GNU Taler

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Learning Objectives

Key escrow and recovery: From Shamir to Anastasis

Real world surveillance

The Bank's Problem

Introduction to GNU Taler

Real-World Crypto

Retail Central Bank Digital Currencies

Taler Cryptography

Digital Change with Cut-and-choose

References

Anastasis[1]

[1] https://anastasis.lu/, based on a BFH Bachelor's thesis by D. Neufeld and D. Meister (2020)

THE PROBLEM

Confidentiality requires only consumer is in control of key material

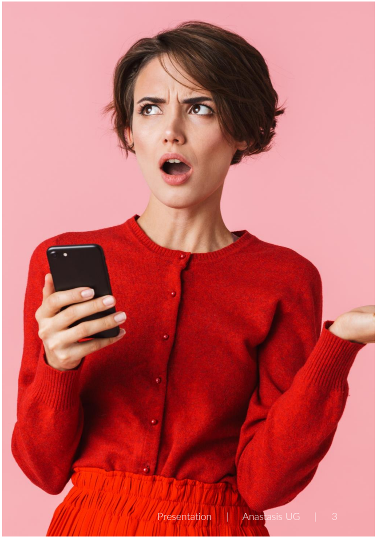
Consumers are unable to simultaneously ensure confidentiality and availability of keys

Cryptographic key-splitting solutions so far are not usable

European e-money issuers using electronic wallets must:[1]

- Enable consumers to always recover their electronic funds (i.e. if devices are lost)
- Not assume consumers are able to remember or securely preserve key material

[1] According to communication from ECB to Taler Systems SA.



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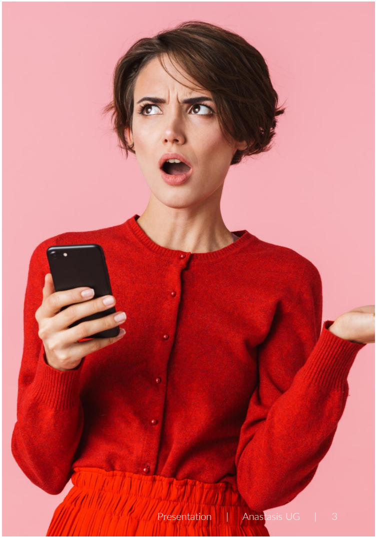
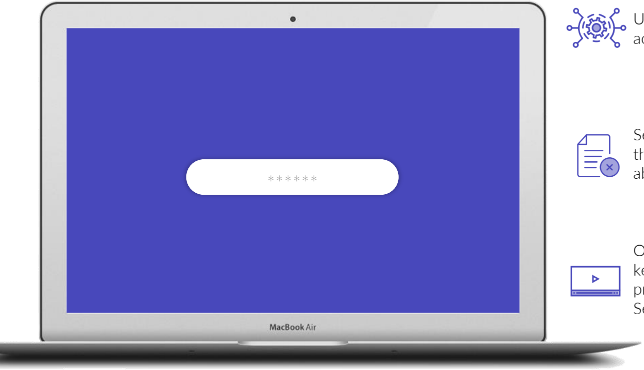


WHAT IS ANASTASIS?

ANASTASIS IS A KEY RECOVERY SERVICE.

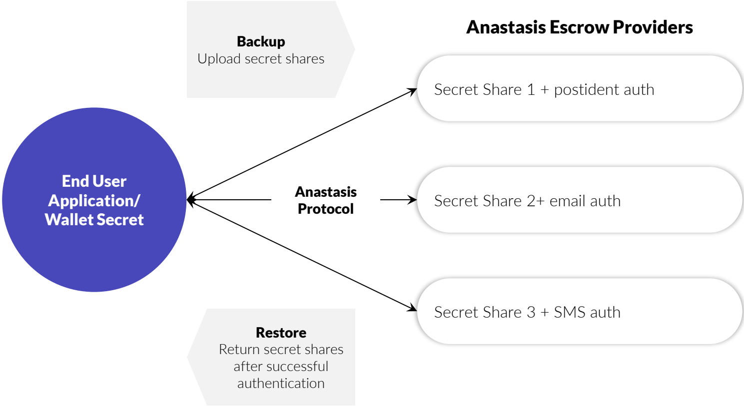


Users split their secret keys across multiple service providers

Service providers learn nothing about the user, except possibly some details about how to authenticate the user

Only the authorized user can recover the key by following standard authentication procedures (SMS TAN, Video-Ident, Security Question, eMail, etc.)

