(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

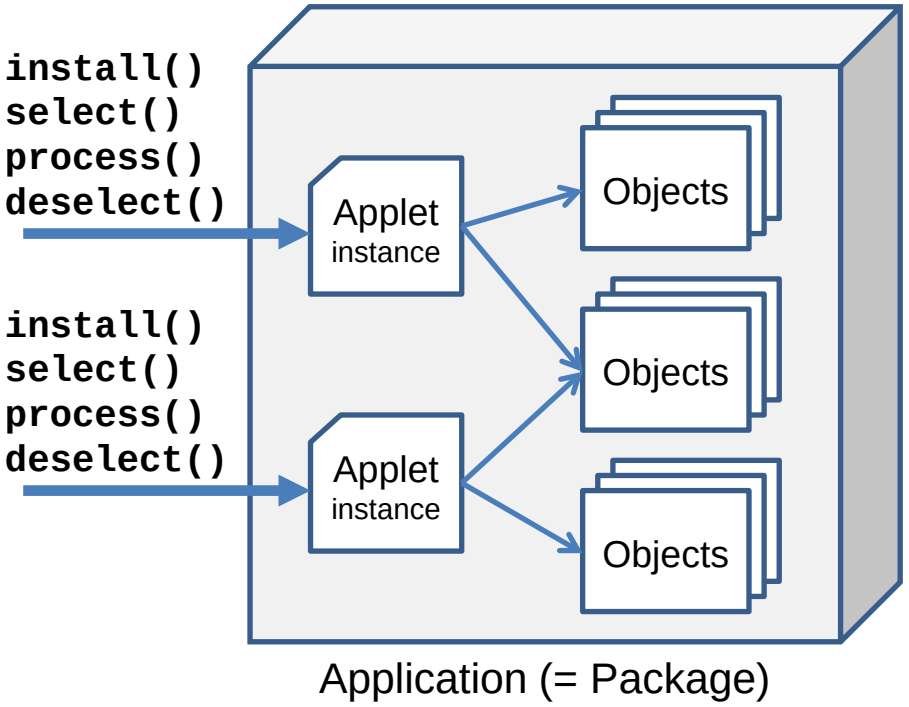
- Java Card Runtime Environment
  - Java Card Virtual Machine
  - Java Card API
- Java specifically designed for smartcards
  - Small footprint designed for tiny devices
    - Limited memory & processing power
  - Limited subset of Java language
    - Reduced set of primitive data types: **`boolean`**, **`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

