(Ab)using foreign VMs: Running Java Card Applets in non-Java Card Virtual Machines

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Outline

● Introduction
  ▶ Java Card
  ▶ Open environment for debugging, testing and rapid prototyping

● Running Java Card Applications in non-Java Card VMs
  ▶ Why do we want this?
  ▶ What issues do we face?
  ▶ Proposed solution

● Conclusion
Java Card Platform

- Java Card Runtime Environment
  - Java Card Virtual Machine
  - Java Card API

- Java specifically designed for smartcards
  - Small footprint designed for tiny devices
    - Limited memory & processing power
  - Limited subset of Java language
    - Reduced set of primitive data types: `boolean, byte, short, int` (optional)
    - Some Java language constructs not supported
    - Most of Java core API not supported
    - No multi-threading
  - Smartcard-specific classes for application life-cycle management, APDU processing, cryptography, ...
Java Card Virtual Machine

- All applications run in one VM
- VM lifetime = smartcard lifetime
  - VM runs from card production until card destruction
  - Code and data storage backed by persistent memory
  - Applications run across power-cycles of the card (from installation until deinstallation)
- Security: application firewalling
  - Strict separation between application contexts
  - Applications cannot access each other’s data (unless explicitly granted permission)
Java Card Applications

- One application consists of one or more applets

- Applet
  - entry-point object
  - life-cycle methods
    - invoked by JCRE
    - `install()`: create and initialize applet instance
    - `select()`: notify applet that it has been selected for command exchange
    - `process()`: forward received command APDU to applet
    - `deselect()`: notify applet that it has been deselected

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Environment for Debugging, Testing and Rapid Prototyping

- Smartcard security prevents in-circuit emulation
  - Dedicated emulator environment necessary

- Emulation of complete run-time environment
  - Complete Java Card API (at least comparable to real cards)
  - Same application life-cycle as with real card

- In-place testing, debugging and prototyping
  - Test and debug in combination with other application components
  - Drop-in replacement for secure element for rapid prototyping
    (→ open but less secure)

- Emulation in Java/Dalvik virtual machine
  - Java Card language = subset of Java
  - Existing VM, existing tools for source-level debugging
  - Same tools as for debugging regular Java/Android applications
Emulator Integration with Android NFC Devices

Android Debugger

Application Layer

Android (Device)

Application using Secure Element

Java Card Applet

Middleware

SEEK/ Open Mobile API

Java Card Emulator

Operating System

Host-based Card Emulation API

NFC Interface

(Ab)using foreign VMs: Running Java Card Applets in non-Java Card Virtual Machines
Issues with Emulation in Java/Dalvik Virtual Machine

- Java Card atomic transaction mechanism
  - Java does not have an atomic transaction mechanism by default
  - Variables/objects involved in transactions cannot easily be rolled-back to a defined boundary

- State of JCRE and applications is not persistent
  - Significant differences between lifetime of Dalvik/Java VM and Java Card VM
  - If emulator environment is terminated (e.g. app closed, device rebooted) the state of the JCRE and all Java Card applets is lost
  - Upon restarting the emulator all applets start at the beginning of their life-cycle

→ Methods for extracting and re-implanting application state necessary!
Goals

● Store and load networks of objects from persistent memory
  ▶ Start at one or more root nodes (Java Card applet instances)
  ▶ No duplication of objects referenced from multiple locations

● Store and load static fields of classes
  ▶ Based on a list of classes or within a package scope

● Java Card applications should be used as-is
  ▶ No modifications to source code should be required
  ▶ No pre- or post-processing of application source code should be required (source-level debug-ability; same code as run on card)

● Should work within typical VMs (e.g. Oracle Java SE VM, Android Dalvik VM)
Existing Methods

- **Java serialization**
  - Serialize/deserialize objects into byte stream
  - Code modifications necessary
  - Serialization can only have one root object
  - Only complete object graph can be serialized/deserialized
**Existing Methods**

- **Aspect-oriented programming (AOP)**
  - Add aspects that intercept read/write access to data
  - Automated pre-/post-processing of program code necessary
  - No source-level debugging of original application

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- **Java Card Application**
- **Aspects**
- **Automated merging**
- **Executed program code**
Existing Methods

- **Object-relational mapping (ORM) / ODMG binding**
  - Map objects to database (relational or object-oriented)
  - Code modifications (annotations, special constructors, getter/setter methods) or automated pre-/post-processing of program code necessary
  - No source-level debugging of original application
Proposed Solution

- Copy object state into serializable state representation
  - Start at defined nodes (applet instances, classes’ static fields)
  - Recursively iterate through objects’ fields using reflection
  - Record list of references
  - Store values of primitive types
  - Record object graph (map fields to an entry in the list of references)

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<td>ObjectState</td>
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<tr>
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<table>
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</table>

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obj : com.mypkg.myclass
field1 : …[]
field2 : short = 42

...
Proposed Solution

- Recreate object graph from object state representation
  - Start at defined node (possible to restore only sub-graphs)
  - Use Objenesis library to instantiate objects without calling their constructor (no special constructors or tagging interfaces necessary)
  - Recursively fill objects’ fields with stored primitive values or restored object references
Proposed Solution

- Store/load object state representation to/from persistent memory
  - State representation designed for easy export to XML and easy import from XML
  - Save to XML file when application is about to close
  - Load and restore from XML file upon start of application

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Save to XML file when application is about to close.
Load and restore from XML file upon start of application.
Conclusion

- Running Java Card applications on standard Java VMs or the Android Dalvik VM permits easy source-level debugging using standard debugger tools
- Problem: Life-cycle of Java Card VM is different from other VMs
  - Applications live in persistent memory
- Created proof of concept to introduce Java Card-style persistence to other Java VMs
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