IRMA: Attribute-Based Identity Management Using Smart Cards

Summer School on Real-World Crypto and Privacy

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Currently we are here...

Security and Privacy Today

Attribute-based identity management

Crypto of ABCs

Smart-card implementation

IRMA: the best of ABCs

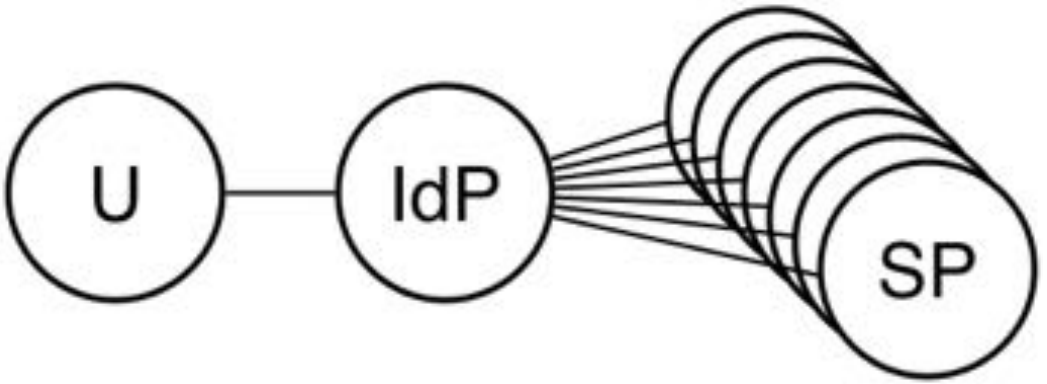
"[By 2025 f]ew individuals will have the energy, interest, or resources to protect themselves from *dataveillance*; privacy will become a *luxury*."

[Pew Research Center, December 2014]

Authentication

- Passwords
  - "38% of adults sometimes think it would be easier to solve world peace than attempt to remember all their passwords" [Harris Interactive, 2012]
- Many accounts at service providers
- Identity management
  - Users
  - Identity provider(s) = Issuer
  - Service providers = Relying party = Verifier

Problems with Identity Management



- Security
  - Single point of failure
  - Valuable target
- Privacy
  - Can log in (?)
  - Linking all user activities
  - Profiling

Authorisation is necessarily identifying

Outline

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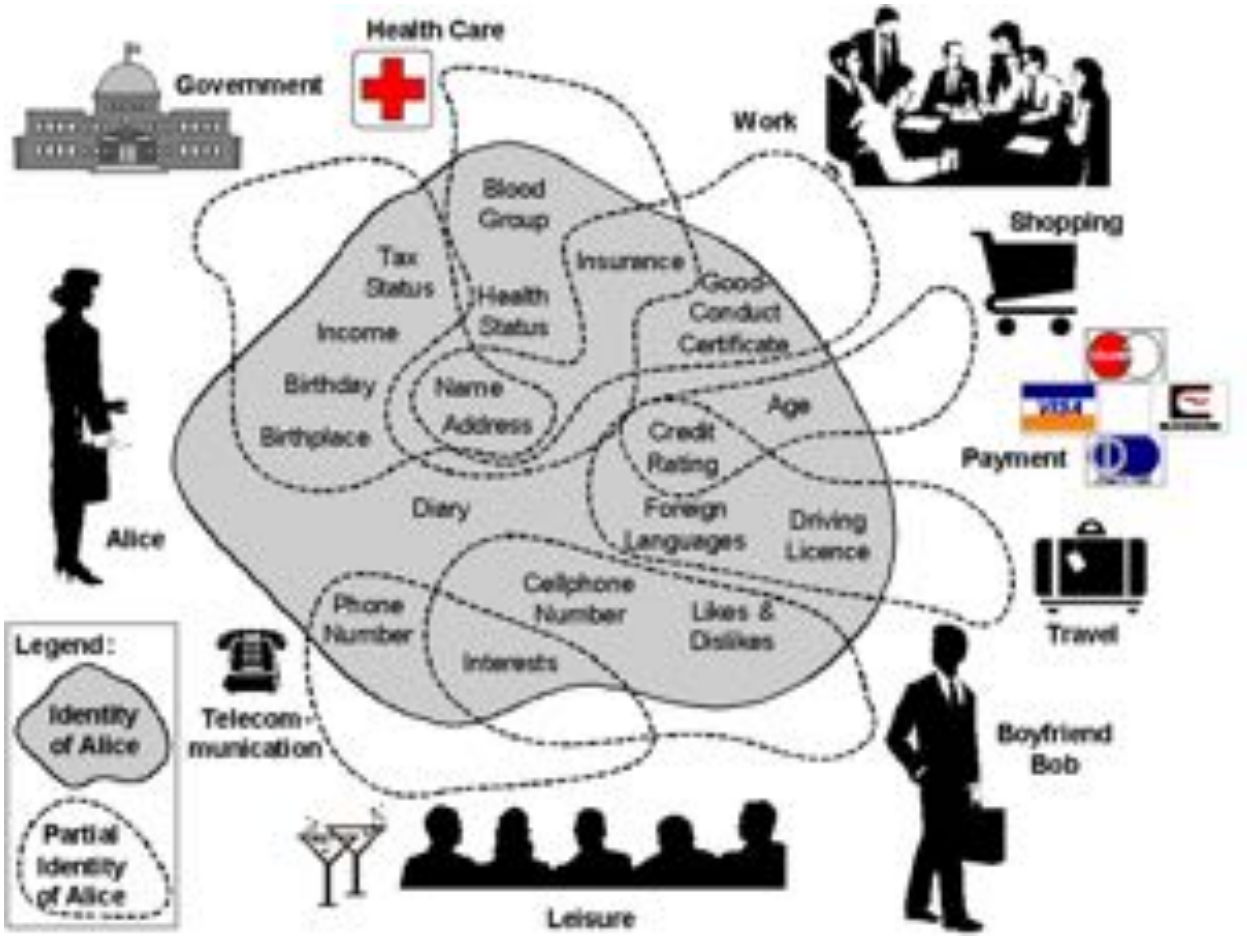
Identity and Attributes



[FIDIS 2005]