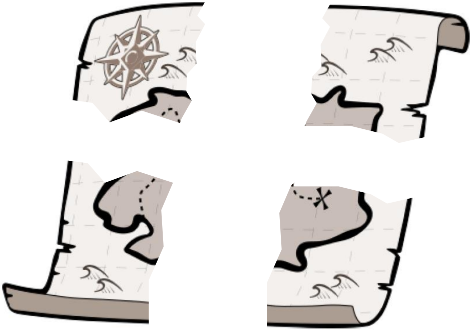
OVERVIEW


Backup
Upload secret shares
Anastasis Escrow Providers
Secret Share 1 + postident auth
End User
Application/
Wallet Secret
Anastasis
Protocol
Secret Share 2+ email auth
Secret Share 3 + SMS auth
Restore
Return secret shares
after successful
authentication

SIMPLIFIED PROCESS FLOW
STEP 1: RECOVERY INFORMATION

SIMPLIFIED PROCESS FLOW

STEP 2: SPLIT RECOVERY INFORMATION

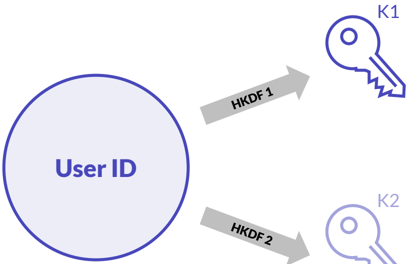


SIMPLIFIED PROCESS FLOW

STEP 3: USER IDENTIFICATION

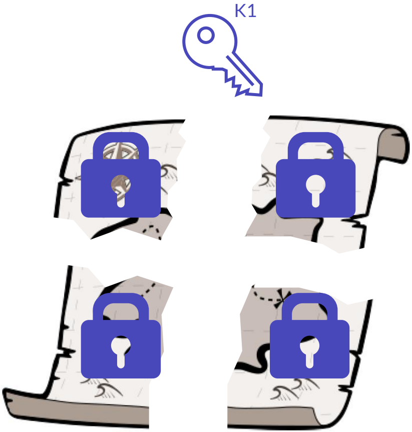
SIMPLIFIED PROCESS FLOW

STEP 4: KEY DERIVATION



SIMPLIFIED PROCESS FLOW

STEP 5: ENCRYPT PARTS



SIMPLIFIED PROCESS FLOW

STEP 6: ADD TRUTH

+ H (answer to security question)

