Security in Times of Surveillance

Are you old enough to buy this?

Zero-Knowledge Age Restriction for GNU Taler

Özgür Kesim

31 May 2024

Code Blau GmbH, FU Berlin, TU Dresden

Prolog

Sponsors

NGI Taler and NGI Pointer programs of the European Commission

NGI TALER

TALER

NGI POINTER

Project *Concrete Contracts* in the *KMU-innovativ* programm

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Who am I

Özgür Kesim,

- security consultant for 20+ years,
- PhD candidate at FU Berlin,
- member of GNU Taler dev-team.

`oec-taler@kesim.org` `@oec@mathstodon.xyz`

What to expect

Deliverable

Present a solution to age restriction and its integration in GNU Taler.

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Drive-By

Show concepts from cryptography by example:

Zero-Knowledge protocol, Security Game and Security Proof

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Non-goals

~~Rigorous~~ introduction into GNU Taler

~~Demos~~

Chapters

Introduction

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The quest for a solution to age restriction

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Discussion & Conclusion

Introduction

Age Restriction in E-commerce

Youth protection

Broad consensus in society about the necessity to protect minors from harmful content.

Also wanted from policy makers:

> *11. Member states should encourage the **use of conditional access tools** by content and service providers in relation to content harmful to minors, **such as age-verification systems**, ...*

From the *Recommendation Rec (2001) 8 of the Committee of Ministers to member states on self-regulation concerning cyber content* of the Council of Europe.

Age restriction in E-commerce

Problem:

Verification of minimum age requirements in e-commerce.

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2. Restricted Accounts
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For age-restriction, the lowest level of authority is:

Parents, guardians and caretakers

Our goal

A design and implementation of an age restriction scheme with the following properties:

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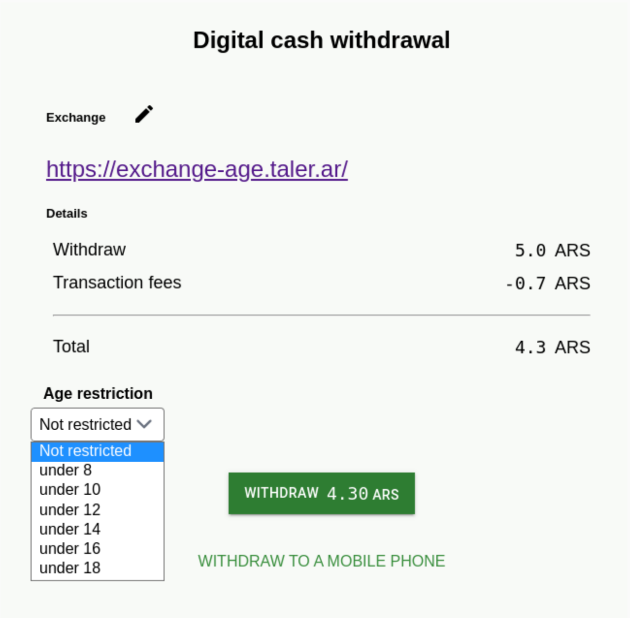
5. is **practical and efficient**.

Teaser



Digital cash withdrawal
Exchange
https://exchange-age.taler.ar/
Details
Withdraw 5.0 ARS
Transaction fees -0.7 ARS
Total 4.3 ARS
Age restriction
Not restricted
Not restricted
under 8
under 10
under 12
under 14
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WITHDRAW 4.30 ARS
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The quest for a solution to age restriction

A journey through cryptic territory

Basic assumption and ideas

Assumption: Bank accounts are under control of adults/guardians.

