IBM Research, Zurich

Anonymous Credentials on a Standard Java Card

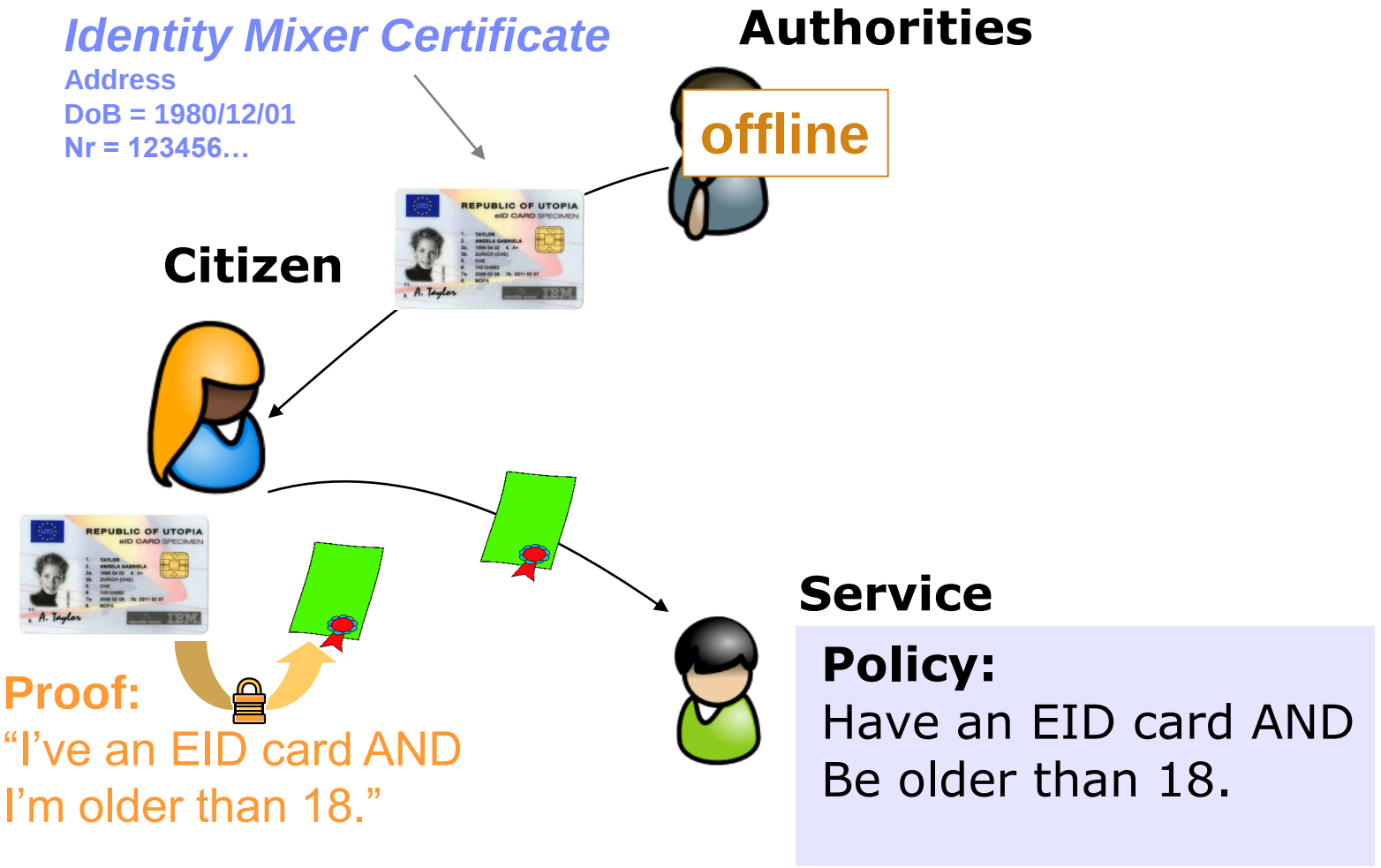
joint work with
supported by

Thomas Gross
Patrik Bichsel, Jan Camenisch, Victor Shoup
IBM's BlueZ Group for Strong Authentication