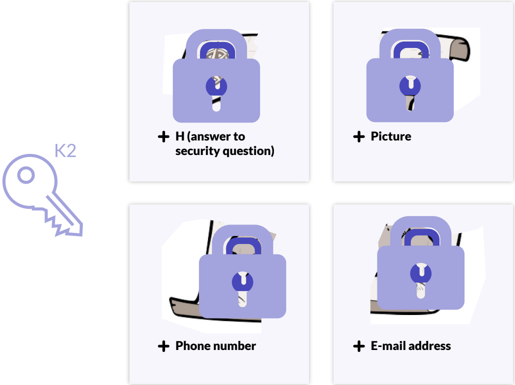
+ Picture

+ Phone number

+ E-mail address

SIMPLIFIED PROCESS FLOW

STEP 7: ENCRYPT TRUTH



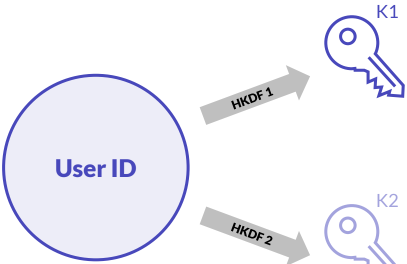
SIMPLIFIED PROCESS FLOW

STEP 8: STORE DATA

SIMPLIFIED PROCESS FLOW

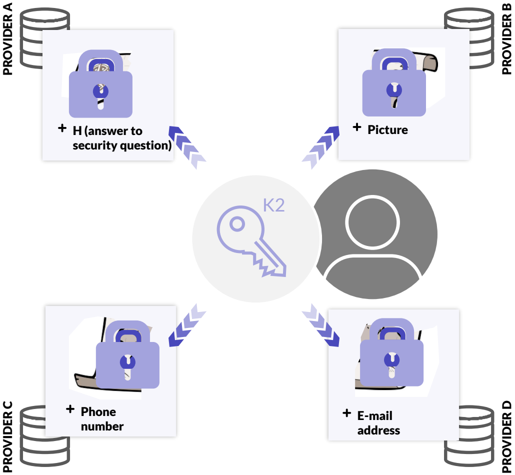
STEP 9: USER IDENTIFICATION

SIMPLIFIED PROCESS FLOW
STEP 10: KEY DERIVATION



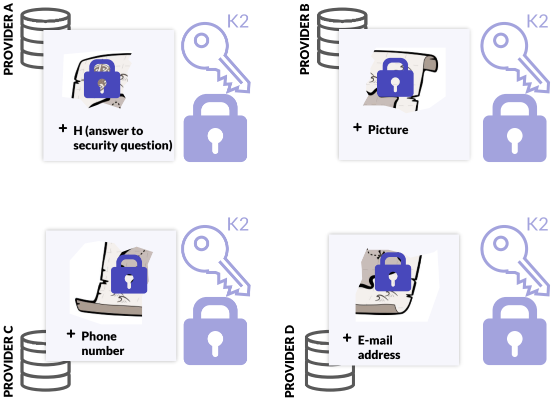
SIMPLIFIED PROCESS FLOW

STEP 11:
PROVIDE KEY



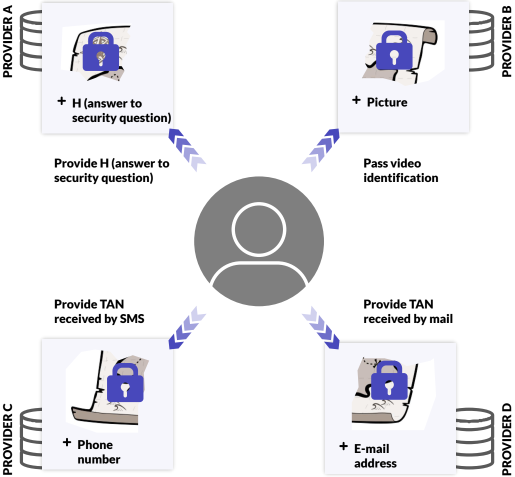
SIMPLIFIED PROCESS FLOW

STEP 12:
DECRYPT TRUTH



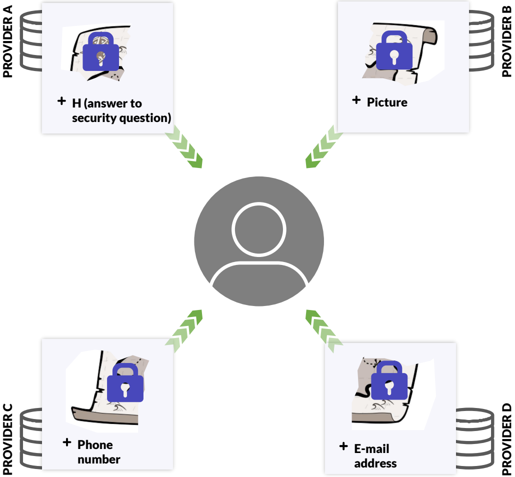
SIMPLIFIED PROCESS FLOW

STEP 13: AUTHENTICATION



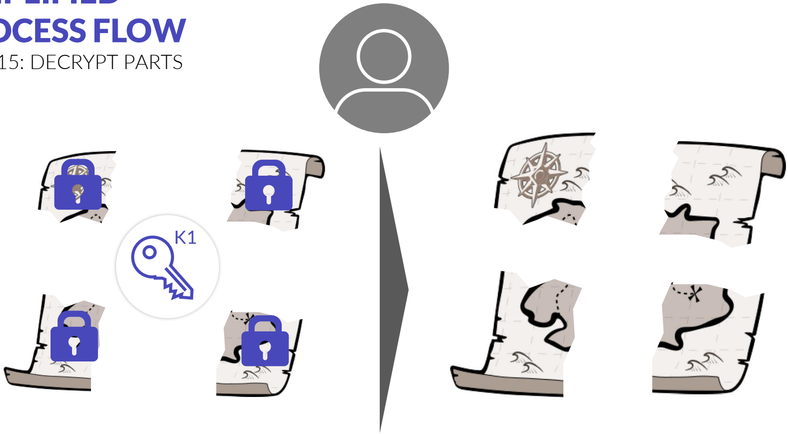
SIMPLIFIED PROCESS FLOW

STEP 14:
RECEIVE PARTS



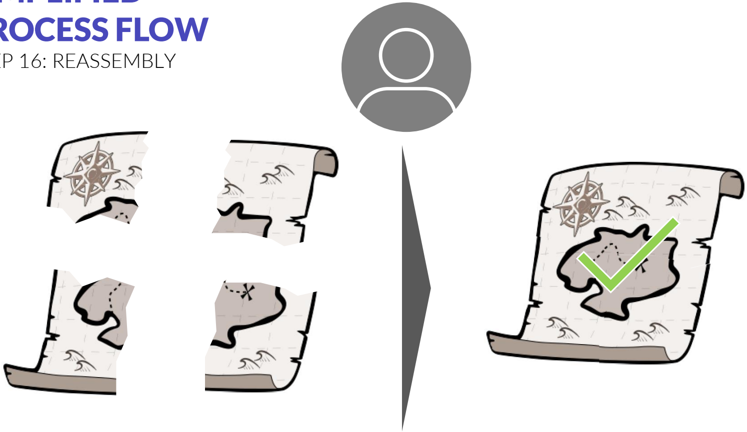
SIMPLIFIED PROCESS FLOW

STEP 15: DECRYPT PARTS



SIMPLIFIED PROCESS FLOW

STEP 16: REASSEMBLY



SIMPLIFICATIONS

THE PREVIOUS ILLUSTRATION MAKES VARIOUS SIMPLIFICATIONS

- Policies to allow more flexible splitting than 4/4
- Recovery document to remember policies and providers
- Distinction between core secret and master secret
- Payment processing
- Provider salts
- Anti-DoS provisions in protocol / request limits
- Versioning
- Liability limitations

UNIQUE SALES PROPOSITIONS (USPS)

1 Distributed trust instead of single point of failure

2 Maximum privacy with respect to authentication data

3 Post-quantum security

4 Ease of use