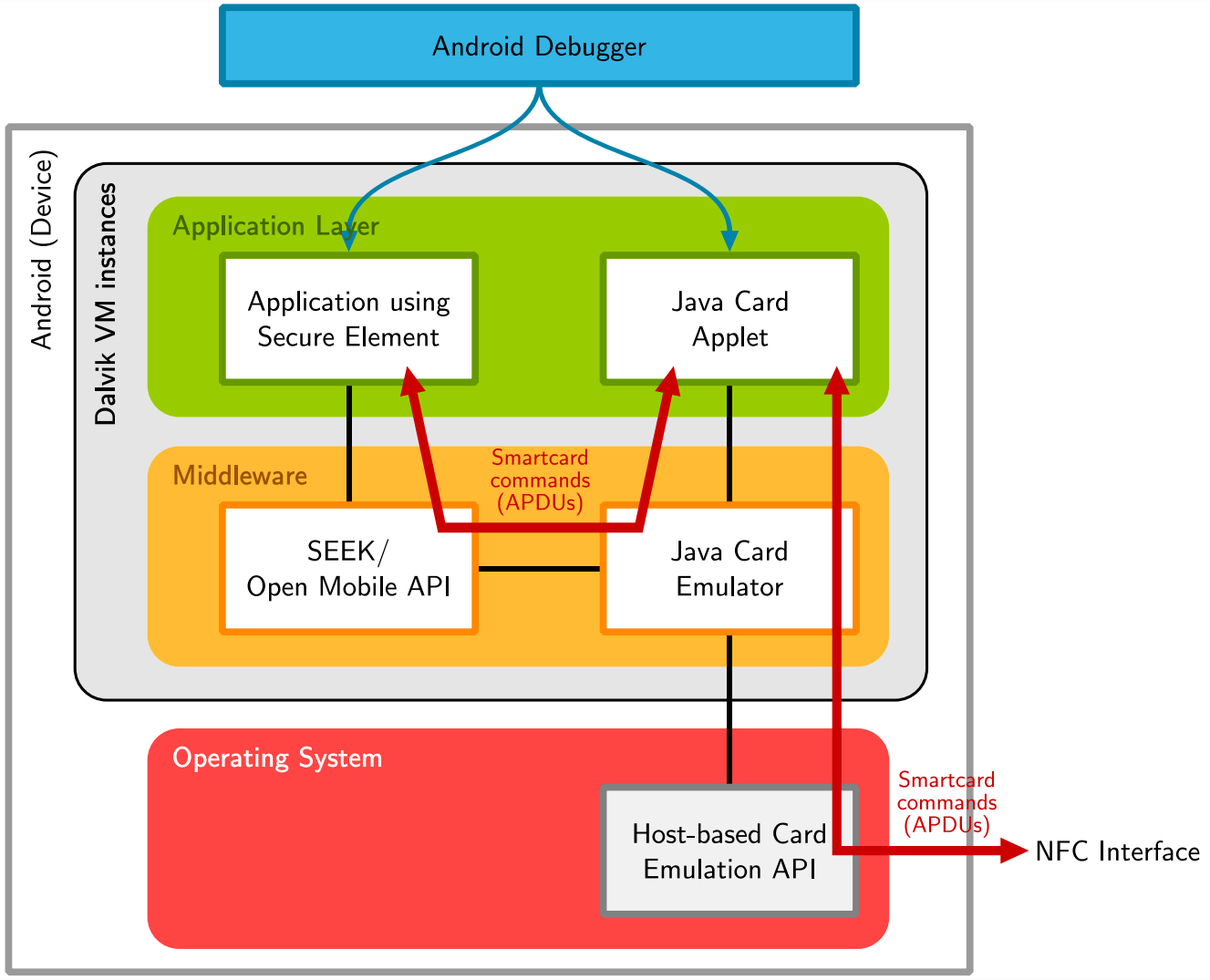
- One application consists of one or more applets
- Applet
  - entry-point object
  - life-cycle methods
    - invoked by JCRE
    - **`install()`**: create and initialize applet instance
    - **`select()`**: notify applet that it has been selected for command exchange
    - **`process()`**: forward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



