Debugging and Rapid Prototyping of NFC Secure Element Applications

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Outline

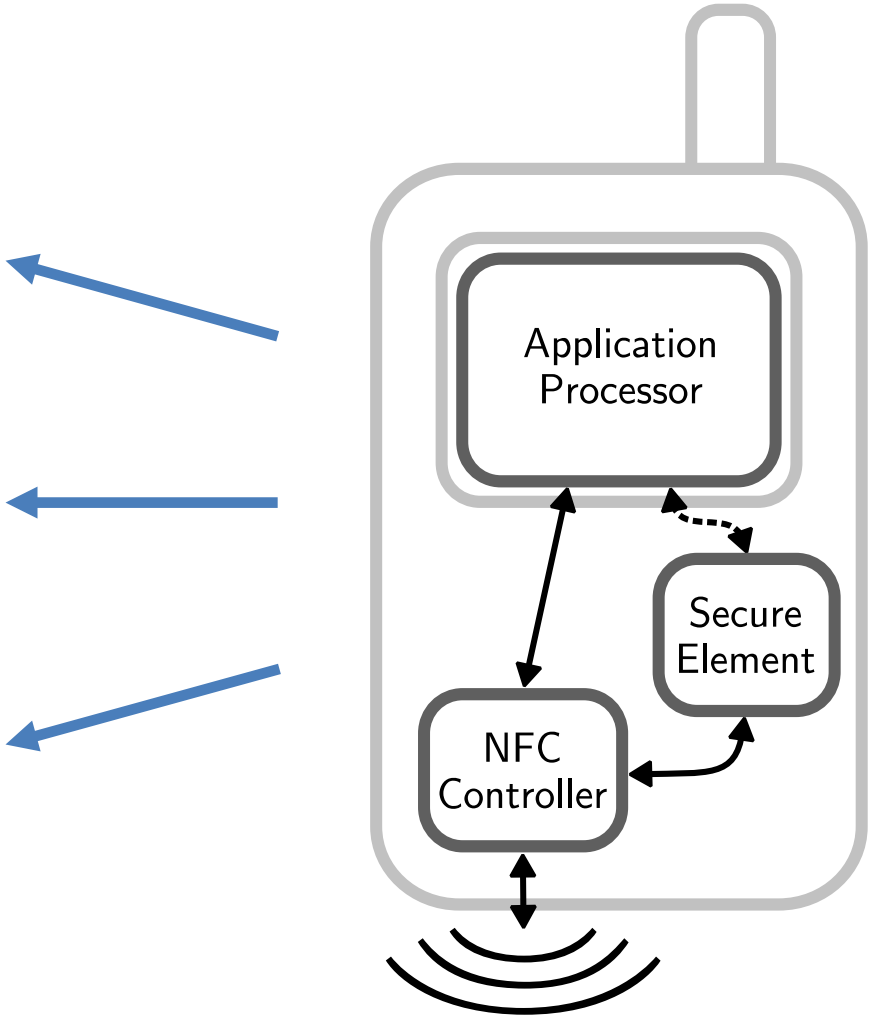
- Introduction
  - NFC in mobile devices
  - Card emulation
  - Java Card
- Debugging, Testing and Rapid Prototyping
  - Current issues
  - Ideal environment
  - Our approach towards a secure element emulator
- Discovered issues
- Conclusion

