practice*: Components without access permissions should be exceptional cases, and inputs *must* be scrutinized (consider splitting components).

Intent Broadcast Permissions

- *Exception:The code broadcasting an Intent can set an access permission restricting which Broadcast Receivers can access the Intent.*
- *Why*: Define what applications can read broadcasts
  - e.g., the FRIEND_NEAR message in our example
- *Implication*: If no permission label is set on a broadcast, any unprivileged application can read it.
- *Best Practice*: Always specify an access permission on Intent broadcasts (unless explicit destination).

Intent Broadcast Permissions

- *Exception*: *The code broadcasting an Intent can set an access permission restricting which Broadcast Receivers can acc*
- *Why*: D oadcasts
  - e.g., th

```
// Notify any receivers
if (location.distanceTo(floc) <= mDistThreshold) {
    Intent i = new Intent(ACTION_FRIEND_NEAR);
    i.putExtra(FriendContent.Location._ID,
            c.getString(c.getColumnIndex(FriendContent.Location._ID)));
    i.putExtra(FriendContent.Location.NICK,
            c.getString(c.getColumnIndex(FriendContent.Location.NICK)));
    i.putExtra(FriendContent.Location.CONTACTS_ID,
            c.getString(c.getColumnIndex(FriendContent.Location.CONTACTS_ID)));
    sendBroadcast(i, "org.siislab.tutorial.permission.FRIEND_NEAR");
}
```

- *Implication*: If no permission label is set on a broadcast, any unprivileged application can read it.
- *Best Practice*: Always specify an access permission on Intent broadcasts (unless explicit destination).

Pending Intents

- *Exception:* PendingIntent objects allow another application to "finish" an operation for you via RPC.
  - Introduced in the v0.9 SDK release (August 2008)
  - Execution occurs in the originating application's "process" space
- *Why*: Allows external applications to send to private components
  - Used in a number of system APIs (Alarm, Location, Notification)
  - e.g., timer in FriendTracker Service
- *Implication*: The remote application can fill in unspecified values.
  - May influence the destination and/or data integrity
  - Allows a form of delegation
- *Best Practice*: Only use Pending Intents as "delayed callbacks" to private Broadcast Receivers/Activities and always fully specify the Intent destination.

Pending Intents

- *Exceptior* ation to "finish" a
  - Introdu
  - Execut " space
- *Why*: Allc ponents
  - Used i ication)
  - e.g., tin

```
private void scheduleTracking() {
    AlarmManager am = (AlarmManager)getSystemService(Context.ALARM_SERVICE);
    Intent i = new Intent();
    i.setClass(this, FriendTracker.class);
    i.setAction(ACTION_POLL_LOCATIONS);
    PendingIntent pi = PendingIntent.getService(this, 0, i, 0);
    am.set(AlarmManager.ELAPSED_REALTIME_WAKEUP,
            SystemClock.elapsedRealtime() + POLL_INTERVAL, pi);
}

private void cancelTracking() {
    AlarmManager am = (AlarmManager)getSystemService(Context.ALARM_SERVICE);
    Intent i = new Intent();
    i.setClass(this, FriendTracker.class);
    i.setAction(ACTION_POLL_LOCATIONS);
    PendingIntent pi = PendingIntent.getService(this, 0, i, 0);
    am.cancel(pi);
}
```

- *Implication*: The remote application can fill in unspecified values.
  - May influence the destination and/or data integrity
  - Allows a form of delegation
- *Best Practice*: Only use Pending Intents as "delayed callbacks" to private Broadcast Receivers/Activities and always fully specify the Intent destination.

Content Provider Permissions

- *Exception: Content Providers have two additional security features*
  - Separate "read" and "write" access permission labels
  - URI permissions allow record level delegation (added Sep 2008)
- *Why*: Provide control over application data
  - e.g., FriendProvider uses read and write permissions
- *Implication*: Content sharing need not be all or nothing
  - URI permissions allow delegation (must be allowed by Provider)
- *Best Practice*: Always define separate read and write permissions.
  - Allow URI permissions when necessary

Content Provider Permissions

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```
<provider android:authorities="friends"
      android:name="FriendProvider"
      android:readPermission="org.siislab.tutorial.permission.READ_FRIENDS"
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</provider>
```

- *Implication*: Content sharing need not be all or nothing
  - URI permissions allow delegation (must be allowed by Provider)
- *Best Practice*: Always define separate read and write permissions.
  - Allow URI permissions when necessary

Service Hooks

- *Exception: A component (e.g., Service) may arbitrarily invoke the checkPermission() method to enforce ICC.*
- *Why:* Allows Services to differentiate access to specific methods.
  - e.g., .addNick() method of IFriendTracker
- *Implication:* The application developer can add reference monitor hooks
- *Best Practice:* Use checkPermission() to mediate "administrative" operations.
  - Alternatively, create separate Services

Service Hooks

- *Except* … *nvoke* *the che*
- *Why*: A… *cific* metho…
  - e.g.,

