Hacking in Parallel

Are you old enough to buy this?

Zero-Knowledge Age Restriction for GNU Taler

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FU Berlin

Chapters

1. TODO: something something

Introduction

Who am I

TODO: who am i

Age restriction in E-commerce

Problem:

Verification of minimum age requirements in e-commerce.

Common solutions:

1. ID Verification
2. Restricted Accounts
3. Attribute-based

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For age-restriction, the lowest level of authority is:

Parents, guardians and caretakers

Our contribution

Design and implementation of an age restriction scheme with the following goals:

1. It ties age restriction to the **ability to pay** (not to ID's)
2. maintains **anonymity of buyers**
3. maintains **unlinkability of transactions**
4. aligns with **principle of subsidiartiy**
5. is **practical and efficient**

Age Restriction

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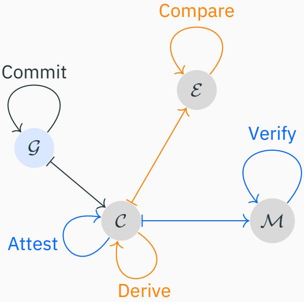

Note: Scheme is independent of payment service protocol.

Formal Function Signatures

Searching for functions

- Commit
- Attest
- Verify
- Derive
- Compare

Formal Function Signatures

Searching for functions with the following signatures

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&\mathrm{Commit}: && (\mathsf{a}, \omega) \mapsto (\mathsf{Q}, \mathsf{P}) && \mathbb{N}_{\mathsf{M}} \times \Omega \to \mathbb{O} \times \mathbb{P},\\
&\mathrm{Attest} && && \\
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Verify

Derive

Compare

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with $\Omega, \mathbb{P}, \mathbb{O}, \mathbb{T}, \mathbb{B}$ sufficiently large sets.

Basic and security requirements are defined later.

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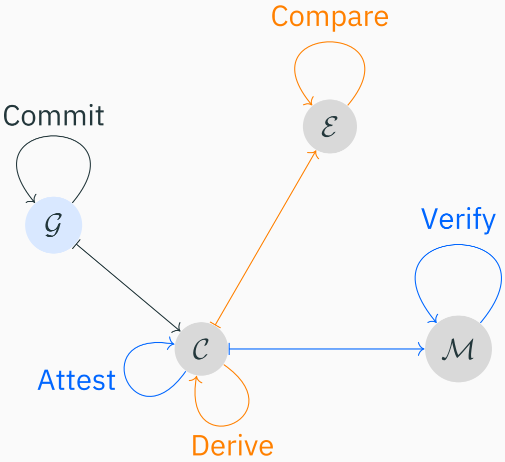
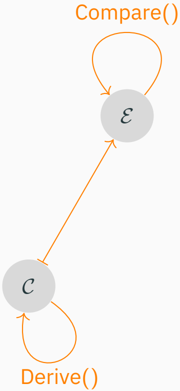
Age restriction



Achieving Unlinkability



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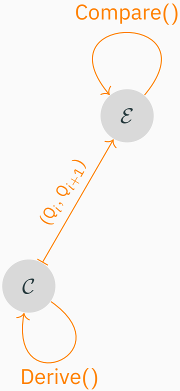

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- Calling Derive() iteratively generates sequence $(Q_0, Q_1, \dots)$ of commitments.
- Exchange calls Compare$(Q_i, Q_{i+1}, .)$

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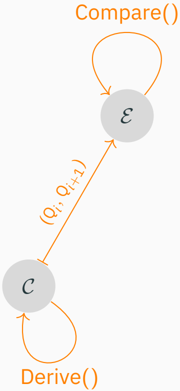

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- Calling Derive() iteratively generates sequence $(Q_0, Q_1, \ldots)$ of commitments.
- Exchange calls Compare$(Q_i, Q_{i+1}, .)$

$\Longrightarrow$ **Exchange identifies sequence**

$\Longrightarrow$ **Unlinkability broken**

Achieving Unlinkability

Define cut&choose protocol DeriveCompare$_\kappa$, using Derive() and Compare().

