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Certifying the Security of Android Applications with **Cassandra**

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Modeling and Analysis of Information Systems (MAIS), TU Darmstadt, Germany

partially based on

- a short talk by David Schneider
  at the 36th IEEE Symposium on Security and Privacy
- a talk by Steffen Lortz
  at the 4th ACM Workshop on Security and Privacy in Smartphones and Mobile Devices

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Motivation

privacy of sensitive data is a problem on Android mobile devices

- they store and collect plenty of sensitive information
- they are (by design) connected to the Internet
- leakage of sensitive data has often been reported in prior work

there are existing security mechanisms for Android, e.g.,

- the permission system
- malware scanning by Google
- other analysis tools from the literature

all of these suffer from (at least) one of two essential problems:

Problem 1: The provided security guarantees are unclear.

Problem 2: The mechanisms are not available to end users.

Our Solution: Cassandra

Certifying App Store for Android

allows user to certify that apps comply with his privacy requirements

- before installation
- using static information flow analysis

our novel contributions:

- a **semantically justified** information flow analysis for Android applications with a soundness proof
  - addresses Problem 1
- a tool making the analysis **available to end users** on their mobile devices
  - addresses Problem 2

Semantically Justified Certification

formal foundation of the analysis

- formal specification of Dalvik bytecode operational semantics
- notion of security defined as a noninterference property

analysis specified by a security type system

- on the bytecode level

$$\frac{M[p] = \texttt{binop}\ x_a, x_b, x_c, bop \quad \mathsf{rda}' = \mathsf{rda}[x_a \mapsto \mathsf{rda}(x_b) \sqcup \mathsf{rda}(x_c) \sqcup se(p)]}{M, region_{P,M}, \mathsf{fda}, \mathsf{mda}, ret, se \vdash p : \mathsf{rda} \to \mathsf{rda}'}$$

$$\frac{M[p] = \texttt{new-instance}\ x_a, c \quad \mathsf{rda}' = \mathsf{rda}[x_a \mapsto se(p)]}{M, region_{P,M}, \mathsf{fda}, \mathsf{mda}, ret, se \vdash p : \mathsf{rda} \to \mathsf{rda}'}$$

$$\frac{M[p] = \texttt{iget}\ x_a, x_b, f \quad \mathsf{rda}' = \mathsf{rda}[x_a \mapsto \mathsf{rda}(x_b) \sqcup \mathsf{fda}(f) \sqcup se(p)]}{M, region_{P,M}, \mathsf{fda}, \mathsf{mda}, ret, se \vdash p : \mathsf{rda} \to \mathsf{rda}'}$$

$$\frac{M[p] = \texttt{iput}\ x_a, x_b, f \quad \mathsf{rda}(x_a) \sqcup \mathsf{rda}(x_b) \sqcup se(p) \sqsubseteq \mathsf{fda}(f)}{M, region_{P,M}, \mathsf{fda}, \mathsf{mda}, ret, se \vdash p : \mathsf{rda} \to \mathsf{rda}}$$

type system proven to be sound

- all typable applications are secure

To our knowledge, this is the first static information flow analysis for Android to be proven sound!

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The Setting

our work is based on work by Barthe et al. for Java bytecode [Barthe, Picardie & Rezk, '06]

however:

- Dalvik bytecode differs from Java bytecode (register- vs. stack-based)
- previous work only focused on a small subset of instructions
- to provide guarantees for real apps, we need to consider more instructions

challenge:

- find a level of abstraction keeping the size of the model small while being suitable for reasoning about information flow

Formal Model of Dalvik Bytecode

formal syntax of Dalvik bytecode

- group patterns of instruction…
  - …that exist for optimization reasons
    (e.g., from bit-lengths of constants, types of arguments, …)
  - …that are parametric in some way
    (e.g., binary operations, …)

