NEXT GENERATION INTERNET

GNU Taler

Christian Grothoff

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Learning objectives

How should we pay?

Introduction to GNU Taler

Blind Signatures

How does cut-and-choose work?

How to prove protocols secure with cryptographic games?

What are the future plans for GNU Taler?

Part I: How should we pay?

Surveillance

Surveillance concerns

- Everybody knows about Internet surveillance.
- But is it **that** bad?
  - You can choose when and where to use the Internet
  - You can anonymously access the Web using Tor
  - You can find open access points that do not require authentication
  - IP packets do not include your precise location or name
  - ISPs typically store this meta data for days, weeks or months

Where is it worse?

This was a question posed to RAND researchers in 1971:

> *"Suppose you were an advisor to the head of the KGB, the Soviet Secret Police. Suppose you are given the assignment of designing a system for the surveillance of all citizens and visitors within the boundaries of the USSR. The system is not to be too obtrusive or obvious. What would be your decision?"*

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"I think one of the big things that we need to do, is we need to get a way from true-name payments on the Internet. The credit card payment system is one of the worst things that happened for the user, in terms of being able to divorce their access from their identity." –Edward Snowden, IETF 93 (2015)

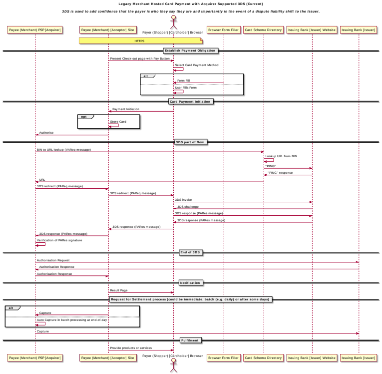
Why is it worse?

- When you pay by CC, the information includes your name
- When you pay in person with CC, your location is also known
- You often have no alternative payment methods available
- You hardly ever can use someone else’s CC
- Anonymous prepaid cards are difficult to get and expensive
- Payment information is typically stored for 6-10 years!

Credit cards have problems, too!

3D secure ("verified by visa") is a nightmare:

- Complicated process
- Shifts liability to consumer
- Significant latency
- Can refuse valid requests
- Legal vendors excluded
- No privacy for buyers



The bank's Problem

- Global tech companies push oligopolies
- Privacy and federated finance are at risk
- Economic sovereingity is in danger

Predicting the future

- Google and Apple will be your bank and run your payment system
- They can target advertising based on your purchase history, location and your ability to pay
- They will provide more usable, faster and broadly available payment solutions; our federated banking system will be history
- After they dominate the payment sector, they will start to charge fees befitting their oligopoly size
- Competitors and vendors not aligning with their corporate "values" will be excluded by policy and go bankrupt
- The imperium will have another major tool for its financial warfare

The Bank of International Settlements on CBDC

The Emergency Act of Canada, February 2022, https://www.youtube.com/watch?v=Neh

Introduction to GNU Taler

Digital cash, made **socially responsible**.

Privacy-Preserving, Practical, Taxable, Free Software, Efficient

What is Taler?

`https://taler.net/en/features.html`

Taler is

- a Free/Libre software *payment system* infrastructure project
- ... with a surrounding software ecosystem
- ... and a company (Taler Systems S.A.) and community that wants to deploy it as widely as possible.

However, Taler is

- *not* a currency
- *not* a long-term store of value
- *not* a network or instance of a system
- *not* decentralized
- *not* based on proof-of-work or proof-of-stake
- *not* a speculative asset / “get-rich-quick scheme”

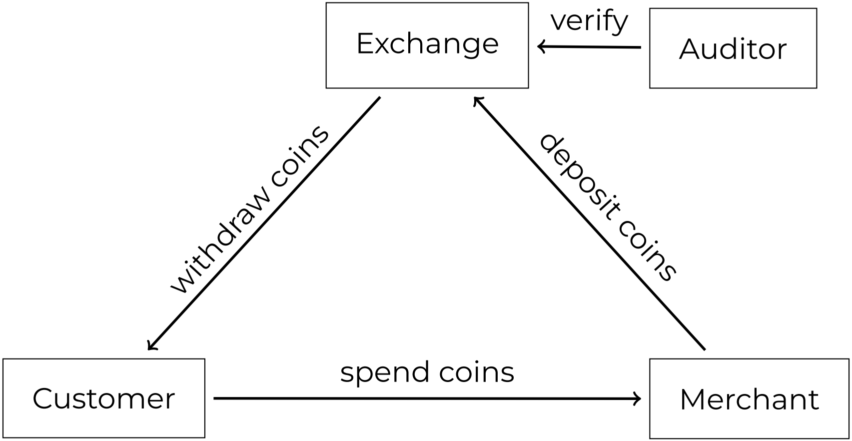
Design goals

... for the GNU Taler payment system

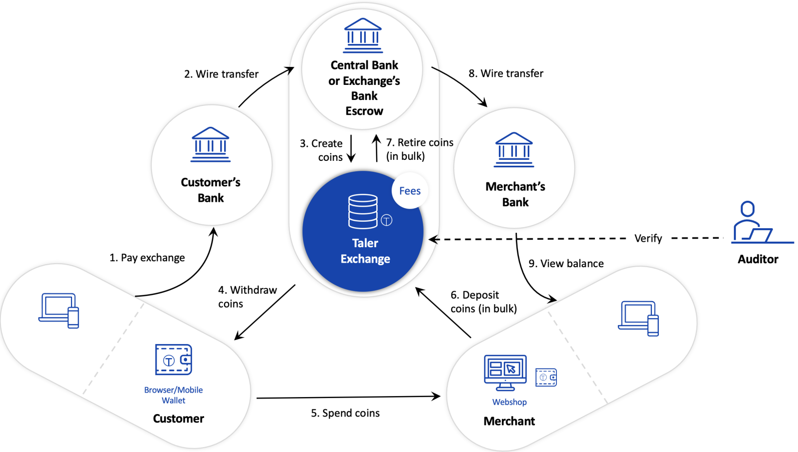
GNU Taler must ...

