QUIRE: Lightweight Provenance for Smart Phone Operating Systems

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Android's security is awesome in theory... and fails in practice.

Android differs from other OSs

Key Point:
Single User System

User separation → Application separation

- One Linux User ID per App
- File system access control via UID
- Permissions bound to App UID

Application separation in theory...

- Private storage for apps
  - Enforced at filesystem level
- Simple permission system
  - Does the calling UID have permission to access this resource?
- Crash Insulation

… but in practice

Application separation is violated all the time

How things work now

- Third party libraries run in the same context as their host app
  - And with the host's permissions
  - And some third party libraries require the host ask for more permissions
- Problems
  - Credential phishing, leaked application data, violation of least privilege, bugs

How things **should** work

- Third party libraries run in their own context as apps
- Apps offer services over Inter Process Communication (IPC) Channels

Two Main Goals

1. Protect apps from third party libraries
    - ex. Bugs, stolen data

2. Protect third party libraries from apps
    - ex. Click Fraud

Advertisements

A big deal to app developers

Angry Birds is making over $1 million a month in ad revenue

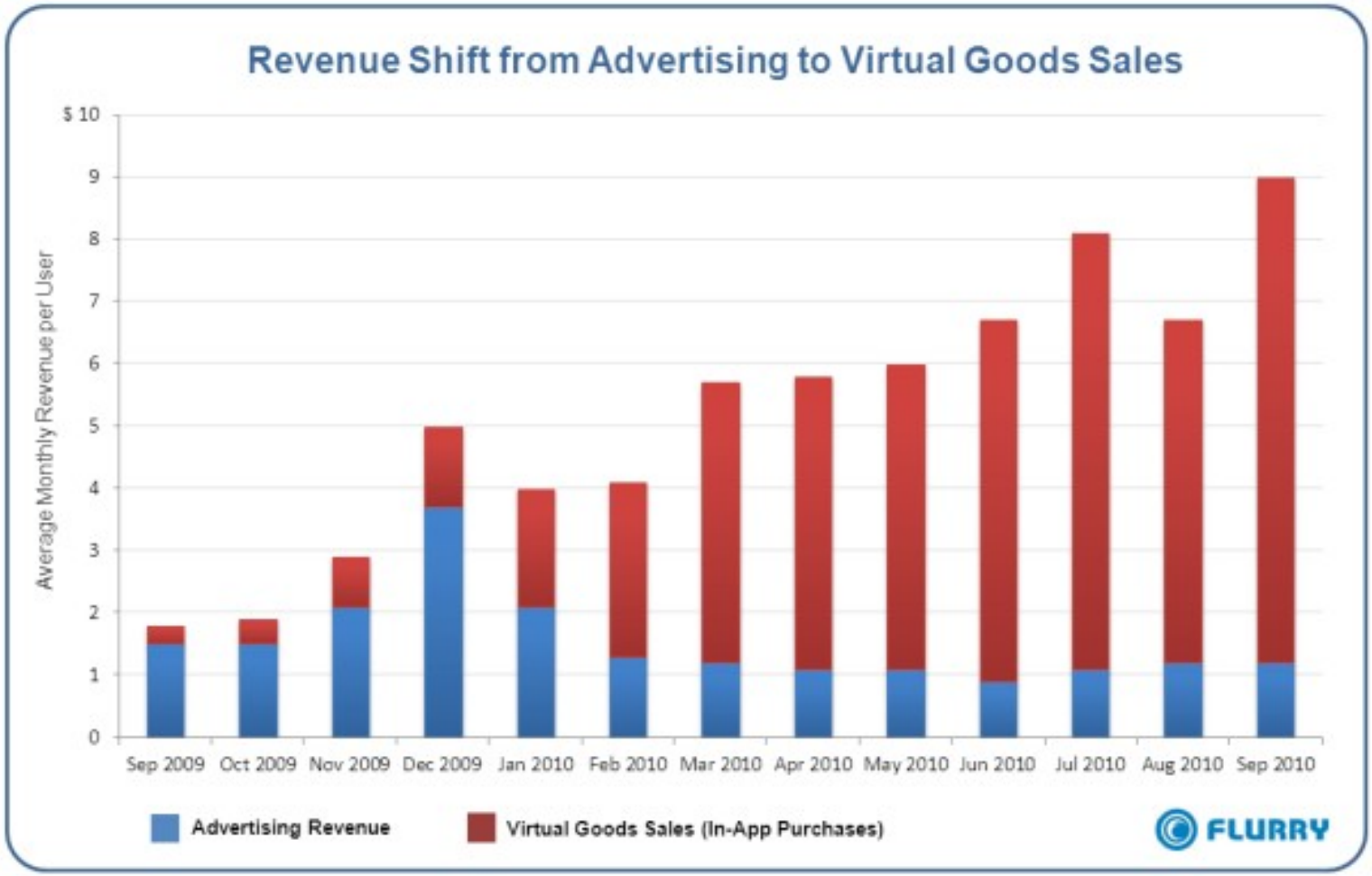
http://googleblog.blogspot.com/2010/12/great-advice-from-industry-experts-on.html

A big deal to the ad providers

Click fraud cost Google
$100 million a year

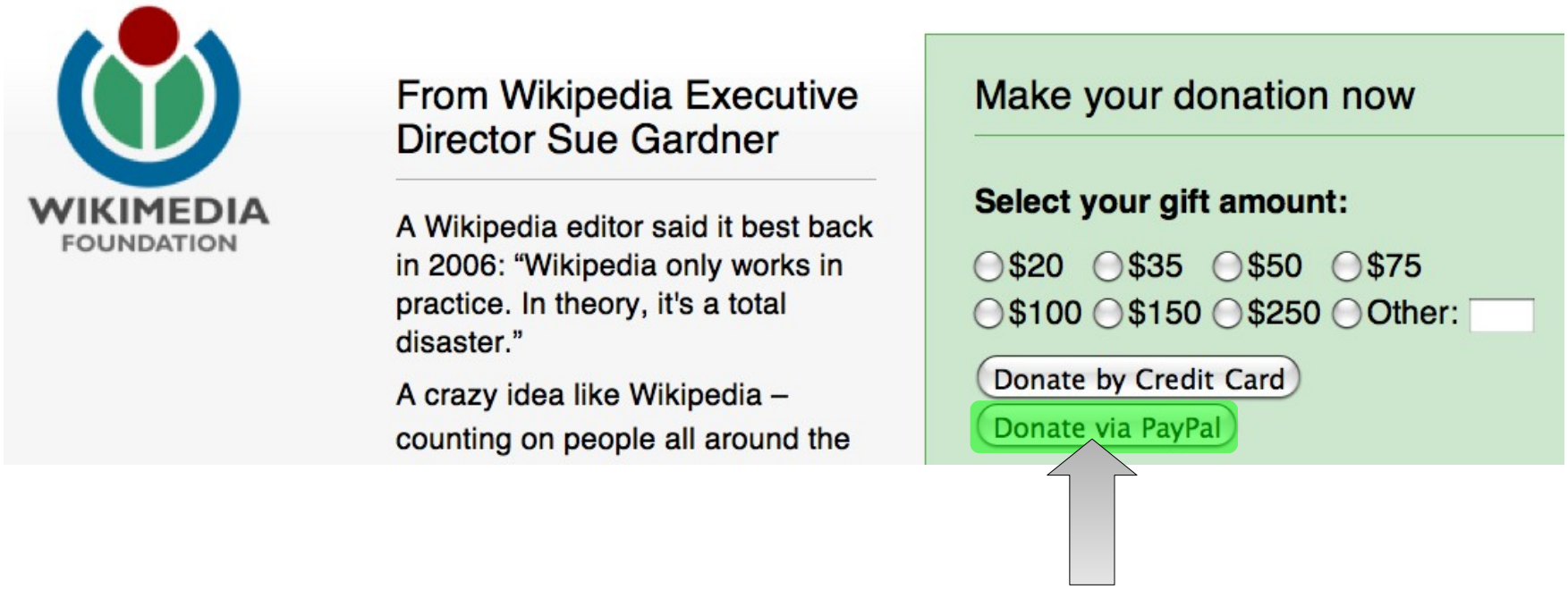
http://adwords.blogspot.com/2007/02/invalid-clicks-googles-overall-numbers.html