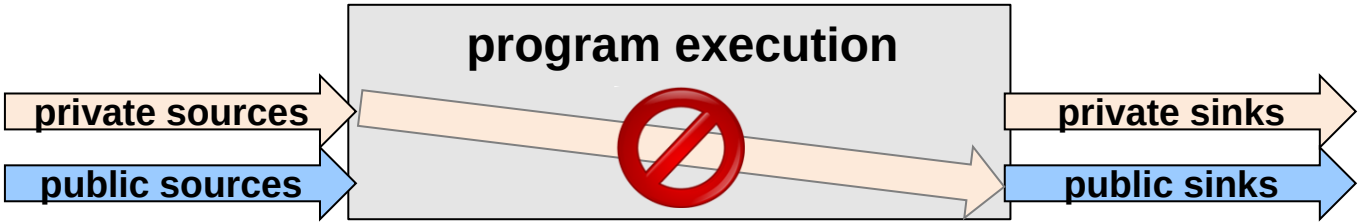
Abstract instruction	Concrete instruction
`const` x_a, n	`const`, `const/4`, `const/16`, `const/high16`
`binop` x_a, x_b, x_c, op	`add-int`, `sub-int`, `mul-int` (+ 13 more)

  - 55 abstract instructions capture 211 of 217 concrete instructions

Security Property

noninterference [Goguen & Meseguer, ‘82]

- the public output of a program must not depend on its secret input
- an observer does not learn secret input by observing the program



two-level lattice of *security domains* $(D, \sqsubseteq)$

- D encodes the levels of confidentiality
- $\sqsubseteq$ encodes how information may flow between domains

indistinguishability relations $\sim_p$

- relate pairs of program configurations that look the same to an observer who can access only public information (depending on the *policy* p)

Security Property

Definition: Security of Methods

A method M of a program P is *secure* w.r.t. a policy p iff any two indistinguishable initial states produce indistinguishable final states.

$$\begin{array}{ccc} \langle 0, \mathrm{r}_1, \mathrm{h}_1 \rangle & \Downarrow_{P,M} & \langle \mathrm{v}_1, h_1' \rangle \\ \sim_p \Big| \quad \Big| \sim_p & & \sim_p \vdots \quad \vdots \sim_p \\ \langle 0, \mathrm{r}_2, \mathrm{h}_2 \rangle & \Downarrow_{P,M} & \langle \mathrm{v}_2, h_2' \rangle \end{array}$$

intuition:

- if only the secret input of a program differs, public output is the same
- hence: the public output does not depend on secret input

Definition: Security of Programs

A program P is *secure* w.r.t. a policy p iff all its entry points are secure w.r.t. p.

Security Type System

the information flow analysis is formalized as a security type system

- typing judgments of the following form:

$$M, region_{P,M}, \mathsf{fda}, \mathsf{mda}, ret, se \vdash n : \mathsf{rda} \rightarrow \mathsf{rda}'$$

- types the instruction at program point n in method M
  - rda and rda' assign security domains to registers before and after execution, respectively

example of a typing rule:

$$\frac{M[p] = \texttt{binop}\ x_a, x_b, x_c, bop \qquad \mathsf{rda}' = \mathsf{rda}[x_a \mapsto \mathsf{rda}(x_b) \sqcup \mathsf{rda}(x_c) \sqcup se(p)]}{M, region_{P,M}, \mathsf{fda}, \mathsf{mda}, ret, se \vdash n : \mathsf{rda} \rightarrow \mathsf{rda}'}$$

Soundness of the Type System

Theorem: Soundness

For all programs P and all policies p

if P is typable with respect to p,

then P is secure with respect to p.