1. ... be implemented as **free software**.
2. ... protect the **privacy of buyers**.
3. ... must enable the state to **tax income** and crack down on illegal business activities.
4. ... prevent payment fraud.
5. ... only **disclose the minimal amount of information necessary**.
6. ... be usable.
7. ... be efficient.
8. ... avoid single points of failure.
9. ... foster **competition**.

Taler overview



Architecture of Taler



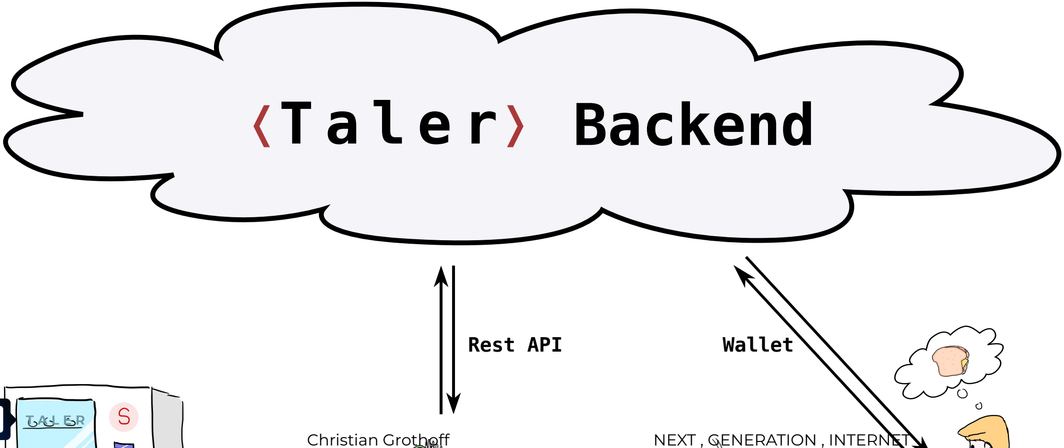
Usability of Taler

`https://demo.taler.net/`

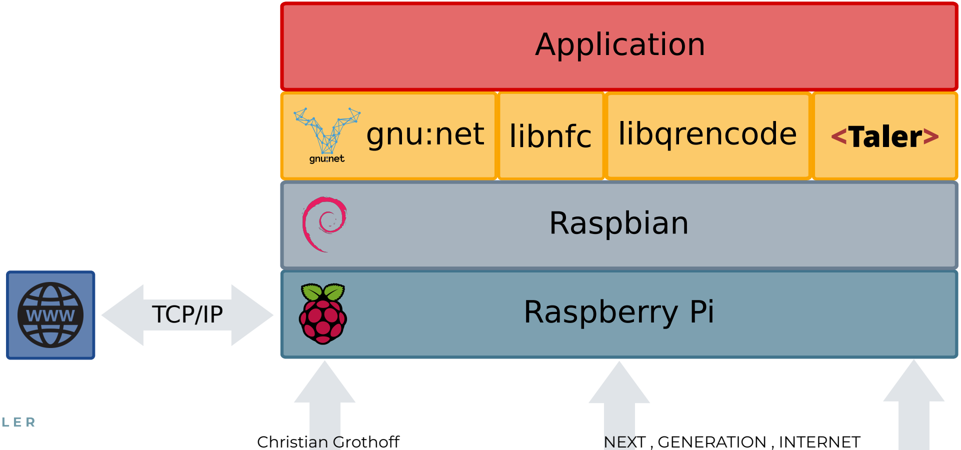
1. Install Web extension.
2. Visit the `bank.demo.taler.net` to withdraw coins.
3. Visit the `shop.demo.taler.net` to spend coins.

The Taler Snack Machine

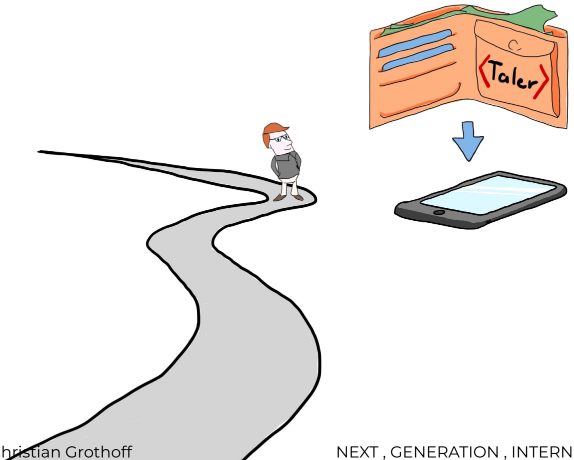
Integration of a MDB/ICP to Taler gateway.
Implementation of a NFC or QR-Code to Taler



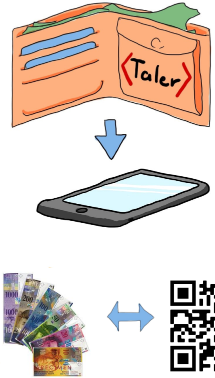
Software architecture for the Taler Snack Machine



Exercise: Install App on Smartphone



Exercise: Withdraw e-cash



Exercise: Use machine!