5 Low cost, scalable cloud-based solution

6 Transparent, Free Software solution

7 Generic API suitable for a range of applications

8 Customers can remain anonymous:
- Minimizes risk to Anastasis service provider in case database is exposed
- Makes it more difficult for attackers to fool authentication procedure

9 E-money issuer does not have to protect consumer data against its own staff and can respect consumer privacy

SOCIAL IMPACT OF ANASTASIS

Low-cost solution with minimal environmental impact

Increases informational self-determination by keeping consumers in control of their data

Free Software contributes to the global Commons

OPERATING MODEL

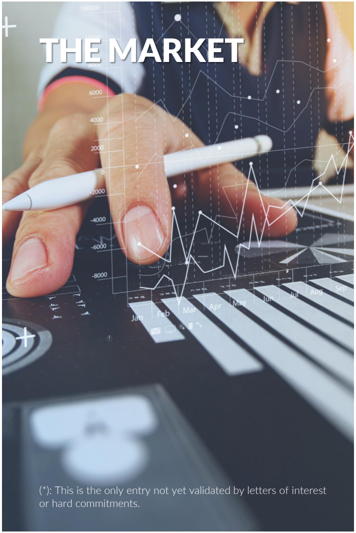
REVENUE

- E-money issuers pay Anastasis UG to offer service to consumers with wallets to satisfy their regulatory requirements (service must exist)
- Wallet operators pay Anastasis UG to assist with technical integration
- Consumers pay Anastasis UG for safekeeping and/or recovery (subscription)

EXPENSES

- Development and operations (staff costs)
- Server infrastructure

THE MARKET



- Electronic wallets for blockchain wallets and/or fiat currencies
- Key store for communication keys, such as OpenPGP or X.509
- Identity management solutions
- Password managers and disk encryption key material (*)

(*): This is the only entry not yet validated by letters of interest or hard commitments.

