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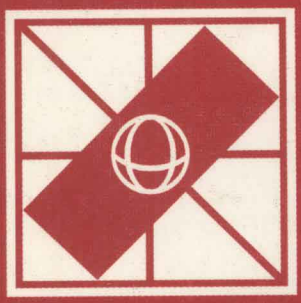

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Preface

This volume contains the proceedings of the 24th IFIP TC 6/WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems (FORTE 2004), held in Madrid, Spain, September 27–30, 2004. FORTE denotes a series of international working conferences on formal description techniques applied to computer networks and distributed systems. The conference series started in 1981 under the name PSTV. In 1988 a second series under the name FORTE was set up. Both series were united to FORTE/PSTV in 1996. Three years ago the conference name was changed to its current form. The last five meetings of this well-established conference series were held in Beijing, China (1999), Pisa, Italy (2000), Cheju Island, Korea (2001), Houston, USA (2002), and Berlin, Germany (2003).

The scope of the papers presented at FORTE 2004 covered semantic models and application of formal description languages (in particular, automata and Petri Nets), as well as the verification and testing of communication and distributed systems. The conference was preceded by 2 half-day tutorials by Roberto Gorrieri and Farn Wang. The proceedings contain the 20 regular papers accepted and presented at the conference. They were selected from 54 submitted papers in a careful selection procedure based on the assessment of three referees for each paper. The proceedings also include the papers contributed by the three invited speakers: Martín Abadi, Tommaso Bolognesi, and Juan Quemada.

FORTE 2004 was organized under the auspices of IFIP TC 6 by Universidad Complutense de Madrid. We would like to express our gratitude to the numerous people who contributed to the success of FORTE 2004. The reviewing process was one of the major efforts during the preparation of the conference, including not only PC members but additional reviewers. Finally, we would like to thank the local organizers for the excellent running of the conference. In particular, Luis Llana (as Web master), Natalia López (as organizing chair), and Fernando Rubio (as publicity chair) deserve a special mention. Last, but not least, we are in debt to Richard van de Stadt, the author of CyberChair, the tool we used to deal with the whole organization process.

We would like to mention that this is the first time that FORTE had three colocated workshops:

- TheFormEMC: 1st International Workshop on Theory Building and Formal Methods in Electronic/Mobile Commerce
- EPEW: 1st European Performance Engineering Workshop
- ITM: 1st International Workshop on Integration of Testing Methodologies

The proceedings of these workshops, which took place on the 1st and 2nd of October in Toledo, are also published by Springer in the LNCS series.

September 2004

David de Frutos-Escrig
Manuel Núñez

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We want to express our gratitude for the collaboration of the former members of the Steering Committee: Ed Brinksma, Stan Budkowski, Elie Najm, and Richard Tenney.

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Table of Contents

A Logical Account of NGSCB

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Abstract. As its name indicates, NGSCB aims to be the "Next-Generation Secure Computing Base". As envisioned in the context of Trusted Computing initiatives, NGSCB provides protection against software attacks. This paper describes NGSCB using a logic for authentication and access control. Its goal is to document and explain the principals and primary APIs employed in NGSCB.

1 Introduction

NGSCB ("Next-Generation Secure Computing Base", formerly known as "Palladium") integrates hardware and software components that aim to help in protecting data and processes against software attacks [8,9,14,15]. The hardware includes a cryptographic co-processor that contains keys and offers basic cryptographic services. The software includes new, trusted operating system components.

While the architecture and the implementation of NGSCB continue to evolve, quite a few of its features have been discussed in public. We believe that it is worthwhile to elucidate them further. Many of these features seem likely to remain important as NGSCB matures, and also appear in other projects and research efforts in the area of Trusted Computing [1,10,12,13,16].

In this paper, we present an attempt to understand the fundamentals of NGSCB in terms of a logic for authentication and access control. This formalism had its origins in the context of the Taos operating system and of the Digital Distributed System Security Architecture [11,12,18]. In this application to NGSCB, we use the logic for describing relationships between principals while abstracting away most of the details of the underlying cryptographic protocols. Although it may be feasible and perhaps attractive, we do not relate the logic to concrete implementations, nor base new implementations on the logic. Our goal is to document the components and primary APIs employed in NGSCB, and to provide concise and principled explanations for them.

At present, one may view all work on NGSCB as "work in progress". This paper is no exception. Because the specifics of NGSCB remain subject to change, we are less concerned with giving a detailed and up-to-the-minute account than with providing a consistent explanation of important concepts and techniques.

The next section reviews the logic. Section 3 reviews the basics of NGSCB. Sections 4, 5, and 6 describe principals, derived authorities, and the certification infrastructure (which is external to NGSCB but necessary for its applications).