NFC in a Mobile Device

Reader/writer mode
Read and write NFC tags

Peer-to-peer mode
Exchange data with other NFC devices

Card emulation mode
Emulate contactless smartcards for use with existing readers



Card Emulation Mode

Secure Element

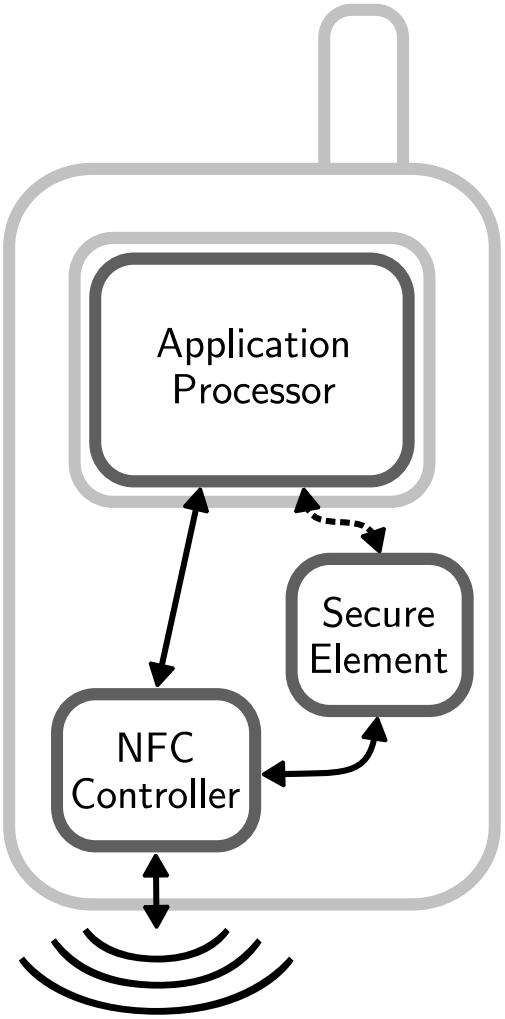
Emulation by secure smartcard chip

- different types: embedded SE, UICC (SIM card), microSD
- complex ecosystem with many players
- difficult/impossible to access by developers and small service providers