MAIN RISKS AND MITIGATIONS

1 **IMPLEMENTATION RISK**
Straightforward design simplifies work

2 **INFORMATION SECURITY RISK**
Privacy-by-design minimizes loss

3 **DISTRIBUTION ON CUSTOMER SIDE**
Strong partners with implementation need

4 **CASH FLOW**
Cloud-based deployment with outsourcing of procedures that amortize only at scale

5 **USABILITY**
Will work with UX expert

Break

What domain of digital communication should we be most concerned about?

Surveilance concerns

- Everybody knows about Internet surveilance.
- But is it **that** bad?

Surveilance concerns

- Everybody knows about Internet surveilance.
- 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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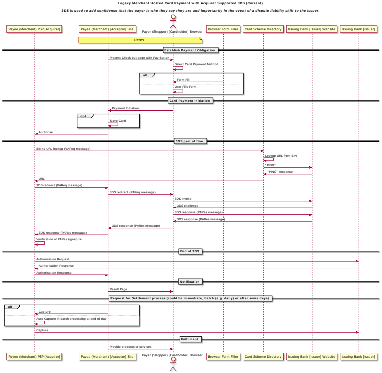
What is worse:

- 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 at least 6 years

Banks 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



Online credit card payments will be replaced, but with what?

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

Do you want to live under total surveillance?

Banking, Surveillance and Physical Security

https://www.youtube.com/watch?v=GyJZViNf2Vk (4'2019)

Break

GNU Taler

Digital cash, made **socially responsible**.

⟨Taler⟩

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

What is Taler?

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

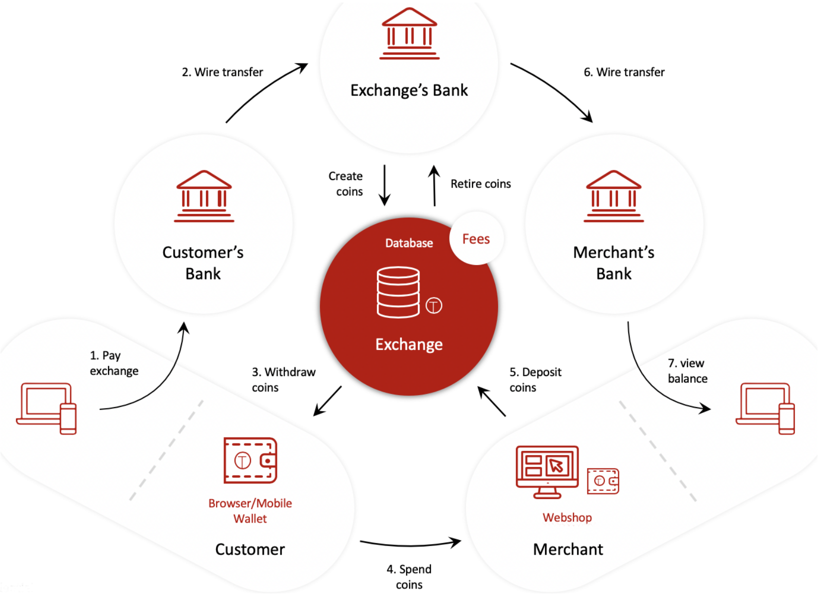
Taler is

- 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"

Taler: Payment System Architecture



The Taler Software Ecosystem

https://taler.net/en/docs.html

Taler is based on modular components that work together to provide a complete payment system:

- **Exchange:** Service provider for digital cash
  - Core exchange software (cryptography, database)
  - Air-gapped key management, real-time **auditing**
  - LibEuFin: Modular integration with banking systems
- **Merchant:** Integration service for existing businesses
  - Core merchant backend software (cryptography, database)
  - Back-office interface for staff
  - Frontend integration (E-commerce, Point-of-sale)
- **Wallet:** Consumer-controlled applications for e-cash
  - Multi-platform wallet software (for browsers & mobile phones)
  - Wallet backup storage providers
  - **Anastasis**: Recovery of lost wallets based on secret splitting