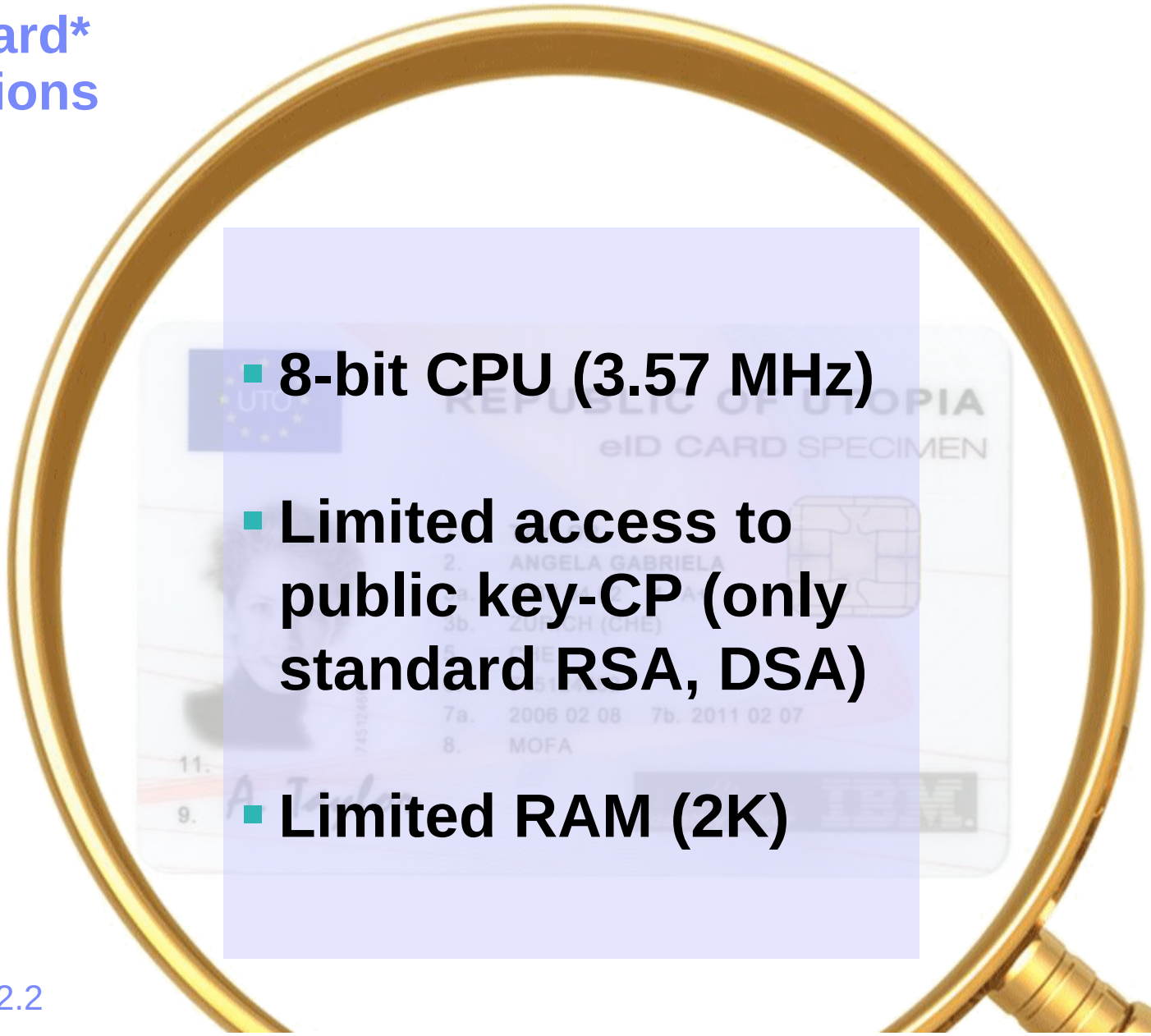
Overview

- Introduction
- Camenisch-Lysyanskaya Signatures
- Problem Statement
- Key Ideas
- Results