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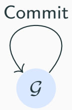

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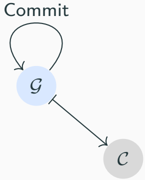

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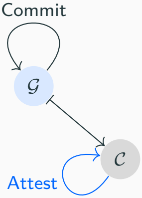

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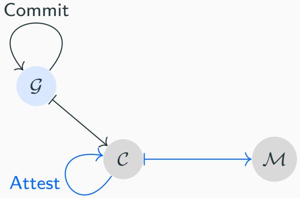

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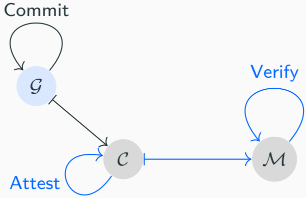

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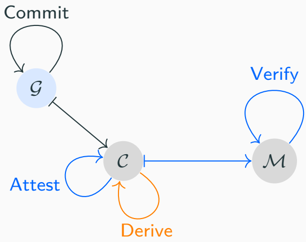

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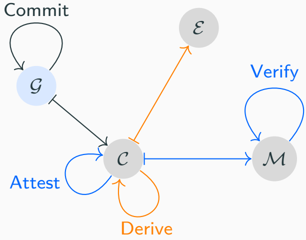

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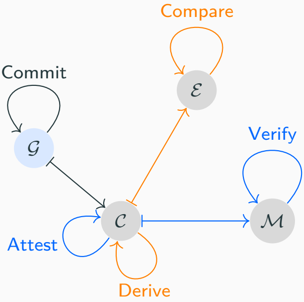

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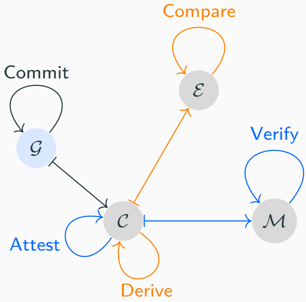
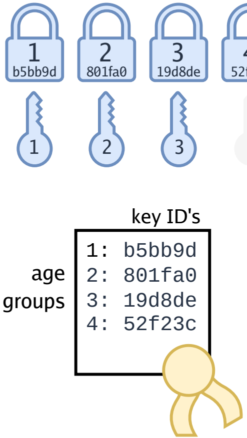
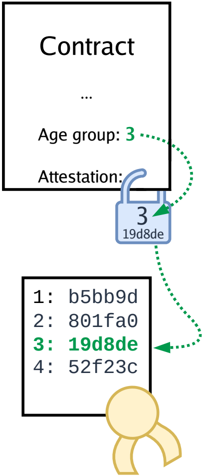
6. `GOTO` 2.



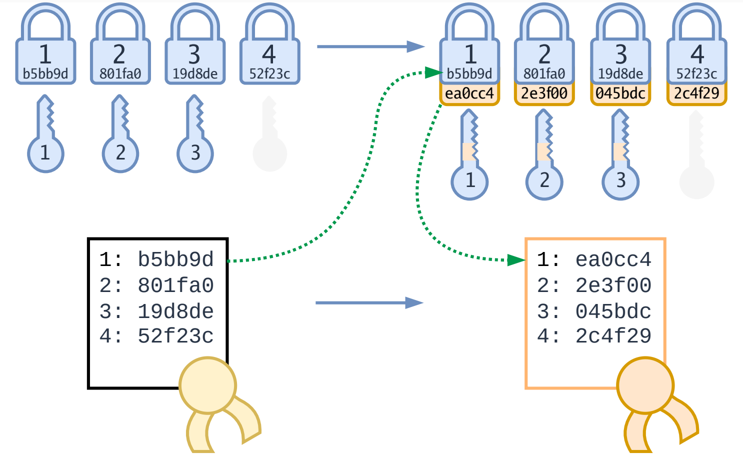
Helpful figure - Commit



Helpful figure - Attest and Verify



Helpful figure - Derive and Compare



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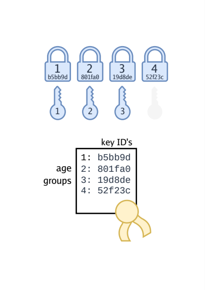

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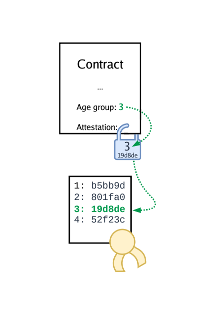

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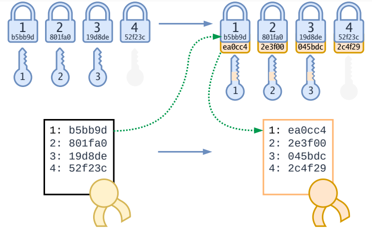

Specification of the Function Signatures

Searching for functions

- Commit
- Attest
- Verify
- Derive
- Compare

Specification of the Function Signatures

Searching for functions with the following signatures

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

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We will define basic and security requirements later.