D. de Frutos-Escrig and M. Núñez (Eds.): FORTE 2004, LNCS 3235, pp. 1-12, 2004.

Section 7 deals with the main system services in logical terms. Section 8 briefly addresses privacy. Section 9 discusses an example. Section 10 concludes.

2 A Brief Logic Review

The logic enables us to describe a system in terms of principals and their statements. The logical formula *P says s* means that principal *P* makes or supports statement *s*. The principal may for example be a user, a piece of hardware, the combination of some hardware and some software, or a cryptographic key.

We also allow compound principals, particularly of the form $P \mid C$. The meaning of $P \mid C$ is "*P* quoting *C*"; we have that $P \mid C$ says *s* when *P* says that *C* says *s*. For instance, *P* may represent a piece of hardware, and *C* a piece of code or a user.

In addition, the logical formula $P \Rightarrow Q$ means that *P* speaks for *Q*, so if *P says s* then *Q says s*, for every *s*. We generally assume the *hand-off axiom* which says that if *Q says* $P \Rightarrow Q$ then indeed $P \Rightarrow Q$. We use the "speaks for" relation for many purposes. For instance, we often write that a key *K* speaks for a principal *P* when *K* is *P*'s public signature key. Typically only *P* knows the corresponding signing key (*K*'s inverse) and can produce signatures that can be checked with *K*. We may also write that a principal speaks for any group of which it is a member; thus, when we write that *P* speaks for a group we typically mean that *P* is or speaks for some member of the group, not necessarily all members of the group. (It would be easy to extend the logic with a membership relation, and to replace "speaks for" with membership in these uses; whether this extension is worth the trouble remains open to debate.) We may represent an access control list (ACL) as the group of the principals authorized by the list. If G_X is the ACL for accessing an object *X*, then *P* speaks for G_X when *P* is authorized to access *X*.

Although the logic does not lead to correctness proofs of the kind expected in high-assurance systems, this logic and its relatives have been useful in several ways in the past. Much as in this paper, the logic has served for describing and documenting the workings of a system, what the system achieves, and on what assumptions it relies, after the fact or in the course of development. In this respect, formal notations do not accomplish anything beyond the reach of careful, precise prose, but they are helpful. The logic has also served in validating particular techniques for authorization, reducing them to logical reasoning, and also as a basis for new techniques; research on stack inspection and proof-carrying authorization exemplify this line of work [3,6,17,18]. Finally, the logic has served as a foundation for languages for writing general security policies [7].

We refer to previous papers for more detailed descriptions of the logic and its applications.

3 Assumptions on NGSCB

We assume that at the root of any NGSCB node there exists a hardware-based security facility that implements cryptosystems, random number generation, and key storage. We use the term *Security Support Component* (*SSC*) to describe this facility

since it has been previously used in related literature. The Trusted Platform Module (TPM) from the Trusted Computing Group [16] may be the main current example of an SSC.

We further assume that the hardware has the capability to load an operating system that can be reliably identified by taking a hash (or *code-id*) of the initial operating system image and data. This operating system, so loaded, will reside in a protected area of memory that cannot be accessed by untrusted code that the operating system might load. Therefore, the hardware has reason to believe that the statements made by the securely loaded operating system can be attributed to the principal identified by the code-id. In turn, the operating system can load a child process and attribute statements made by that child process to the principal identified by the hash of its code and data. Following one existing nomenclature for NGSCB, we call the securely loaded operating system the *Nexus*, and we call any child process that it loads a *Nexus Computing Agent* (*NCA*). The Nexus may be implemented, for example, by combining a virtual-machine hypervisor with a trusted guest operating system [10,15]. For simplicity, we focus on situations with one distinguished Nexus and one distinguished NCA; of course, other software may be running on the hardware at the same time.

Finally, we assume trusted input and output paths for communication with users. In particular, the hardware may guarantee that only a particular Nexus receives input from the keyboard and can send output to a display. The Nexus may in turn provide a similar guarantee to a particular NCA.

These assumptions are consistent with previous, public descriptions of NGSCB, such as the ones found in papers and on the Web. Those descriptions, like most informal descriptions, are however incomplete and imprecise in some respects. One of the goals of the present logical account is to complement those descriptions, with additional details (some of them validated in private conversations with the NGSCB team, and some of them conjectured rather than based on an official NGSCB design), and with a partial rationale for the workings of NGSCB.

4 Principals

Next we enumerate principals relevant for NGSCB security.

The following principals are particular to each NGSCB node. Each node will have different instances of them.