Example: Age Proof with Strong Privacy



Java Card* Limitations



- 8-bit CPU (3.57 MHz)
- Limited access to public key-CP (only standard RSA, DSA)
- Limited RAM (2K)

*: JCOP 41/v2.2

Basis: Camenisch-Lysyanskaya Signatures

[Camenisch & Lysyanskaya '01]

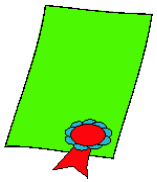
Public key of signer: RSA modulus n and $a_i, b, d \in QR_n$,

Secret key: factors of n

Signature of L attributes $m1, \ldots, mL \in \{0,1\}^\ell$: (c,e,s)

For random prime $e > 2^\ell$ and integer $s \approx n$, compute c such that

$$d = a_1^{m1} \cdot \ldots \cdot a_L^{mL} \; b^s \; c^e \mod n$$



Theorem: ***Signature scheme is secure against adaptively chosen message attacks under SRSA assumption.***

[SRSA: Barić & Pfitzmann '97 and Fujisaki & Okamoto '97]

Basis: Camenisch-Lysyanskaya Signatures

[Camenisch & Lysyanskaya '01]

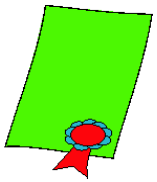
Public key of signer: RSA modulus n and $a_i, b, d \in QR_n$,

Secret key: factors of n

Signature of L attributes $m1, \ldots, mL \in \{0,1\}^\ell$: (c,e,s)

For random prime $e > 2^\ell$ and integer $s \approx n$, compute c such that

$$d = a_1^{m1} \cdot \ldots \cdot a_L^{mL} \; b^s \; c^e \mod n$$



Theorem: ***Signature scheme is secure against adaptively chosen message attacks under SRSA assumption.***

[SRSA: Barić & Pfitzmann '97 and Fujisaki & Okamoto '97]

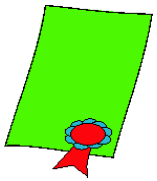
Basis: Camenisch-Lysyanskaya Signatures

[Camenisch & Lysyanskaya '01]

Signature of L attributes $m1, \ldots, mL \in \{0,1\}^{\ell}$: (c,e,s)

For random prime $e > 2^{\ell}$ and integer $s \approx n$, compute c such that

$$d = a_1^{m1} \cdot \ldots \cdot a_L^{mL} \; b^s \; c^e \mod n$$



Abstractly requires computation of:

$$A_1^{x1} \cdot \ldots \cdot A_i^{xi} \cdot \ldots \cdot A_L^{xL} \mod n$$

where xi correspond to attributes in the certificates and potentially $|xi| > |n|$

Problem Statement

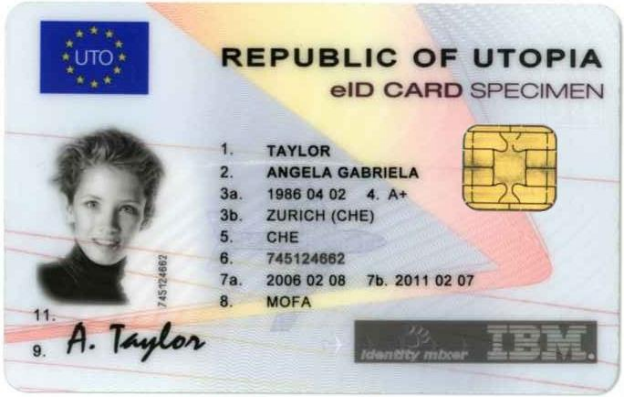
[Independent result: Sterckx, Preneel, Verbauwhede '07]

Run anonymous credential system autonomously and securely on a standard off-the-shelf Java Card.