Digital Identity

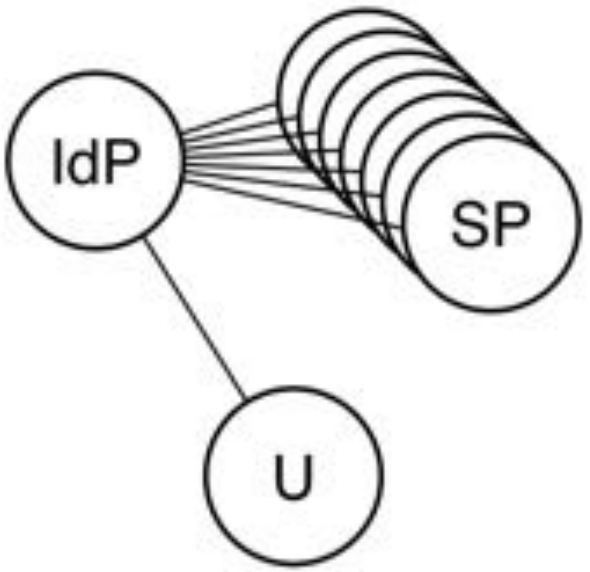
- Attributes
- Partial identities

- Identifying and non-identifying attributes

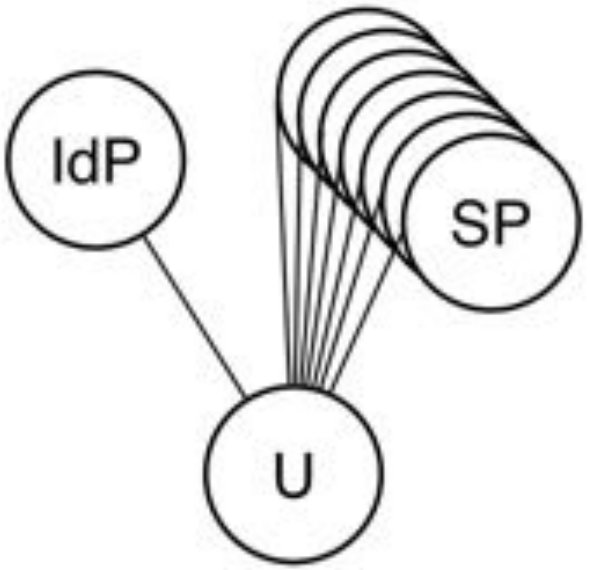
- Username + authentication + lookup

- Authorisation based on attributes
  - Directly looking up relevant attributes
  - Identifying and non-identifying authorisation (DEMO: ≥ 18)