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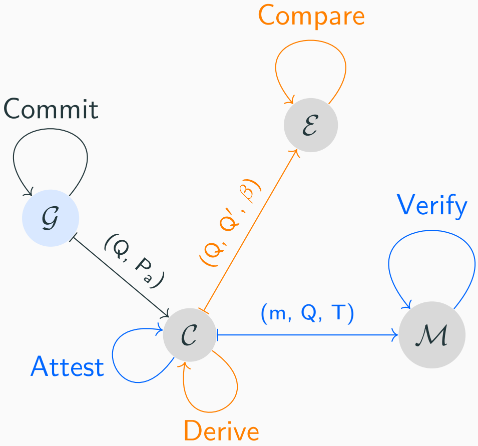
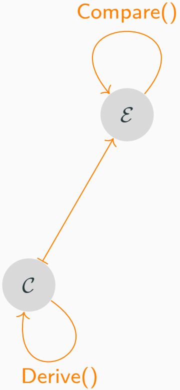
Naïve scheme



Problem of unlinkability



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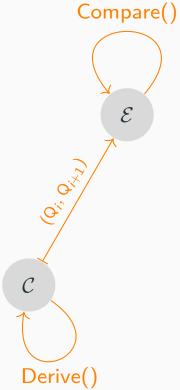

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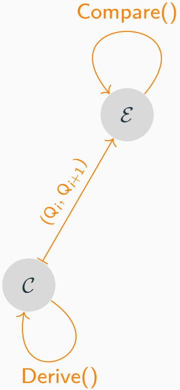

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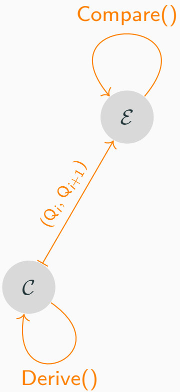

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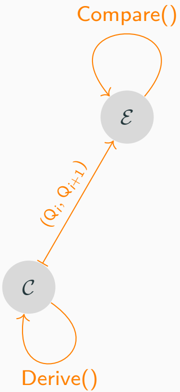

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$\Longrightarrow$ Exchange identifies sequence

$\Longrightarrow$ **Unlinkability broken**

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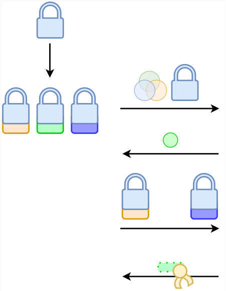

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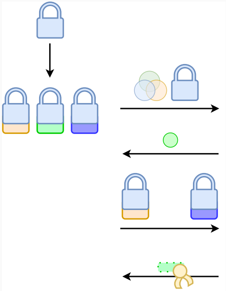

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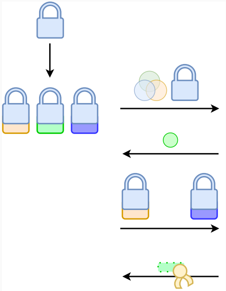

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$\mathcal{C}$: 1. generates $(\mathsf{Q}_1, \dots, \mathsf{Q}_\kappa)$ and $(\beta_1, \dots, \beta_\kappa)$ from Q_0 by calling κ times Derive$(\mathsf{Q}_0, \mathsf{P}_0, \omega_i)$

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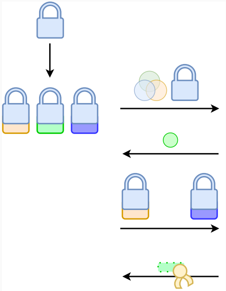

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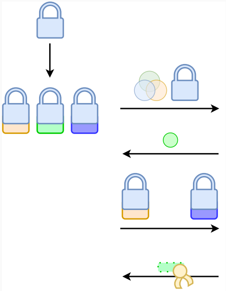

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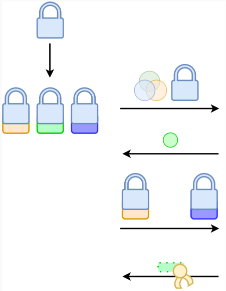