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
  - Exisiting VM, existing tools for source-level debugging
  - Same tools as for debugging regular Java/Android applications

Emulator Integration with Android NFC Devices



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

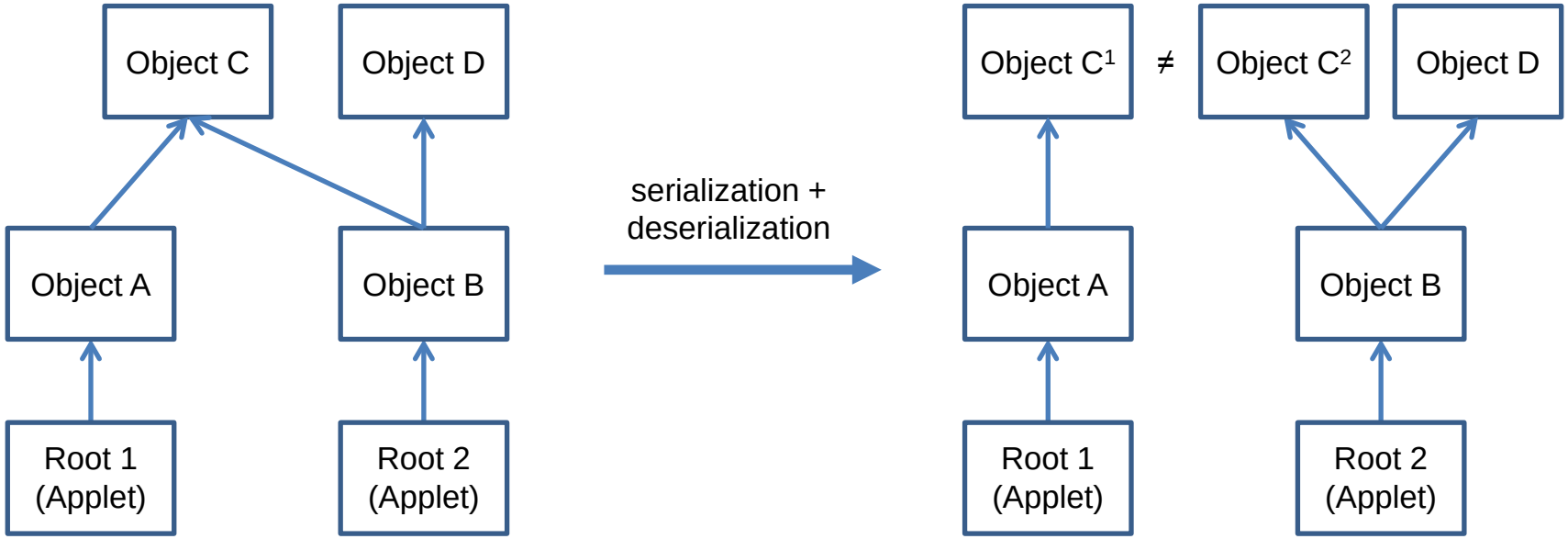
→ *Methods for extracting and re-implanting application state necessary!*