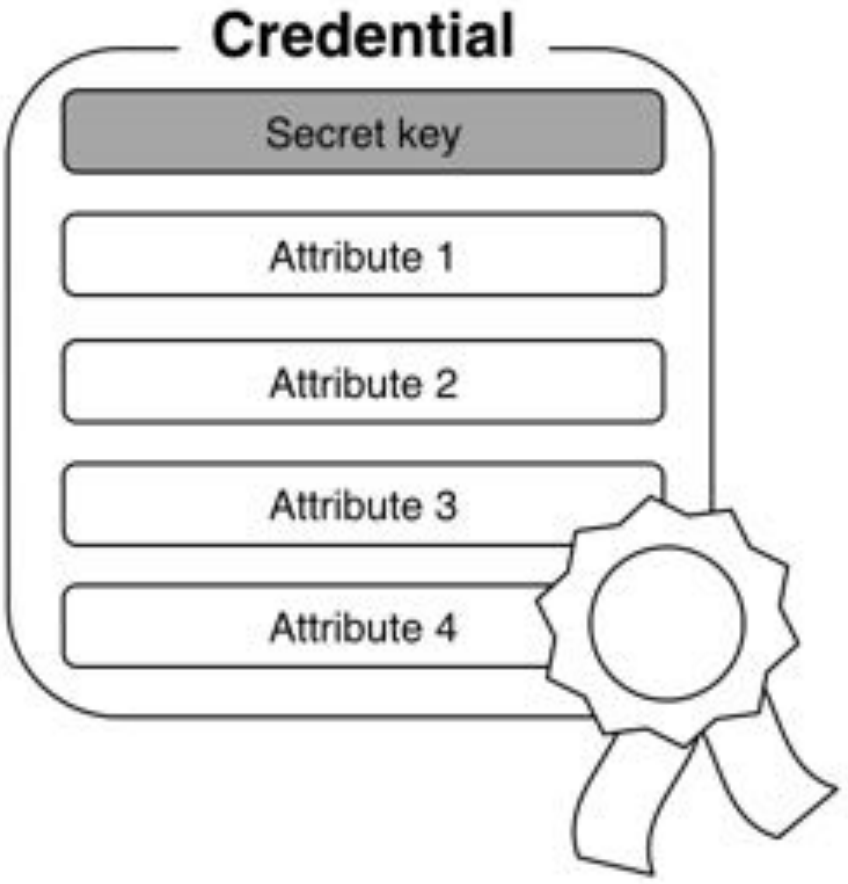
Identity Management



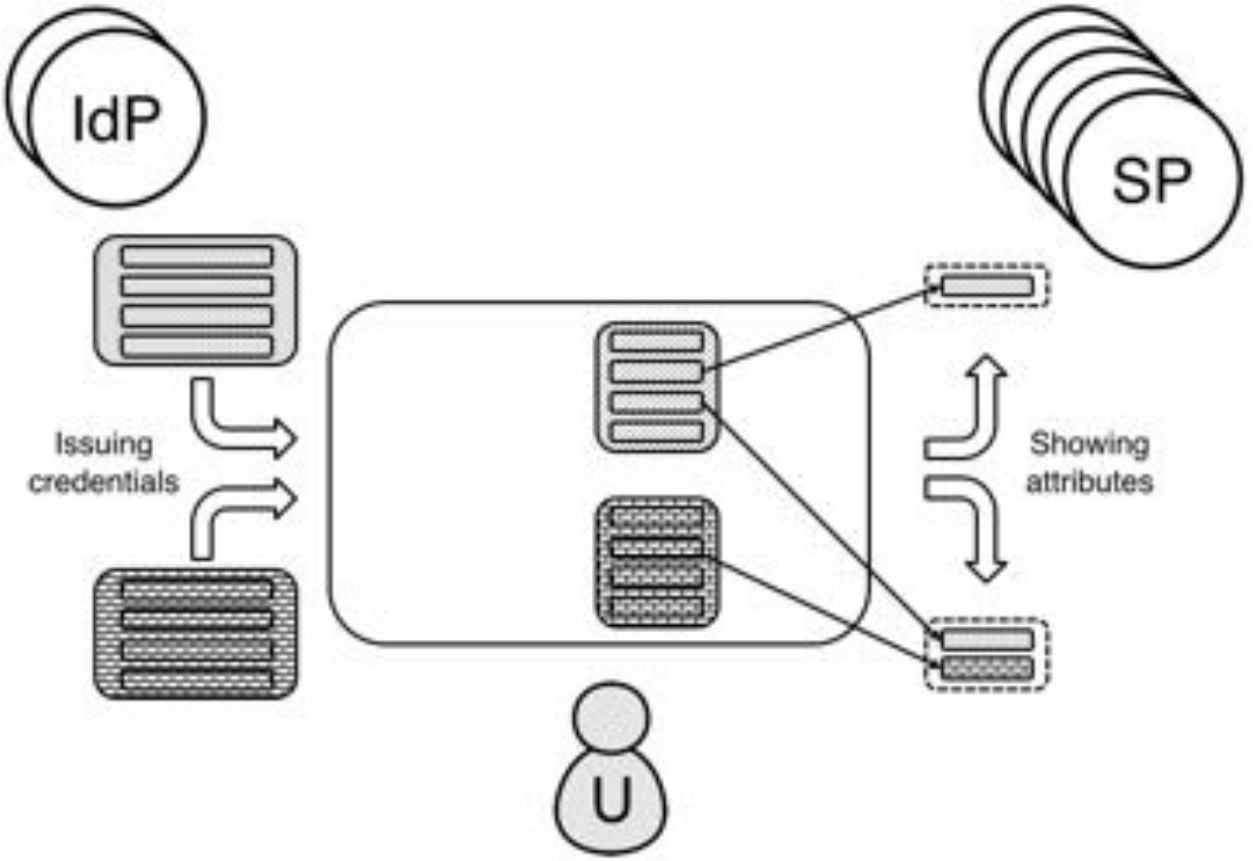
Attribute-Based Identity Management



Attribute-Based Credential



Issuing and Showing



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Plan for Crypto

- Commitment
- Zero-knowledge proof
- Attribute-based credential (ABC)
- Selective disclosure

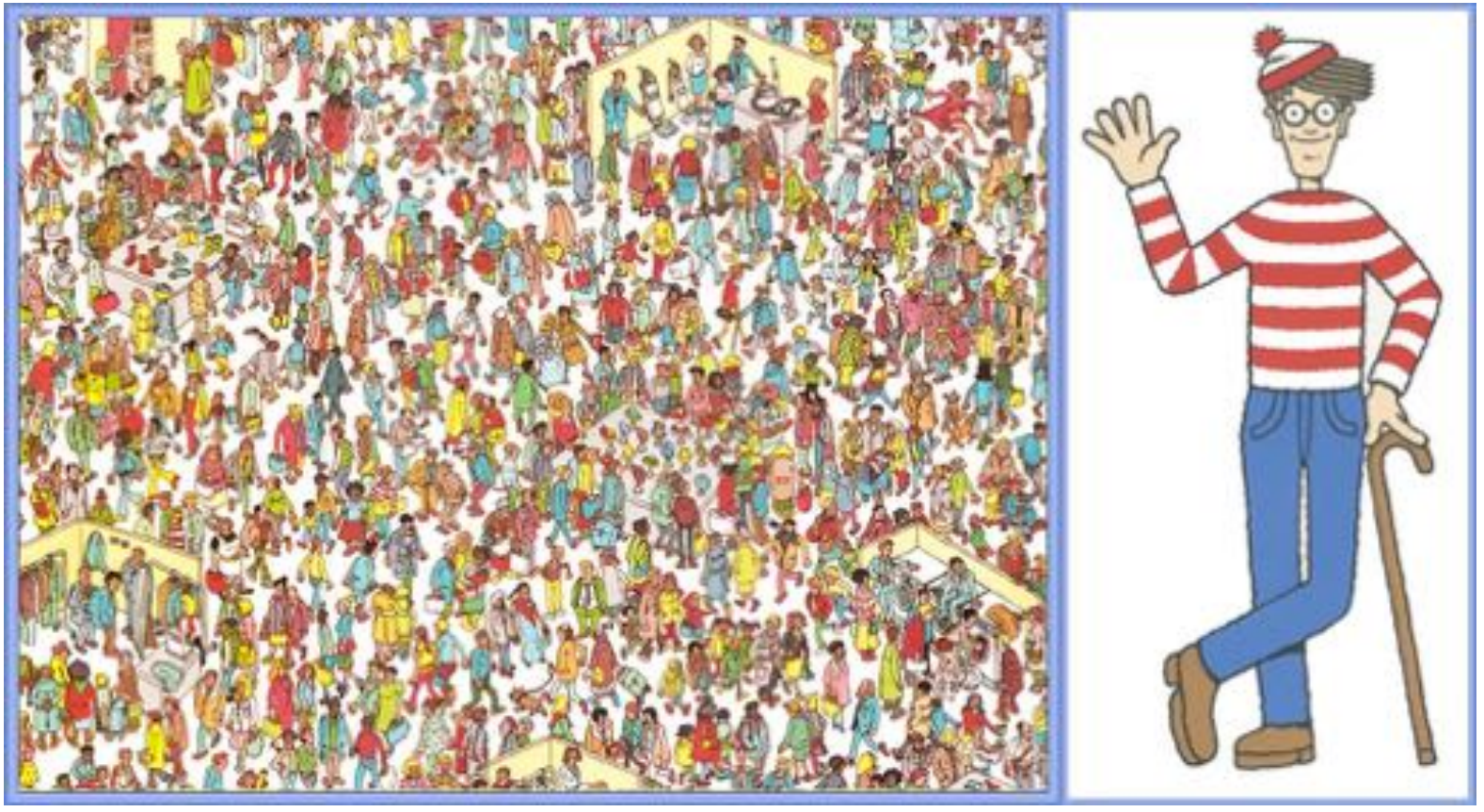
Commitment

- (Temporary) secret in a box with a padlock
- ... and a key.