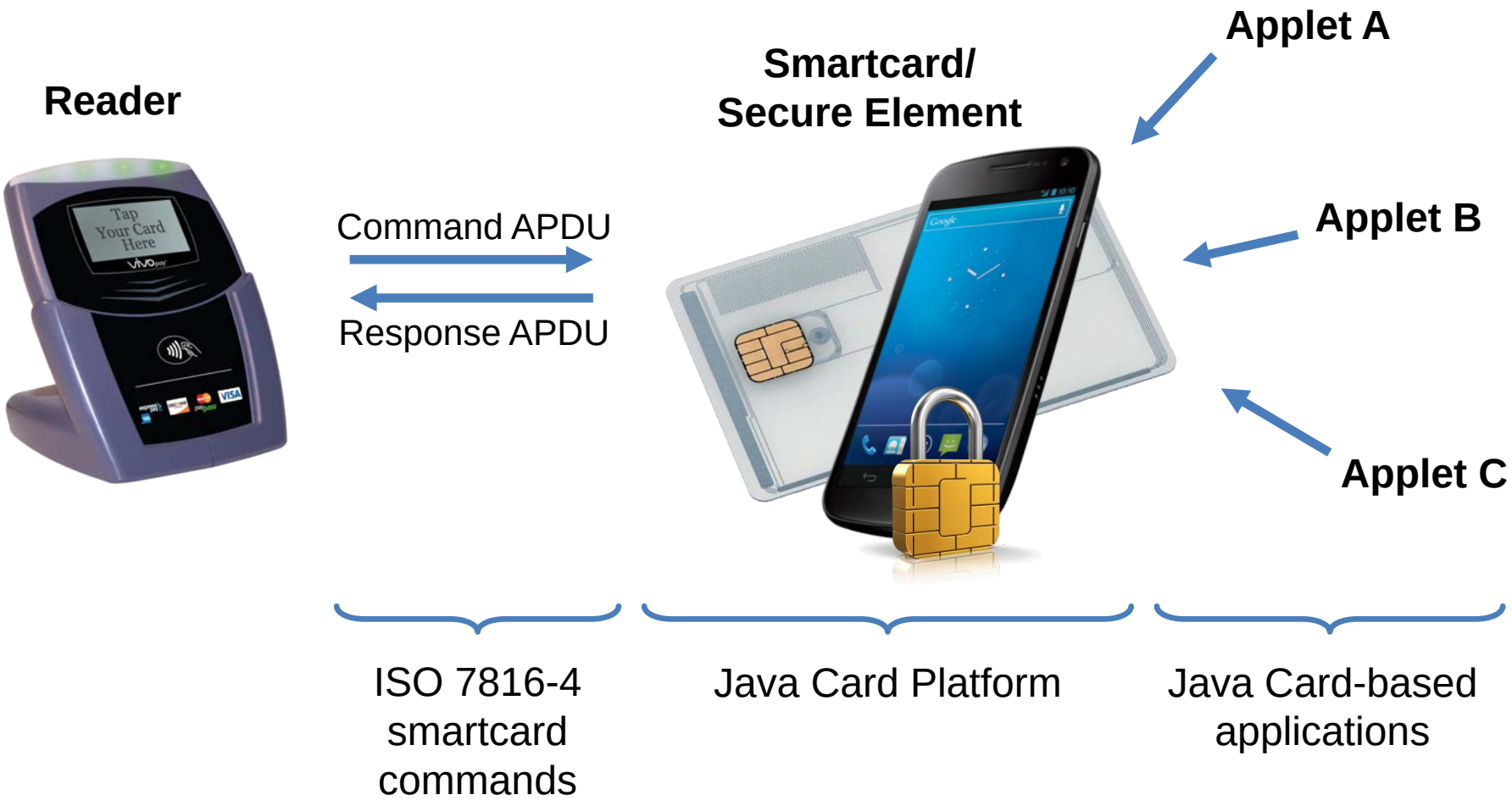
Host-based Card Emulation

Emulation by app on application processor

- flexible and open
- ***no*** secure smartcard chip
- secure element in the cloud possible



Smartcards and Secure Elements



Java Card Platform

- Java Card Runtime Environment
  - Java Card Virtual Machine
  - Java Card API
  - Specific security features
- Java specifically designed for smartcards
  - Small footprint designed for tiny devices
    - Limited memory
    - Limited processing power
  - Limited subset of Java language
    - Reduced set of primitive data types: **`boolean`**, **`byte`**, **`short`**, optional: **`int`**
    - 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 memory 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 Applets

- One application consists of one or more applets
- Applet is application's entry-point object
- Contains several 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

Debugging and Testing Java Card Applications

- On smartcard hardware
  - Testing with real smartcard and reader infrastructure
  - Problem: smartcard is secure chip
    - Does not provide debug interface
    - No on-chip debugging
    - No source-level debugging
- In smartcard simulator
  - Source-level debugging (with some simulators)
  - Problem: limited capabilities of most simulators
    - e.g. limited API support, etc.
  - Problem: no communication with real reader infrastructure

Rapid Prototyping of Java Card Applications

- On smartcard hardware
  - Problem: complex secure element ecosystem
    - Difficult/impossible to get access (particularly for prototyping)
- In smartcard simulator
  - Problem: not usable for show-casing of applications