Solution to Problem 1: The provided security guarantee is clear.

we have…

- …a precise, formal definition of security
- …a proven guarantee that the analysis enforces this notion of security

Availability to End Users

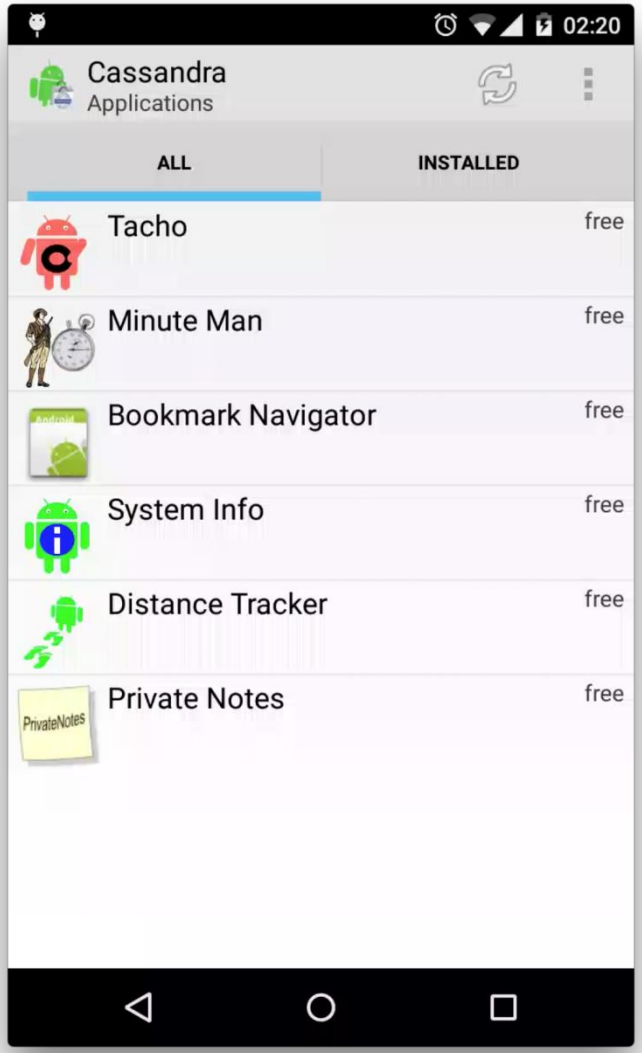
Problem 2: The mechanisms are not available to end users.

goal: make analysis available to end users on their mobile devices

challenges:

- users have different security requirements
  - how can a non-expert user express his requirements in a security policy?
- mobile devices have limited resources
  - certifying applications on the device is costly

Cassandra in Action



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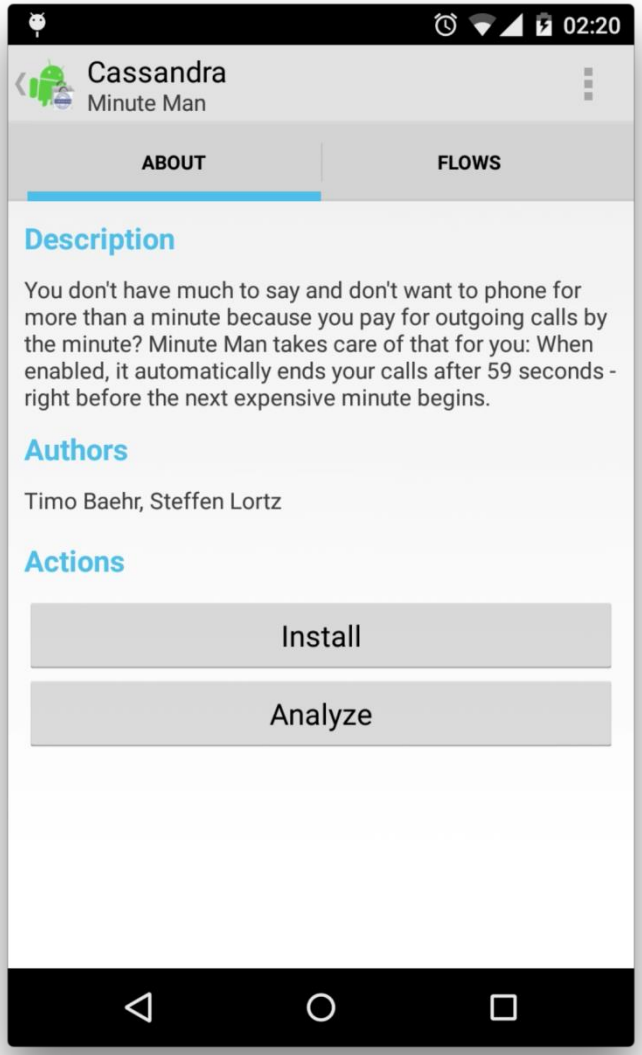