- Phases:
  - Commit
  - Opening
- Examples (related to the DL problem):
  - $h = g^x \pmod{p}$. Commit: h, g, p; Opening: x.
  - $h = g^r \cdot g_1^x \pmod{p}$. Commit: h, g, g_1, p; Opening: r, x.

- Computational hiding and perfect binding.
  OR
- Perfect hiding and computational binding. [Damgård 99]

Where's Waldo?—Zero-Knowledge Proof



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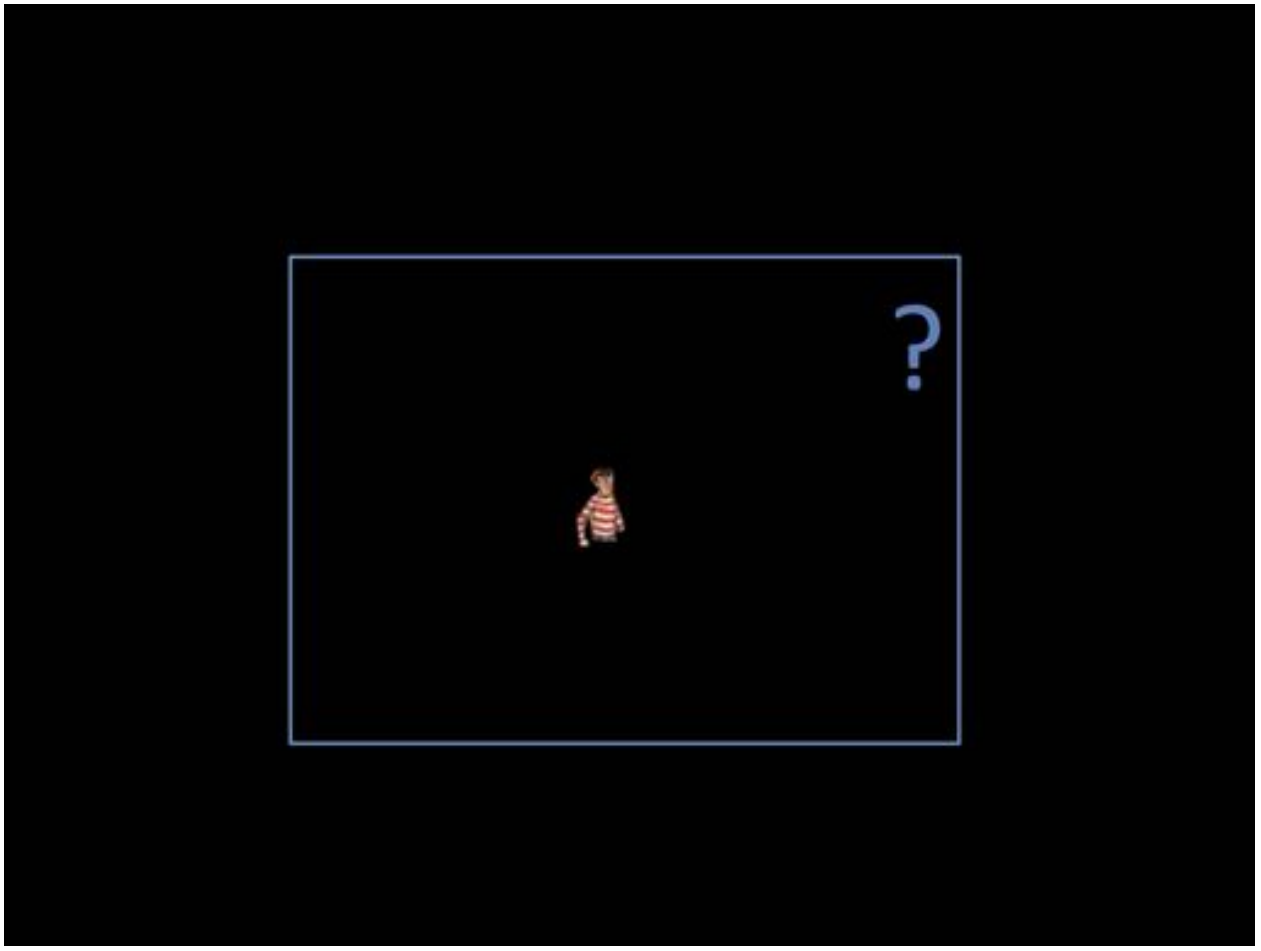
Where's Waldo?—Zero-Knowledge Proof



[Naor et al. 99]

