

Security and Trust Architectures for Protecting Sensitive Data on Commodity Computing Platforms

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Kurzfassung (Summary in German)

Viele Computer-Anwendungen benötigen eine sichere Ausführungsumgebung, um die Vertraulichkeit und Integrität ihrer Daten zu schützen. Obwohl es bereits verschiedene Ansätze in der Kryptographie und in der Anwendungssicherheit gibt, schlagen diese in der Praxis letztendlich fehl aufgrund unsicherer Betriebssysteme und falscher Annahmen bezüglich der Vertrauenswürdigkeit der zugrunde liegenden Computerplattformen.

Die Entwicklung sicherer Betriebssysteme war und ist immer noch ein komplexes Problem. In der Vergangenheit entwickelte sich deshalb die Idee des *Sicherheitskerns*: Alle relevante Sicherheitsfunktionalität wurde innerhalb eines kleinen Kerns implementiert, der folgende Eigenschaften hatte: komplette Kontrolle über alle Objekte; Selbstschutz gegen Manipulation; und geringe Codegröße zur Erleichterung einer formalen Verifikation. Es stellte sich jedoch heraus, daß selbst die Konstruktion einer solchen kleinen vertrauenswürdigen Basis in der Praxis bereits aufwendig und schwierig war. Zudem wiesen frühe Implementierungen eine sehr schlechte Performanz auf. Daher ist die Idee des Sicherheitskerns nie in die Entwicklung von Standardbetriebssystemen eingeflossen.

In dieser Dissertation präsentieren wir Sicherheitsarchitekturen, die in der Lage sind, sensible Daten auch auf gewöhnlichen (PC-)Computerplattformen zu schützen. Die Integration von *Trusted Computing* Technologie in heutige Standardplattformen erlaubt die Einbettung zusätzlicher Sicherheitsfunktionen direkt in die Hardware. Außerdem besitzen moderne Prozessoren hardware-seitig unterstützte Virtualisierungstechnologie. Basierend auf diesen Funktionalitäten, sowie neuer Ergebnisse zur Konstruktion von Mikrokernen, verwenden wir die Idee der Sicherheitskerne wieder und entwerfen Sicherheitsarchitekturen, die Endbenutzer verwenden können, um ihre Systeme und ihre Daten gegen eine Vielzahl von Bedrohungen zu schützen.

Ein erster Beitrag dieser Arbeit ist die Verbesserung von Sicherheitsarchitekturen, die Virtualisierung verwenden. Ein wichtiger Aspekt in diesem Kontext ist die Virtualisierung von Hardware-Sicherheitsmodulen wie die des Trusted Platform Module (TPM). Wir präsentieren daher das *property-based vTPM*, ein flexibles und datenschutz-erhaltendes virtuelles TPM. Es integriert verschiedene Ansätze zur Ermittlung des Integritätszustandes einer Plattform und zur Erstellung von kryptographischen Schlüsseln. Dies ermöglicht einen flexibleren Umgang mit Softwareupdates und Migration von virtuellen Maschinen bei gleichzeitiger Beachtung der erforderlichen Sicherheitseigenschaften.

Ein weiterer Beitrag ist der Entwurf und die Implementierung einer Sicherheitsarchitektur gegen Phishing-Angriffe, d.h. Angriffe, die versuchen Passwörter eines Be-

nutzers zu stehen. Die Hauptidee hierbei ist ein *trusted password wallet (TruWallet)*, das sich anstelle des Benutzers um den Login-Vorgang auf Webseiten kümmert. Dazu speichert TruWallet sicher alle Passwörter des Benutzers und führt die Login-Vorgänge aus. Im Gegensatz zu anderen Ansätzen liefert TruWallet Schutz gegen die stärkste Art des Phishing-Angriffs, nämlich gegen Phishing-Malware, die auf dem Rechner des Anwenders läuft.

Wir zeigen ferner eine Sicherheitsarchitektur, um über mehrere Plattformen hinweg gemeinsam genutzte Informationen zu schützen. Diese Architektur basiert auf dem Konzept von *Trusted Virtual Domains (TVDs)* und realisiert im wesentlichen eine verteilte Informationsflußkontrolle. Wir erweitern dieses Konzept über die übliche Verwendung in Rechenzentren hinaus und beziehen auch Plattformen von Endanwendern ein. Um deren spezielle Anforderungen zu berücksichtigen, entwerfen wir eine transparente Verschlüsselung von mobilen Datenträgern (z.B. USB-Sticks), die konform zu einer gegebenen Informationssicherheitspolitik arbeitet. Außerdem evaluieren wir eine vollständige Implementierung des TVD-Konzepts auf einem existierenden Desktop-Betriebssystem.