Part III: Blind Signatures

Reminder: RSA

Generate random p, q primes and e such that

$$GCD((p-1)(q-1), e) = 1 \tag{1}$$

- Define $n = pq$,
- compute d such that $ed \equiv 1 \mod (p-1)(q-1)$.
- Let $s := m^d \mod n$.
- Then $m \equiv s^e \mod n$.

RSA Summary

- Public key: n, e
- Private key: $d \equiv e^{-1} \mod \phi(n)$ where $\phi(n) = (p-1) \cdot (q-1)$
- Encryption: $c \equiv m^e \mod n$
- Decryption: $m \equiv c^d \mod n$
- Signing: $s \equiv m^d \mod n$
- Verifying: $m \equiv s^e \mod n$?

These equations are heavily simplified and should not be used like this in production!

Low Encryption Exponent Attack

- e is known
- m maybe small
- $C = m^e < n$?
- If so, can compute $m = \sqrt[e]{C}$

$\Rightarrow$ Small e can be bad!

Padding and RSA Symmetry

- Padding can be used to avoid low exponent issues (and issues with $m = 0$ or $m = 1$)
- Randomized padding defeats chosen plaintext attacks
- Padding breaks RSA symmetry:

$$D_{A_{priv}}(D_{B_{priv}}(E_{A_{pub}}(E_{B_{pub}}(m)))) \neq m \tag{2}$$

- PKCS#1 / RFC 3447 define a padding standard

Blind signatures with RSA [2]

1. Obtain public key (e, n)
2. Compute $f := FDH_n(m)$, $f < n$.
3. Generate random blinding factor $b \in \mathbb{Z}_n$
4. Transmit $f' := fb^e \mod n$

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1. Receive f'.
2. Compute $s' := f'^d \mod n$.
3. Send s'.

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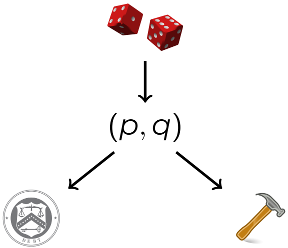
Applications for blind signatures

- Untraceable payments
- Unlinkable access tokens (PrivacyPass)

Provider setup: Create a denomination key (RSA)

1. Generates random primes p, q.
2. Computes $n := pq$,
   $\phi(n) = (p-1)(q-1)$
3. Picks small $e < \phi(n)$ such that
   $d := e^{-1} \mod \phi(n)$ exists.
4. Publishes public key (e, n).



Merchant setup: Create a signing key (EdDSA)

- Generates random $m \mod o$ as private key
- Computes public key $M := mG$

Capability: $m \Rightarrow$ 

$\downarrow$

m

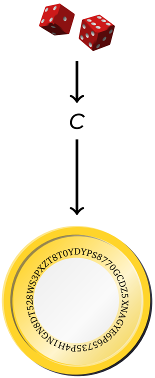
$\downarrow$

M

Customer: Create a planchet (EdDSA)

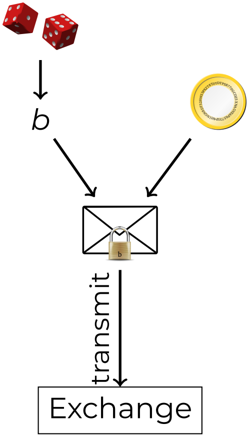
- Generates random $c \mod o$ as private key
- Computes public key $C := cG$

Capability: $c \Rightarrow$ 



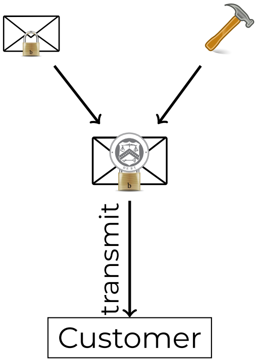
Customer: Blind planchet (RSA)

1. Obtains public key (e, n)
2. Computes $f := FDH_n(C), f < n$.
3. Generates random blinding factor $b \in \mathbb{Z}_n$
4. Transmits $f' := fb^e \mod n$



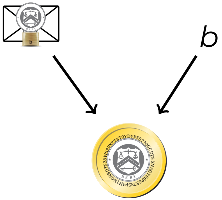
Provider: Blind sign (RSA)

1. Receives f'.
2. Computes $s' := f'^d \mod n$.
3. Sends signature s'.

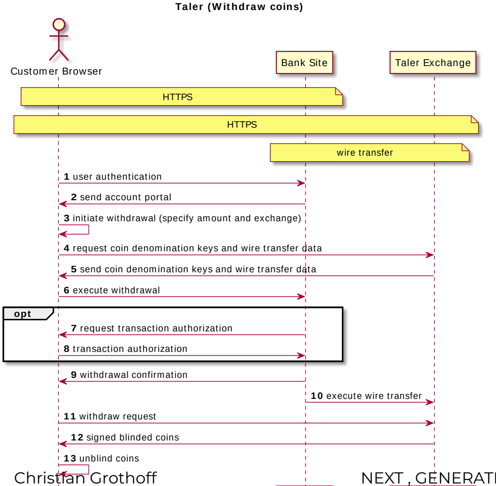


Customer: Unblind signature (RSA)