Taler: Unique Regulatory Features for CBs

https://www.snb.ch/en/mmr/papers/id/working_paper_2021_03

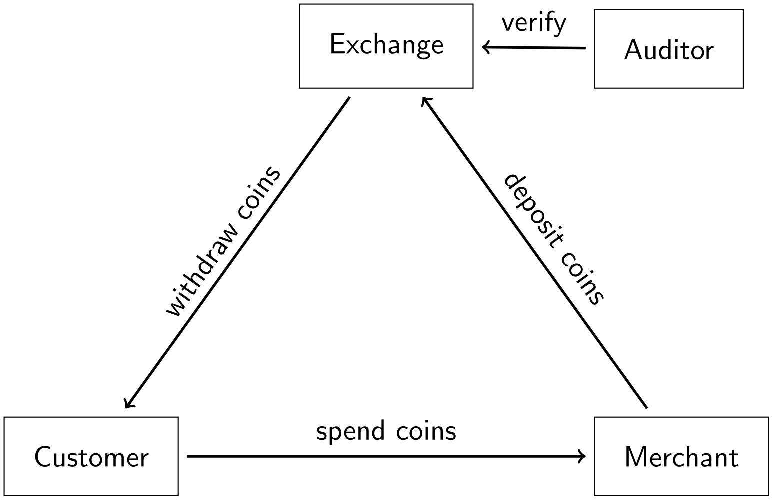
- Central bank issues digital coins equivalent to issuing cash
  $\Rightarrow$ monetary policy remains under CB control
- Architecture with consumer accounts at commercial banks
  $\Rightarrow$ no competition for commercial banking (S&L)
  $\Rightarrow$ CB does not have to manage KYC, customer support
- Withdrawal limits and denomination expiration
  $\Rightarrow$ protects against bank runs and hoarding
- Income transparency and possibility to set fees
  $\Rightarrow$ additional insights into economy and new policy options
- Revocation protocols and loss limitations
  $\Rightarrow$ exit strategy and handles catastrophic security incidents
- Privacy by cryptographic design not organizational compliance
  $\Rightarrow$ CB cannot be forced to facilitate mass-surveillance

Design goals for the GNU Taler Payment System

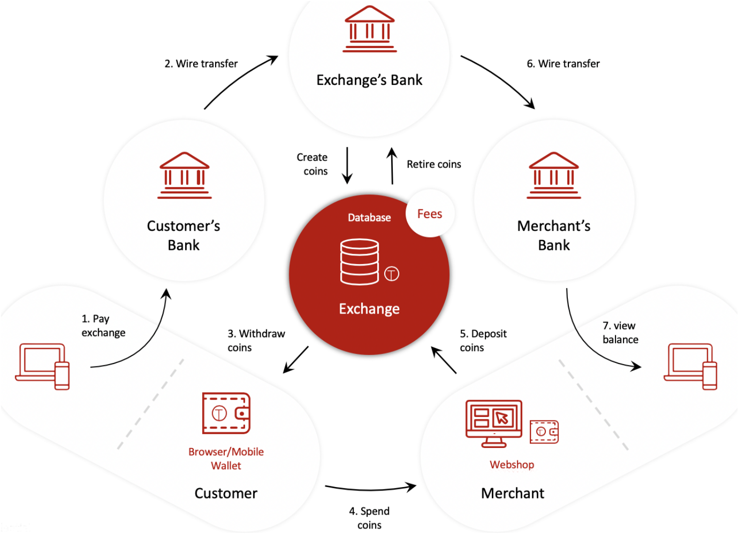
GNU Taler must ...

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**.

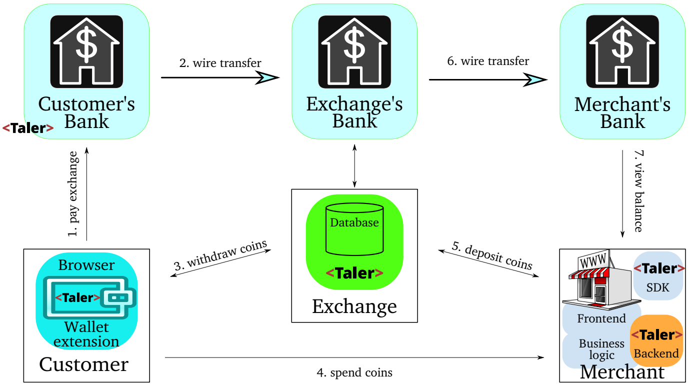
Taler Overview



Architecture of Taler



Architecture of Taler



⇒ Convenient, taxable, privacy-enhancing, & resource friendly!