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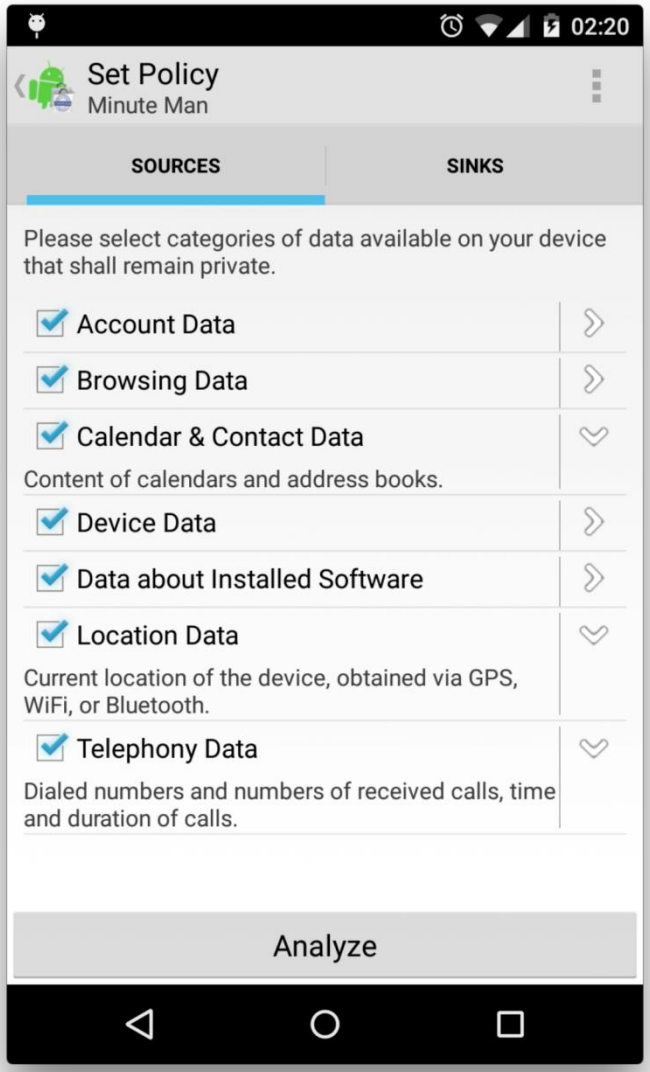