The next step: Micro-payments



http://blog.flurry.com/bid/48418/Madison-Avenue-and-the-Land-of-Make-Believe

Motivation: Mobile Payment



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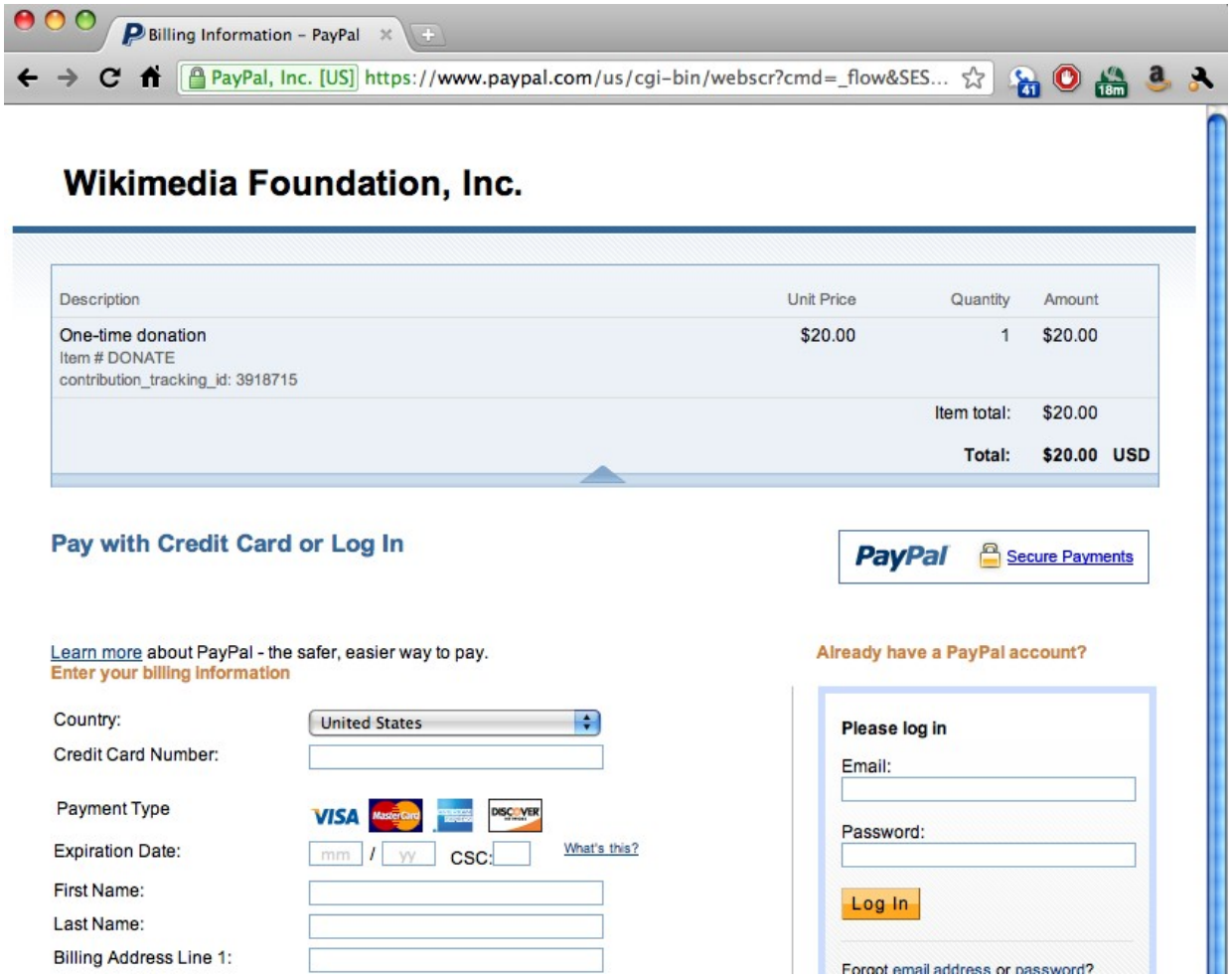
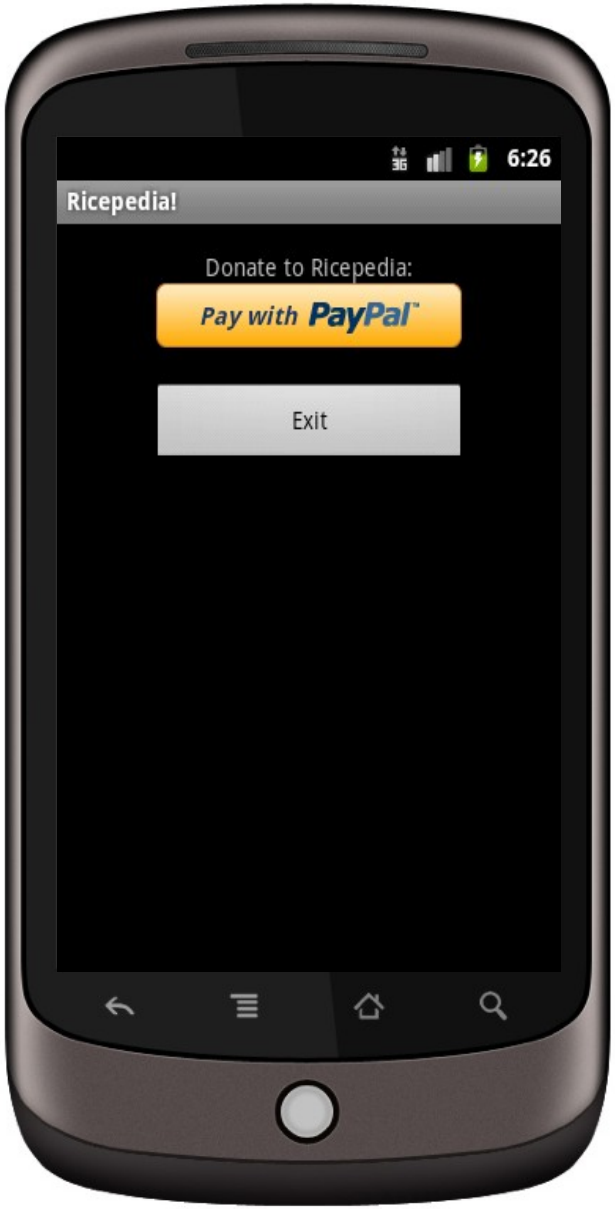
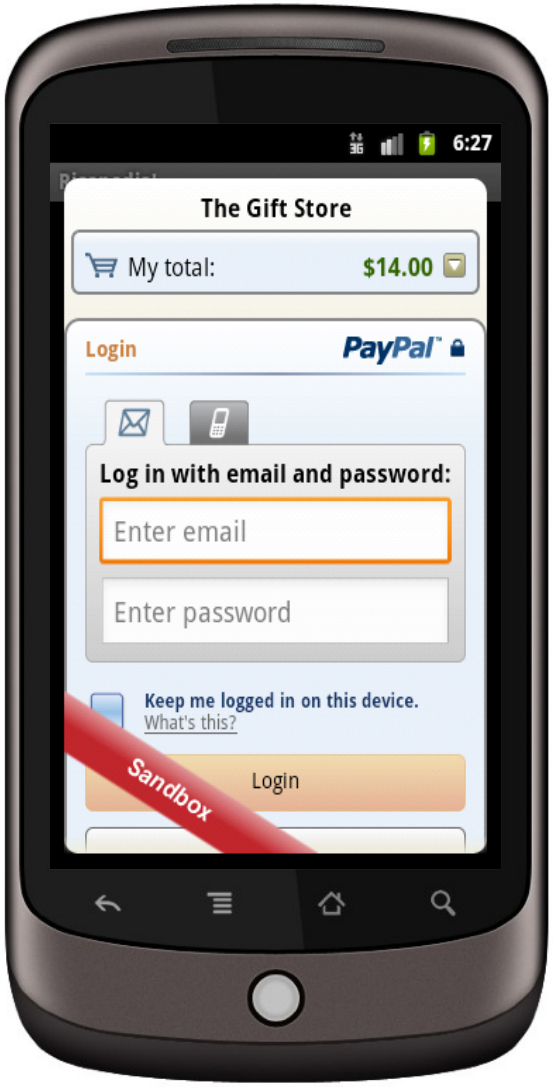


- Visual clues
- URL indicates this is PayPal
- SSL indicators

Motivation: Mobile Payment



Motivation: Mobile Payment



- No visual clues that this is PayPal
- Hosting app could spoof this dialog
- PayPal code running in same context as hosting app
- Hosting app needs internet permission to use this library

Our Approach: QUIRE

Quire n.

2. A collection of leaves of parchment or paper, folded one within the other, in a manuscript or book.

Two methods

- Protect apps from third party libs
  - Enforce application separation
  - Augment IPC with call chain provenance
- Protect third party services from apps
  - Data integrity from OS verified statements
  - Trusted path for user input
  - Attestation of on-phone state to remote endpoints

Trusted OS

- Mutually untrusting apps use OS to authenticate IPC
- Register shared secret between app and OS
- IPC messages signed with shared secret
- Authenticated later by OS service
- Network service creates RPC attestations

Caveat: Rooted phones can't be trusted

Principals

- On-Phone principal
  - UID assigned at install time, unambiguous
- Off-Phone principal
  - Can't use UID, only meaningful on phone
  - Resolve UIDs to signing key or package name
  - Signed by OS

MAC functions

- Built from crypto hash functions (e.g., HMAC-SHA1)
  - Radically faster than digital signatures
- Require a shared secret
  - Can only be verified if you know the secret
- Our approach: each app shares secret with the kernel
  - Requires syscall to verify a MAC

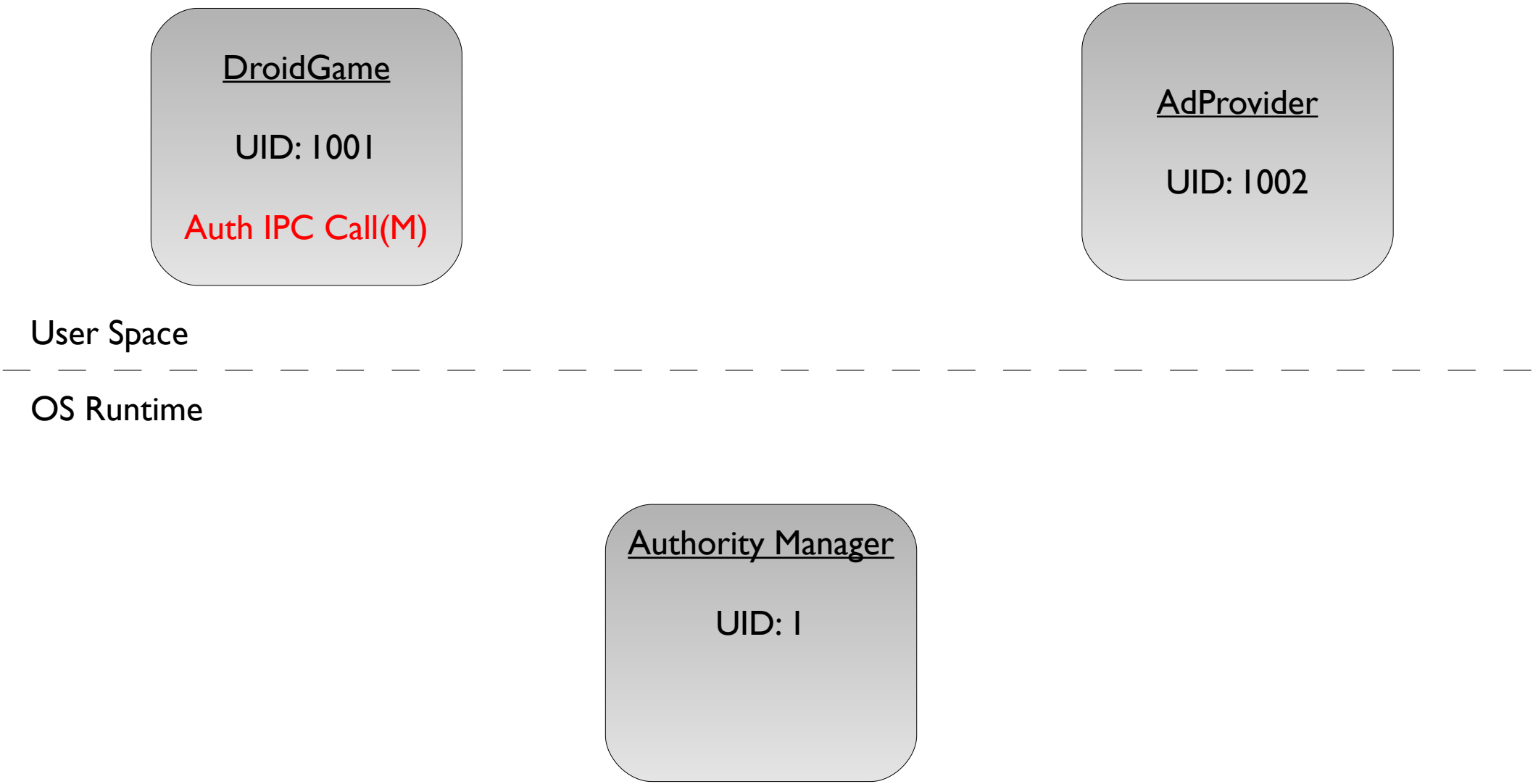
Verifiable Statements

- Fundamental unit of authenticated communication
  - Attached to objects passed over IPC
- Verified with a MAC over the principal's secret shared with the OS
- OS authentication service can verify a statement upon request