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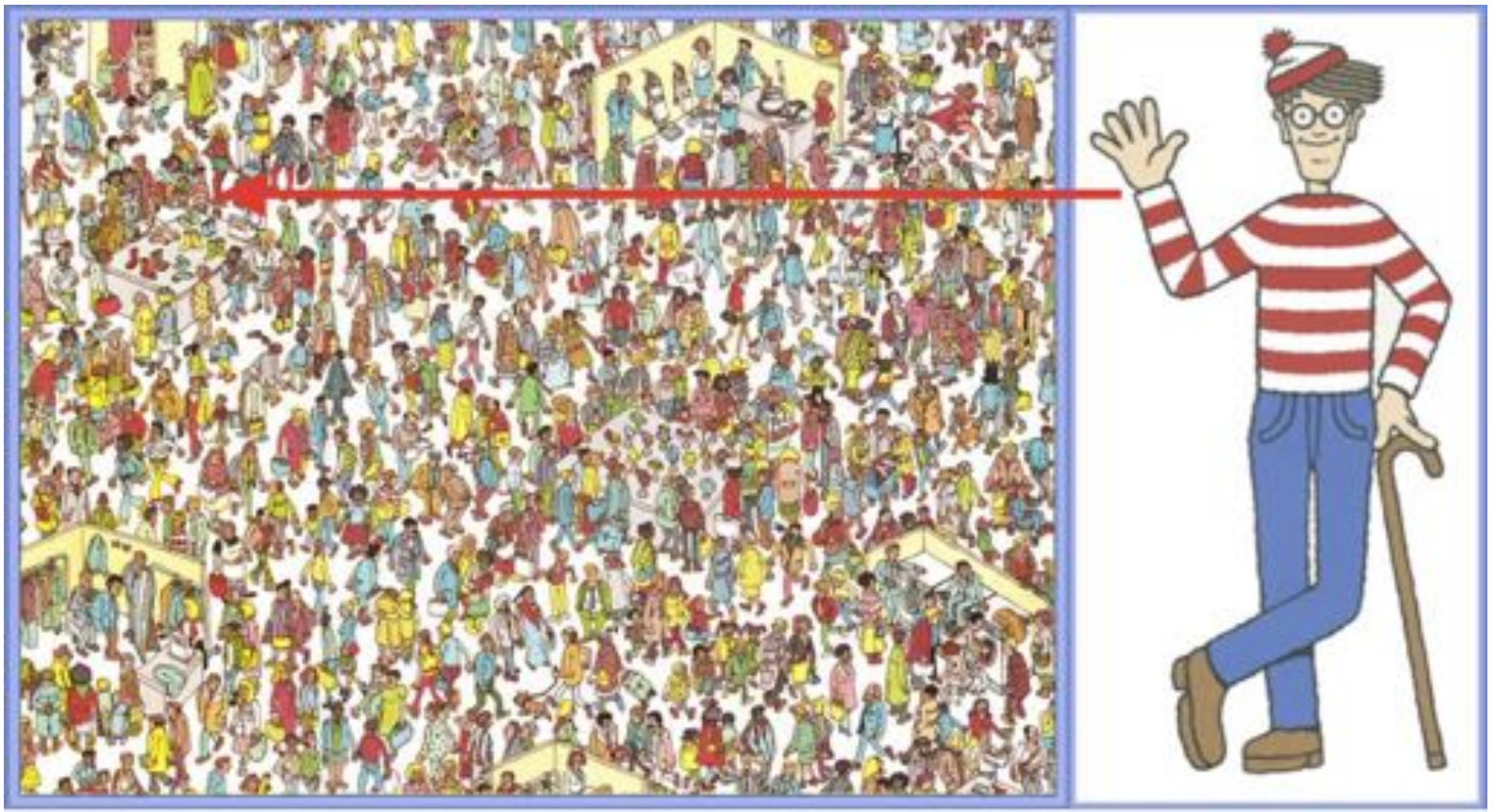
Where's Waldo?



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Schnorr's Proof of Knowledge [Schnorr 91]

- Let us work in $\mathbb{G}$ of order q
- Discrete logarithm: "I know the discrete logarithm $\log_g h$."
- $\mathrm{PK}\{\chi | h = g^{\chi}\}$—**P***roof of* **K***nowledge*
- Interactive

	Prover	$\mathbb{G}, g, q, h = g^x$	**Verifier**
	Secret: x		
(1)	$w \in_R \mathbb{Z}_q$		
	$a := g^w$	$\xrightarrow{a}$	
(2)		$\xleftarrow{c}$	$c \in_R \mathbb{Z}_q$
(3)	$r := c \cdot x + w \pmod q$	$\xrightarrow{r}$	$a \stackrel{?}{=} g^r \cdot h^{-c}$

(1) Commitment
(2) Challenge
(3) Response

How to Design ABCs? – In Three Simple Steps

Step 1 Take a commitment scheme

Step 2 Generalise it to multiple values

Step 3 Sign the extended commitment

Step +1 Apply here and there zero-knowledge proofs

IBM's Idemix Based on CL

- Camenisch–Lysyanskaya (CL) signature [CL 01, CL 02]
- Strong RSA assumption [BP 97, FO 97]
  - **RSA** ($n = pq$) $\Longrightarrow$ Taking the eth root is hard
  - **Strong** $\Longrightarrow$ DL is hard
  - Group QR_n:
    - p, q are safe primes
    - Quadratic residues in $\mathbb{Z}_n^*$
    - QR_n is a subgroup of order $\varphi(n)/4$
  - Some group elements that you'll see: $A, Z, S, R, R_1, R_2, R_3, \ldots$
  - Some further integers (exponents): $e, v, a, \ldots$
- Let's "design" Idemix's ABCs

Step 1: Commitment

Take a commitment scheme – Pedersen on a_1

$$R^{a} \cdot R_1^{a_1} \text{ where } a \text{ is random.}$$

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Step 2: Generalisation

Extend it to multiple values – generalise Pedersen on $(a_1, \ldots, a_L)$

$$R^a \cdot \underbrace{R_1^{a_1} \cdot \ldots \cdot R_L^{a_L}}_{\prod_{i=1}^{L} R_i^{a_i}}$$

where a is random.

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Step 3: Signature

Sign the extended commitment – CL on attributes: $a_1, \ldots, a_L$

$$A := \left(\qquad\qquad \right)^{1/e} \pmod{n}$$

Step 3: Signature

Sign the extended commitment – CL on attributes: $a_1, \ldots, a_L$

$$A := \left(\frac{}{R^a \cdot \prod_{i=1}^{L} R_i^{a_i}} \right)^{1/e} \pmod{n}$$

Step 3: Signature

Sign the extended commitment – CL on attributes: $a_1, \ldots, a_L$

$$A := \left(\frac{Z}{S^v \cdot R^a \cdot \prod_{i=1}^{L} R_i^{a_i}} \right)^{1/e} \pmod{n}$$

where (a), v, e are random.