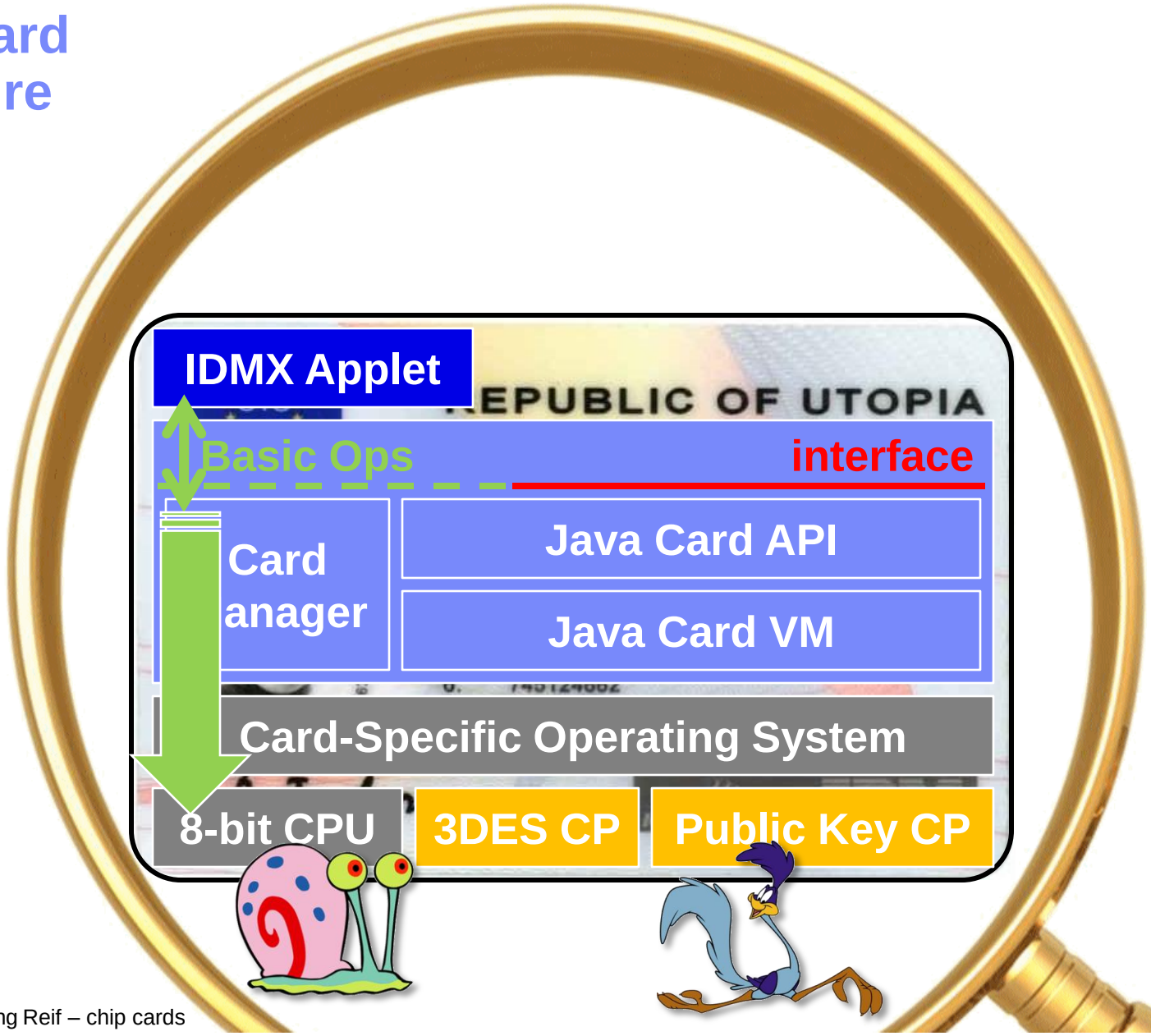
Autonomy
All data on card
Malicious terminal