Contrast: Java stack inspection

- Same ABLP logic for the design
  - Quoting chains to reduce privileges
- Annotating Java stack vs. Android IPCs
  - Much lower overhead on Android
  - Supports Android native code transparently
  - Requires recompiling Android apps

Statement Creation



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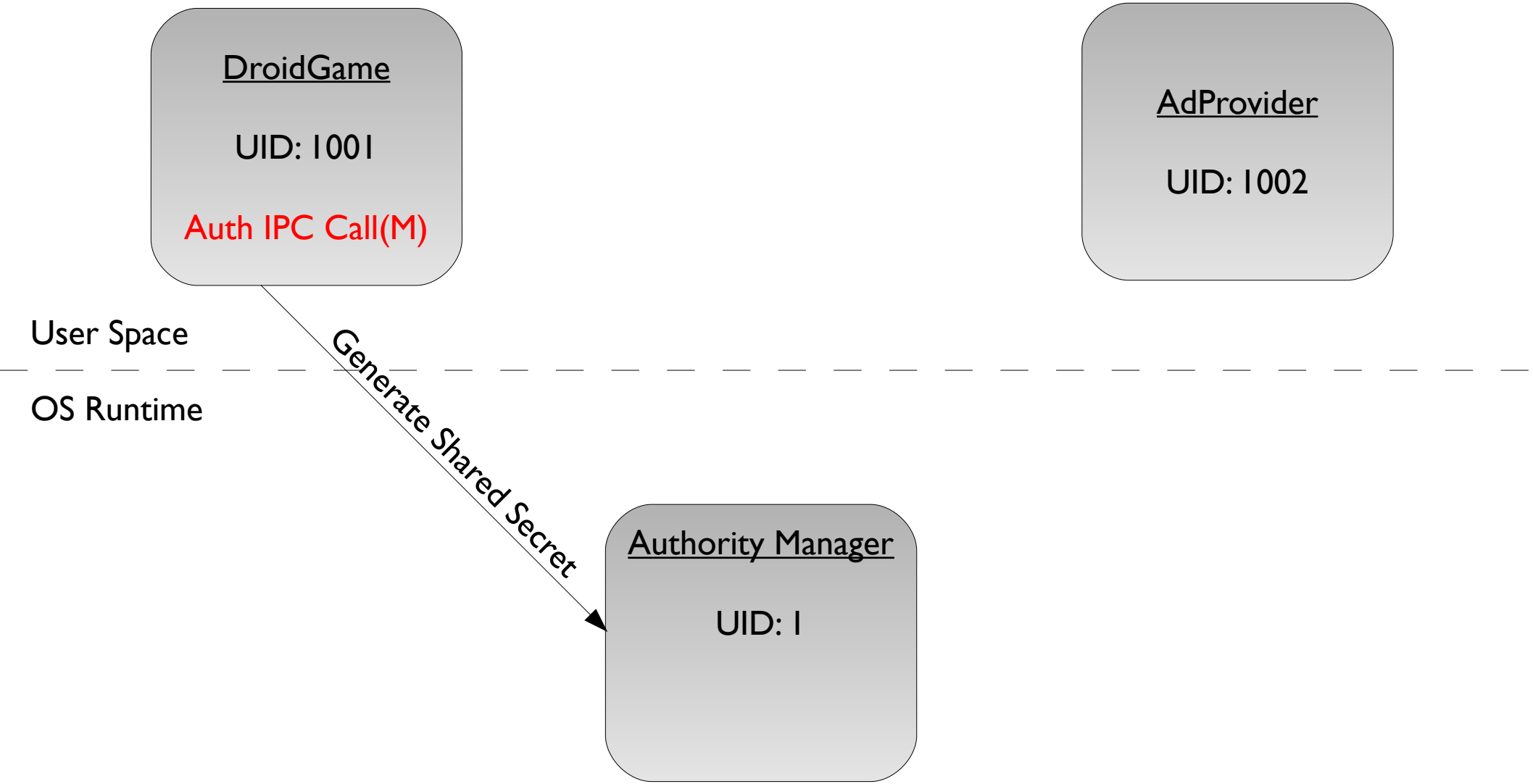
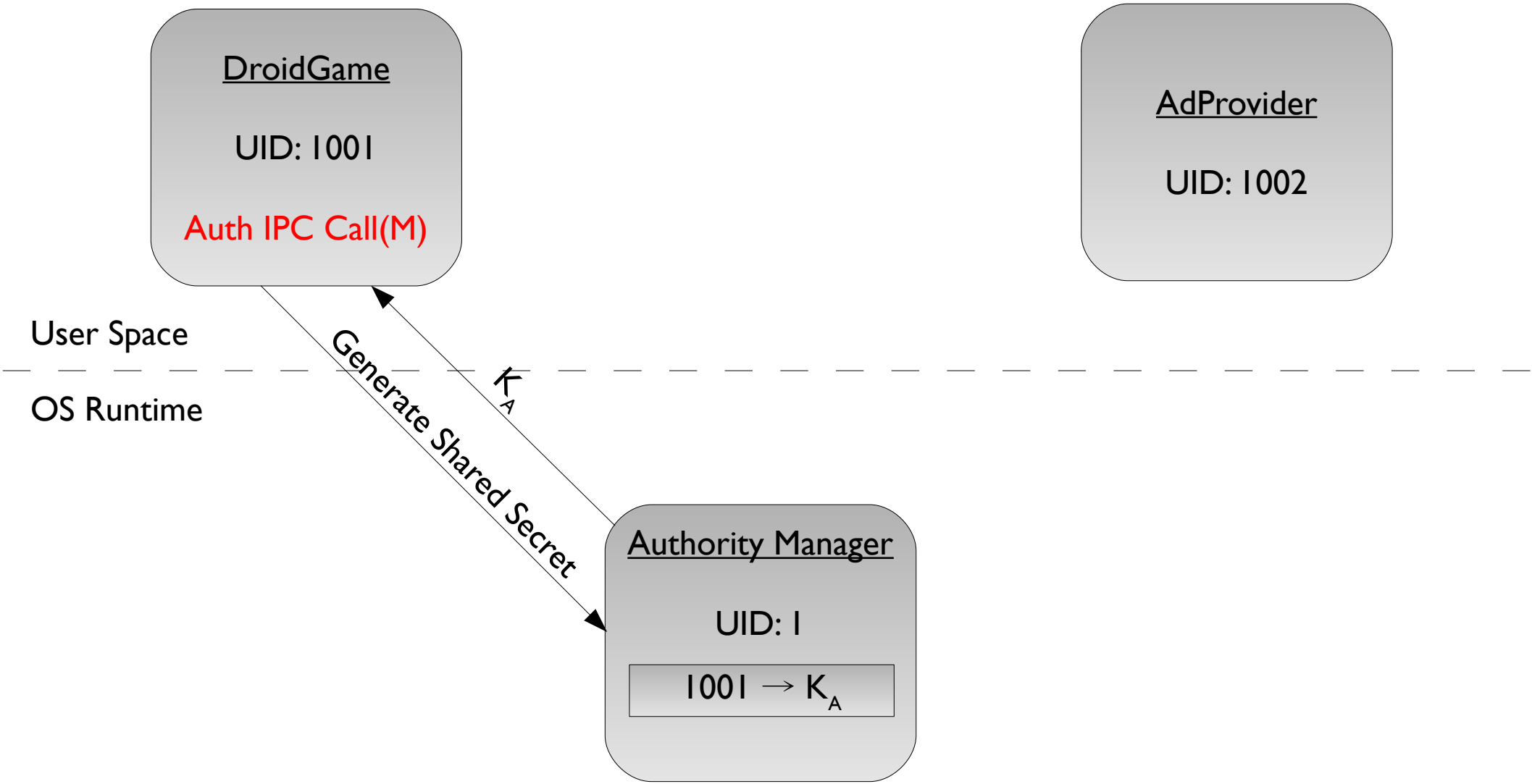