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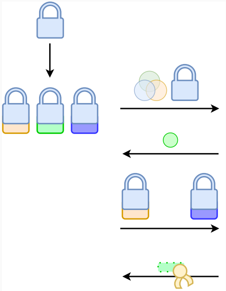

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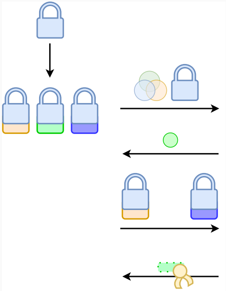

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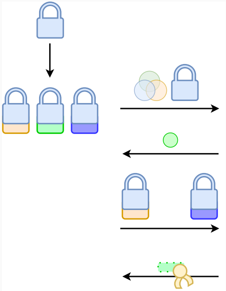

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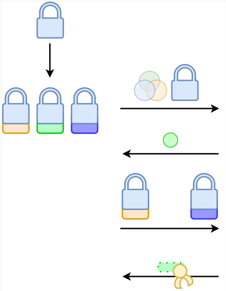

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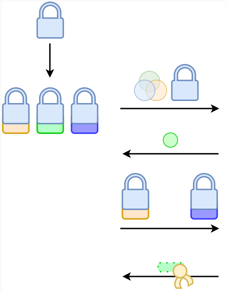

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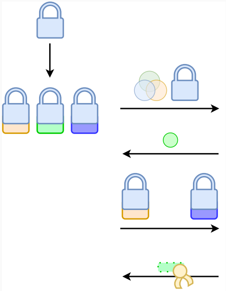

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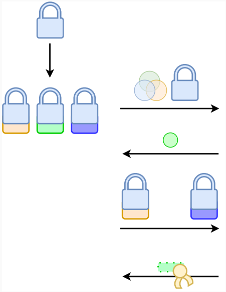

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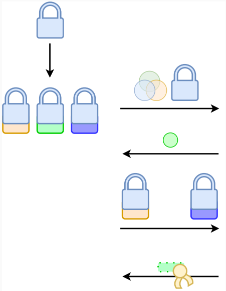

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If all steps succeed, Q_γ is the new commitment.

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With DeriveCompare$_\kappa$

- $\mathcal{E}$ learns nothing about Q_γ or $H(\mathsf{Q}_\gamma)$,
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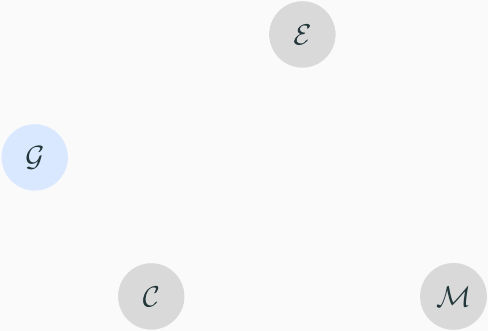
Notes:

- similar to the cut&choose *refresh* protocol in GNU Taler
- still need to define Derive() and Compare().

Refined scheme



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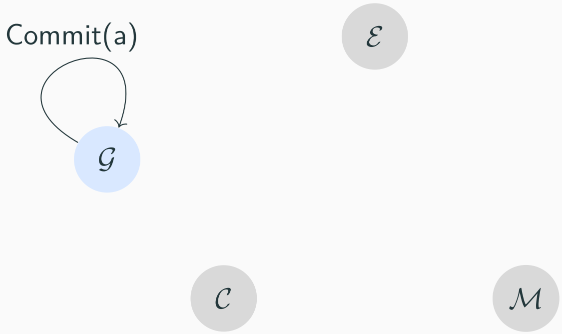

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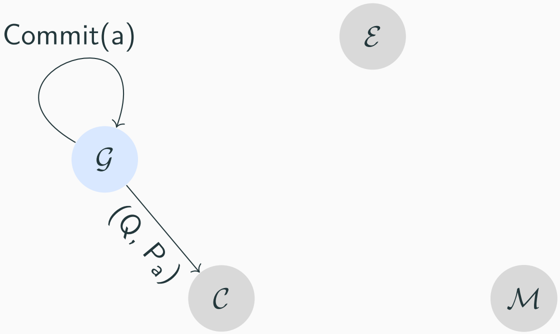