Security
CL-Signatures
Realistic keys

Efficiency
Proof in seconds

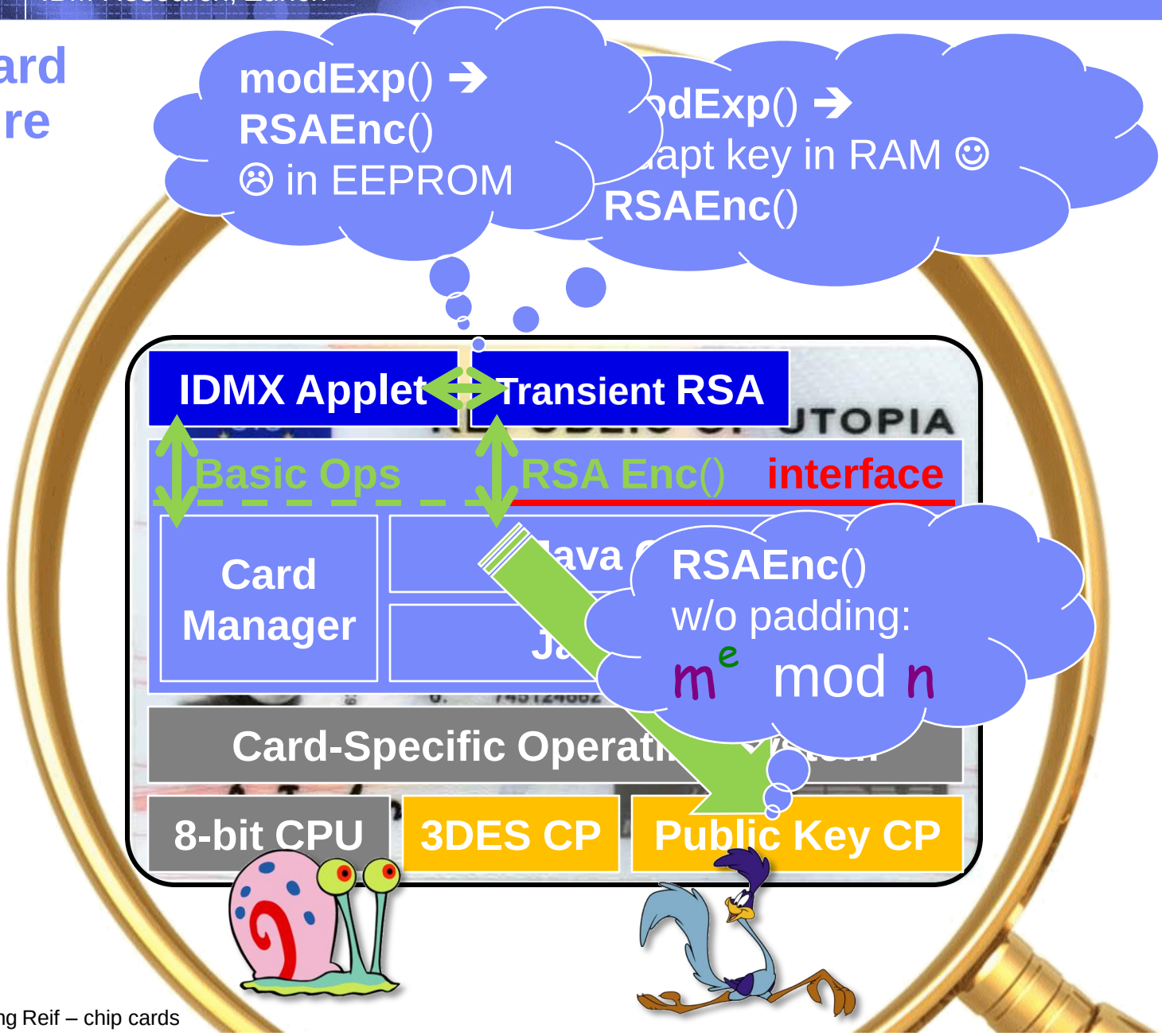


Java Card Structure



Source: Prof. Wolfgang Reif – chip cards

Java Card Structure



Source: Prof. Wolfgang Reif – chip cards

(Ab-)Using Standard RSA Interface

- **Recall RSA Encryption:** $m^e \bmod n$ (Limited size of e)
- **ModExp() with Big Exponents** ➔ Split exponents:

$$\begin{aligned} A_1^{x1} A_2^{x2} &= A_1^{x11 + x12*2k} \; A_2^{x21 + x22*2k} \bmod n \\ &= A_1^{x11} (A_1^{2k})^{x12} \; A_2^{x21} (A_2^{2k})^{x22} \bmod n \\ &= A_1^{x11} A'_1{}^{x12} \; A_2^{x21} A'_2{}^{x22} \bmod n \end{aligned}$$