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)

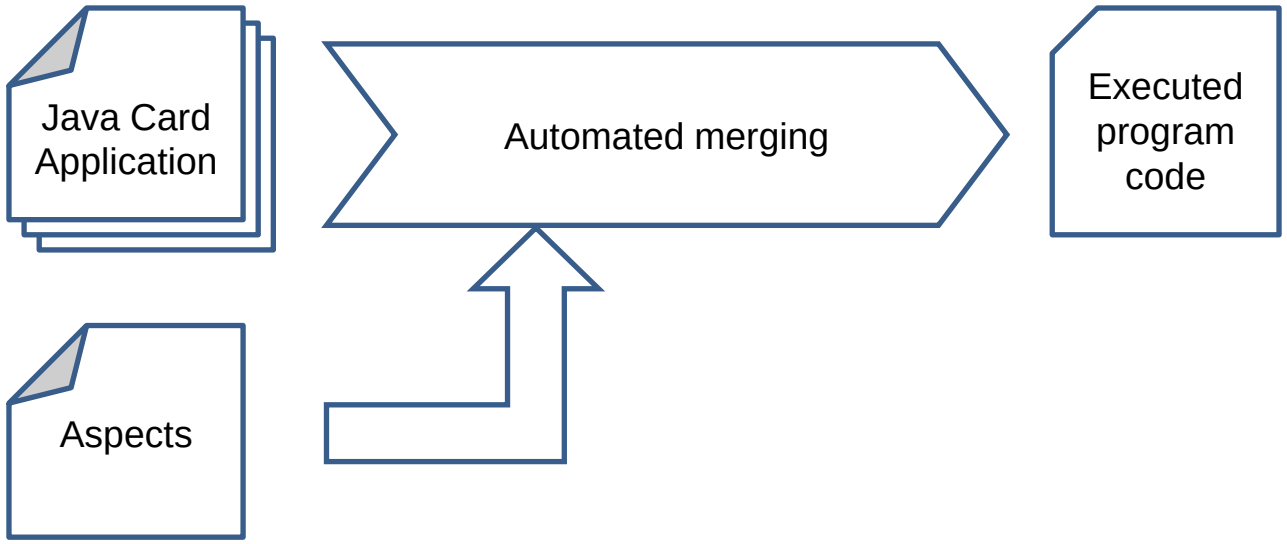
Existing Methods

- 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



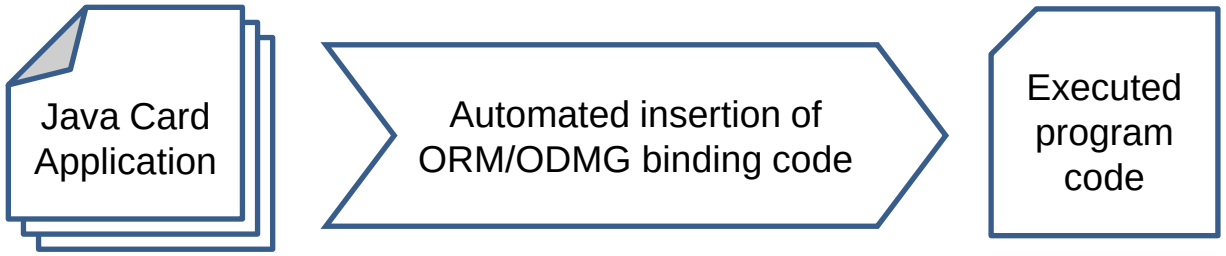
Existing Methods

- 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



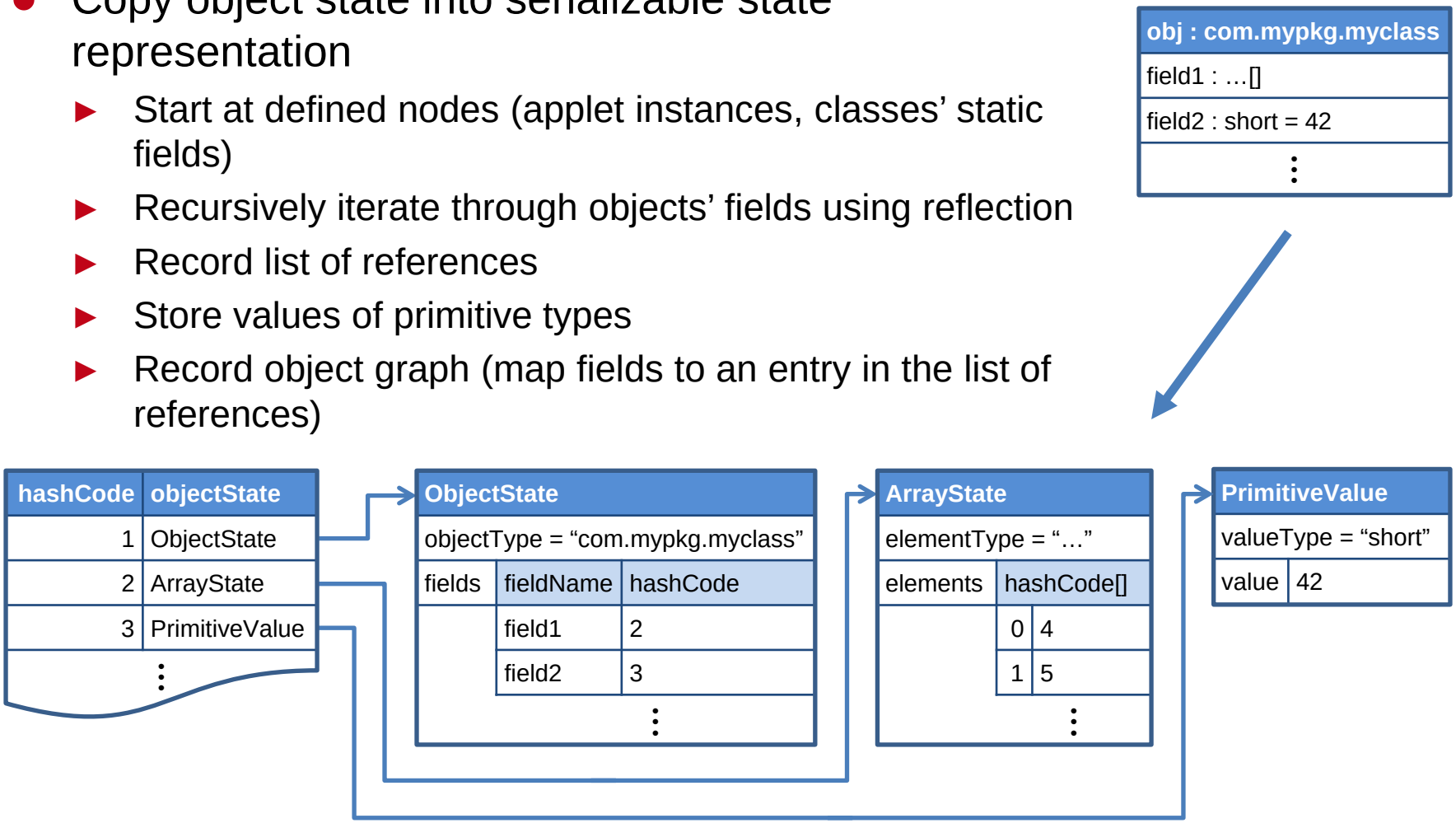
Existing Methods