Achieving Unlinkability

Define cut&choose protocol $\text{DeriveCompare}_\kappa$, using Derive() and Compare().

Sketch:

1. $\mathcal{C}$ derives commitments $(Q_1, \dots, Q_\kappa)$ from Q_0 by calling Derive() with blindings $(\beta_1, \dots, \beta_\kappa)$
2. $\mathcal{C}$ calculates $h_0 := H\left(H(Q_1, \beta_1)||\dots||H(Q_\kappa, \beta_\kappa)\right)$
3. $\mathcal{C}$ sends Q_0 and h_0 to $\mathcal{E}$
4. $\mathcal{E}$ chooses $\gamma \in \{1, \dots, \kappa\}$ randomly
5. $\mathcal{C}$ reveals $h_\gamma := H(Q_\gamma, \beta_\gamma)$ and all (Q_i, β_i), except (Q_γ, β_γ)
6. $\mathcal{E}$ compares h_0 and $H\left(H(Q_1, \beta_1)||...||h_\gamma||...||H(Q_\kappa, \beta_\kappa)\right)$ and evaluates $\text{Compare}(Q_0, Q_i, \beta_i)$.

Note: Scheme is similar to the *refresh* protocol in GNU Taler.

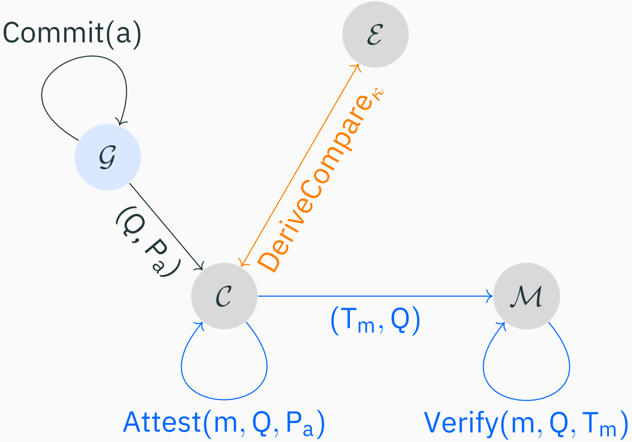
Achieving Unlinkability

With DeriveCompare$_\kappa$

- $\mathcal{E}$ learns nothing about Q_γ,
- trusts outcome with $\frac{\kappa-1}{\kappa}$ certainty,
- i.e. $\mathcal{C}$ has $\frac{1}{\kappa}$ chance to cheat.

Note: Still need Derive and Compare to be defined.

Refined scheme



Basic Requirements

Candidate functions

(Commit, Attest, Verify, Derive, Compare)

must first meet *basic* requirements:

- Existence of attestations
- Efficacy of attestations
- Derivability of commitments and attestations

Basic Requirements

Existence of attestations

$$\underset{\substack{a\in\mathbb{N}_M\\ \omega\in\Omega}}{\forall} : \mathrm{Commit}(a,\omega) =: (Q,P) \implies \mathrm{Attest}(m,Q,P) = \begin{cases} T\in\mathbb{T}, \text{ if } m\leq a\\ \perp \text{ otherwise}\end{cases}$$

Efficacy of attestations

$$\mathrm{Verify}(m,Q,T) = \begin{cases} 1, \text{if } \underset{P\in\mathbb{P}}{\exists} : \mathrm{Attest}(m,Q,P) = T\\ 0 \text{ otherwise}\end{cases}$$

$$\forall_{n\leq a} : \mathrm{Verify}\big(n, Q, \mathrm{Attest}(n,Q,P)\big) = 1.$$

etc.

Security Requirements

Candidate functions must also meet *security* requirements. Those are defined via security games:

- Game: Age disclosure by commitment or attestation

$\leftrightarrow$ Requirement: Non-disclosure of age

- Game: Forging attestation

$\leftrightarrow$ Requirement: Unforgeability of minimum age

- Game: Distinguishing derived commitments and attestations

$\leftrightarrow$ Requirement: Unlinkability of commitments and attestations

Meeting the security requirements means that adversaries can win those games only with negligible advantage.

Adversaries are arbitrary polynomial-time algorithms, acting on all relevant input.