- **ModMultiply():** RSA interface can only do exponentiation ➔ Reduce multiply to **modExp()** by binomial formula:

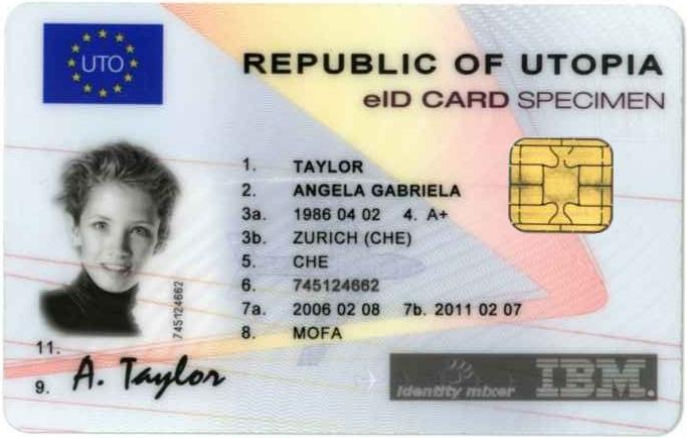
$$A * B = ((A+B)^2 - A^2 - B^2)/2 \bmod n$$

Execution Times Full Proof (Including Communication)

Modulus	1280 bit	1536 bit	1984 bit
Precomputation	**5203 ms**	**7828 ms**	**13250 ms**
Compute A’	2125 ms	2906 ms	5000 ms
Compute T1	3078 ms	4922 ms	8250 ms
Policy-dependent	**2234 ms**	**2625 ms**	**3298 ms**
Compute 1 Response	562 ms	656 ms	828 ms
Total	**7437 ms**	**10453 ms**	**16548 ms**

Results

- **Anonymous credential system on standard Java Card**
  - JCOP 41/v2.2
  - Future: Java Card 3.0 standard



- **Attributes:** Focus on proof of possession
  - rely on hardware tamper resistance for statement, and
  - detect / revoke broken cards.
- **Autonomous:** secure in face of untrusted terminal
- **Efficient:** 10 sec (at 1536 bits)

  7.5 sec pre-computation / 2.5 sec on-line

I'm happy to answer questions…

Identity Mixer Community Site:

idemix.wordpress.com

- See what's going on…
- Look at the spec…
- Download the library…

BACKUP

Detailed Performance Analysis: Modulus 1536 bit

Amortized Estimates over 1000 Ops, Upper Bound on Parameter Length, Percent Rounded Down

Function	Time	Ops	Percent
Multiplication	**4’653 ms**	**9 Ops**	**39 %**
↳Addition	2988 ms	36 Ops	25 %
↳ModSquare	243 ms	27 Ops	2 %
ModExp	**4’308 ms**	**10 Ops**	**36 %**
SRNG	**1’088 ms**	**16 Ops**	**9 %**
TRNG	**815 ms**	**1 Op**	**6 %**
Addition	**581 ms**	**7 Ops**	**4 %**
Digest	**220 ms**	**10 Ops**	**1 %**
Total	**11’665 ms**		

Recall: The Strong RSA Assumption

Flexible RSA Problem: *Given RSA modulus n and $z \in QR_n$ find integers e and u such that*

$$u^e = z \bmod n$$

(Recall: $QR_n = \{x : \text{exist } y \text{ s.t. } y^2 = x \bmod n\}$)

- Introduced by Barić & Pfitzmann '97 and Fujisaki & Okamoto '97
- Hard in generic algorithm model [Damgård & Koprowski '01]

Signature Scheme based on the SRSA I

[Camenisch & Lysyanskaya '02]

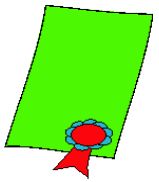
Public key of signer: RSA modulus n and $a_i, b, d \in QR_n$