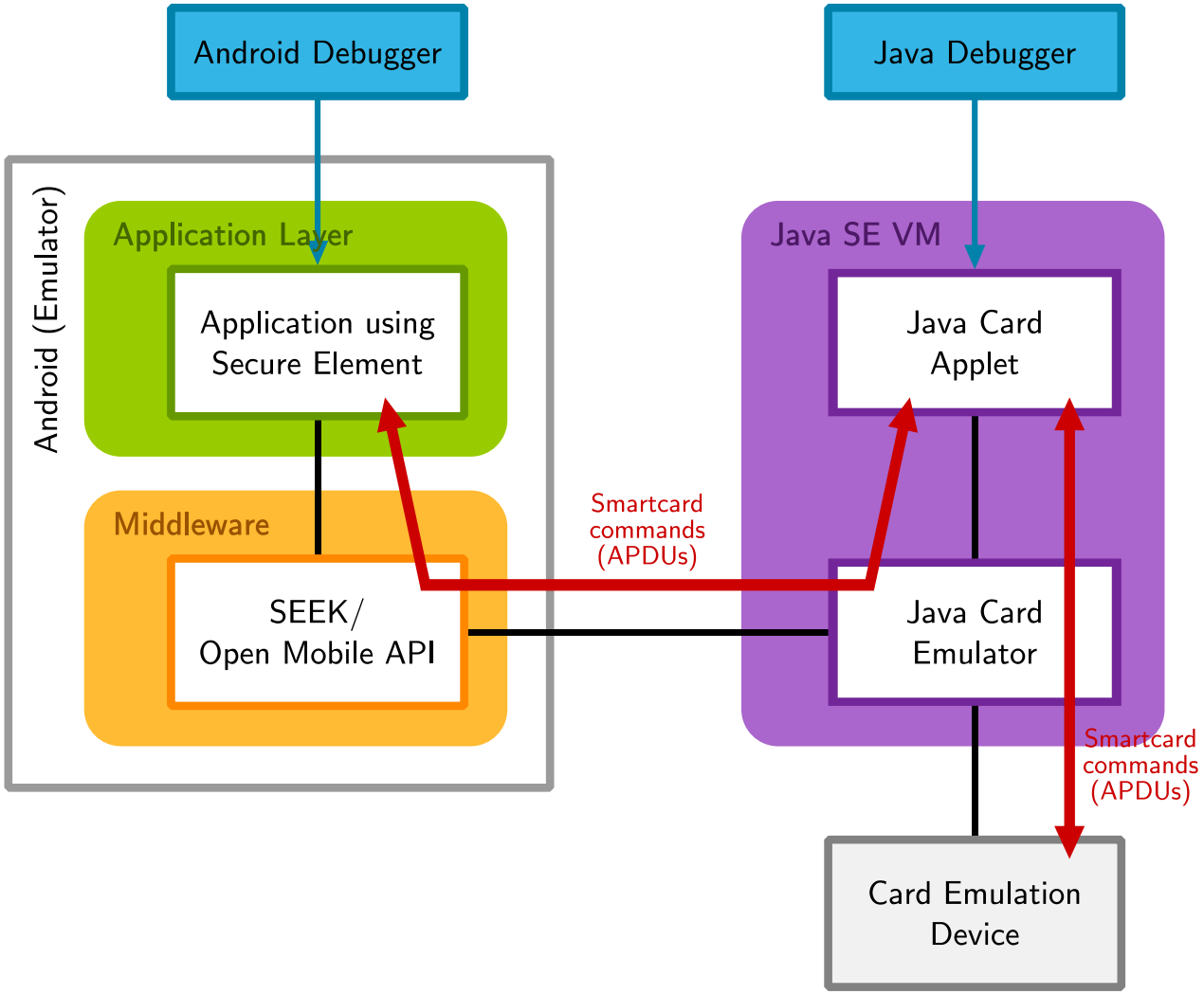
Ideal Environment for Debugging and Rapid Prototyping

- Emulation of complete run-time environment
  - Complete Java Card API (at least comparable to real cards)
  - Same application life-cycle as with real card
- Source-level debugging with existing debugger tools
  - Use same tools as for debugging regular Java applications
- In-place testing, debugging and prototyping
  - Test and debug in combination with other application components
    - Connect emulator to real smartcard readers
    - Connect emulator to software through smartcard/secure element APIs
  - Drop-in replacement for secure element for rapid prototyping
    - Integrate emulator into mobile device platform as “secure element”
    - Trade openness for security