```
private final IFriendTracker.Stub mBinder = new IFriendTracker.Stub() {
    public boolean isTracking() {
        return mTracking;
    }

    public boolean addNickname(String nick, int contactId) {
        if (FriendTracker.this.checkCallingPermission(PERMISSION_FRIEND_SERVICE_ADD)
                != PackageManager.PERMISSION_GRANTED) {
            throw new SecurityException("Requires " + PERMISSION_FRIEND_SERVICE_ADD);
        }
        ContentResolver r = FriendTracker.this.getContentResolver();
        ContentValues values = new ContentValues();
        values.put(FriendContent.Location.NICK, nick);
        values.put(FriendContent.Location.CONTACTS_ID, contactId);
        Uri uri = r.insert(FriendContent.Location.CONTENT_URI, values);
        return (uri == null ? false : true);
    }
};
```

- *Implication*: The application developer can add reference monitor hooks
- *Best Practice*: Use checkPermission() to mediate "administrative" operations.
  - Alternatively, create separate Services

Protected APIs

- *Exception: The system uses permission labels to mediate access to certain resource APIs*
- *Why:* The system needs to protect network and hardware resources
  - e.g., Applications request the `android.permission.INTERNET` label to make network connections.

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

- *Implication:* Allows the system or a user to assess how "dangerous" an application may be.
- *Best Practices:* Judiciously request permissions for protected APIs

Permission Protection Levels

- *Exception: Permission requests are not always granted*
  - Permissions can be:
    - normal - always granted
    - dangerous - requires user approval
    - signature - matching signature key
    - signature or system - same as signature, but also system apps
- *Why*: Malicious applications may request harmful permissions
  - e.g., privacy implications of receiving FRIEND_NEAR
- *Implication*: Users may not understand implications when explicitly granting permissions.
- *Best Practice*: Use signature permissions for application "suites" and dangerous permissions otherwise
  - Include informative descriptions

Permission Protection Levels

- *Exception*: *Permission requests are not always granted*
  - Permissi
    - normal
    - dangerc
    - signatur
    - signatur

```
<permission android:name="org.siislab.tutorial.permission.FRIEND_NEAR"
    android:label="@string/permlab_friendNear"
    android:description="@string/permdesc_friendNear"
    android:protectionLevel="dangerous">
</permission>


<string name="permlab_friendNear">receive friend near notification</string>
<string name="permdesc_friendNear">Allows an application to receive a
    notification when a friend is near. Malicious applications may
    monitor your proximity to your friends</string>
```

s

- *Why*: Malicious applications may request harmful permissions
  - e.g., privacy implications of receiving FRIEND_NEAR
- *Implication*: Users may not understand implications when explicitly granting permissions.
- *Best Practice*: Use signature permissions for application "suites" and dangerous permissions otherwise
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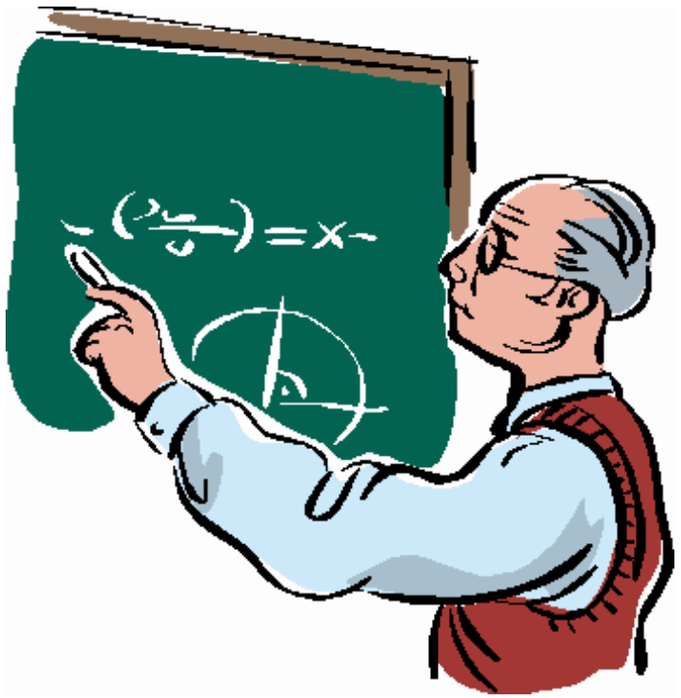
Lessons in Defining Policy

- Relatively straightforward model with policy defined in the manifest file ... but many exceptions
- Some thought is needed to avoid ...
  - "Spoofing" Intent messages (FriendReceiver)
  - Privacy leaks (e.g., FRIEND_NEAR broadcast)
- The policy expands into the code
  - Broadcast permissions, checkPermission(), etc
- Keeping malicious applications from acquiring permissions is tricky



Install-time Verification

- *Deficiency*: Android does not have a way to holistically evaluate system and application policy or specify security goals
  - For example, to evaluate if the system and installed applications fulfill some security requirement
  - *Will granting a permission break the phone's security?*

- Kirin - enhanced installer we have been developing
  - Extracts policy from the manifest files of all applications
  - Uses Prolog to generate automated proofs of compliance of provided "policy invariants"
  - Evaluation must only be performed at install-time, and therefore does not impact runtime performance

Summary

- It is highly likely that Android is going to be installed many millions of cell phones within the next 12 months.
  - If you are building applications, you need to be aware of what access other applications are going to be able to do to your user ...
  - *Take away*: *be defensive*!
- Android security is complex beast, and this tutorial is a first step towards understanding and dealing with it.
- If you want to learn more, consult Android documentation (the security model description is lacking),
- Recommendation: http://code.google.com/android/intro/

Thank you

Presentation Slides and Code Examples
http://siis.cse.psu.edu/android_sec_tutorial.html

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The Pennsylvania State University
http://siis.cse.psu.edu

Google Android SDK and Documentation
http://code.google.com/android

Android Platform Source Code
http://source.android.com