Statement Creation



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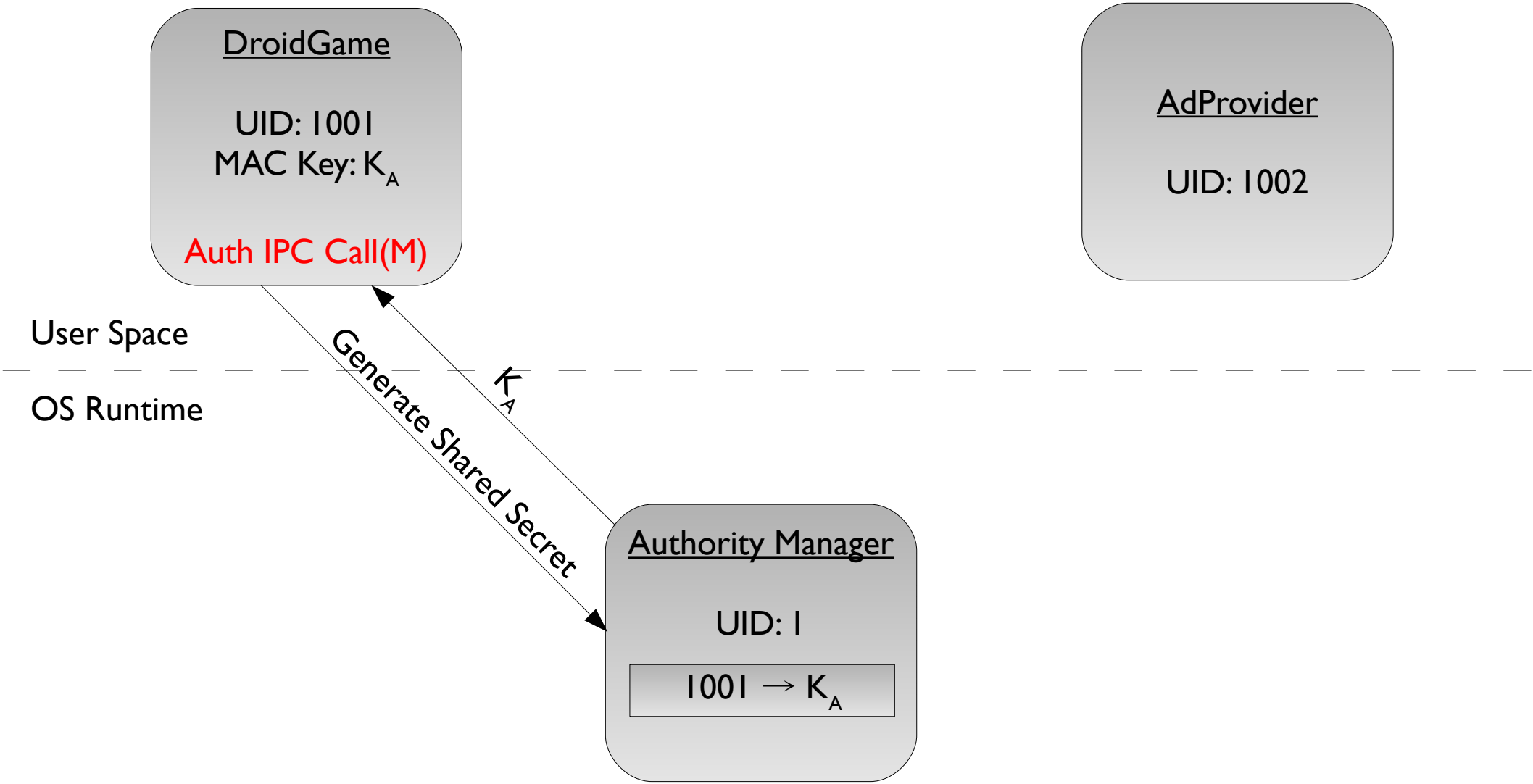

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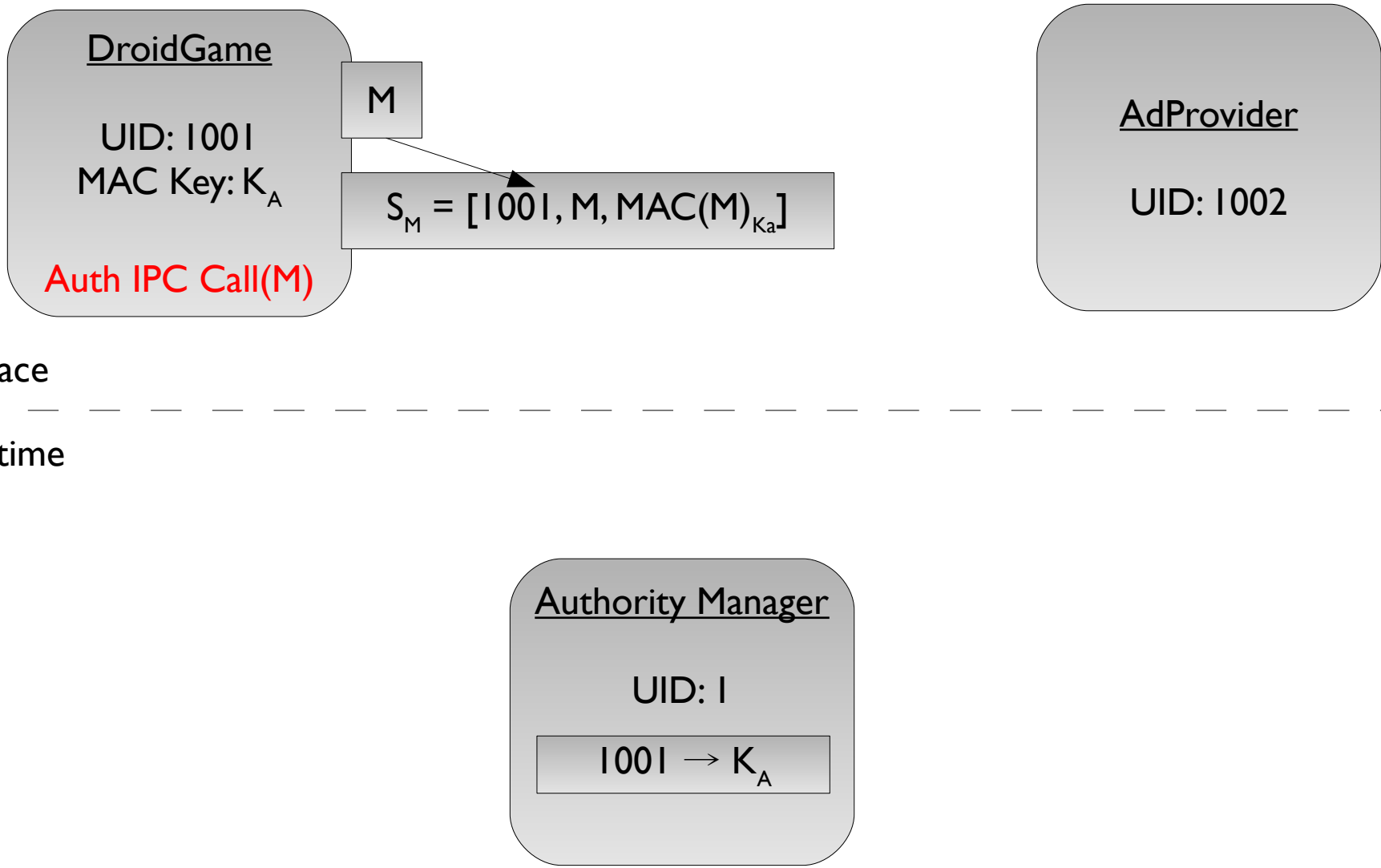

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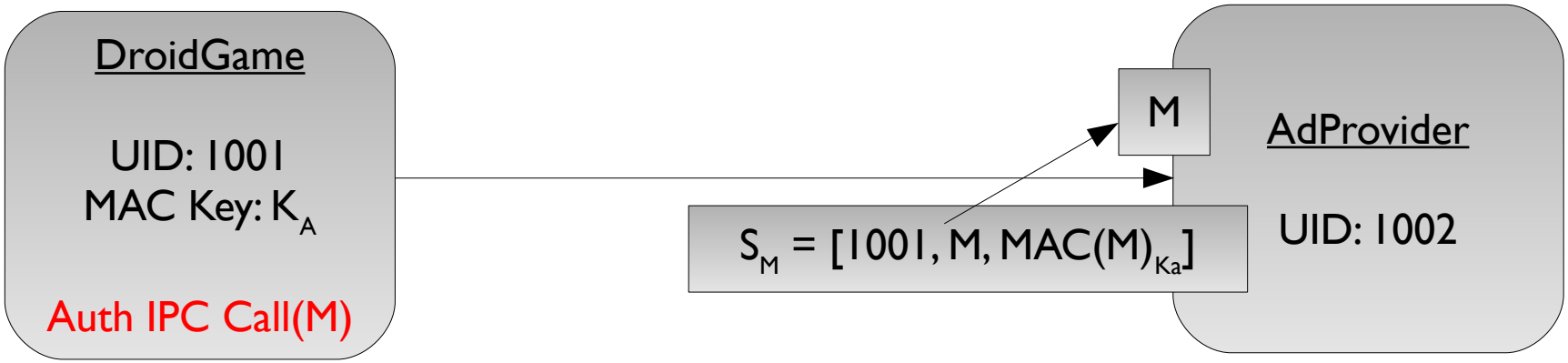
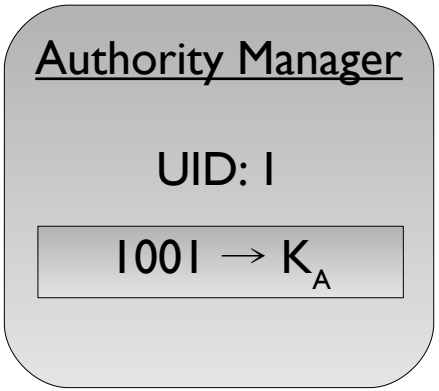
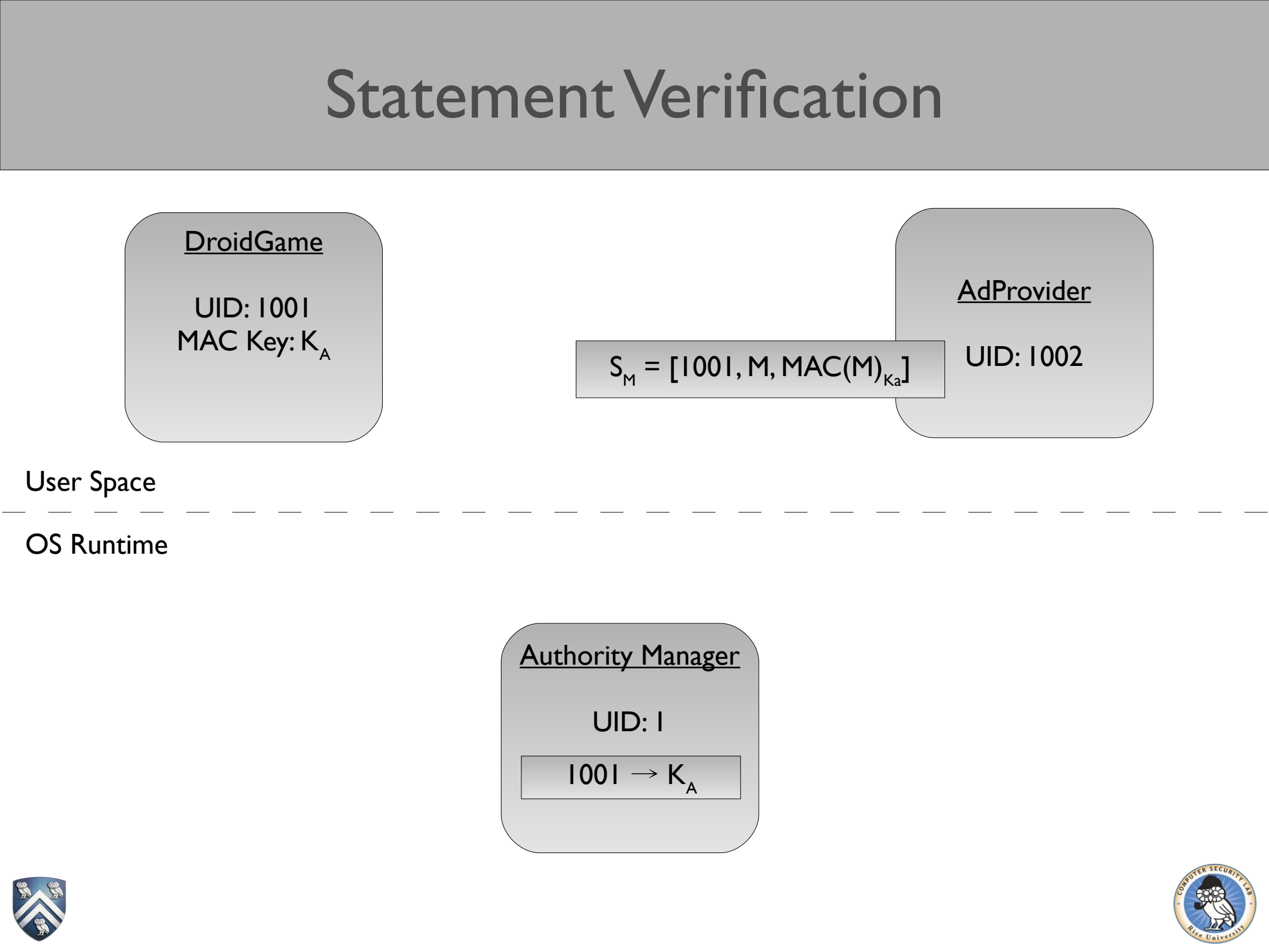