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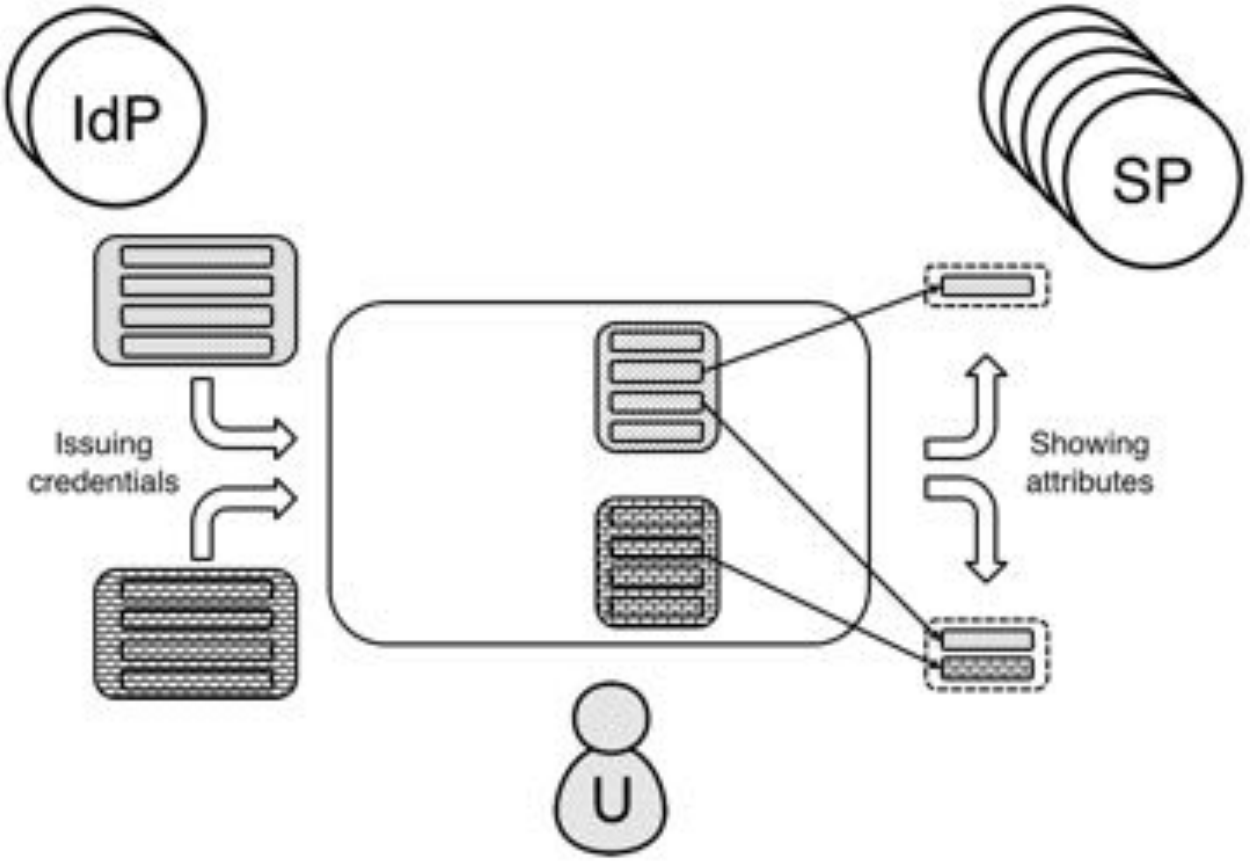
CL Signature: Idemix ABCs

$$(A, e, v) \text{ where } A \equiv \left(\frac{Z}{S^v \cdot R^a \cdot \prod_{i=1}^{L} R_i^{a_i}} \right)^{1/e} \pmod{n}$$

- Commitment
  - Binding: computational (representation problem)
  - Hiding: perfect (randomised)
- CL Signature
  - Private key: p, q; Public key: $n = pq$, Z, S, "all Rs"
  - A bit like RSA: $(\cdot)^{1/e} \pmod{n}$
  - More complicated: advanced functions
- Issuing: blind signature (zero-knowledge proof)

Issuing and Showing



CL Signature: Verification

Signature:

$$(A, e, v) \text{ where } A \equiv \left(\frac{Z}{S^v \cdot R^a \cdot \prod_{i=1}^{L} R_i^{a_i}} \right)^{1/e} \pmod{n}$$

- Public key: $n, Z, S, R, R_1, \ldots, R_L$
- Attributes (block of messages): $(a), a_1, \ldots, a_L$
- Verification:

$$Z \stackrel{?}{\equiv} A^e \cdot S^v \cdot \underbrace{R^a \cdot \prod_{i=1}^{L} R_i^{a_i}}_{R'} \pmod{n}$$

- IdP $\longrightarrow$ U; U $\longrightarrow$ V

CL Signature Randomisation

Signature:

$$(A, e, v) \text{ where } A \equiv \left(\frac{Z}{S^v \cdot R'}\right)^{1/e} \pmod{n}$$

- Select random r
- $\overline{A} := A \cdot S^{-r} \pmod{n}$, $\overline{v} := v + er$
- Indeed, $(\overline{A}, e, \overline{v})$ is valid:

$$\overline{A}^e S^{\overline{v}} R' \equiv A^e S^{-er} S^v S^{er} R' \equiv A^e S^v R' \equiv Z \pmod{n}.$$

- Can we achieve untraceability with randomisation?

What about e?

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What about e? – *i.e.* How to hide e?

- Randomised signature: $(\overline{A}, e, \overline{v})$

$$\overline{A}^{e} S^{\overline{v}} \cdot R^{a} \cdot \prod_{i=1}^{L} R_i^{a_i} \equiv Z \pmod{n}.$$

- Representation problem is hard:

$$n;\ Z;\ (\overline{A}, S, R, R_1, \ldots, R_L) \xrightarrow{?} \text{“}(e, \overline{v}, a, a_1, \ldots, a_L)''$$

- So, U proves that she knows:

$$\mathrm{PK}\{(\varepsilon, \overline{\nu}, \alpha, \alpha_1, \ldots, \alpha_L) : Z \equiv \overline{A}^{\varepsilon} S^{\overline{\nu}} R^{\alpha} \prod_{i=1}^{L} R_i^{\alpha_i} \pmod{n}\}.$$

But then selective disclosure is easy!

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Selective disclosure

- Zero-knowledge proof about all exponents:

$$\mathrm{PK}\{(\varepsilon, \overline{\nu}, \alpha, \alpha_1, \ldots, \alpha_L) : Z \equiv \overline{A}^{\varepsilon} S^{\overline{\nu}} R^{\alpha} \prod_{i=1}^{L} R_i^{\alpha_i} \pmod{n}\}.$$

- Disclose some and prove the rest:

U $\longrightarrow$ V disclose: a_1, a_2 and prove:

$$\mathrm{PK}\{(\varepsilon, \overline{\nu}, \alpha, \alpha_3, \ldots, \alpha_L) : Z \cdot R_1^{-a_1} \cdot R_2^{-a_2} \equiv \overline{A}^{\varepsilon} S^{\overline{\nu}} R^{\alpha} \prod_{i=3}^{L} R_i^{\alpha_i} \pmod{n}\}.$$

In Sum: ABCs are Powerful!