Schließlich schauen wir uns einige besondere Anwendungsszenarien an, die zwar ebenfalls eine vertrauenswürdige Plattform benötigen, aber nicht notwendigerweise einen permanent laufenden Software-Sicherheitskern. Dazu nutzen wir die erweiterten Funktionen moderner Hauptprozessoren, um eine sichere Ausführungsumgebung bereitzustellen, auf der wir einen *Unidirectional Trusted Path (UTP)* realisieren, d.h. einen vertrauenswürdigen Kommunikationspfad in nur eine Richtung: vom lokalen Anwender zu einer entfernten Partei. Wir evaluieren eine vollständige Implementierung dieses Ansatzes und zeigen, daß UTP eine Alternative für CAPTCHAs sein kann und daß man damit eine sichere Transaktionsbestätigung für Online-Einkäufe realisieren kann.

Die vorgestellten Sicherheitsarchitekturen dieser Dissertation ermöglichen den Schutz sensibler Daten (sowohl persönlicher als auch gemeinsam genutzter) auf heute üblichen Computerplattformen. Die präsentierten Ergebnisse zeigen, daß eine sichere Ausführung von Anwendungen ermöglicht werden kann, wenn man eine kleine Sicherheitsschicht unter der normalen Betriebssystemumgebung ausführt. Dies kann so realisiert werden, ohne die Funktionsvielfalt und Kompatibilität vorhandener Standardbetriebssysteme zu verlieren.

Abstract

Many applications rely on a secure execution environment in order to provide confidentiality and integrity of their data. Although various approaches both in cryptography and application security exist, they finally fail because of insecure operating systems and false assumptions in practice about the trustworthiness of the underlying computing platform.

The design and implementation of secure operating systems was and is still a complex problem. The idea of the *security kernel* evolved in the past to overcome this problem: All relevant security functionality was implemented in a small kernel which provided a complete control over shared objects, a sufficient protection of itself against tampering, and was small enough to allow a formal verification of its correctness. However, it turned out that even the construction of this small trusted computing base was already a hard problem in practice and early implementations suffered from poor performance. Hence, the idea was not adopted in mainstream operating systems.

In this thesis, we present security architectures that are able to protect sensitive data on commodity computing platforms. The incorporation of *trusted computing* concepts in commodity platforms allows for additional security functionality embedded directly into the hardware. In addition, modern main processors include support for hardware virtualization. Based on these functionalities as well as recent results in the construction of microkernels, we reuse the idea of security kernels and design security architectures that end-users can use to protect their systems and their data against a number of threats.

The first major contribution of this thesis is the improvement of security architectures that use virtualization. A crucial aspect in this context is the virtualization of hardware security modules like the Trusted Platform Module (TPM). We therefore present the *property-based vTPM*, a flexible and privacy-preserving design of a virtual TPM. It integrates different approaches for measuring the platform's state and for key generation, which results in enhanced support of both software updates and migration of virtual machines, without losing the required security properties.

Another main contribution is the design and implementation of a security architecture against phishing attacks, i.e., attacks that try to steal passwords from users. The key idea is a *trusted password wallet (TruWallet)* that removes the burden of authentication from users when they login to web sites. TruWallet stores all passwords and automatically performs the login at the server on behalf of the user. In contrast to other approaches against phishing, the combination of the wallet, an underlying security kernel, and the incorporation of trusted computing functionality provides protection measures against the

strongest type of phishing attacks, i.e., phishing malware running on the user's computer.

We also present a security architecture to protect shared information across different computing platforms. This architecture is based on the existing concept of *Trusted Virtual Domains (TVDs)*, which essentially realizes a distributed enforcement of information flow control. We extend this concept beyond its usually proposed usage in data centers to include individual computing platforms of end-users. To address the specific needs of end-users, we design a transparent cryptographic data protection of mobile storage devices (e.g., USB memory sticks) according to the information security policy, and we evaluate a full implementation of the TVD concept on an existing desktop operating system.

Finally, we look into special application scenarios that require a trustworthy platform, but which can be realized without the need for a persistently running security kernel in software. We therefore leverage the enhanced functionality of modern processors to provide a secure execution environment, and build a *Unidirectional Trusted Path (UTP)*, i.e., a trusted path from the local user to a remote party. We evaluate a full implementation of this approach, and we show how it can be used as alternative for CAPTCHAs, or to create a secure transaction confirmation for online purchases.

The security architectures presented in this thesis enable the protection of sensitive personal data and the protection of information sharing on commodity computing platforms. The results demonstrate that a secure execution of applications can be provided by introducing a small security layer underneath the normal operating environment without losing the feature-richness and compatibility of commodity operating systems.

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