Pseudorandom Signatures

Relations among Privacy Notions for Digital Signatures

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Digital Signatures

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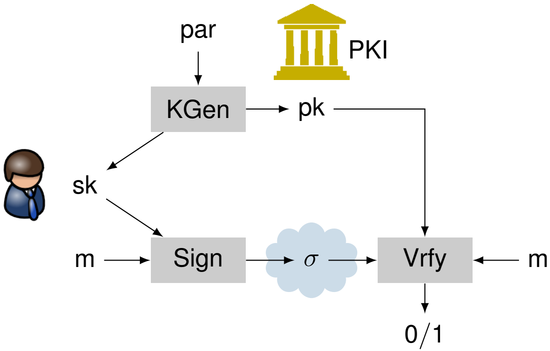
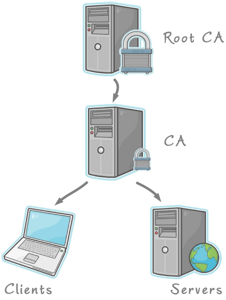




Digital signatures do not offer privacy!

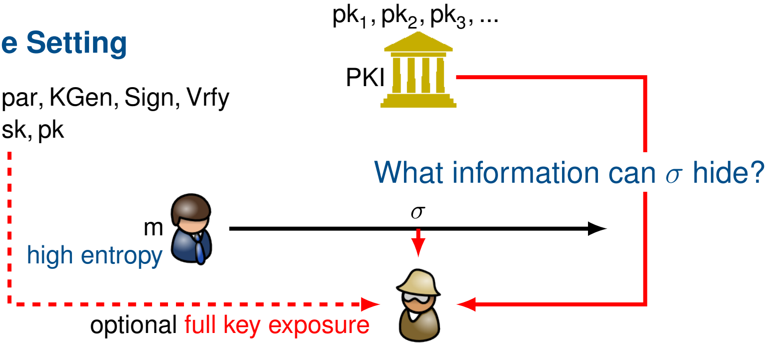
. . . due to public verification.

Privacy for Digital Signatures

Is privacy for digital signatures thus hopeless?

Not quite!

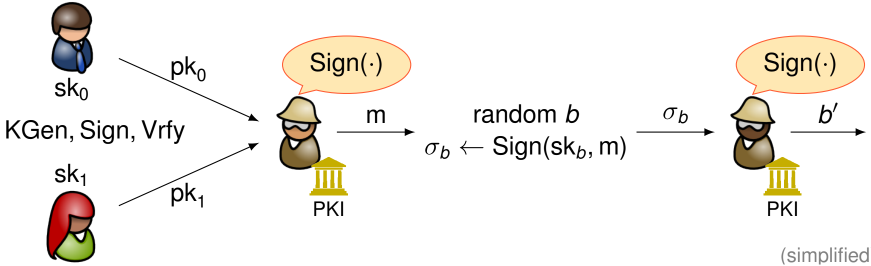
The Setting



Anonymous Signatures

Anonymous Signatures (ANON)

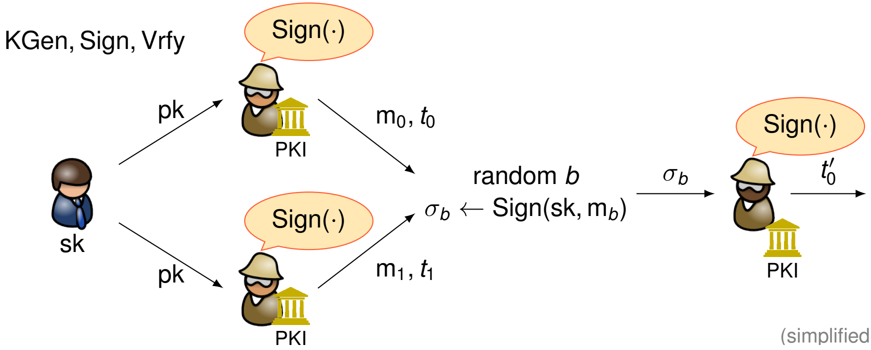
- Yang, Wong, Deng, Wang @ PKC 2006
- Fischlin @ PKC 2007
- Bellare, Duan @ eprint 2009 (non-standard signatures)
- Saraswat, Yun @ ProvSec 2009 (non-standard signatures)
- Zhang, Imai @ IEICE Trans. 92-A 2009 (non-standard signatures)



(simplified)

Confidential Signatures (CONF)

- Dent, Fischlin, Manulis, Stam, Schröder @ PKC 2010 (strong, mezzo, weak)
- Canetti @ CRYPTO 1997 (preliminary ideas)



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Applications and Theoretical Aspects of Privacy-Friendly Signatures

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Signatures are often sent together with signed message.

