On the Static Analysis of Hybrid Mobile Apps

A Report on the State of Apache Cordova Nation

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Abstract

Developing mobile applications is a challenging business: developers need to support multiple platforms and, at the same time, need to cope with limited resources, as the revenue generated by an average app is rather small. This results in an increasing use of cross-platform development frameworks that allow developing an app once and offering it on multiple mobile platforms such as Android, iOS, or Windows.
Apache Cordova is a popular framework for developing multi-platform apps. Cordova combines HTML5 and JavaScript with native application code. Combining web and native technologies creates new security challenges as, e.g., an XSS attacker becomes more powerful.
In this paper, we present a novel approach for statically analysing the foreign language calls. We evaluate our approach by analysing the top Cordova apps from Google Play. Moreover, we report on the current state of the overall quality and security of Cordova apps.
Keywords: static program analysis, static application security testing, Android, Cordova, hybrid mobile apps.

Outline

1 Motivation: Hybrid Mobile Apps and their Security Challenges

2 Real World Cordova Usage

3 Static Analysis for Hybrid Apps: Building a Unified Call Graph

4 Quality of the Unified Call Graph

5 Conclusions

What is a Hybrid App?

Native, HTML5, or hybrid

Native apps

Java \ Swift \ C#

- Developed for a specific platform
- All features available

Web apps

HTML5 and JS

- Hosted on server, all platforms
- No access to device features

Platform-specific

Platform-independent

What is a Hybrid App?

Native, HTML5, or hybrid

Native apps

Java \ Swift \ C#

- Developed for a specific platform
- All features available

Hybrid apps

HTML5, JS, and native

- Build once, run everywhere
- Access to device features through plugins

Web apps

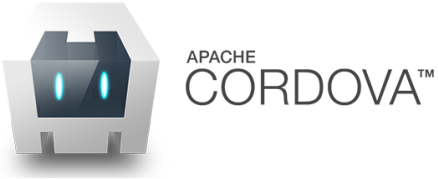
HTML5 and JS

- Hosted on server, all platforms
- No access to device features

Platform-specific

Platform-independent

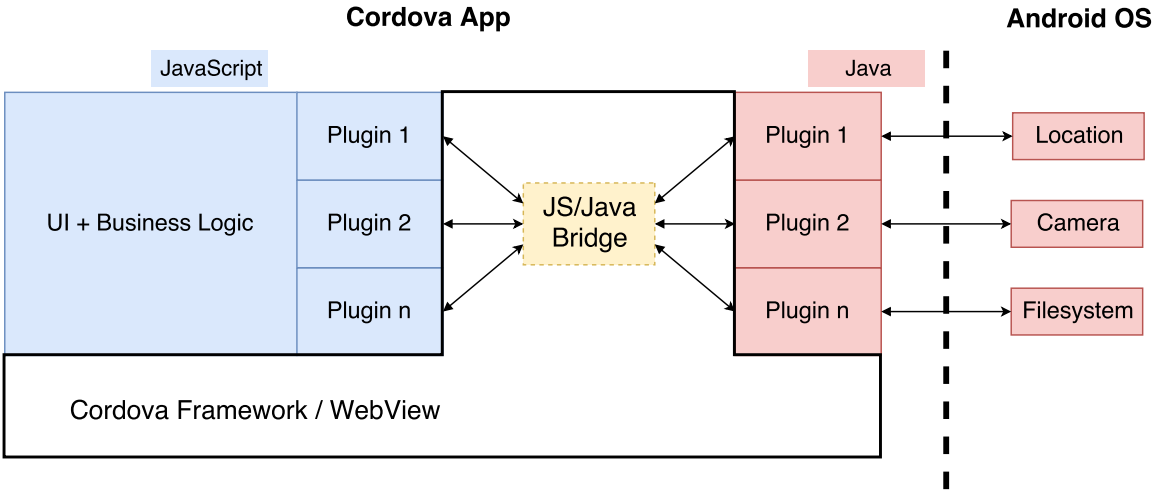
Why Apache Cordova?