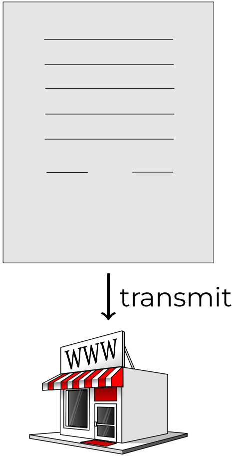
1. Receives s'.
2. Computes $s := s'b^{-1} \mod n$



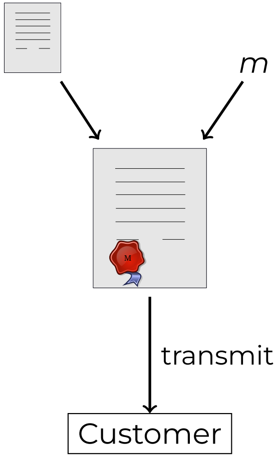
Withdrawing coins on the Web



Customer: Build shopping cart



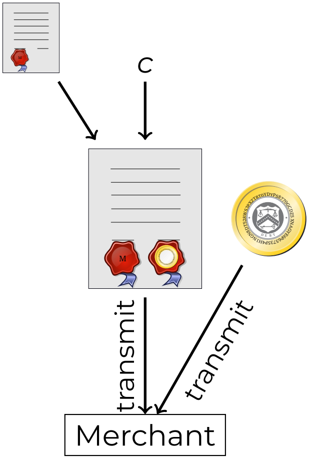
Merchant: Propose contract (EdDSA)



1. Complete proposal D.
2. Send D, $EdDSA_m(D)$

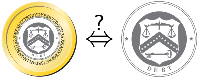
Customer: Spend coin (EdDSA)

1. Receive proposal D, $EdDSA_m(D)$.
2. Send s, C, $EdDSA_c(D)$



Merchant and provider: Verify coin (RSA)

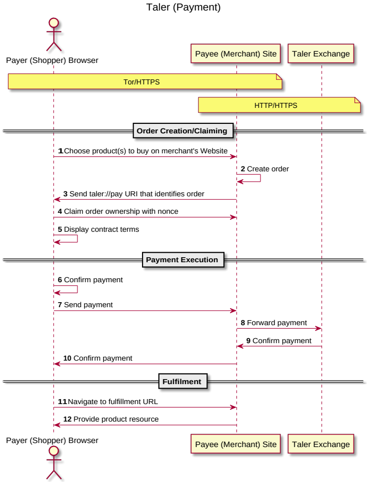
$$s^e \mod n \stackrel{?}{\equiv} FDH_n(C)$$



The provider (Taler: exchange) does not only verify the signature, but also checks that the coin was not double-spent.

GNU Taler is an online payment system.

Payment processing with blind signatures



Part IV: How does cut-and-choose work?

Taxability

We say Taler is taxable because:

- Merchant's income is visible from deposits.
- Hash of contract is part of deposit data.
- State can trace income and enforce taxation.

Limitations:

- withdraw loophole
- *sharing* coins among family and friends

Other contemporary payment systems have similar limitations on identification, and thus these limitations should not be a legal issue.

Giving change

It would be inefficient to pay EUR 100 with 1 cent coins!

- Denomination key represents value of a coin.
- Exchange may offer various denominations for coins.
- Wallet may not have exact change!
- Usability requires ability to pay given sufficient total funds.

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Key goals:

- maintain unlinkability
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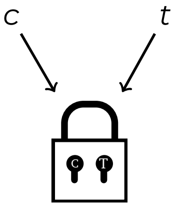
Method:

- Contract can specify to only pay *partial value* of a coin.
- Exchange allows wallet to obtain *unlinkable change* for remaining coin value.

Diffie-Hellman (ECDH)

1. Create private keys $c, t \mod o$
2. Define $C := cG$
3. Define $T := tG$
4. Compute DH:
   $cT = c(tG) = t(cG) = tC$

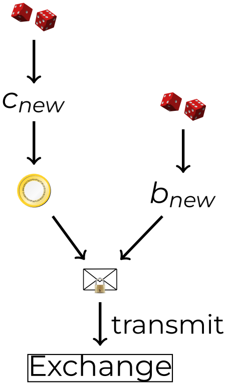


Strawman solution

Given partially spent private coin key c_{old}:

1. Pick random $c_{new} \mod o$ private key
2. Compute $C_{new} := c_{new}G$ public key
3. Pick random b_{new}
4. Compute $f_{new} := FDH(C_{new})$, $m < n$.
5. Transmit $f'_{new} := f_{new} b^e_{new} \mod n$

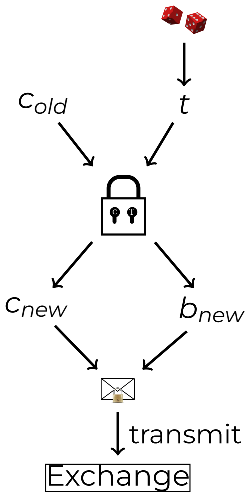
... and sign request for change with c_{old}.