User Space

OS Runtime



Statement Verification



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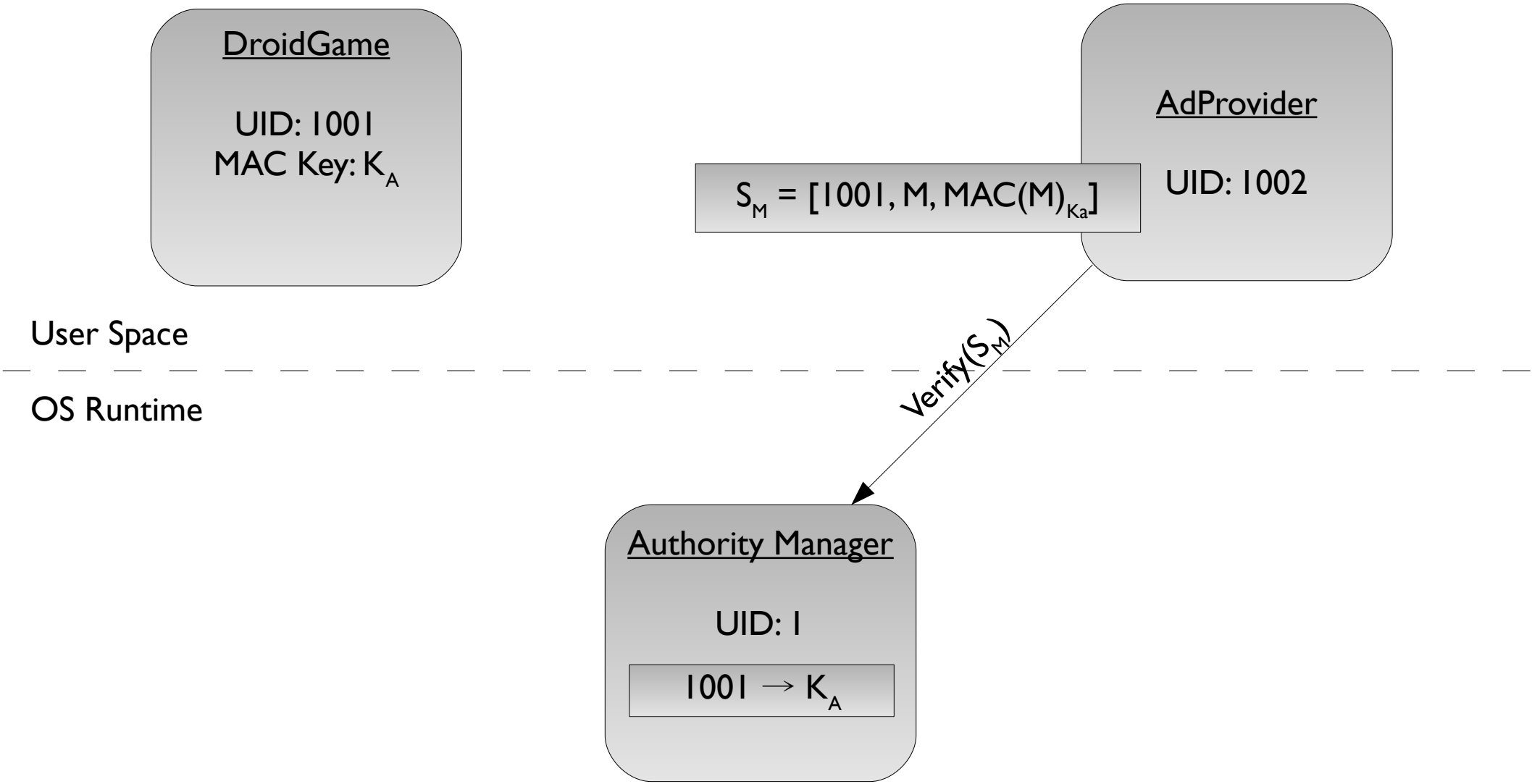

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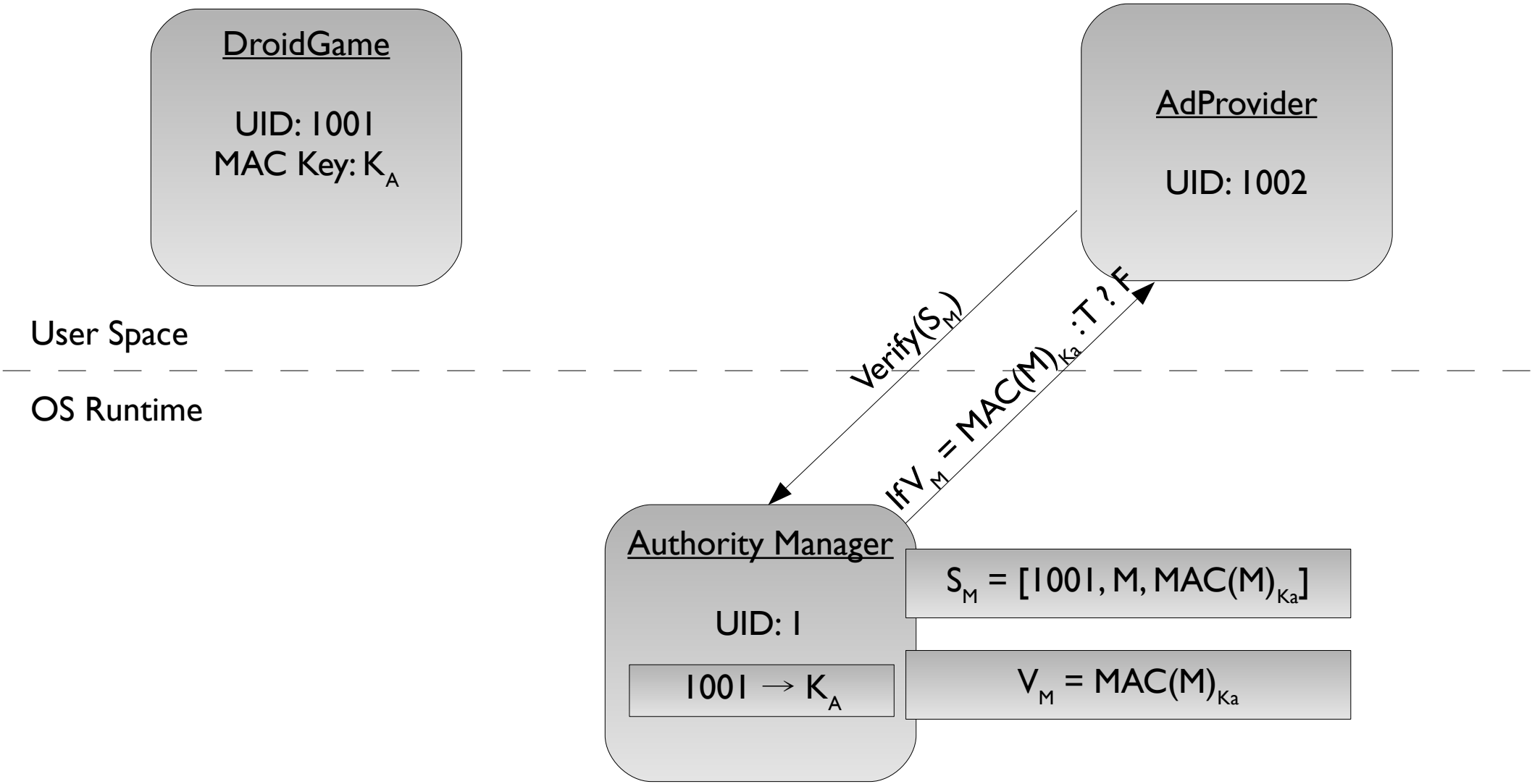


Ad Example - Conclusions

- Sample policy
  - Assume Ad Payout **if** *AdProvider* can verify a click originated from the OS
  - *OS UI Manager* → *an app* → *AdProvider app* → RPC to *AdProvider.com*