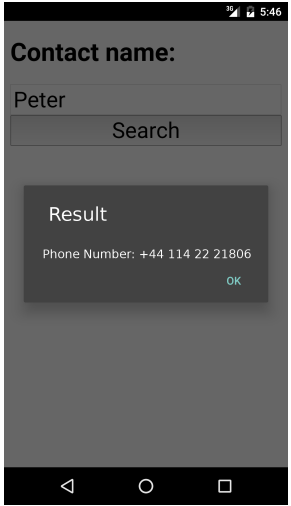
https://cordova.apache.org/

- Apache Cordova is most popular hybrid app framework
- Open source
- Many companies offer Apache Cordova plus commercial plugins (e.g., Adobe PhoneGap or SAP Kapsel)

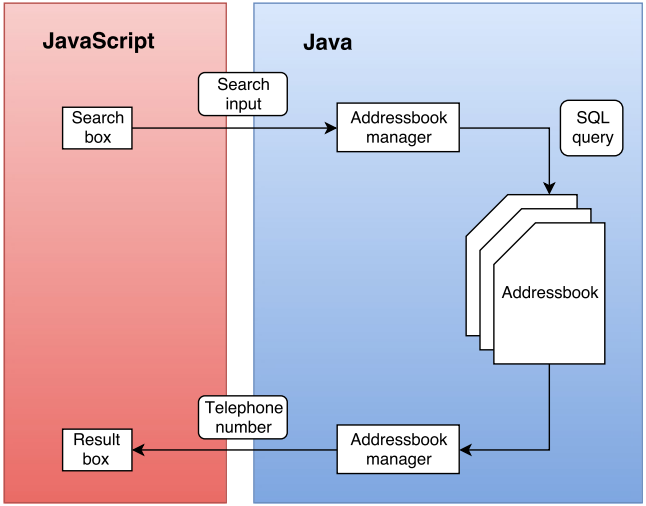
The Apache Cordova Framework for Android



Example app


5:46
Contact name:
Peter
Search
Result
Phone Number: +44 114 22 21806
OK

Technical view



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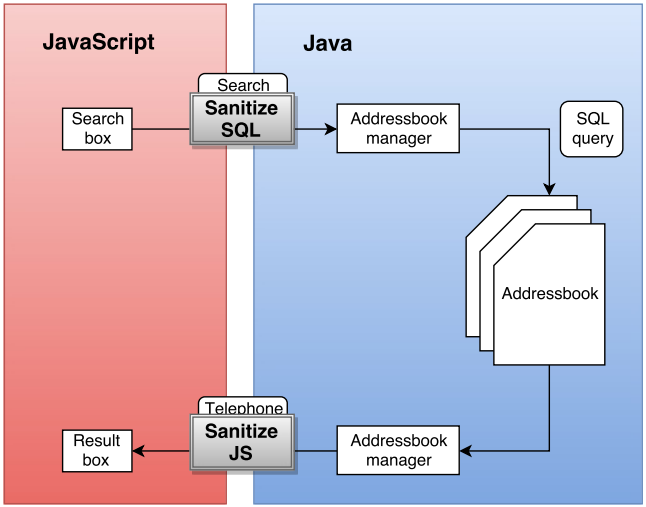