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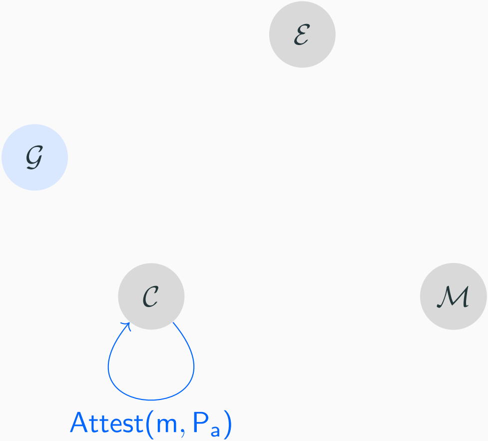

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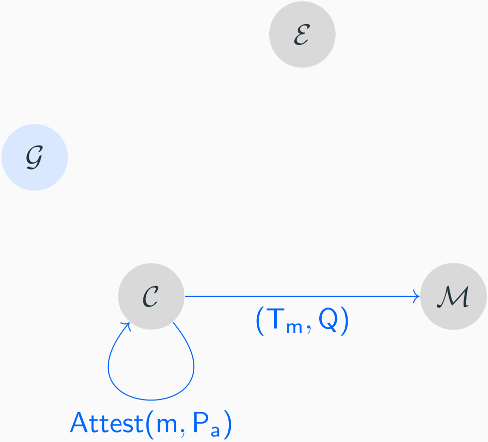

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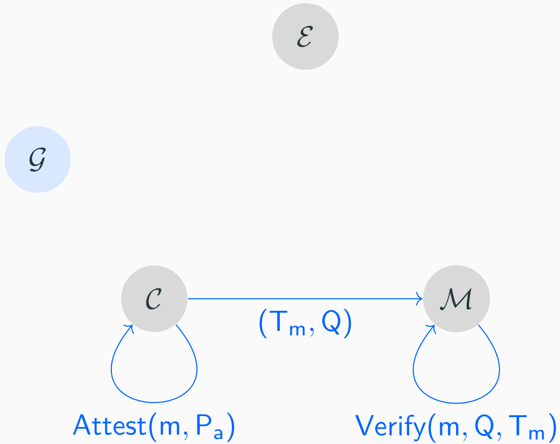

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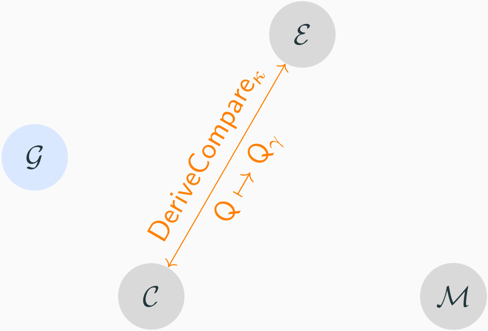

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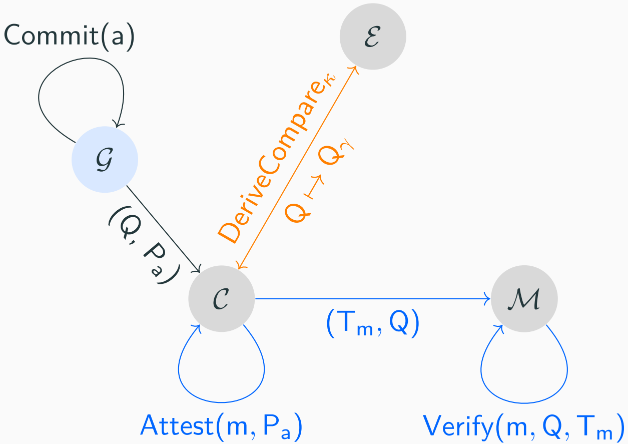

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We need more requirements.

Requirements

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Candidate functions

$$(\mathrm{Commit}, \mathrm{Attest}, \mathrm{Verify}, \mathrm{Derive}, \mathrm{Compare})$$

must meet *basic requirements*:

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More details in the published paper and Appendix.

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

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Simplified Example

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Requirement: Unforgeability of minimum age

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

Our task

Finding functions

$$(\mathsf{Commit}, \mathsf{Attest}, \mathsf{Verify}, \mathsf{Derive}, \mathsf{Compare})$$

that meet the basic and security requirements.