- Security
  - Authenticity
  - Integrity
  - Non-transferability
- Privacy
  - Issuer unlinkability
  - Multi-show unlinkability
  - Selective disclosure (data minimisation)
- Technics
  - IBM's idemix [CL 01, CL 02]
  - Microsoft's U-Prove [Brands 99]

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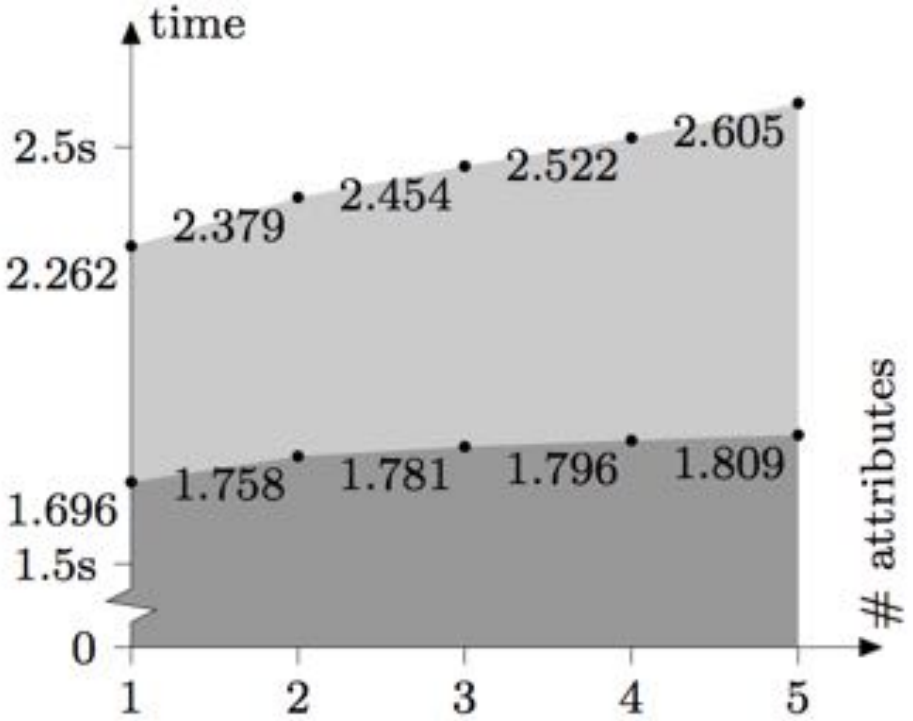
Why Smart Cards?

- Secure
- User-friendly

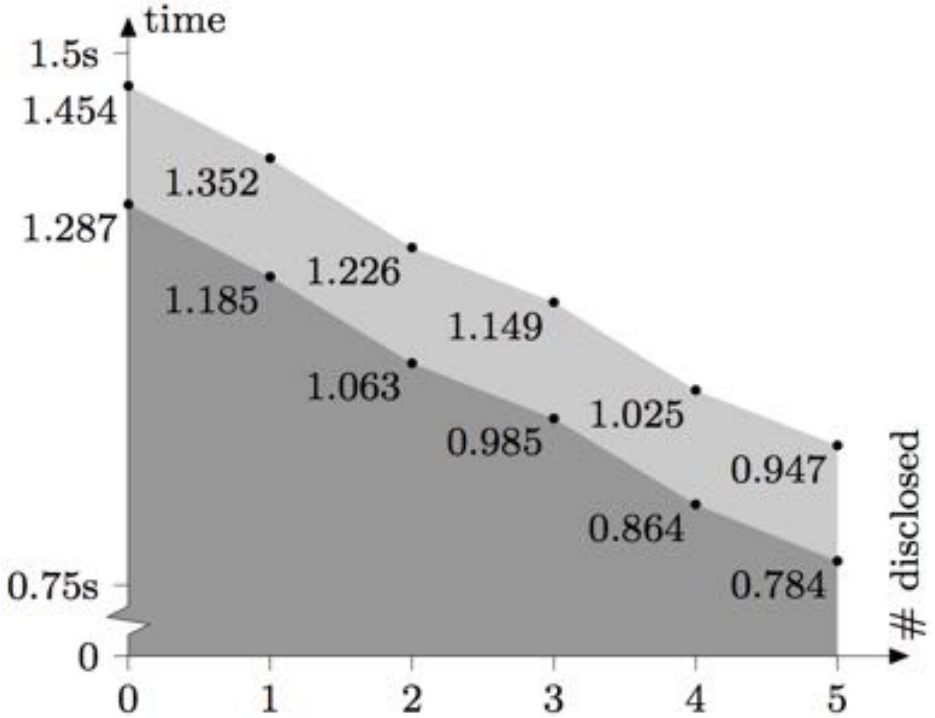
- Feels private
- Looks private

- Restrictions
  - No user interface (DEMO: Card management)
  - JavaCard? No (too restricted API)
  - MULTOS (Infineon SLE78 chip)
  - Small RAM
  - Slow EEPROM

Performance: Issuing [VA 13]



Performance: Showing [VA 13]



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IRMA Team

"I Reveal My Attributes"