Confused Deputy Attacks

- Example
  - Some App C protects the user's fine grained GPS location
  - App B has permission to retrieve the GPS information from C, but App A does not
  - A can escalate its privilege by triggering B to act on A's behalf

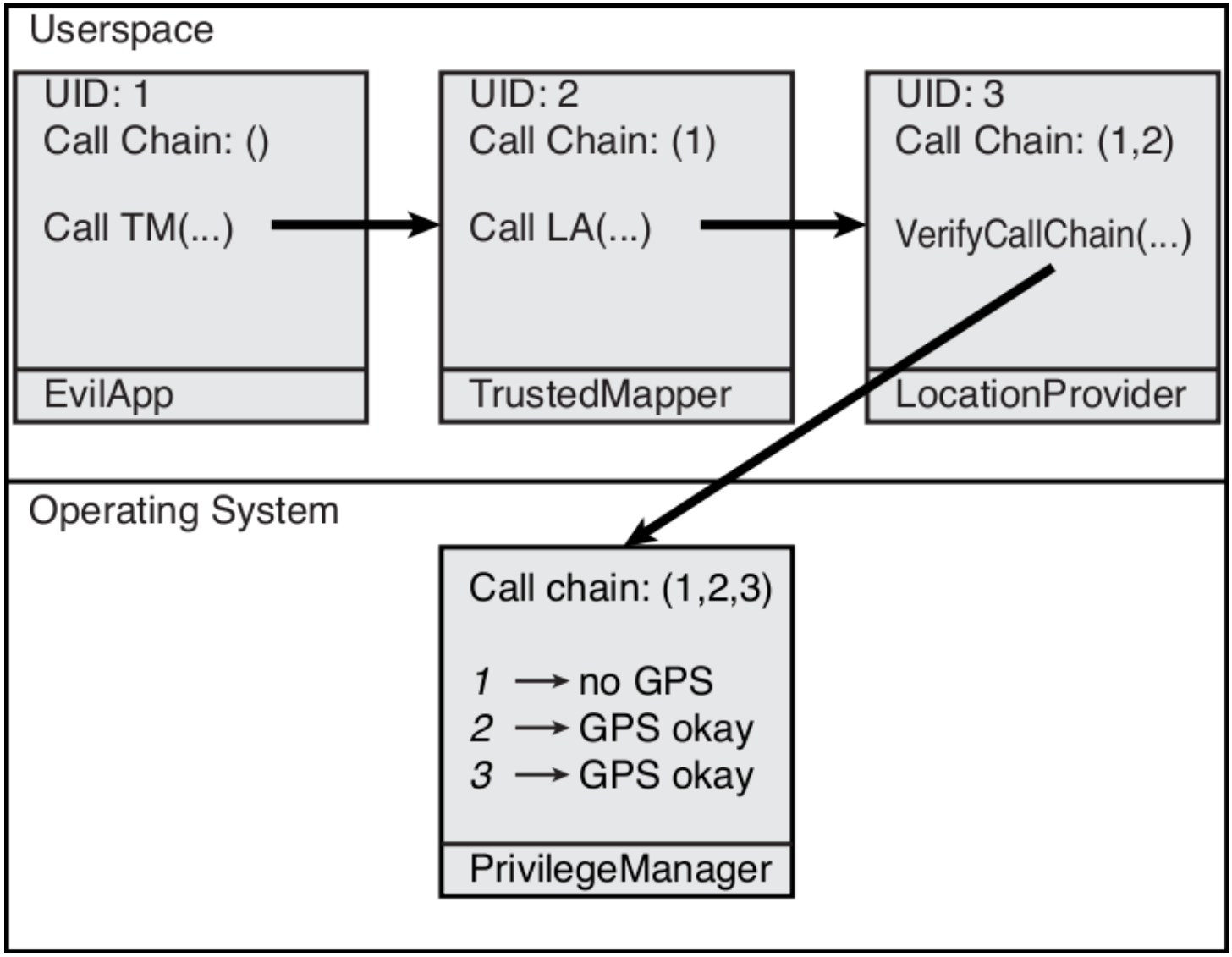
Augmented IPC

- An app can protect itself by quoting the app or call chain that called it
  - "I want access to the GPS, but only because A asked me to get it"
- We use Abadi, Burrows, Lampson, and Plotkin (ABLP) Logic to reason about this

Key Point

- Quoting can only reduce an app's privilege level
  - *B says A says X* means
    - B told you "don't just do it because you trust me, make sure you're okay with A as well."
    - Insight: quoting strictly reduces privileges
- Therefore there's no need to encrypt or MAC the call chain (cheap!)
- MAC-based statements when necessary (also cheap)

Confused Deputy Example



Implementation

- 2300 lines of modifications to the Android 2.3 OS runtime libraries
  - Main Components
    - Authority Manager OS service
    - IPC stub/proxy code generator
    - Network Provider
  - SHA-1 HMAC used for message authentication
    - Implemented as an Intrinsic VM function to avoid Java / JNI slowdown

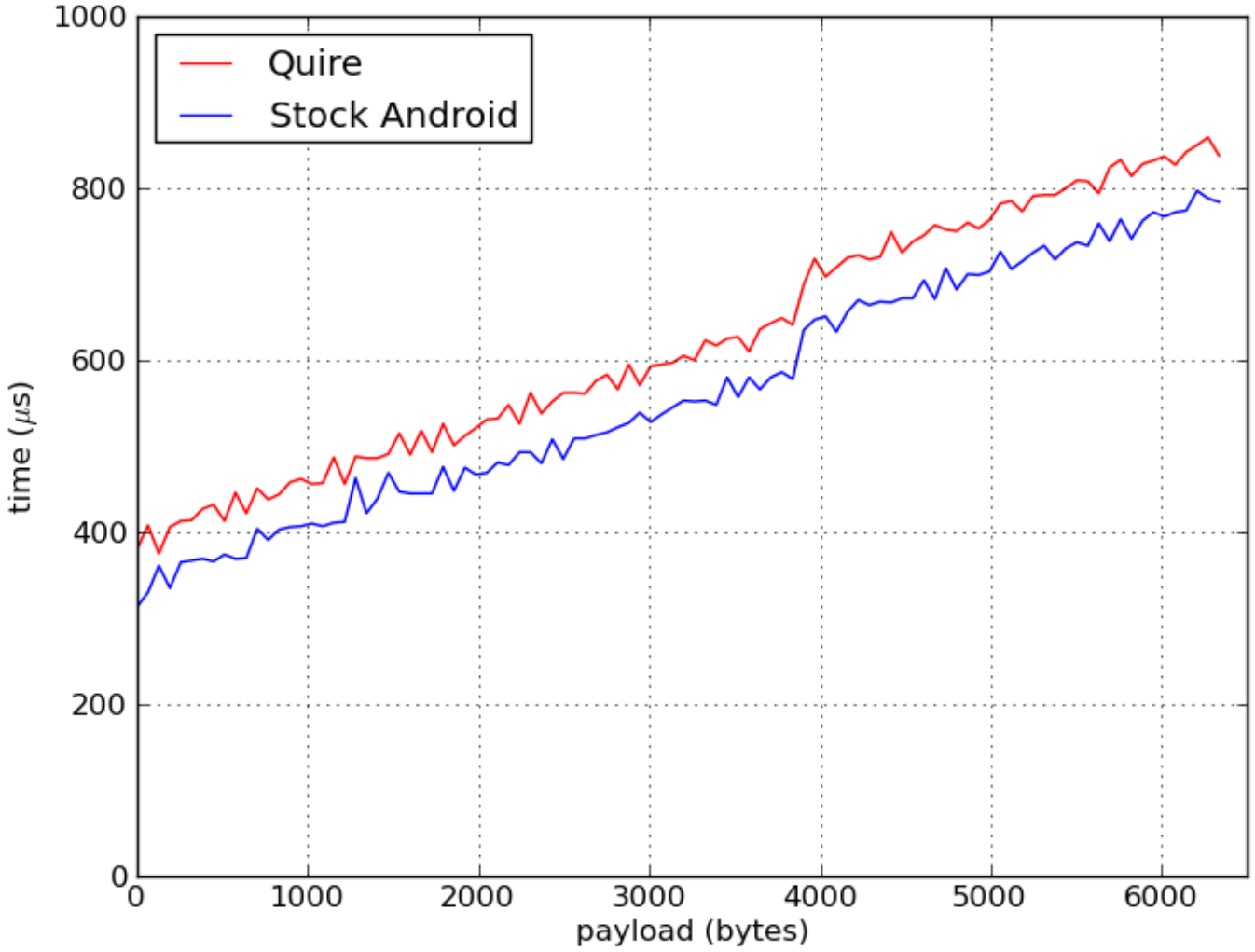
Experimental Methodology

- All experiments performed on Nexus One dev phone running Android 2.3 OS
  - 1 Ghz ARM core
  - 512 MB RAM
  - 512 MB Flash
  - Replacement of CPU intensive live wallpaper with static image to normalize CPU load
- "Stock" Android – 2.3 Gingerbread from 12/23/10
- "Quire" build based on same source with modifications