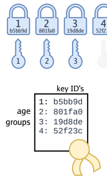
A solution to our quest

Instantiation with ECDSA

We propose a solution based on ECDSA.

Think: One key-pair per age group.

Definition of Commit with ECDSA



To Commit to age group $a \in \{1, \ldots, M\}$

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

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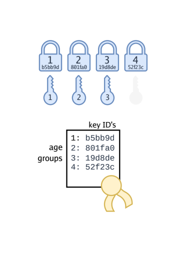

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2. Guardian then **drops** all private keys p_i for $i > \mathsf{a}$:

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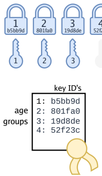
Definition of Commit with ECDSA



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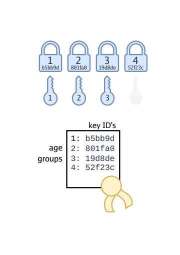

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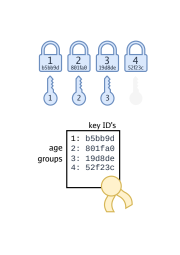

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Proof: $\vec{\mathsf{P}}_\mathsf{a} := (p_1, \ldots, p_\mathsf{a}, \bot, \ldots, \bot)$

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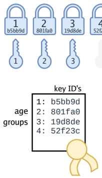

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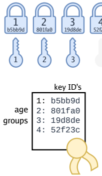
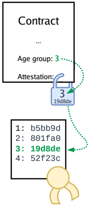
3. Guardian gives child $\langle \vec{Q}, \vec{P}_a \rangle$

Attest and Verify with ECDSA





Child has

- ordered public-keys $\vec{Q} = (q_1, \ldots \quad \ldots \quad \ldots, q_M)$,
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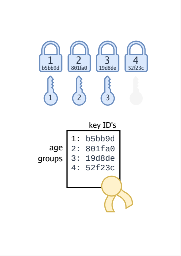

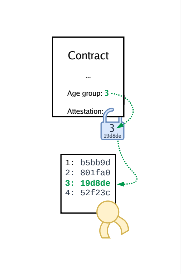

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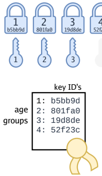
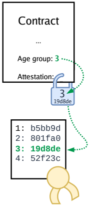
To Attest a minimum age (group) $m \leq a$:

Sign a message with ECDSA using private key p_m.

The signature σ_m is the attestation.

Attest and Verify with ECDSA





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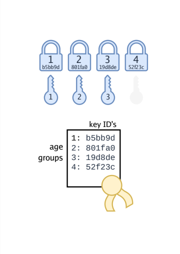

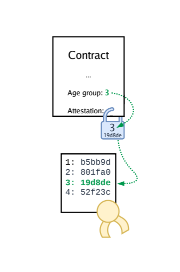

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To Verify a minimum age (group) m**:**

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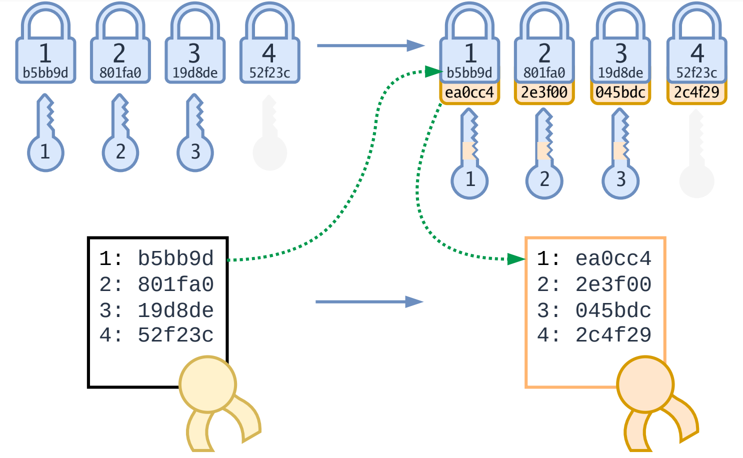
Reminder: Derive and Compare