Security Requirements

Game $G_{\mathcal{A}}^{\mathsf{FA}}(\lambda)$—Forging an attest:

1. $(\mathsf{a}, \omega) \xleftarrow{\$} \mathbb{N}_{\mathsf{M}-1} \times \Omega$
2. $(\mathsf{Q}, \mathsf{P}) \leftarrow \mathsf{Commit}(\mathsf{a}, \omega)$
3. $(\mathsf{m}, \mathsf{T}) \leftarrow \mathcal{A}(\mathsf{a}, \mathsf{Q}, \mathsf{P})$
4. Return 0 if $\mathsf{m} \leq \mathsf{a}$
5. Return $\mathsf{Verify}(\mathsf{m}, \mathsf{Q}, \mathsf{T})$

Requirement: Unforgeability of minimum age

$$\underset{\mathcal{A} \in \mathfrak{A}(\mathbb{N}_{\mathsf{M}} \times \mathbb{O} \times \mathbb{P} \to \mathbb{N}_{\mathsf{M}} \times \mathbb{T})}{\forall} : \Pr\Big[G_{\mathcal{A}}^{\mathsf{FA}}(\lambda) = 1\Big] \leq \epsilon(\lambda)$$

Solution/Instantiation

Solution: Instantiation with ECDSA

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1. Guardian generates ECDSA-keypairs, one per age (group):

$$\langle (q_1, p_1), \ldots, (q_M, p_M) \rangle$$

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2. Guardian then **drops** all private keys p_i for $i > \mathsf{a}$:

$$\Big\langle (q_1, p_1), \ldots, (q_\mathsf{a}, p_\mathsf{a}), (q_{\mathsf{a}+1}, \bot), \ldots, (q_\mathsf{M}, \bot) \Big\rangle$$

- $\vec{\mathsf{Q}} := (q_1, \ldots, q_\mathsf{M})$ is the *Commitment*,
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3. Guardian gives child $\langle \vec{\mathsf{Q}}, \vec{\mathsf{P}}_\mathsf{a} \rangle$

Instantiation with ECDSA

Child has

- ordered public-keys $\vec{\mathsf{Q}} = (q_1, \ldots, q_{\mathsf{M}})$,
- (some) private-keys $\vec{\mathsf{P}} = (p_1, \ldots, p_{\mathsf{a}}, \perp, \ldots, \perp)$.

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To Attest a minimum age $\mathsf{m} \leq \mathsf{a}$:

Sign a message with ECDSA using private key p_m

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To Verify a minimum age m**:**

Verify the ECDSA-Signature σ with public key q_m.

Instantiation with ECDSA

Child has $\vec{\mathsf{Q}} = (q_1, \ldots, q_\mathsf{M})$ and $\vec{\mathsf{P}} = (p_1, \ldots, p_\mathsf{a}, \perp, \ldots, \perp)$.

Instantiation with ECDSA

Child has $\vec{\mathsf{Q}} = (q_1, \ldots, q_\mathsf{M})$ and $\vec{\mathsf{P}} = (p_1, \ldots, p_\mathsf{a}, \perp, \ldots, \perp)$.

To Derive new $\vec{\mathsf{Q}}'$ and $\vec{\mathsf{P}}'$: Choose random $\beta \in \mathbb{Z}_g$ and calculate

$$\vec{\mathsf{Q}}' := (\beta * q_1, \ldots, \beta * q_\mathsf{M}),$$
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Note: $(\beta p_i) * G = \beta * (p_i * G) = \beta * q_i$

$\beta * q_i$ is scalar multiplication on the elliptic curve.

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Exchange gets $\vec{\mathsf{Q}} = (q_1, \ldots, q_\mathsf{M})$, $\vec{\mathsf{Q}}' = (q'_1, \ldots, q'_\mathsf{M})$ and β

To Compare, calculate: $(\beta * q_1, \ldots, \beta * q_\mathsf{M}) \stackrel{?}{=} (q'_1, \ldots, q'_\mathsf{M})$

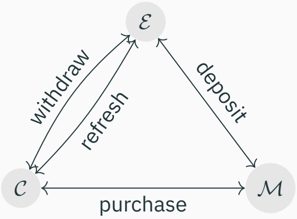
Instantiation with ECDSA

Functions (Commit, Attest, Verify, Derive, Compare)
as defined in the instantiation with ECDSA

- meet the basic requirements,
- also meet all security requirements.
  Proofs by security reduction, details are in the paper.