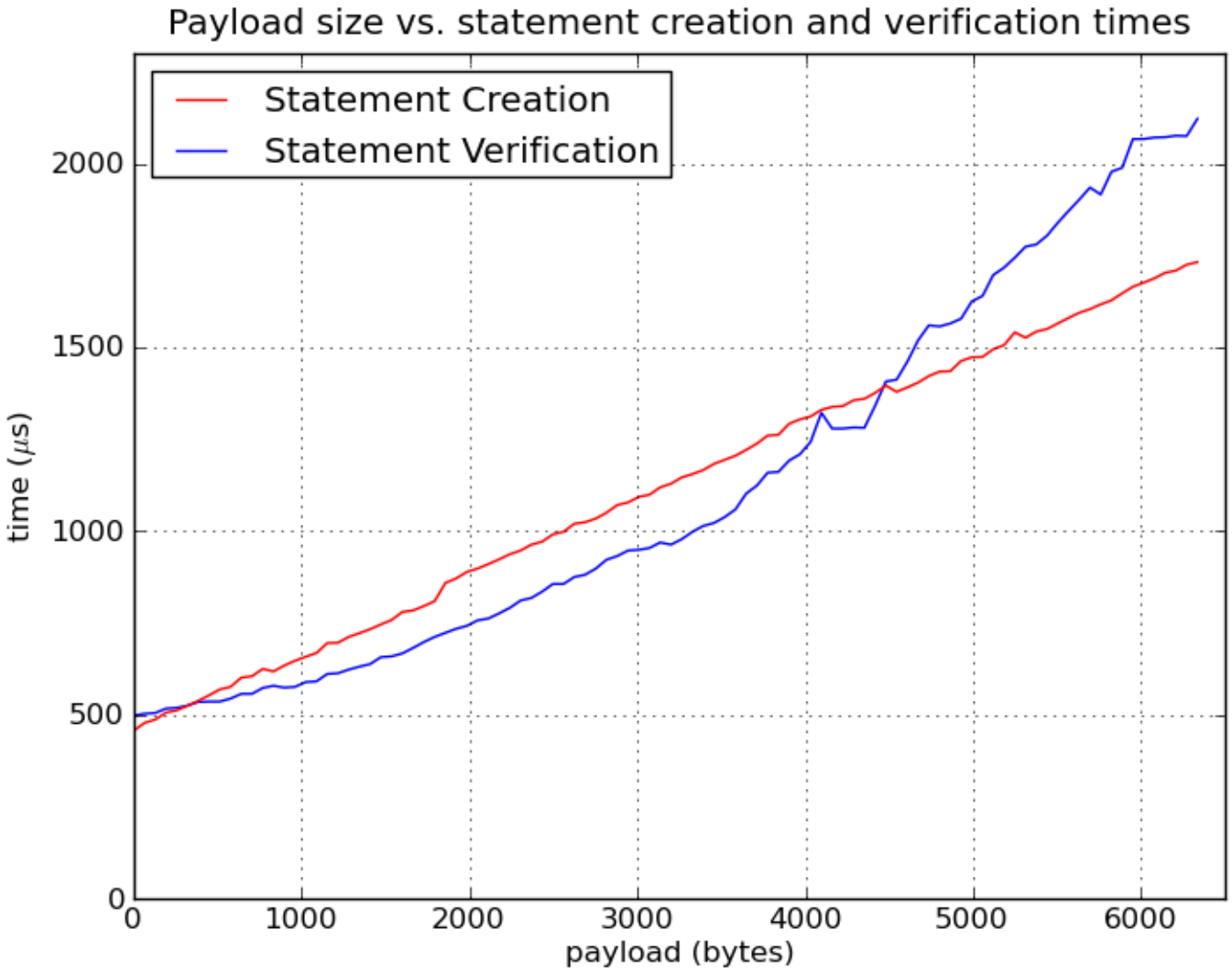
Microbenchmarks

- Purpose
  - Analyze augmented IPC performance as it compares to stock Binder IPC calls
  - Measure verifiable statement creation and verification
- Methodology
  - Average of 10k operations with varying payload sizes and statement depths
  - Issues: Garbage Collection, JIT Compiler, Imprecise timer

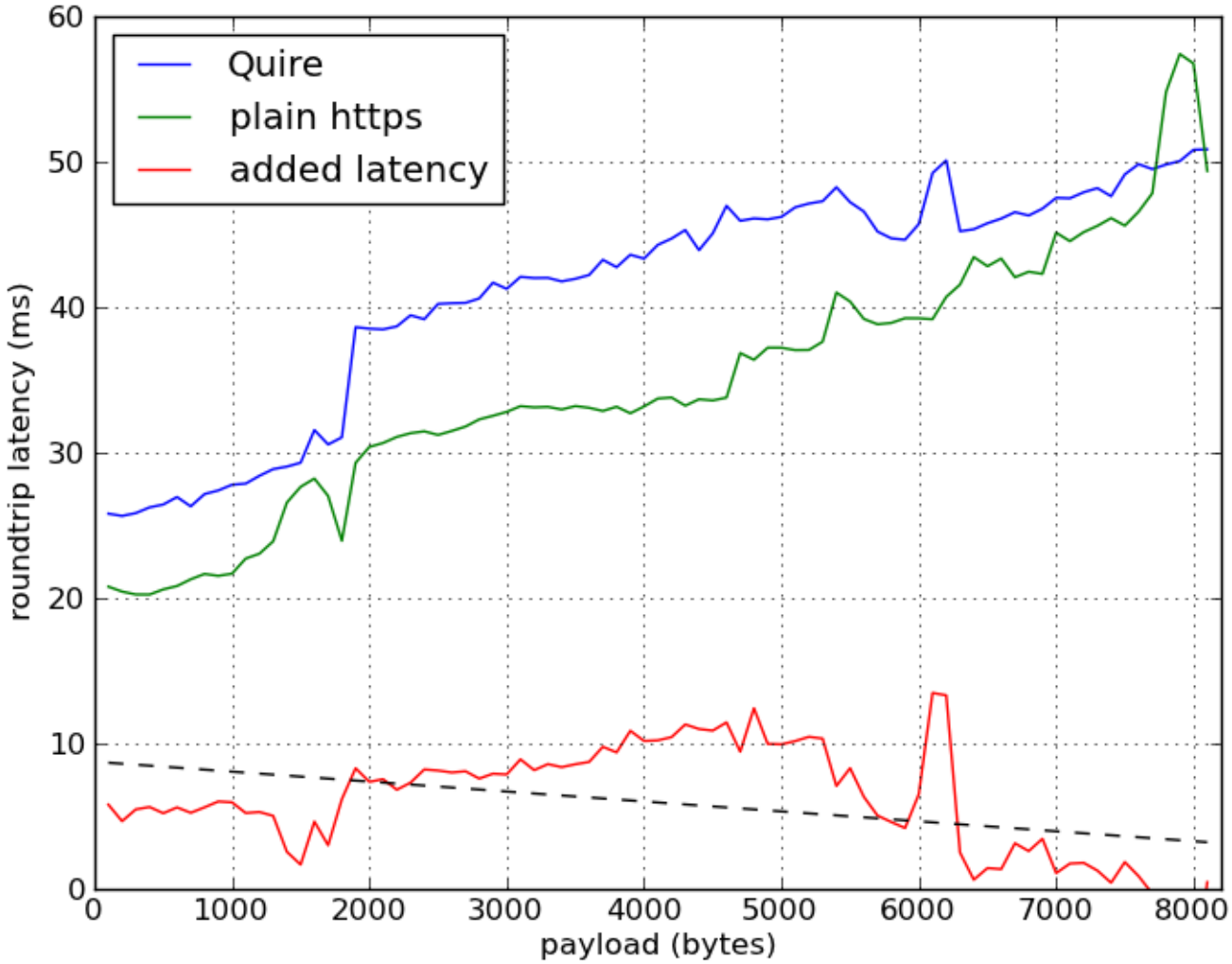
Augmented IPC Performance



Authenticated Statement Performance



Authenticated RPC Performance



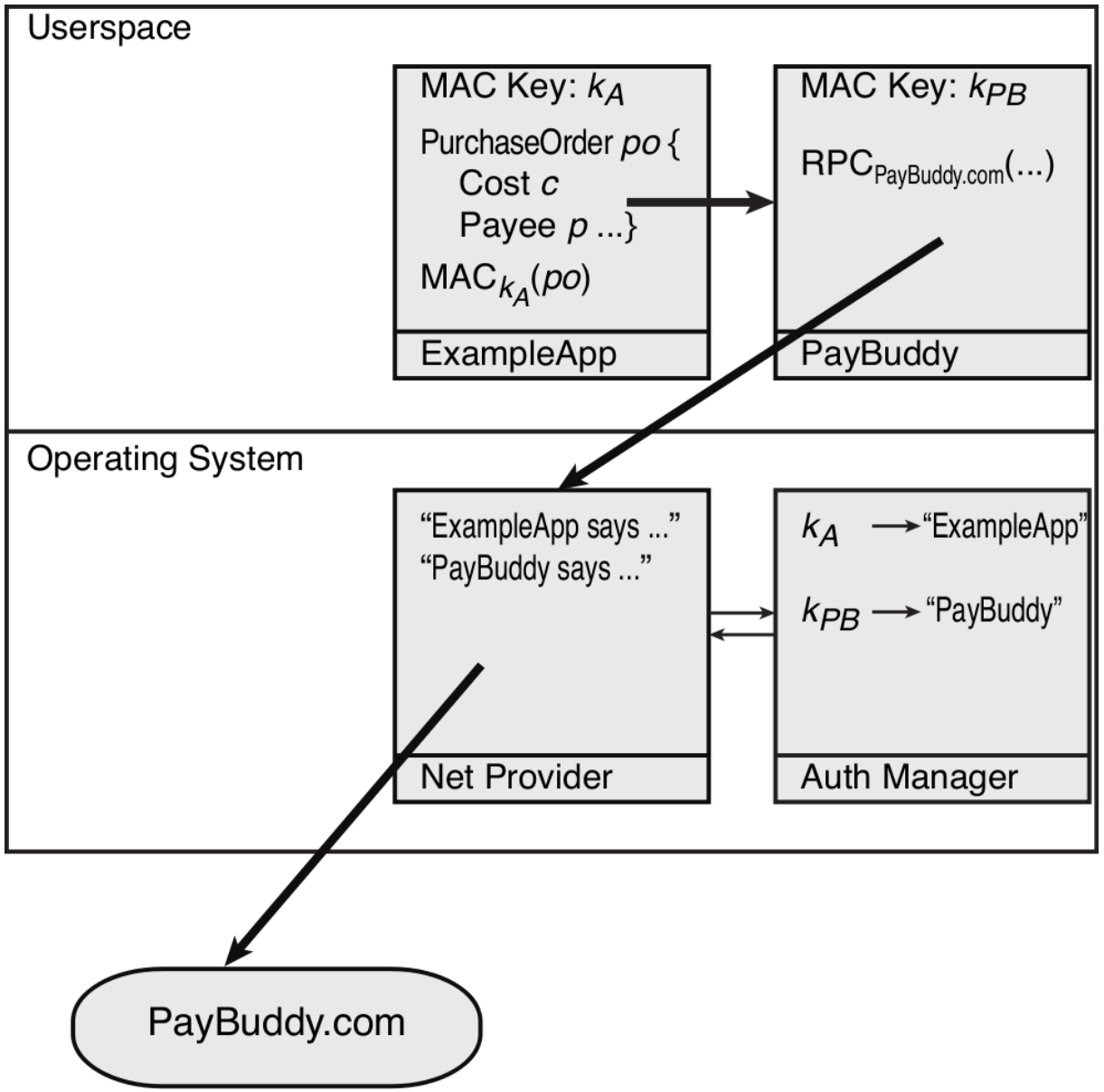
Analysis

- Provenance carrying IPC results in 20% overhead vs. stock Android (no crypto, cheap)
- Verification and creation of crypto statements are also cheap (symmetric crypto)
- Microbenchmarks represent worst case scenario