However, anonymous/confidential signatures are useful in

- anonymous auctions (where bid is revealed later)
- anonymous key exchange
- output signing of secure multi-party computation

But signatures (e.g., in European passports [Bringer et al. @ ACNS 2010]) might already be distinguishable by the signing algorithm and parameters used

Existence of anonymous/confidential signatures also raises theoretical questions:

- How are ANON and CONF related?
- Can signature schemes achieve both ANON and CONF?
- Is there a limit on the information that can be hidden?

Relationship between ANON and CONF

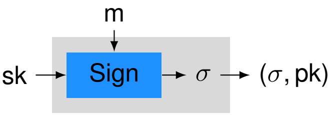
ANON

CONF

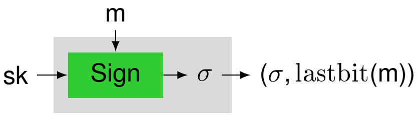
We have two privacy notions, but the work isn't complete. . .

ANON and CONF are independent privacy notions:

- existance of non-private signature schemes (e.g., FDH-RSA)
- black-box separation of ANON and CONF



confidential but not anonymous



anonymous but not confidential

“State-of-the-Art” Privacy Snapshot

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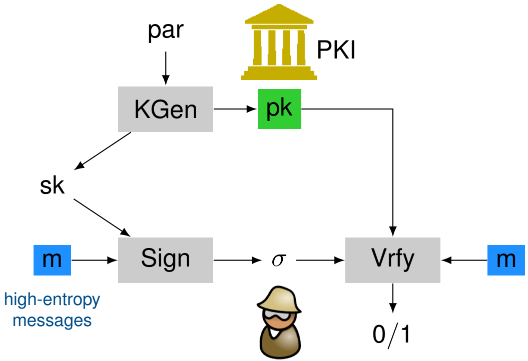
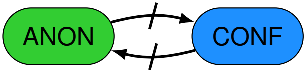




Can we achive ANON and CONF at the same time?

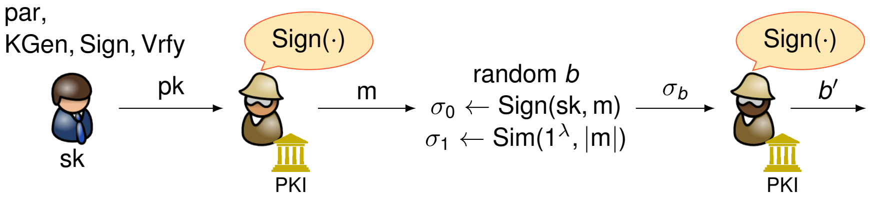
Indistinguishable Signatures

Intuition

Sign(sk, m) $\approx$ Sim(1^λ, |m|) — Sim implicitly knows (par, KGen, Sign, Vrfy)

Indistinguishable Signatures (IND)

There exists a simulator Sim s.t. for all adversaries



(simplified)

Examples of IND Signatures

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IND signature schemes exist in different crypto settings, e.g.,

- Probabilistic FDH-RSA with padding $\sigma = (H_N(m, r)^d + kN, r)$

  where $H_N\colon \{0,1\}^* \to \mathbb{Z}_N$, $k \in_R [0, \lfloor Z_\lambda / N \rfloor - 1]$, $Z_\lambda \in \mathbb{N}$ of 2λ bits.

- Schnorr scheme (shared $\mathbb{G} = \langle g \rangle$) $\sigma = (c = H(g^r, m), s = sk \cdot c + r \bmod q)$

  where $H\colon \{0,1\}^* \to \mathbb{Z}_q$ and $sk \in_R \mathbb{Z}_q$ is the secret key.

- Boneh-Boyen scheme (shared $e\colon \mathbb{G}_1 \times \mathbb{G}_2 \to \mathbb{G}_T$) $\sigma = (g_1^{1/(x+m+yr)}, r)$

  for uniform $m \in_R \mathbb{Z}_q$ — can be dropped with “hash-then-sign” in ROM.

“So-Far” Privacy Snapshot

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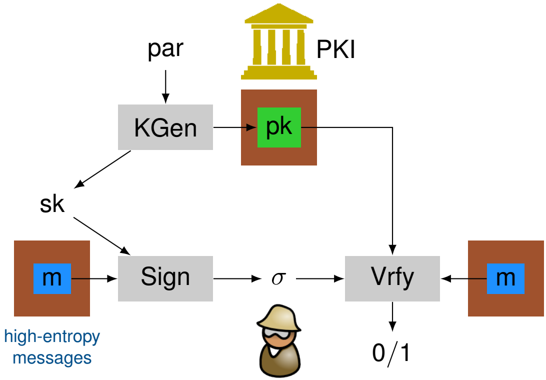