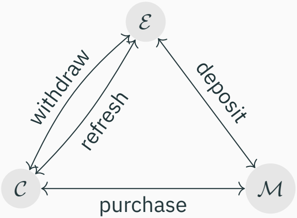
Integration with GNU Taler

GNU Taler



- Protocol suite for online payment services
- Based on Chaum's blind signatures
- Allows for change and refund (F. Dold)
- Privacy preserving: anonymous and unlinkable payments

GNU Taler



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- Coins are public-/private key-pairs (C_p, c_s).
- Exchange blindly signs FDH(C_p) with denomination key d_p
- Verification:

$$1 \stackrel{?}{=} \text{SigCheck}\big(\text{FDH}(C_p), D_p, \sigma_p\big)$$

(D_p = public key of denomination and σ_p = signature)

Integration with GNU Taler

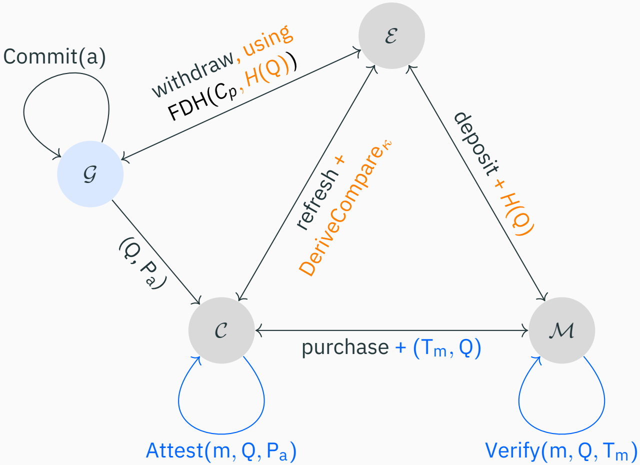
To bind an age commitment Q to a coin C_p, instead of signing FDH(C_p), $\mathcal{E}$ now blindly signs

$$\text{FDH}(C_p, H(\text{Q}))$$

Verfication of a coin now requires H(Q), too:

$$1 \stackrel{?}{=} \text{SigCheck}\big(\text{FDH}(C_p, H(\text{Q})), D_p, \sigma_p\big)$$

Integration with GNU Taler



Instantiation with Edx25519

Paper also formally defines another signature scheme: Edx25519.

- Scheme already in use in GNUnet,
- based on EdDSA (Bernstein et al.),
- generates compatible signatures and
- allows for key derivation from both, private and public keys, independently.

Current implementation of age restriction in GNU Taler uses Edx2551

Discussion, Related Work, Conclusion

Discussion

- Our solution can in principle be used with any token-based payment scheme
- GNU Taler best aligned with our design goals (security, privacy and efficiency)
- Subsidiarity requires bank accounts being owned by adults
    - Scheme can be adapted to case where minors have bank accounts
        - Assumption: banks provide minimum age information during bank transactions.
        - Child and Exchange execute a variant of the cut&choose protocol.
- Our scheme offers an alternative to identity management systems (IMS)

Related Work

- Current privacy-perserving systems all based on attribute-based credentials (Koning et al., Schanzenbach et al., Camenisch et al., Au et al.)
- Attribute-based approach lacks support:
  - Complex for consumers and retailers
  - Requires trusted third authority
- Other approaches tie age-restriction to ability to pay (”debit cards for kids”)
  - Advantage: mandatory to payment process
  - Not privacy friendly

Conclusion

Age restriction is a technical, ethical and legal challenge.

Existing solutions are

- without strong protection of privacy or
- based on identity management systems (IMS)

Our scheme offers a solution that is

- based on subsidiarity
- privacy preserving
- efficient
- an alternative to IMS

Thank you! Questions?

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Nothing to see here