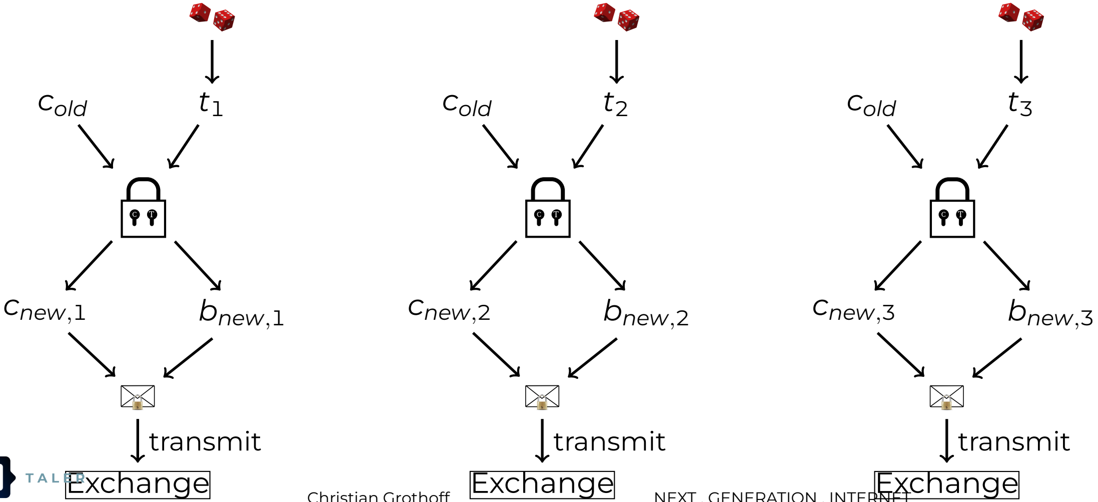
Customer: Transfer key setup (ECDH)

Given partially spent private coin key c_{old}:

1. Let $C_{old} := c_{old}G$ (as before)
2. Create random private transfer key $t \mod o$
3. Compute public transfer key $T := tG$
4. Compute $X := c_{old}(tG) = t(c_{old}G) = tC_{old}$
5. Derive c_{new} and b_{new} from X using HKDF
6. Compute $C_{new} := c_{new}G$
7. Compute $f_{new} := FDH(C_{new})$
8. Transmit $f'_{new} := f_{new}b^e_{new}$



Cut-and-Choose



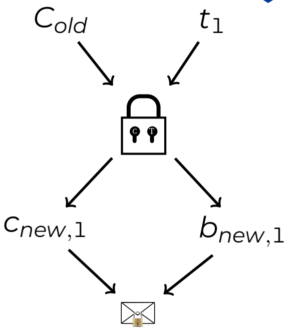
Exchange: Choose!

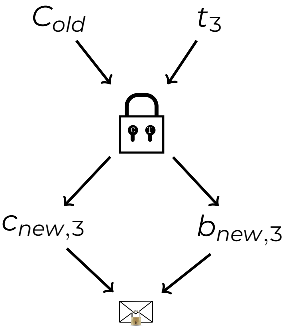
Exchange sends back random $\gamma \in \{1, 2, 3\}$ to the customer.

Customer: Reveal

1. If $\gamma = 1$, send t_2, t_3 to exchange
2. If $\gamma = 2$, send t_1, t_3 to exchange
3. If $\gamma = 3$, send t_1, t_2 to exchange

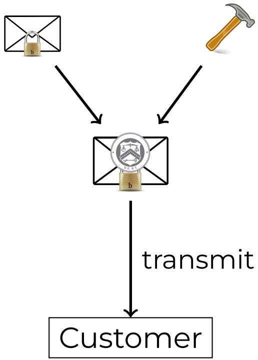
Exchange: Verify ($\gamma = 2$)





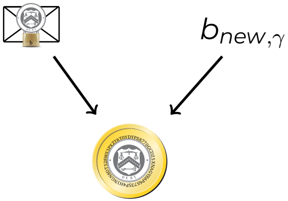
Exchange: Blind sign change (RSA)

1. Take $f'_{new,\gamma}$.
2. Compute
   $s' := f'^{d}_{new,\gamma} \mod n$.
3. Return signature s'.



Customer: Unblind change (RSA)

1. Receive s'.
2. Compute $s := s' b_{new,\gamma}^{-1} \mod n$.

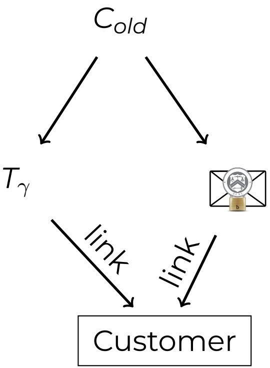


Exchange: Allow linking change

Given C_{old}

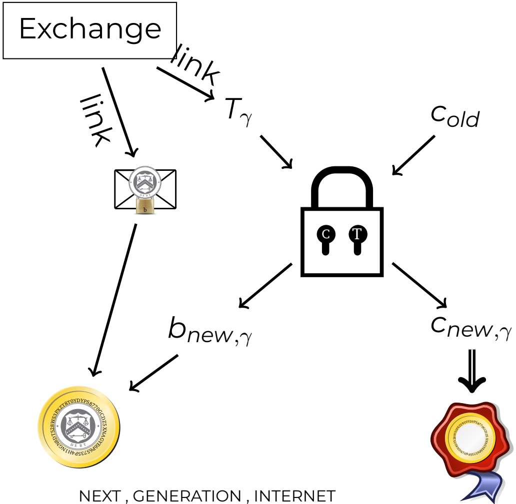
return T_γ and

$$s := s' b_{new,\gamma}^{-1} \mod n.$$



Customer: Link (threat!)

1. Have c_{old}.
2. Obtain T_γ, s from exchange
3. Compute $X_\gamma = c_{old} T_\gamma$
4. Derive $c_{new,\gamma}$ and $b_{new,\gamma}$ from X_γ
5. Unblind $s := s' b_{new,\gamma}^{-1} \mod n$



Refresh protocol summary

- Customer asks exchange to convert old coin to new coin
- Protocol ensures new coins can be recovered from old coin

$\Rightarrow$ New coins are owned by the same entity!