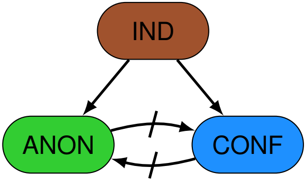

- IND signatures may still leak par!
  possible to distinguish between security parameters, groups
- IND signatures may still leak specification of (KGen, Sign, Vrfy)!
  possible to distinguish between the (instantiations of) schemes

Pseudorandom Signatures

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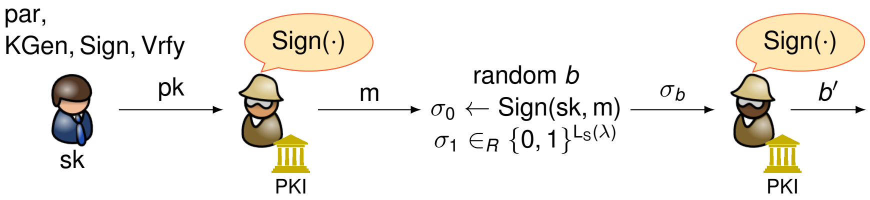
Intuition

Sign(sk, m) $\approx$ random string from $\{0,1\}^{L_S(\lambda)}$

where $L_S(\lambda)$ is the length of signatures output by a scheme S on security parameter λ

Pseudorandom Signatures (PR)

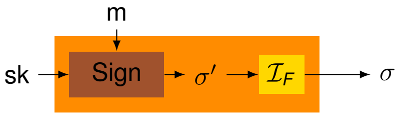


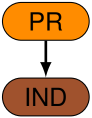
(simplified)

Note: Multiple PR signatures can always be extended to some common length L

IND-to-PR Compiler

- converts IND signatures into PR signatures — in the standard model
- uses admissible encoding $F \colon \{0,1\}^{L_S(\lambda)} \to R$ (Brier et al. @ CRYPTO 2010)
  - F is efficient and invertible by $\mathcal{I}_F$, which maps to uniform distribution in $\{0,1\}^{L_S(\lambda)}$
  - admissible encodings exist for elliptic curves, $\mathbb{Z}_N$, $QR(p)$ and are aggregatable





- suitable for IND schemes with regular Sim (uniform output)
- aggregation of encodings helps if σ contains elements from various sets
- very efficient

Direct PR Compiler

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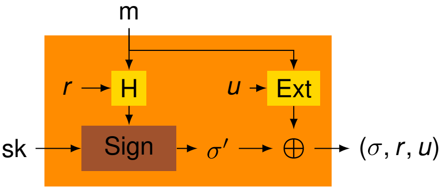
- works for arbitrary (incl. non-private) signatures — in the standard model
- bases on construction of ANON signature scheme by Fischlin @ PKC 2007
- implies that Fischlin's scheme achieves PR $\Rightarrow$ IND $\Rightarrow$ CONF

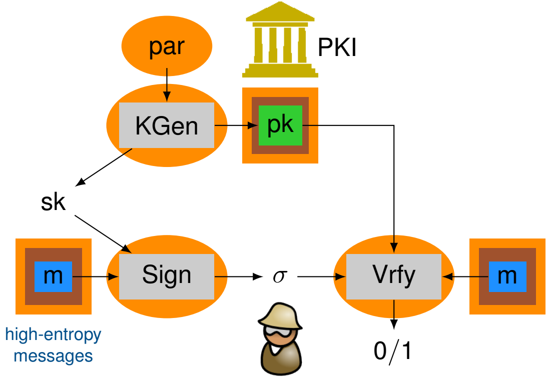
Idea: PR compiler extracts randomness from m to encrypt the signature

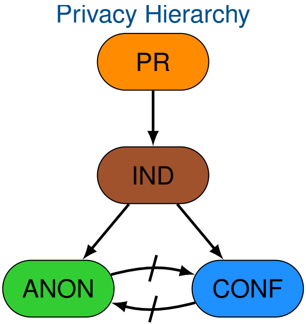


uses associated randomness extractor and hash function

$r, u, \mathrm{H}(\mathrm{m}, r), \mathrm{Ext}(\mathrm{m}, u) \approx r, u, \mathrm{H}(\mathrm{m}, r), v$

Final Privacy Snapshot





many of our results also hold in case of full key exposure

Summary

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Privacy **is** possible for digital signatures!

- complete privacy hierarchy for signatures (PR $\Rightarrow$ IND $\Rightarrow$ $\{$ANON, CONF$\}$)
- constructions for IND-variants of FDH-RSA, Schnorr, Boneh-Boyen
- two generic compilers (IND-to-PR, direct PR) in the standard model

- pseudorandom (PR) signatures hide all information about the signing process — including parameters, instantiations, schemes

All results in our full paper @ **http://eprint.iacr.org/2011/673**, including

- details on full key exposure
- impossibility results for
  - information recovering signatures (generalization of message recovery)
  - deterministic signatures

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