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

$$\begin{aligned} \vec{\mathsf{Q}}' &= (q'_1, \;\ldots\;\ldots\;\ldots\;, q'_{\mathsf{M}}) && := (\beta * q_1, \ldots\;\ldots, \beta * q_{\mathsf{M}}), \\ \vec{\mathsf{P}}' &= (p'_1, \ldots, p'_{\mathsf{a}}, \perp, \ldots, \perp) && := (\beta p_1, \ldots, \beta p_{\mathsf{a}}, \perp, \ldots, \perp) \end{aligned}$$

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Note:

- $\beta * q_i$ is scalar multiplication on the elliptic curve.
- $p'_i * G = (\beta p_i) * G = \beta * (p_i * G) = \beta * q_i = q'_i$

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Exchange gets $\vec{Q} = (q_1, \ldots, q_M)$, $\vec{Q}' = (q'_1, \ldots, q'_M)$ and β

To Compare, calculate: $(\beta * q_1, \ldots, \beta * q_M) \stackrel{?}{=} (q'_1, \ldots, q'_M)$

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.

Security proofs by reduction, details are in the paper.

Example: Proof of Unforgeability

Proof by reduction:

Game $G^{\mathsf{FA}}_{\mathcal{A}}$: 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:

$$\underset{\mathcal{A}}{\forall} : \Pr\Big[G^{\mathsf{FA}}_{\mathcal{A}} = 1\Big] \leq \epsilon$$

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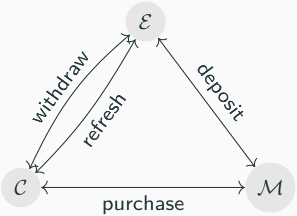
$\Longrightarrow$ So winning this game would require to existentially forge the signature, which is negligible.

Integration with GNU Taler

GNU Taler

https://www.taler.net



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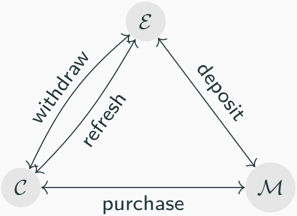

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- Coins are public-/private key-pairs (C_p, c_s).
- Exchange blindly signs $H(C_p)$ with denomination key d_p:

$$\beta(\sigma_p) = \text{BlindSign}\big(\beta\left(H(C_p)\right), d_p\big)$$

- Verification:

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

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

Integration with GNU Taler

Binding age restriction to coins

To bind an age commitment Q to a coin C_p, instead of blindly signing $H(C_p)$

$$\beta(\sigma_p) = \text{BlindSign}\big(\beta\,(H(C_p))\,, d_p\big)$$

$\mathcal{E}$ now blindly signs $H(C_p \parallel H(\text{Q}))$

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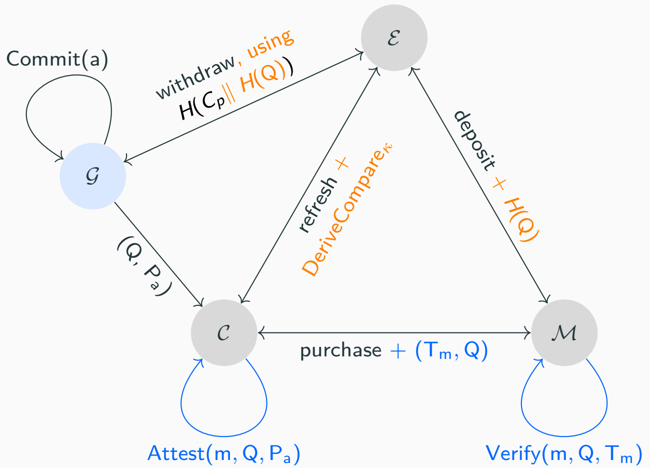
Therefore, verfication of a coin now requires $H(\text{Q})$, too:

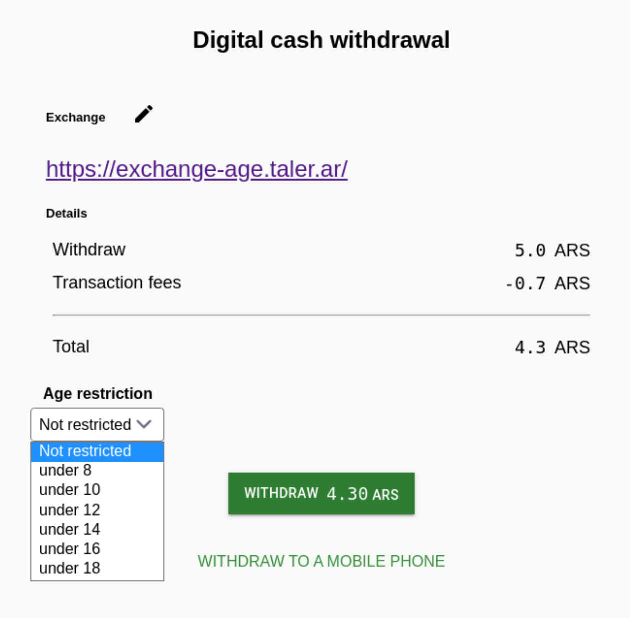
$$1 \stackrel{?}{=} \text{SigCheck}\big(H\,(C_p \parallel H(\text{Q}))\,, D_p, \sigma_p\big)$$

Integration with GNU Taler

Integrated schemes



Age restriction in the wallet



Discussion & Conclusion

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Technical aspects and challenges

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  - cut&choose protocol `age-withdraw` implemented

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- Our scheme offers an alternative to identity management systems (IMS), where applicable

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Our scheme offers an option that

- aligns with subsidiarity
- preserves privacy
- is efficient
- and an alternative to IMS

Thank you!

Questions?

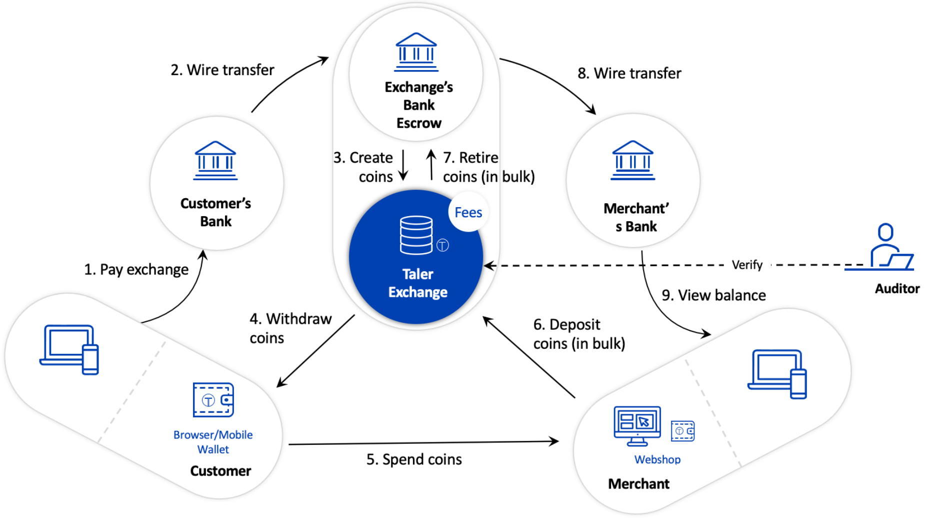
`oec-taler@kesim.org`

`@oec@mathstodon.xyz`

Interested in GNU Taler?

Intro:	`https://taler.net`
Learn:	`https://docs.taler.net`
Develop:	`https://git.taler.net`, `https://bugs.taler.net`
Connect:	`https://ich.taler.net`
NGI Taler:	`https://ngi.taler.net`

Taler Overview



Basic Requirements - Details

back to Basic Requirements

Existence of attestations

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

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Basic Requirements - Details

back to Basic Requirements

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Derivability of commitments and attestations ...

More details in the published paper.

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back to *taler* or *binding*

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back to *taler* or *binding*

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back to *taler* or *binding*

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$\implies$ σ is a valid RSA signature to message m.

back to *taler* or *binding*

Instantiation with Edx25519

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We also formally define another signature scheme, Edx25519:

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

Current implementation of age restriction in GNU Taler uses Edx25519.

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 additional authority

- Other approaches tie age-restriction to ability to pay ("debit cards for kids")
  - Advantage: mandatory to payment process
  - Not privacy friendly