Example: Get Phone Number

```
function showPhoneNumber(name) {
    var successCallback = function(contact) {
        alert("Phone number: " + contacts.phone);
    }
    var failureCallback = ...
    cordova.exec(successCallback, failureCallback, "ContactsPlugin", "find", [{"name" : name}]);
}
```

```
class ContactsPlugin extends CordovaPlugin {
    boolean execute(String action, CordovaArgs args, CallbackContext callbackContext) {
        if ("find".equals(action)) {
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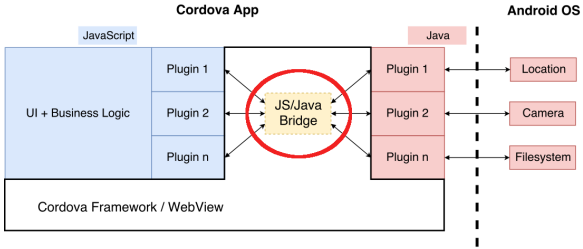
First security assessment

- Problem: JS/Java Bridge is vulnerable to injection attacks
- For regular apps: Static Application Security Testing (SAST)
- But: No support for cross-language analysis
- **Our goal:**
  Provide basis (call graph) to apply SAST to hybrid mobile apps



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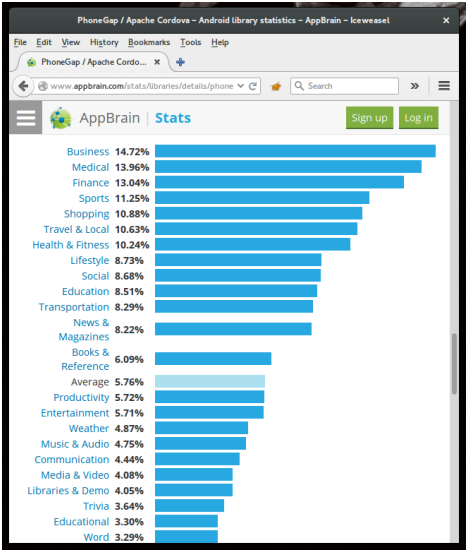
What we were interested in

Main goals:

- Understand the use of Cordova
- Learn requirements for Cordova security testing tools

Looking for answers for questions like

- How many apps are using Cordova?
- How is Cordova used by app developers?
- Are cross-language calls common or not?



Test sets

Selection of apps

- all apps that ship Cordova from Google's Top 1000:
  - 100 apps ship Cordova plugins
  - only 50 actually use Cordova (5%)
- three selected apps from SAP (using SAP Kapsel)
- one artificial test app (to test our tool)

Manual analysis of 8 apps (including one from SAP)

- to understand the use of Cordova
- to assess the quality of our automated analysis

What we have learned: plugin use

Plugins are used for

- accessing device information
- showing native dialog boxes and splash screens
- accessing network information
- accessing the file storage
- accessing the camera
- . . .

But: Many different versions and some even modified!

Plugin	
device	52%
inappbrowser	50%
dialogs	40%
splashscreen	36%
network-information	28%
file	28%
console	24%
camera	22%
statusbar	22%
PushPlugin	22%

What we have learned: app size

App size:

- mobile apps are not always small
- SAP apps seem to be larger than the average

Exceptional apps:

- No HTML/JS in APK
- Ship Cordova, but do not use it

App	Category	JS [kLoC]	Java [kLoC]
sap_{01}	Finance	35.5	17.0
sap_{02}	Business	345.3	53.5
sap_{03}	Business	572.3	135.8
app_{01}	Finance	26.3	17.8
app_{02}	Finance	11.2	16.8
app_{03}	Social	4.6	103.7
app_{04}	Business	37.5	16.8
app_{05}	Finance	20.0	44.8
app_{06}	Finance	30.4	24.3
app_{07}	Travel & Local	129.0	304.0
app_{08}	Entertainment	36.7	23.0
app_{09}	Lifestyle	36.3	44.7
app_{10}	Finance	43.7	18.4
app_{11}	Business	14.0	438.9
⋮	⋮	⋮	⋮

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Challenges

Based on the examined apps:

- Cordova relies heavily on dynamic mechanisms, both on JavaScript and Java side
- Developers modify their plugins and sometimes implement their own

Deep framework analysis

- Closest to the actual program
- But: Framework very expensive

Modelling framework

- Models the Cordova framework
- Analyses plugins

Modelling plugins

- Models both framework and plugins
- Analyses only UI and business logic part
- But: Developers can write own plugins

Our approach:

analyze plugins, but model the Cordova framework

- First build call graphs of Java and JavaScript separatly
- Connect them using four heuristics that exploit frequent coding patterns:
  - ConvertModules
  - ReplaceCordovaExec
  - FilterJavaCallSites
  - FilterJSFrameworks
- **Result:**
  Unified Call Graph

ConvertModules

```
define("com.foo.contacts", function(require, exports, module) {
    exports.find = function(successCallback, name) {
        cordova.exec(successCallback, null, "ContactsPlugin", "find", [{"name" : name}]);
    }
});
...
var successCallback = function(contact) {
    alert("Phone number: " + contacts.phone);
}
plugins.contacts.find(successCallback, "Peter");
```

Problem:

- Not all callback functions are defined within the plugin
- Difficult to track callback functions from app code

Solution:

- Substitute dynamic mechanism with unique, global variable

ConvertModules