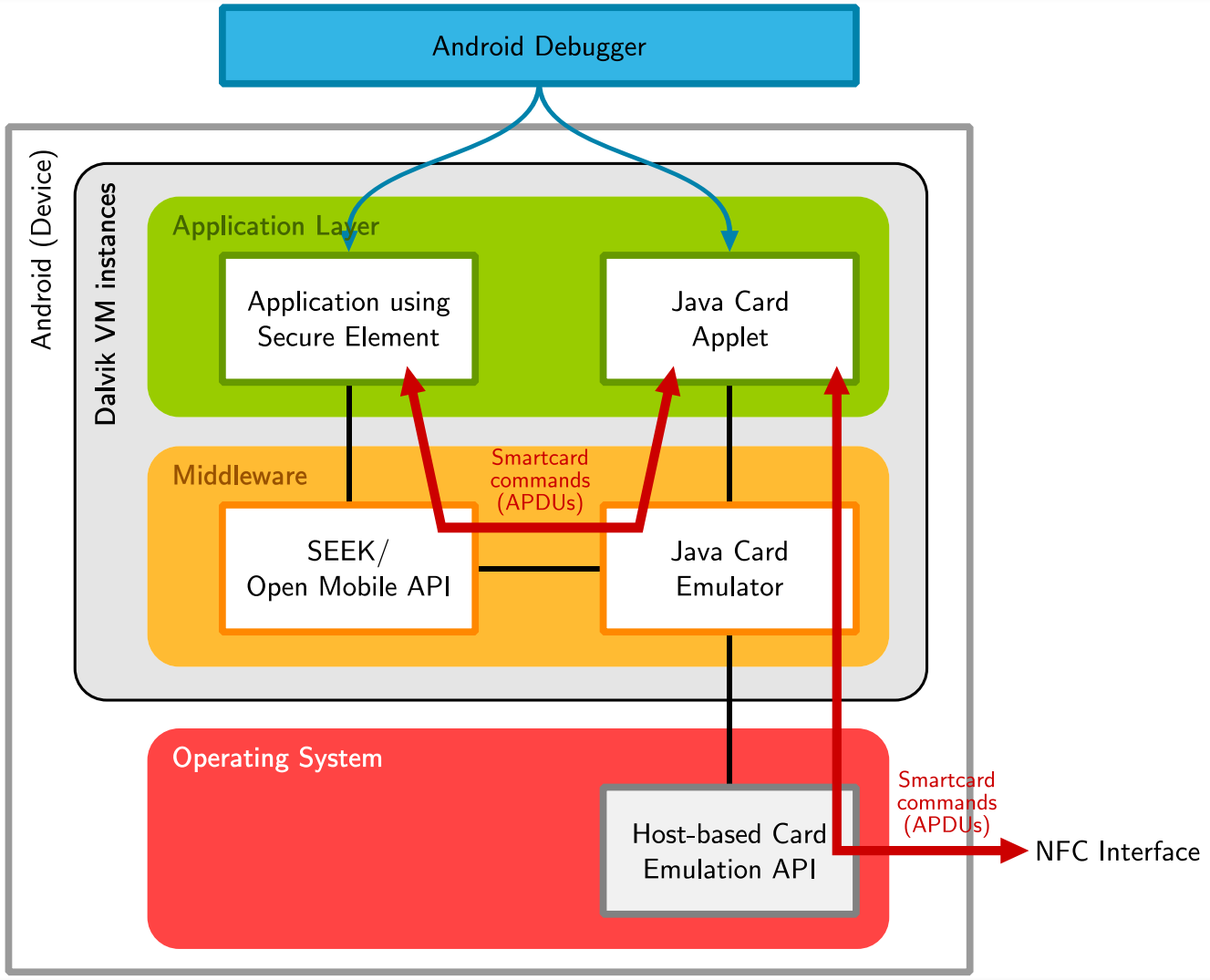
Secure Element Emulator

- Idea: extend existing open-source Java Card simulator
- jCardSim
  - Implements large portions of Java Card API
  - Runs on top of standard Java virtual machine (no Java Card VM)
    - Source-level debugging with standard Java debugger
- TBD
  - In-place testing/debugging
    - Connect with smartcard reader hardware
    - Integrate in mobile device as “secure element”
  - jCardSim only supports short simulation cycles
    - JCRE state and application state do not persist across simulation sessions
  - jCardSim lacks some core functionality
    - Atomic transaction mechanism
    - Logical channel management
  - Integration into Android
    - Run on top of Dalvik VM instead of Java VM