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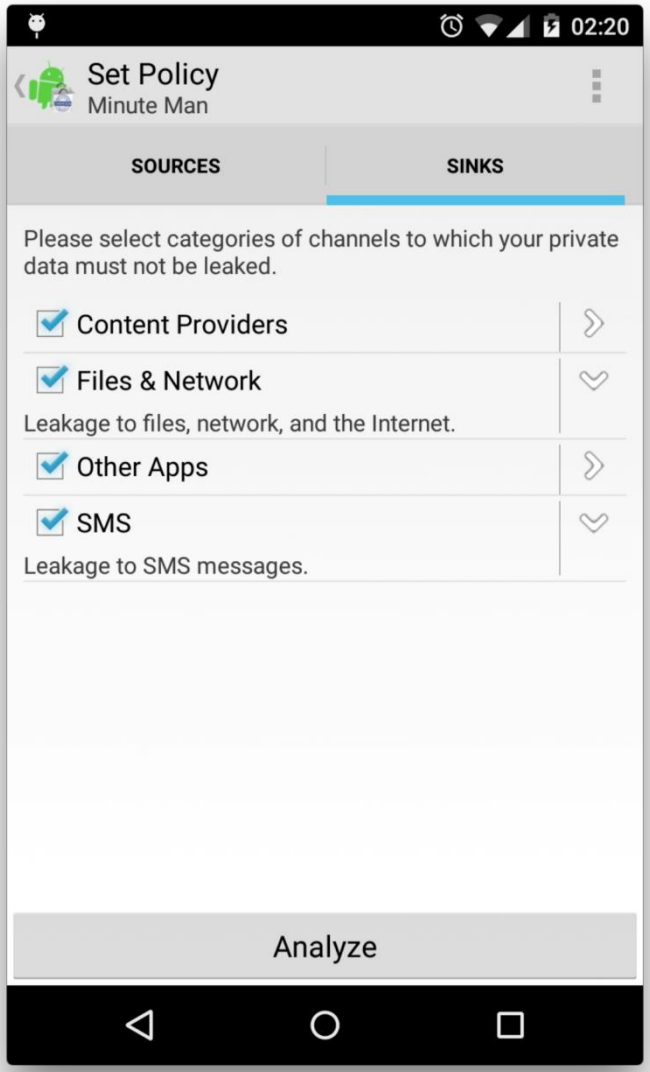

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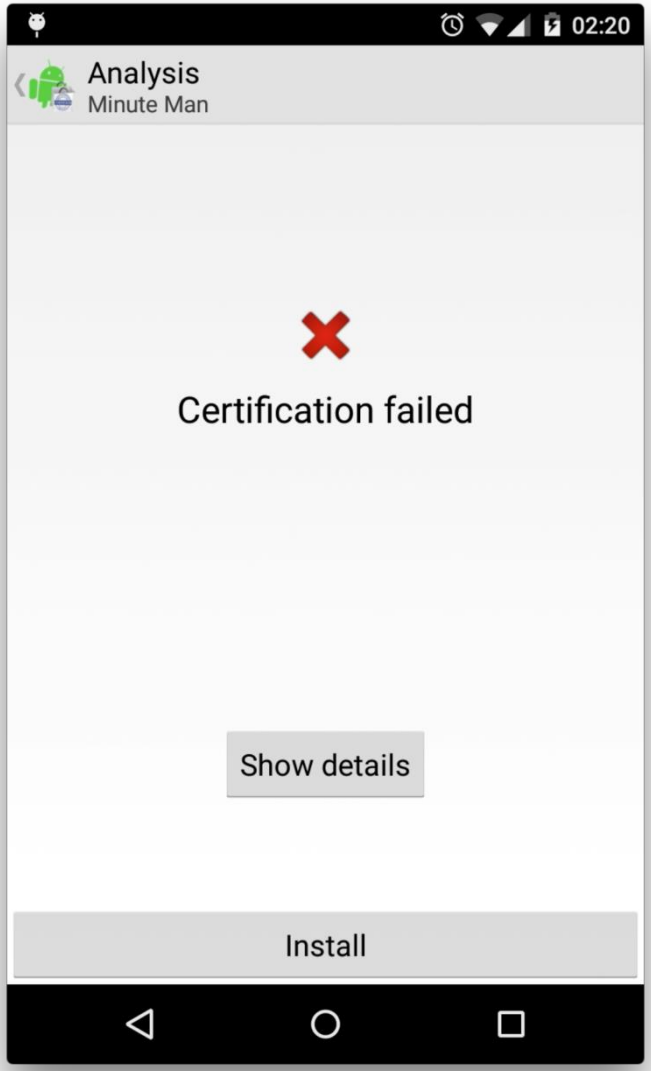