```
define("com.foo.contacts", function(require, exports, module) {
    plugins.contacts.find = function(successCallback, name) {
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});
...
var successCallback = function(contact) {
    alert("Phone number: " + contacts.phone);
}
plugins.contacts.find(successCallback, "Peter");
```

Problem:

- Not all callback functions are defined within the plugin
- Difficult to track callback functions from app code

Solution:

- Substitute dynamic mechanism with unique, global variable

ConvertModules: Results

- Most useful for
  - small plugins
  - more precise analysis
- Allows finding of callback functions in app code
- Less errors due to less ambiguity of dynamic mechanism

ReplaceCordovaExec

```
function showPhoneNumber(name) {
    var successCallback = function(contact) {
        alert("Phone number: "+contacts.phone);
    }

    cordova.exec(successCallback, null, "ContactsPlugin", "find", [{"name" : name}]);
}
```

Problem:

- Callback call sites are hard to find
- No context-sensitivity

Solution:

- Stub the exec method

ReplaceCordovaExec

```
function showPhoneNumber(name) {
    var successCallback = function(contact) {
        alert("Phone number: "+contacts.phone);
    }
    function stub1(succ, fail) {
        succ(null);
        fail(null);
    }
    stub1(successCallback, null, "ContactsPlugin", "find", [{"name" : name}]);
}
```

Problem:

- Callback call sites are hard to find
- No context-sensitivity

Solution:

- Stub the exec method

ReplaceCordovaExec: Results

- Neccessary to find any Java to JavaScript calls
- Most apps use exec to communicate, only some bypass it
- Inexpensive way to get context-sensitivity where it is needed the most

FilterJavaCallSites