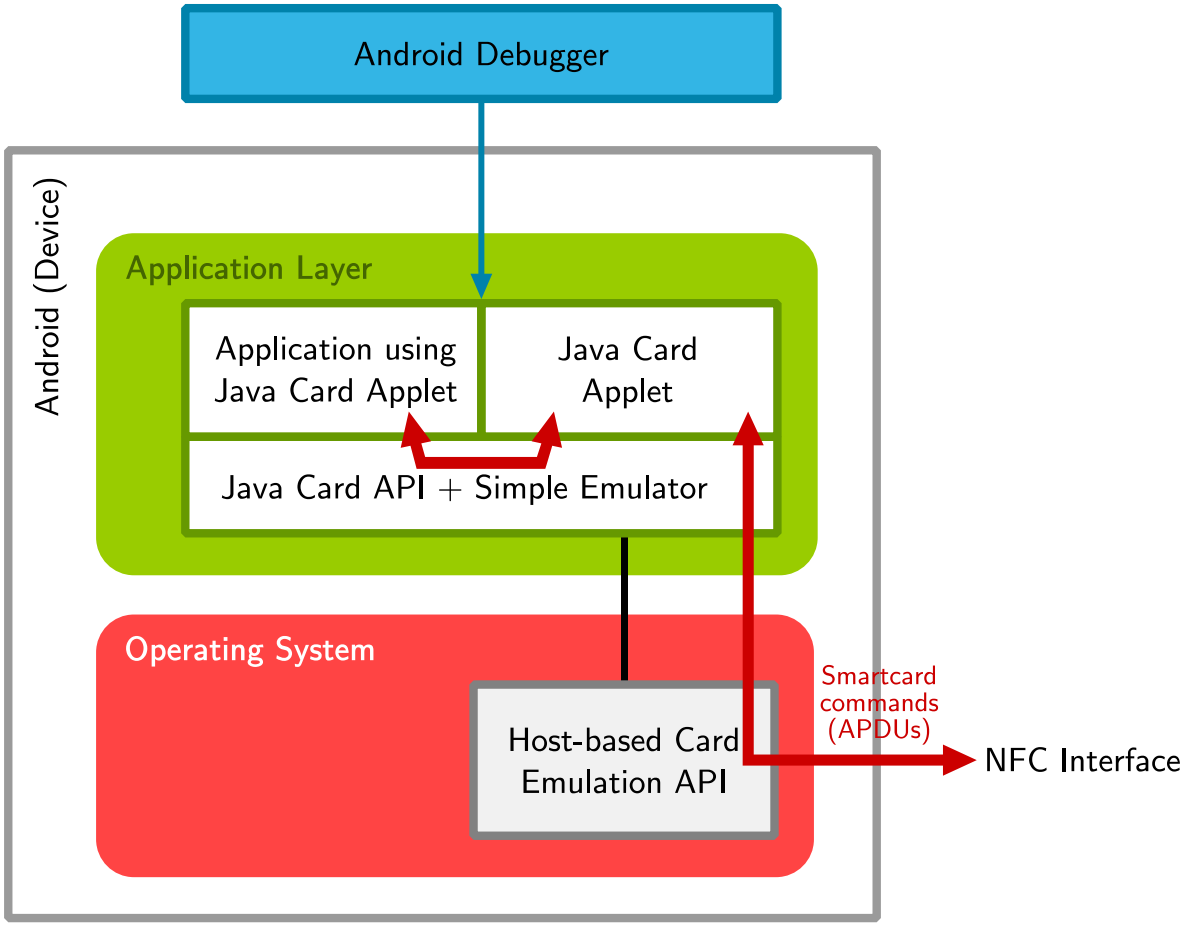
Integration with Android Emulator



Integration with Android NFC Device



Our first prototype



Issues discovered with our prototype

- Java Card atomic transaction mechanism
  - Card tearing not an issue
    - Regular smartcard: tearing causes power-loss/reset
    - Emulator: execution completes after interruptions of the RF connection
      - Transaction mechanism is not necessary in that case
  - Roll-back of transactions is not possible
    - 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 (app closed, device rebooted, etc) 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!*

Conclusion

- Developed new concepts for in-system debugging of secure element applications / Java Card applications
  - In-place debugging with other system components
    - Secure element API
    - RF interface
  - Drop-in replacement for secure element for rapid prototyping
    - Open environment but less/no security
- Created a first proof-of-concept prototype
  - Successful emulation and in-place debugging of simple applet
    - Even single-stepping through code possible
  - Identified several unresolved issues based on the prototype
    - Different life-cycle of Java Card VM in comparison to other Java VMs
    - Use of persistent memory technology for storing objects

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