K_0	the permanent public key of the SSC
K_T	a per-boot public key of the SSC
S_0	the master symmetric key of the SSC
S_T	a per-boot symmetric key derived from S_0

The inverse of the key K_0 and the symmetric key S_0 never leave the SSC hardware; the inverse of the key K_T and the symmetric key S_T may or may not leave the hardware, as discussed below. We rely on asymmetric cryptography (public-key operations with K_0, K_T, and their inverses) primarily for digital signatures, rather than for public-key encryption. When encryption is needed, we indicate it explicitly. The

symmetric key S_0 may be replaced with a pair of keys for asymmetric encryption, with only minor changes.

The following principals represent software images. There can, of course, be many different images in which we might be interested. For simplicity of exposition, we will be concerned with only two:

C_{NEX}	the code-id of a particular Nexus
C_{NCA}	the code-id of a particular NCA

The following principals complete the cast; they provide the context outside an NGSCB system:

M	a manufacturer of SSC hardware
V	a vendor or author of Nexus software
A	a vendor or author of NCA software
K_M	M's public signature key
K_V	V's public signature key
K_A	A's public signature key
G_M	a group of public signature keys for SSCs produced by M
G_V	a group of code-ids for Nexus software images produced by V
G_A	a group of code-ids for NCA software images produced by A
CA	a trusted certification authority

5 Derived Authorities

It would be possible for an SSC to make statements only with its permanent public key K_0. However, it is desirable to sign as few certificates as possible with this key. Therefore, we assume that, at boot time, the SSC generates a temporary key pair, consisting of the public key K_T and its inverse. Then K_0 transfers all of its authority to K_T. This hand-off of authority is captured in the following statement:

$$K_0 \text{ says } K_T \Rightarrow K_0$$

The certificate described here, and all subsequent certificates mentioned in this paper, should be considered valid only for a limited period of time. The logic does not directly model time, so we do not represent time formally; one could probably add it with a modest effort.

In this formulation, we assume that the SSC holds the temporary secret key (the inverse of K_T) in hardware and uses the key for signing statements on behalf of other principals on the local machine. This key could instead reside in the Nexus and be accessed through a similar interface. In this case, the key would no longer be protected within the SSC, so the two arrangements entail different security properties.

Because of the secure loading steps described above, a successfully loaded Nexus will have the authority of the compound principal $K_T \mid C_{NEX}$. An SSC can run any Nexus software, but the rights of a specific Nexus instance are exactly those of the SSC parameterized by the code-id of the Nexus. Similarly, an NCA loaded on top of a Nexus would speak as $K_T \mid C_{NEX} \mid C_{NCA}$.

6 Certification Infrastructure

In order to deduce anything useful about statements made by the software running on an NGSCB node, we must have trust assumptions. We hypothesize the presence of a certification authority *CA* that makes statements that are globally trusted. In particular, we trust *CA* to specify the set of acceptable NGSCB nodes and the set of trusted Nexus and NCA software images; we express this trust as follows:

$$CA \Rightarrow G_M$$
$$CA \Rightarrow G_V$$
$$CA \Rightarrow G_A$$

We simplify a bit here: in practice, *CA* will almost always be implemented by a hierarchy of certification authorities and there will be multiple subgroups of G_M, G_V, and G_A, according to the intended applications and trust relationships.

Next, we must give some key (or set of keys) the authority to certify membership in the groups G_M, G_V, and G_A. We represent such statements in the following certificates:

$$CA \text{ says } K_M \Rightarrow G_M$$
$$CA \text{ says } K_V \Rightarrow G_V$$
$$CA \text{ says } K_A \Rightarrow G_A$$

Finally, we use the signing keys that correspond to K_M, K_V, and K_A for making membership certificates for the specific hardware/software stack that we intend to construct:

$$K_M \text{ says } K_0 \Rightarrow G_M$$
$$K_V \text{ says } C_{NEX} \Rightarrow G_V$$
$$K_A \text{ says } C_{NCA} \Rightarrow G_A$$

Combining the certificates and trust assumptions, we can derive:

$$K_0 \Rightarrow G_M$$
$$C_{NEX} \Rightarrow G_V$$
$$C_{NCA} \Rightarrow G_A$$

Note that if K_0 is a member of G_M (so $K_0 \Rightarrow G_M$ in our model) then K_0 can also define new group members of G_M. In particular, $K_0 \Rightarrow G_M$ and $K_0 \text{ says } K_T \Rightarrow K_0$ imply that $K_T \Rightarrow G_M$. Using a primitive membership relation rather than "speaks for" would remove this possibility.

7 Programmatic Interface

The programmatic interface of NGSCB supports the sealing of information and hardware-based attestation. Next we explain those functions in terms of the logic and of the definitions of the previous sections.