Secret key: factors of n

To sign k messages $m1, \ldots, mk \in \{0,1\}^{\ell}$:

- choose random prime $e > 2^{\ell}$ and integer $s \approx n$
- compute c such that

$$d = a_1^{m1} \cdot \ldots \cdot a_k^{mk} \, b^s \, c^e \mod n$$

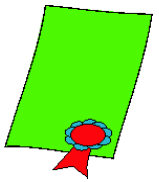


- signature is (c,e,s)

Signature Scheme based on the SRSA II

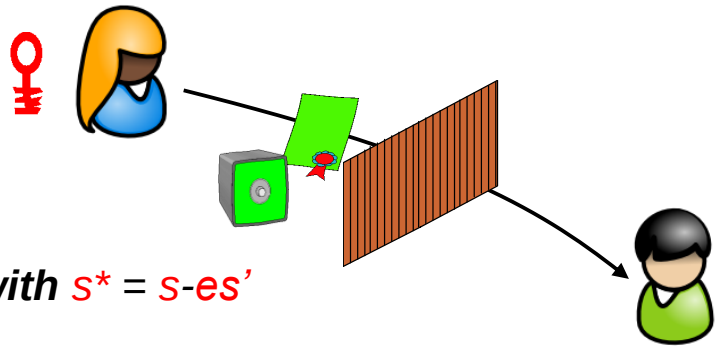
A signature (c,e,s) on messages $m1, \ldots, mk$ is valid iff:

- $m1, \ldots, mk \in \{0,1\}^{\ell}$:
- $e > 2^{\ell}$
- $d = a_1^{m1} \cdot \ldots \cdot a_k^{mk} \, b^s \, c^e \bmod n$



Theorem: *Signature scheme is secure against adaptively chosen message attacks under SRSA assumption.*

Proof of Knowledge of a Signature



Observe:

Let $c' = c\, b^{s'} \bmod n$ ***with random*** s'

then $d = c'^{e}\, a_1^{m1} \cdot \ldots \cdot a_k^{mk}\, b^{s^*} \pmod n$, ***with*** $s^* = s - es'$

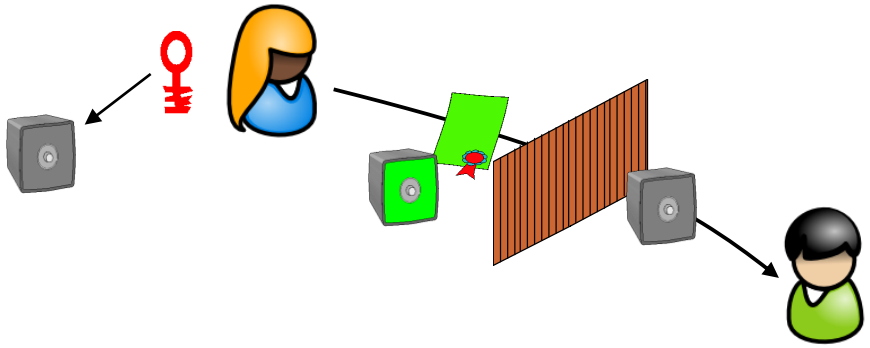
i.e., (c', e, s^*) ***is a also a valid signature!***

Therefore, to prove knowledge of signature on some m

- provide c'
- $PK\{(e, m1, \ldots, mk, s) : \quad d := c'^{e}\, a_1^{m1} \cdot \ldots \cdot a_k^{mk}\, b^{s}$

$$\wedge \quad mi \in \{0,1\}^{\ell} \quad \wedge \quad e \in 2^{\ell+1} \pm \{0,1\}^{\ell} \quad \}$$

Proof of Knowledge of a Signature



Using second Commitment

assume second group n, a, b, n

2nd commitment $C = a_1^{sk} b^{s^*}$

To prove knowledge of signature on some m

provide c'

$PK\{(e, m1, \ldots, mk, s, s^*) :$

$$C = a_1^{m1} b^{s^*} \wedge d := c'^{e} a_1^{m1} \cdot \ldots \cdot a_k^{mk} b^{s} \}$$