```
class ContactsPlugin extends CordovaPlugin {
    boolean execute(String action, CordovaArgs args, CallbackContext callbackContext) {
        if ("find".equals(action)) {
            String name = args.get(0).name;
            find(name, callbackContext);
        } else if ("create".equals(action)) ...
    }
    void find(String name, CallbackContext callbackContext) {
        Contact contact = query("SELECT ... where name=" + name);
        callbackContext.success(contact);
    }
}
```

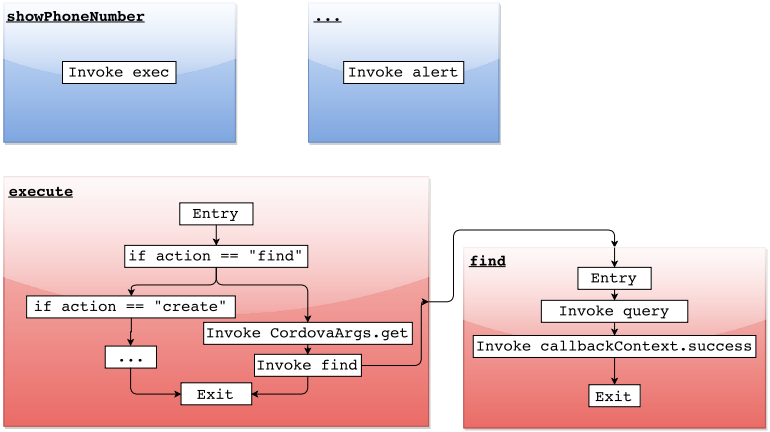
Problem:

- How to determine the targets of the `callbackContext` calls?
- Can we use the pattern of the `action` usage?

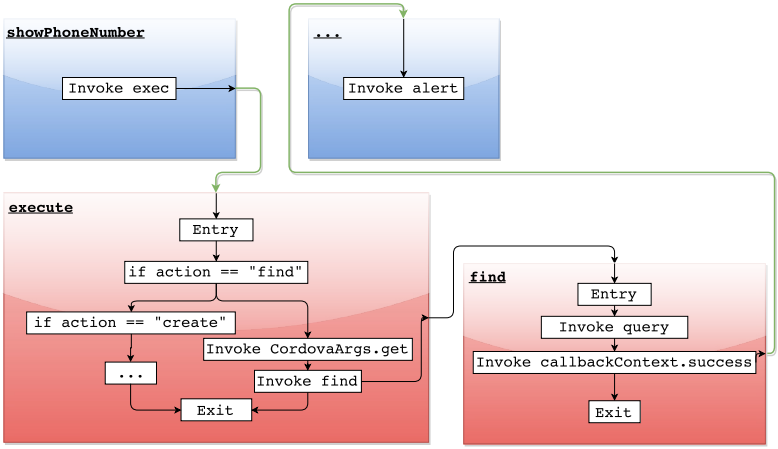
Solution:

- Determine which `callbackContext` calls are reachable

FilterJavaCallSites: details



FilterJavaCallSites: details



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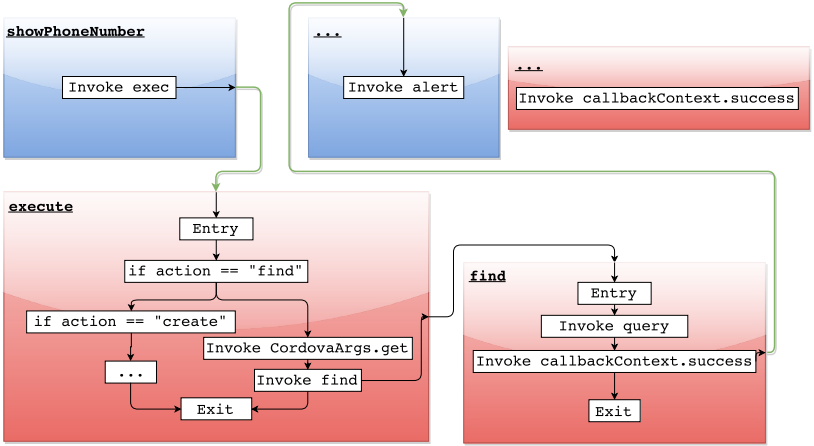

FilterJavaCallSites: results

- Developers all use `action` variable similarly
- Therefore: Many incorrect edges avoided
- But: A few calls from Java to JavaScript are missed now
- Some store the `callbackContext` and call asynchronously

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What we have learned: app size and cross-language calls

Cross-language calls:

- calls from Java to JS: very common
- calls from JS to Java: surprisingly uncommon

App	Category	Java2JS	JS2Java	JS [kLoC]	Java [kLoC]
sap_{01}	Finance	2	12	35.5	17.0
sap_{02}	Business	20814	39	345.3	53.5
sap_{03}	Business	9531	75	572.3	135.8
app_{01}	Finance	9	13	26.3	17.8
app_{02}	Finance	2	10	11.2	16.8
app_{03}	Social	2349	31	4.6	103.7
app_{04}	Business	1	6	37.5	16.8
app_{05}	Finance	6	26	20.0	44.8
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app_{11}	Business	0	0	14.0	438.9
⋮	⋮	⋮	⋮	⋮	⋮

Recall and Precision

- Recall:

$$\frac{\textit{Correctly reported calls}}{\textit{All reported calls}}$$

- Precision:

$$\frac{\textit{Correctly reported calls}}{\textit{Calls actually present}}$$

App	kLoC	kNodes	Plugins	Recall	Precision	Calls
app_{01}	43	9	5	33%	75%	17
app_{02}	27	8	4	100%	66%	13
app_{03}	106	18	8	1%	93%	61
app_{04}	53	14	3	100%	100%	7
app_{05}	64	10	7	33%	66%	29
app_{06}	53	8	12	35%	97%	316
sap_{01}	52	19	6	100%	66%	15
dvhma	17	7	4	100%	100%	15

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Summary

- Hybrid mobile apps are getting more popular
  - they are recommended at SAP
- Hybrid mobile apps are juicy targets
  - E.g., gain access to the app via the JS part . . .
  - . . . and use the app's permissions to steal data
- **Unified Call Graph** is a first step in bringing the full power of SAST to hybrid apps
- Quality largely depends on used call graph builders
- Future work: Data-flow analysis on top of Unified Call Graph

Thank you for your attention!

Any questions or remarks?

Bibliography

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In Juan Caballero and Eric Bodden, editors, *International Symposium on Engineering Secure Software and Systems (ESSoS)*, Lecture Notes in Computer Science. Springer-Verlag, 2016.