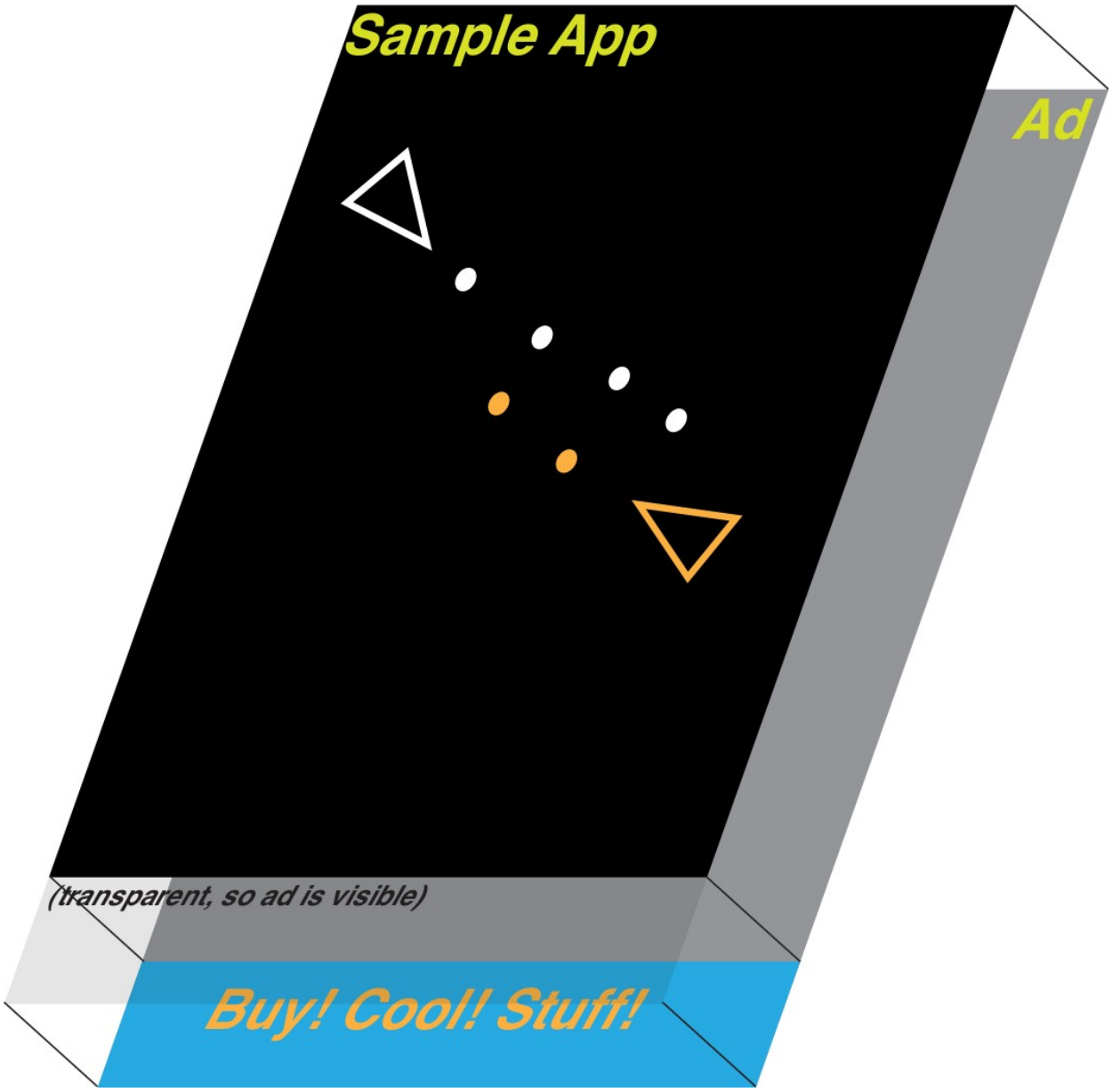
Applications built with Quire

- PayBuddy
  - Secure mobile payment system
  - IPC call chain and data integrity communicated to remote endpoint
- Mobile Ad System
  - Verifiable clicks from OS
  - UI mechanisms to detect pop-overs

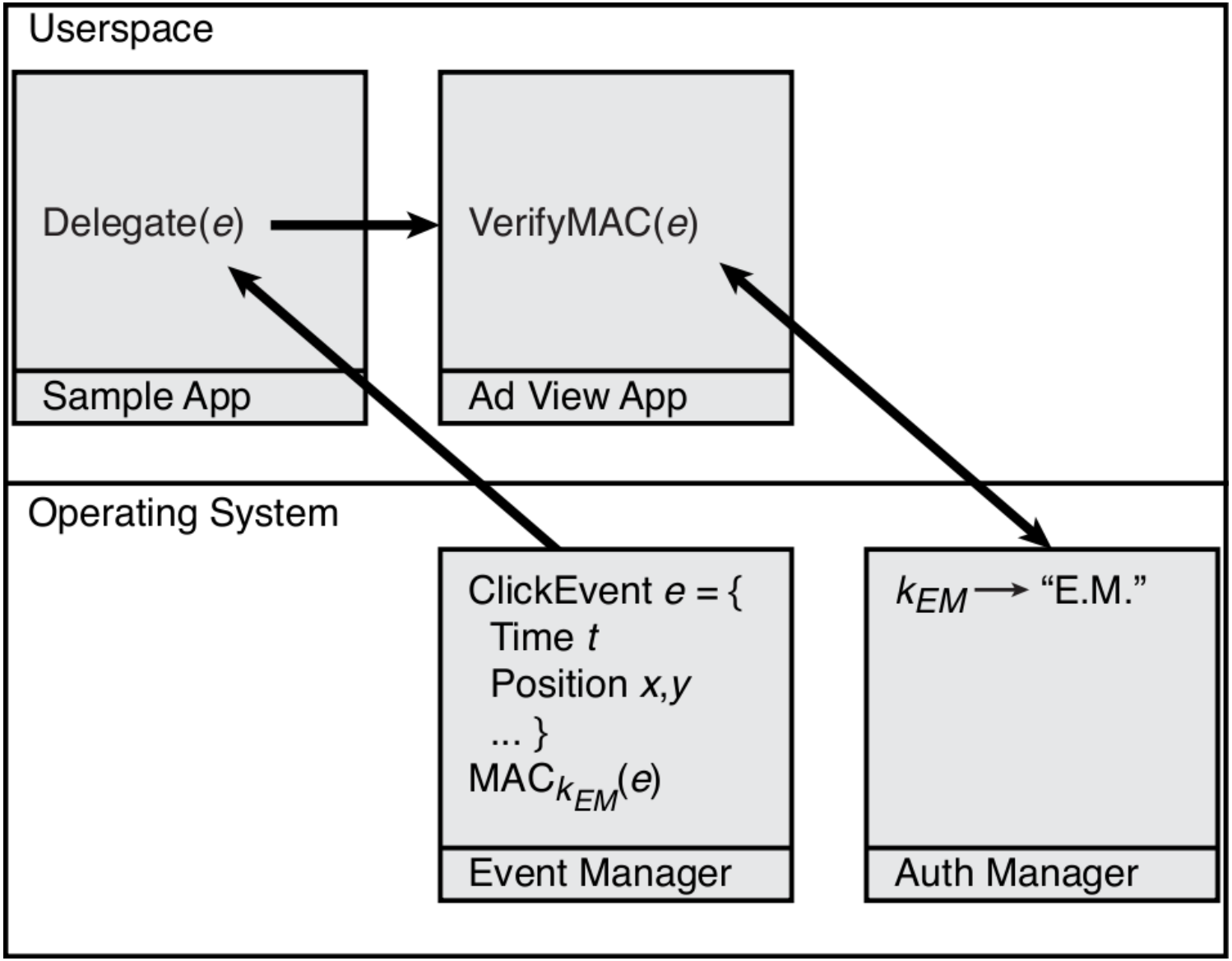
PayBuddy


Userspace
MAC Key: k_A
PurchaseOrder po {
Cost c
Payee p ...}
$MAC_{k_A}(po)$
ExampleApp
MAC Key: k_{PB}
$RPC_{PayBuddy.com}(...)$
PayBuddy
Operating System
"ExampleApp says ..."
"PayBuddy says ..."
Net Provider
k_A → "ExampleApp"
k_{PB} → "PayBuddy"
Auth Manager
PayBuddy.com

Mobile Ad System



Mobile Ad System



Related Approaches

- Define sensitive resources and protect them
  - Taint tracking
  - Stack inspection
- Statically verify third party code
  - Google's Native Client
  - Java bytecode verification
- Process-like isolation
  - Chrome, Gazelle

Taint Tracking: Overview

- Define taint sources
  - Private app data, GPS info, IMEI, user input, etc.
- Define taint sinks
  - Internet, Bluetooth, display...
- Propagate taint from a source to all objects that touch the source, repeat.
- If a tainted object ever hits a taint sink, yell!

Taint Tracking: Issues

- Requires annotation of application code
- Native code can strip taint
- Definition of a taint source?
- False positives

Static Analysis

- Google's Native Client
  - Statically analyzes code to prevent buffer overflow, return-to-libc, and other shellcode attacks against x86 code
  - Only works on x86 (for now), requires special libraries + recompilation of existing code

Process-like Separation

- Android and modern browsers closely related
  - Mutually untrusting principals
  - Third party code
  - Application / Origin segregation
- Same class of problems
  - Click fraud
  - Credential phishing
  - Ad driven services
- Notable: HTTP "Origin" header similar to our statements

Conclusions

Quire:

- Adds provenance to IPC and RPC
- Enables true application separation + apps as services
- Useful to applications and third party services
- Minimizes coding effort

Future directions

- Integrate static analysis? Foundation for web browser security?