Thus, the refresh protocol allows:

- To give unlinkable change.
- To give refunds to an anonymous customer.
- To expire old keys and migrate coins to new ones.
- To handle protocol aborts.

Transactions via refresh are equivalent to *sharing* a wallet.

Part V: How to prove protocols secure with cryptographic games?

Reminder: Cryptographic games

An *oracle* is a party in a game that the adversary can call upon to indirectly access information that is otherwise hidden from it.
For example, **IND-CPA** can be formalized like this:

- Setup: Generate random key k, select $b \in \{0, 1\}$ for $i \in \{1, \dots, q\}$.
- Oracle: Given M_0 and M_1 (of same length), return $C := \texttt{enc}(k, M_b)$.

The adversary wins, if it can guess b with probability greater than $\frac{1}{2} + \epsilon(\kappa)$ where $\epsilon(\kappa)$ is a negligible function in the security parameter κ.

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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Principle of Subsidiarity is violated

Principle of Subsidiarity

Functions of government—such as granting and restricting rights—should be performed *at the lowest level of authority possible*, as long as they can be performed *adequately*.

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Functions of government—such as granting and restricting rights—should be performed *at the lowest level of authority possible*, as long as they can be performed *adequately*.

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

Parents, guardians and caretakers

Age restriction

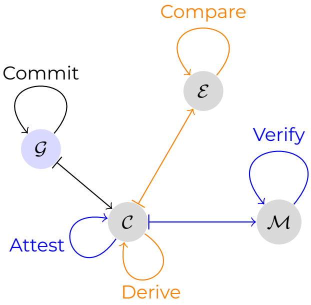
Design goals

1. Tie age restriction to the **ability to pay** (not to ID’s)
2. maintain **anonymity of buyers**
3. maintain **unlinkability of transactions**
4. align with **principle of subsidiartiy**
5. be **practical and efficient**

Age restriction

Assumptions and scenario

- Assumption: Checking accounts are under control of eligible adults/guardians.
- *Guardians* **commit** to an maximum age
- *Minors* **attest** their adequate (minimum) age
- *Merchants* **verify** the attestations
- Minors **derive** age commitments from existing ones
- *Exchanges* **compare** the derived age commitments



Formal function signatures

Searching for functions with the following signatures

$$\begin{aligned}
\text{Commit}: &\quad (\mathsf{a}, \omega) \mapsto (\mathsf{Q}, \mathsf{P}) & \mathbb{N}_\mathsf{M} \times \Omega \to \mathbb{O} \times \mathbb{P}, \\
\text{Attest}: &\quad (\mathsf{m}, \mathsf{Q}, \mathsf{P}) \mapsto \mathsf{T} & \mathbb{N}_\mathsf{M} \times \mathbb{O} \times \mathbb{P} \to \mathbb{T} \cup \{\bot\}, \\
\text{Verify}: &\quad (\mathsf{m}, \mathsf{Q}, \mathsf{T}) \mapsto b & \mathbb{N}_\mathsf{M} \times \mathbb{O} \times \mathbb{T} \to \mathbb{Z}_2, \\
\text{Derive}: &\quad (\mathsf{Q}, \mathsf{P}, \omega) \mapsto (\mathsf{Q}', \mathsf{P}', \beta) & \mathbb{O} \times \mathbb{P} \times \Omega \to \mathbb{O} \times \mathbb{P} \times \mathbb{B}, \\
\text{Compare}: &\quad (\mathsf{Q}, \mathsf{Q}', \beta) \mapsto b & \mathbb{O} \times \mathbb{O} \times \mathbb{B} \to \mathbb{Z}_2,
\end{aligned}$$

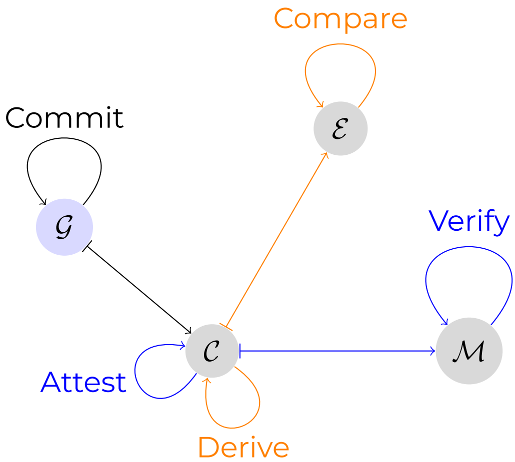
with $\Omega, \mathbb{P}, \mathbb{O}, \mathbb{T}, \mathbb{B}$ sufficiently large sets.

Basic and security requirements are defined later.

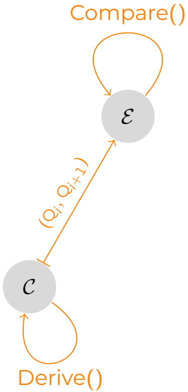
Mnemonics:
$\mathbb{O}$ = *c$\mathbb{O}$mmitments*, Q = *Q-mitment* (commitment), $\mathbb{P}$ = *$\mathbb{P}$roofs*, P = *Proof*,
$\mathbb{T}$ = *a$\mathbb{T}$testations*, T = *aTtestation*, $\mathbb{B}$ = *$\mathbb{B}$lindings*, β = *βlinding*.