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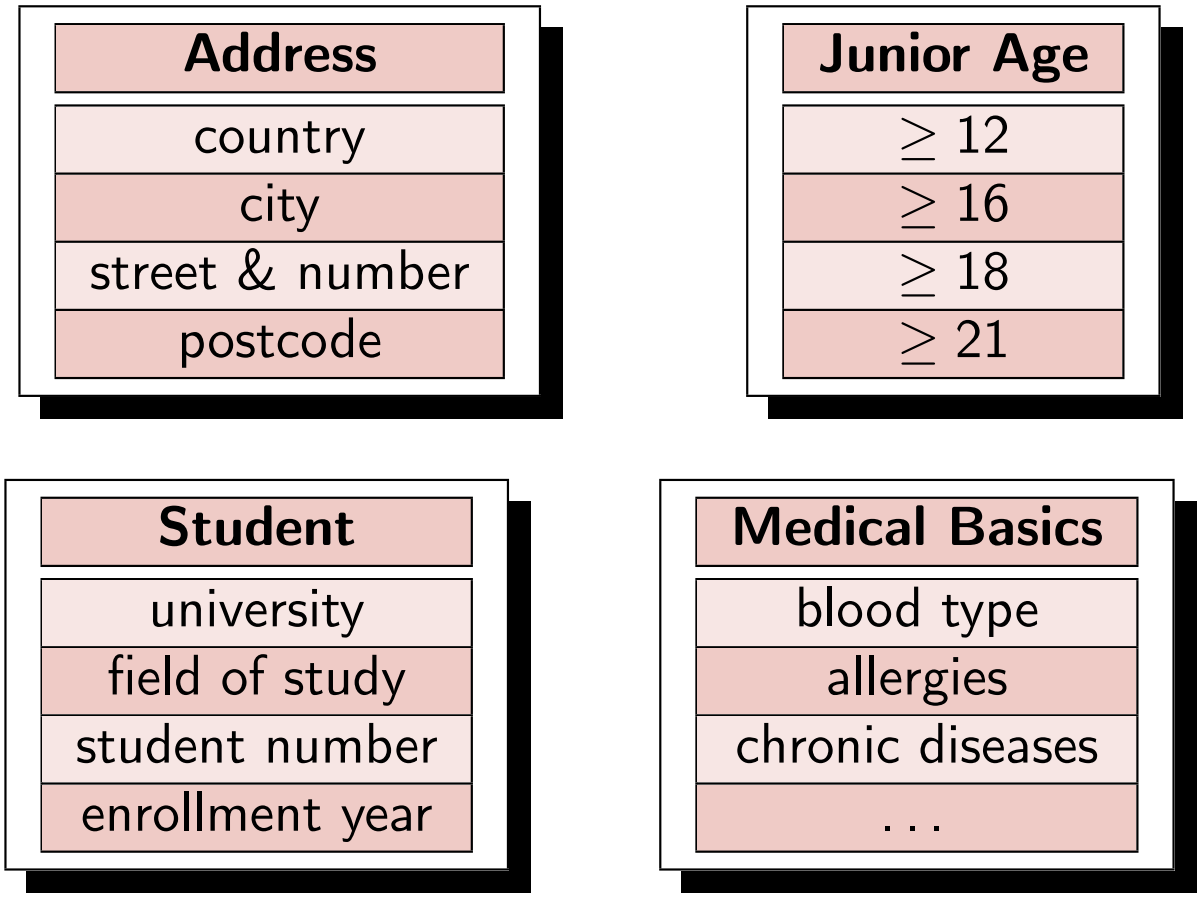
The IRMA Card

Front

Back

ABC Examples



Challenges: ABCs on Smart Cards

- Card anonymity
- Card life cycle

- Credential design
- Online and offline use cases (DEMO: IRMA Tube)

- User authentication (PIN)
- Certification of issuers and verifiers
- Secure channel between card and verifier

- User interfaces (consent!)
- Card management

- Card revocation
- Preventing abuse of anonymity

Summary

- "Attributes rather than identifiers"
- Attribute-based identity management is becoming practical
- Privacy and user control (without losing functionality)
- Nice crypto

- Lots of further questions
  - Deployment
  - Socio-technical aspects
  - Combat suspicion against anonymity
  - To make other attribute-based technologies practical

Questions?

IRMA-related References 1

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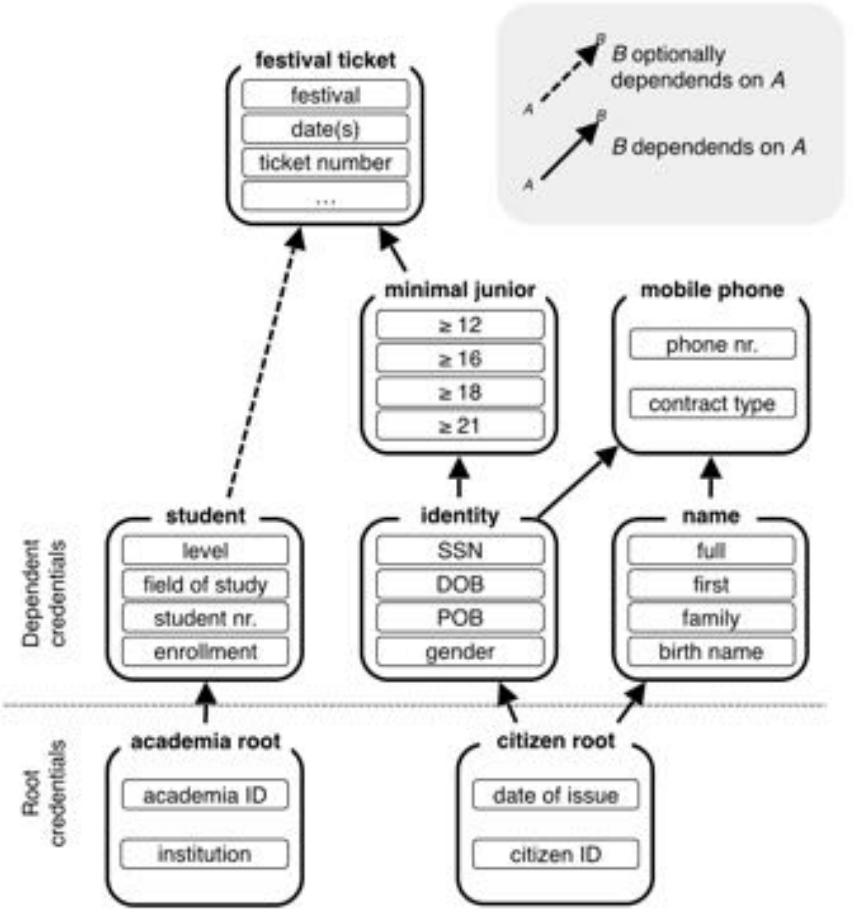
Credential "Tree"



Schnorr Signature, *i.e.* Schnorr with Fiat–Shamir [FS 86]

- Discrete logarithm: "I know the discrete logarithm $\log_g h$."
- Non-interactive: $\mathrm{SPK}\{\chi | h = g^{\chi}\}(n)$

Prover	$\mathbb{G}, g, q, h = g^x, \mathcal{H}$	**Verifier**
Secret: x		
	$\xleftarrow{n}$	$n \in_R \mathbb{Z}_q$
$w \in_R \mathbb{Z}_q$		
$a := g^w$		
$c := \mathcal{H}(a, n)$		
$r := c \cdot x + w \pmod q$	$\xrightarrow{a,r}$	$a \stackrel{?}{=} g^r \cdot h^{-\mathcal{H}(a,n)}$

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