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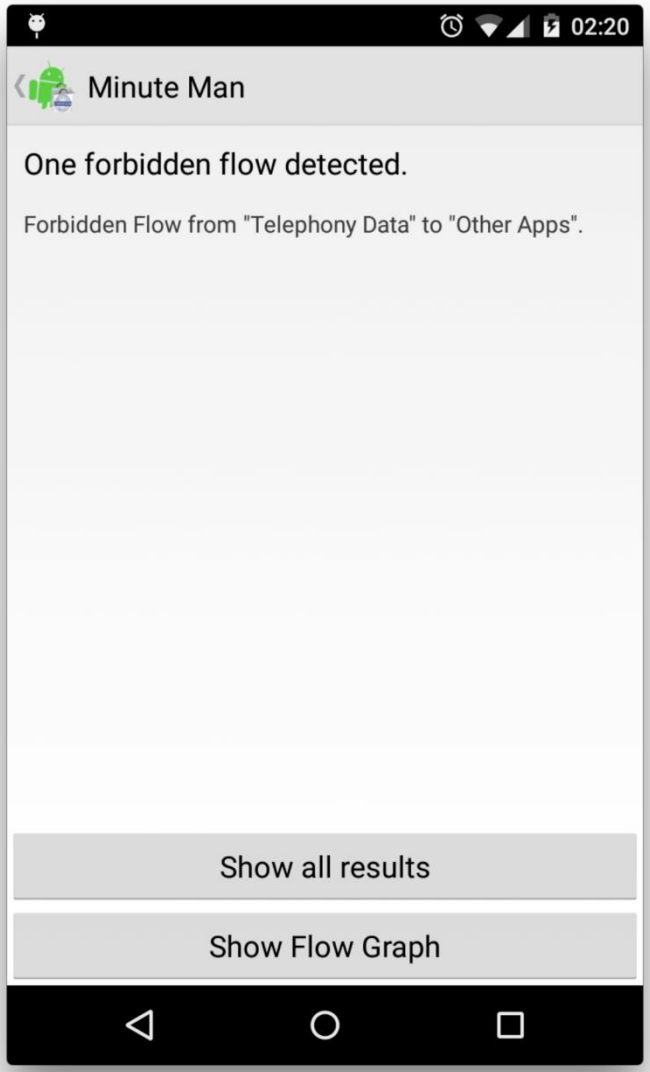

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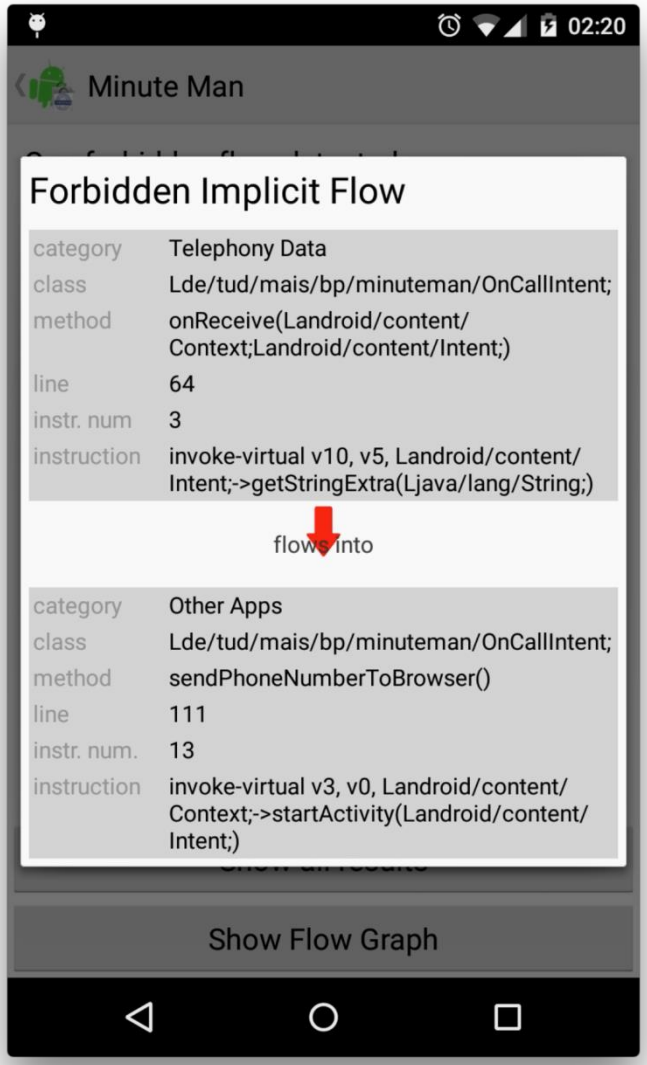