- 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



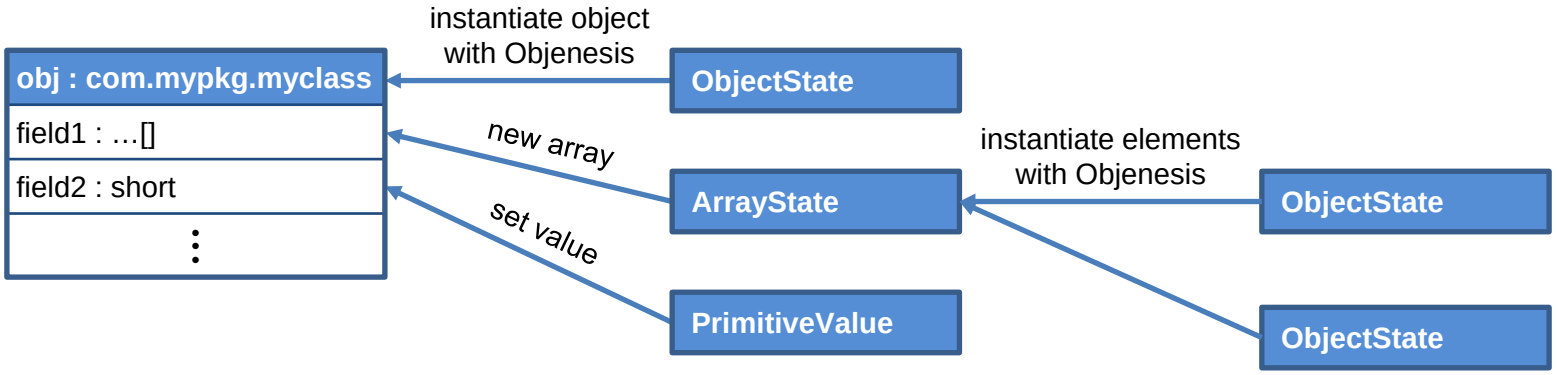
Proposed Solution

- 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)



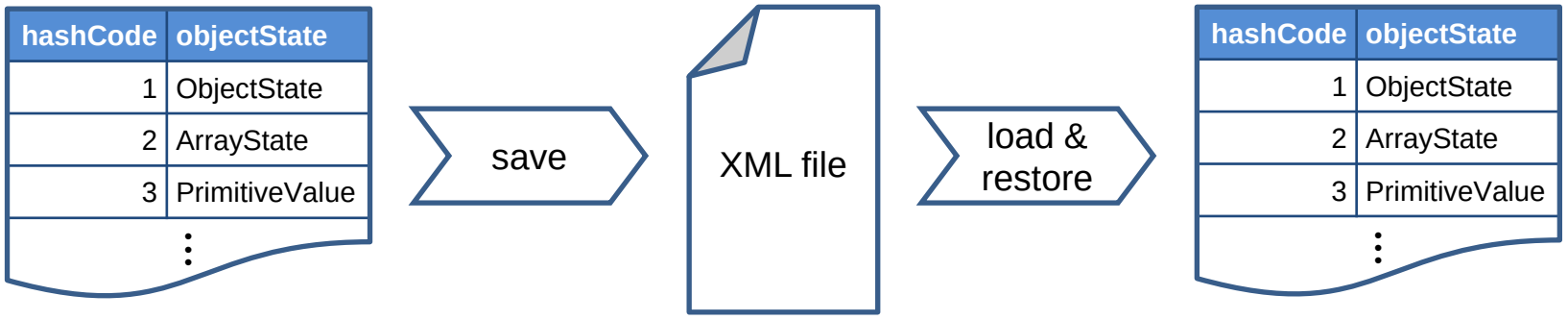
Proposed Solution

- 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



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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