Age restriction

Naïve scheme



Achieving unlinkability



Simple use of Derive() and Compare() is problematic.

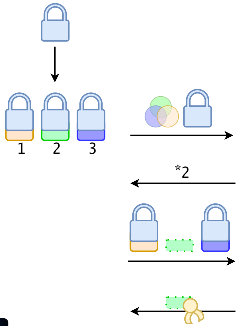
- Calling Derive() iteratively generates sequence $(Q_0, Q_1, \dots)$ of commitments.
- Exchange calls Compare$(Q_i, Q_{i+1}, .)$

$\Longrightarrow$ **Exchange identifies sequence**

$\Longrightarrow$ **Unlinkability broken**

Achieving unlinkability

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



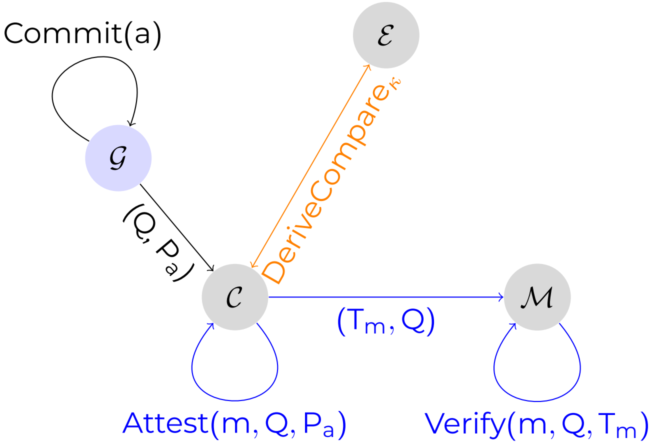
1. $\mathcal{C}$ derives commitments $(Q_1, \ldots, Q_\kappa)$ from Q_0 by calling Derive() with blindings $(\beta_1, \ldots, \beta_\kappa)$
2. $\mathcal{C}$ calculates $h_0 := H\left(H(Q_1, \beta_1)||\ldots||H(Q_\kappa, \beta_\kappa)\right)$
3. $\mathcal{C}$ sends Q_0 and h_0 to $\mathcal{E}$
4. $\mathcal{E}$ chooses $\gamma \in \{1, \ldots, \kappa\}$ 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 Compare(Q_0, Q_i, β_i).
7. On success Q will be the result

Achieving unlinkability

With $\text{DeriveCompare}_\kappa$

- $\mathcal{E}$ 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.



Basic requirements

Candidate functions

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

must first meet *basic* requirements:

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

Basic requirements
Formal details

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
Simplified example

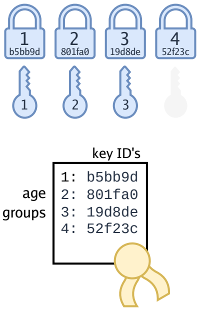
Game $G_{\mathcal{A}}^{\mathsf{FA}}(\lambda)$—Forging an attest:

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

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

Solution: Instantiation with ECDSA



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

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

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

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

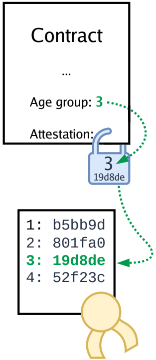
$$\Big\langle (q_1, p_1), \ldots, (q_a, p_a), (q_{a+1}, \bot), \ldots, (q_M, \bot) \Big\rangle$$

   - $\vec{Q} := (q_1, \ldots, q_M)$ is the *Commitment*,
   - $\vec{P}_a := (p_1, \ldots, p_a, \bot, \ldots, \bot)$ is the *Proof*

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

Instantiation with ECDSA

Definitions of Attest and Verify



Child has

- ordered public-keys $\vec{Q} = (q_1, \ldots, q_M)$,
- (some) private-keys $\vec{P} = (p_1, \ldots, p_a, \perp, \ldots, \perp)$.

To Attest a minimum age $m \leq a$:

Sign a message with ECDSA using private key p_m

Merchant gets

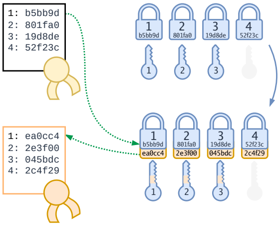
- ordered public-keys $\vec{Q} = (q_1, \ldots, q_M)$
- Signature σ

To Verify a minimum age m:

Verify the ECDSA-Signature σ with public key q_m.

Instantiation with ECDSA

Definitions of Derive and Compare



Child has $\vec{Q} = (q_1, \ldots, q_M)$ and $\vec{P} = (p_1, \ldots, p_a, \perp, \ldots, \perp)$.

To Derive new $\vec{Q}'$ and $\vec{P}'$:

Choose random $\beta \in \mathbb{Z}_g$ and calculate

$$\vec{Q}' := (\beta * q_1, \ldots, \beta * q_M),$$
$$\vec{P}' := (\beta p_1, \ldots, \beta p_a, \perp, \ldots, \perp)$$

Note: $(\beta p_i) * G = \beta * (p_i * G) = \beta * q_i$

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

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

To Compare, calculate:

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

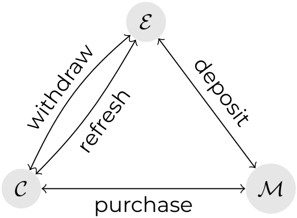
Instantiation with ECDSA

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

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

Integration with GNU Taler

Key operations in the original system



- 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

Binding age restriction to coins

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

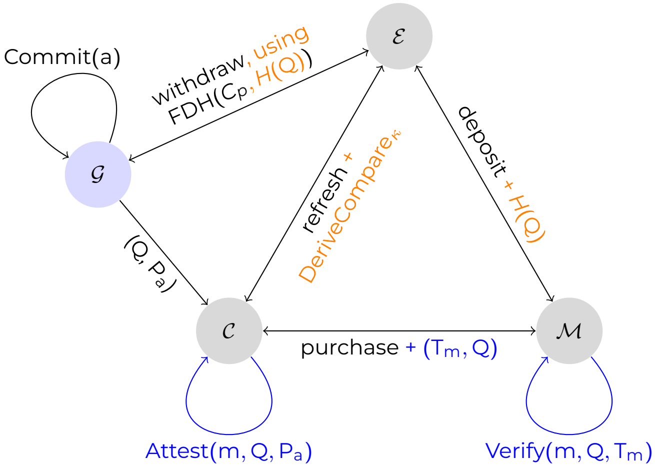
$$\text{FDH}(C_p, H(\text{Q}))$$

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

Integrated schemes



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 Edx25519.

Discussion

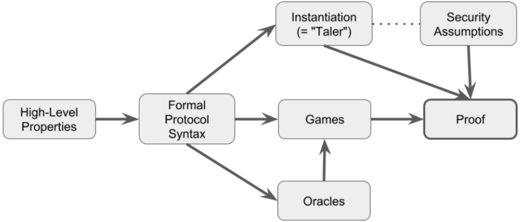
- Approach can be used with any token-based payment scheme
- Subsidiarity requires bank accounts being owned by adults
- Scheme can be adapted to case where minors have bank accounts
  - Assumption: banks provide minimum age information during bank transactions.
  - Child and Exchange execute a variant of the cut&choose protocol.

Part VI: What are the future plans for GNU Taler?

Summary

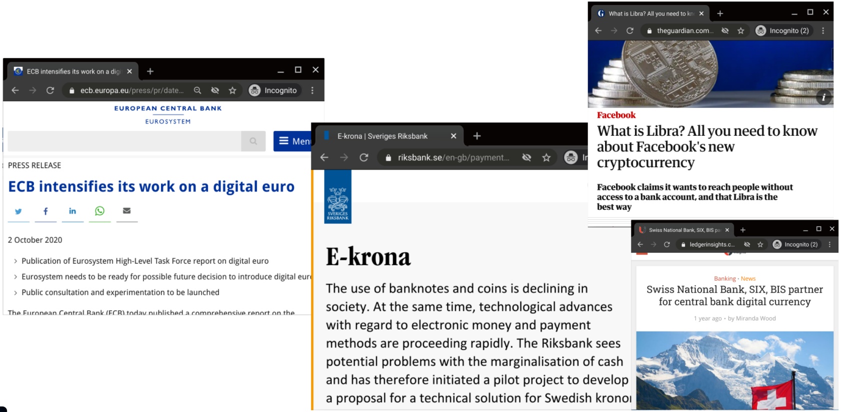
GNU Taler:

- Gives change, can provide refunds
- Integrates nicely with HTTP, handles network failures
- Has high performance
- Is Free Software
- Includes formal security proofs



CBDC initiatives and GNU Taler

Many initiatives are currently at the level of requirements discussion:



Unique regulatory features for CBs

1. Central bank issues digital coins equivalent to issuing cash
2. Architecture with consumer accounts at commercial banks
3. Withdrawal limits and denomination expiration
4. Income transparency and possibility to set fees
5. Revocation protocols and loss limitations
6. Privacy by cryptographic design not organizational compliance

Political support needed, talk to your representatives!

Ongoing work

- Post-quantum blind signatures
- Unlinkable subscriptions and discounts
- Privacy-preserving donations
- Integration into more physical machines
- Integration with KYC/AML providers
- SAP integration
- Deployment for regional currency in Basel
- Design and usability for illiterate and innumerate users
- Internationalization $\Rightarrow$ `https://weblate.taler.net/`

`https://bugs.taler.net/` tracks open issues.

Open issues / Future Work

- Support more core banking / blockchain protocols
- Wallet backup and recovery with Anastasis
- Defeat spam with micropayments
- Implement *usable* card game on Polkadot
- Break more HSMs (side-channels, fault injection)
- Currency conversion
- Integration with e-commerce frameworks (Prestashop, OpenCart, ECWID, ...)
- Federated exchange (wads)
- ...

Help needed, talk to us (e.g. at `https://ich.taler.net/`)

Visions

- Be paid to read advertising, starting with spam
- Give welfare without intermediaries taking huge cuts
- Forster regional trade via regional currencies
- Eliminate corruption by making all income visible
- Stop the mining by making crypto-currencies useless for anything but crime

References I

Jeffrey Burdges, Florian Dold, Christian Grothoff, and Marcello Stanisci.
Enabling secure web payments with GNU Taler.
In Claude Carlet, M. Anwar Hasan, and Vishal Saraswat, editors, *6th International Conference on Security, Privacy and Applied Cryptographic Engineering*, number 10076 in LNCS, pages 251–270. Springer, Dec 2016.

David Chaum.
Blind Signature System, pages 153–153.
Springer US, Boston, MA, 1984.

References II

David Chaum, Christian Grothoff, and Thomas Moser.
How to issue a central bank digital currency.
In *SNB Working Papers*, number 2021-3. Swiss National Bank, February 2021.

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