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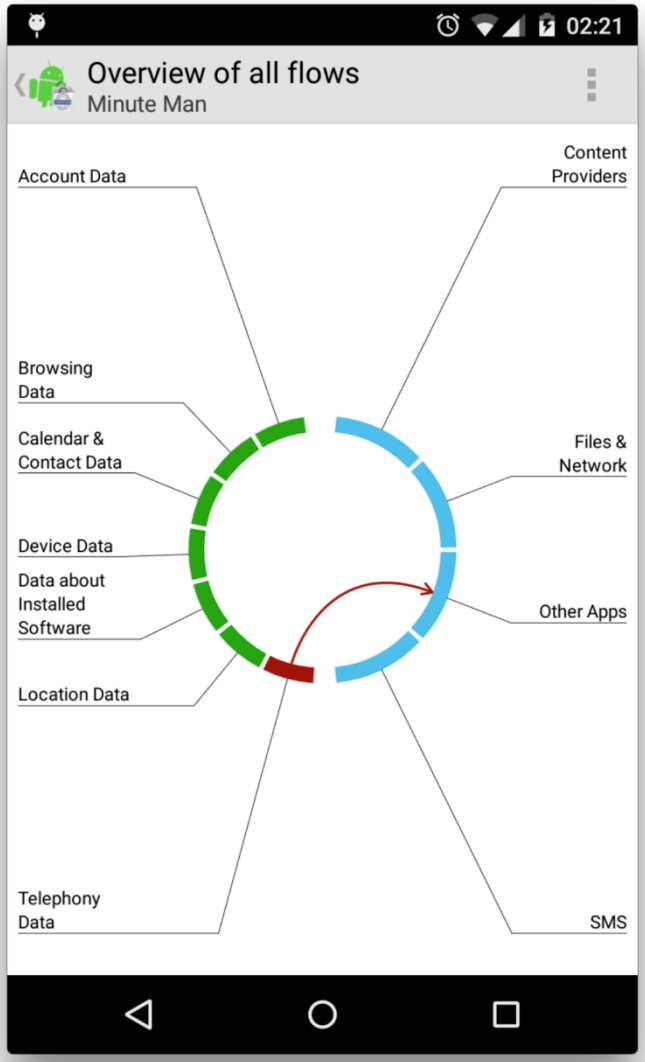

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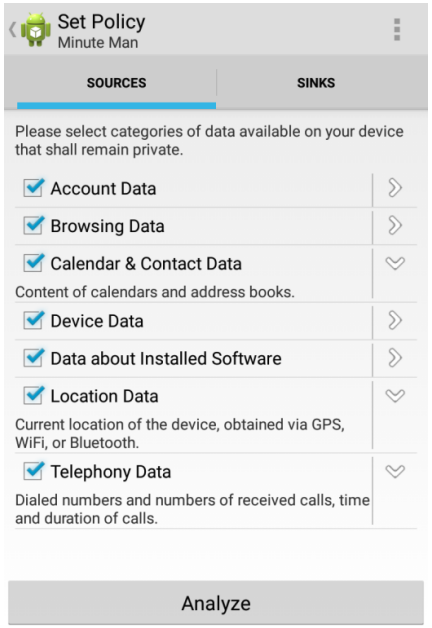
Certifying Applications

input to the certification:

- a partial security typing determined from the user's choice of categories

output of the certification:

- a complete and valid security typing of the app, if possible
- hence, certification is type inference
- the complete typing is a *security certificate*



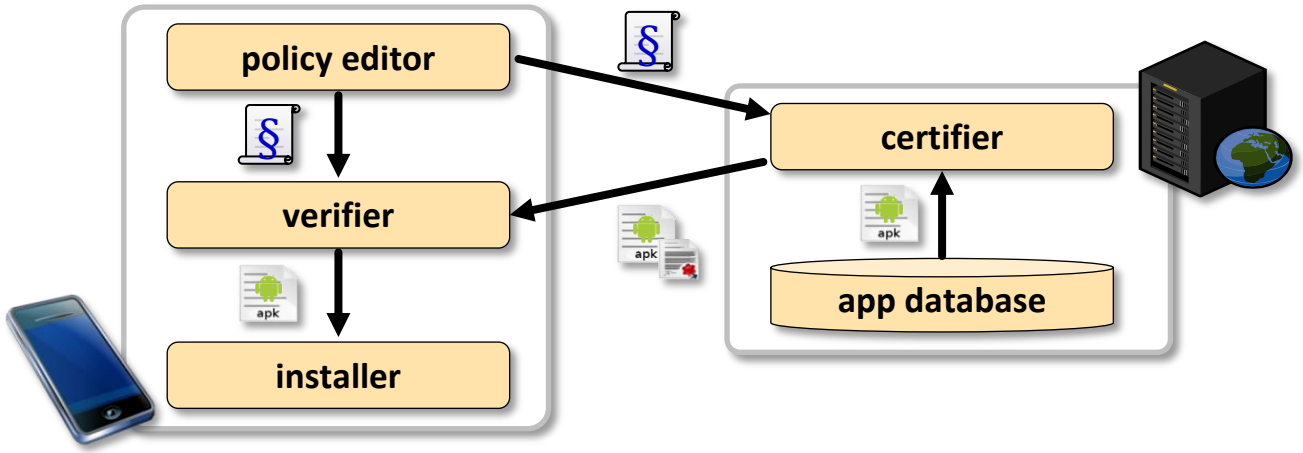
can exceed the resources of a mobile device

- limited computing power: may take too long to be convenient
- limited power: may drain the battery

hence: certify applications on the server that distributes apps

Architecture

we use *proof-carrying code* [Necula, '97]



- compute the security certificate for an app and policy on the server
  - complex type inference
- transmit the certificate along with the application to the mobile device
- verify the certificate on the mobile device
  - quick and simple type check
- cache certificates to increase response time

Main Contributions

in summary, our contributions are:

- a **formal operational semantics** for a large subset of the Dalvik bytecode instruction set
- a **semantically justified** static information flow analysis for Android applications with a soundness proof

Solution to Problem 1: The provided security guarantee is clear.

- an architecture and a tool making the analysis **available to end users** on their mobile devices

Solution to Problem 2: The solution is available to end users.

Cassandra: Present and Future

used as the basis of the **RS³ Certifying App Store**

- integrates different security technologies into an app store
- presented by a poster at S&P ’15

ongoing:

- experimental evaluation with open source apps from F-Droid

next goal:

- certification of third-party apps

to get more info about Cassandra:

- visit: http://www.mais.informatik.tu-darmstadt.de/cassandra.html
- read our paper:

  S. Lortz, H. Mantel, A. Starostin, T. Bähr, D. Schneider, and A. Weber.
  Cassandra: Towards a Certifying App Store for Android. In Proceedings of the 4th ACM Workshop on Security and Privacy in Smartphones and Mobile Devices, 2014.

Cassandra

Thank you for your attention!

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http://www.reliably-secure-software-systems.de