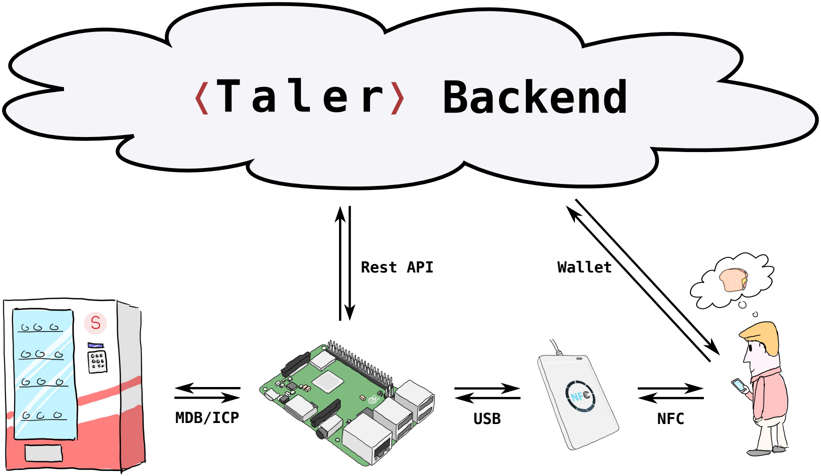
Usability of Taler

`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.

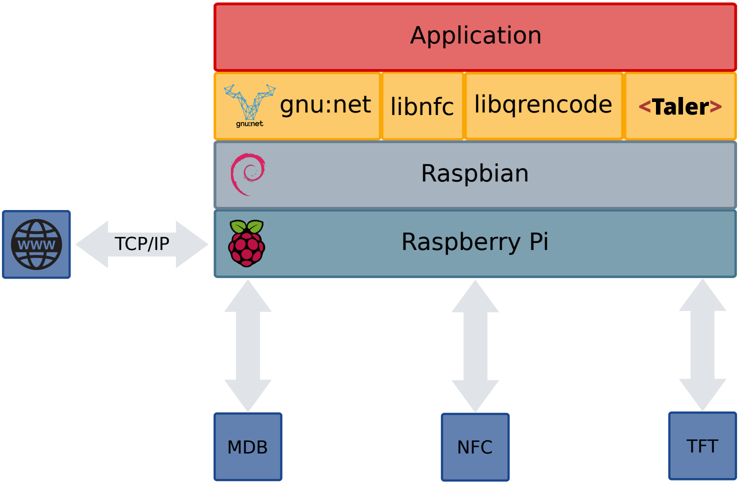
Example: The Taler Snack Machine[2]

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

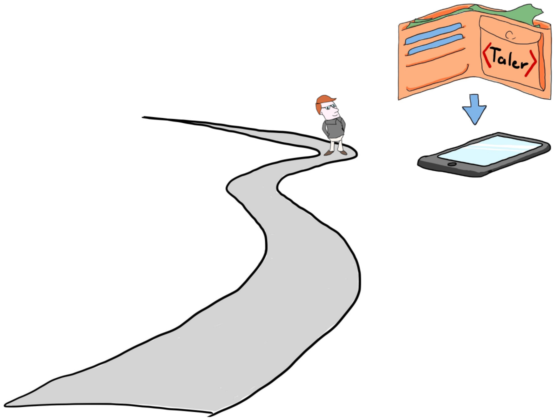


[2] By M. Boss and D. Hofer

Software architecture for the Taler Snack Machine

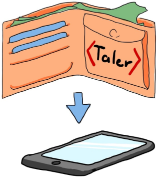


User story: Install App on Android[3]



[3] https://wallet.taler.net/

User story: Withdraw e-cash

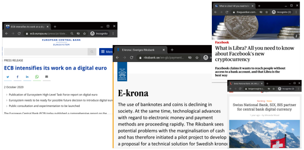


User story: Use machine!

CBDC Initiatives and Taler

Many initiatives are currently at the level of requirements discussion:

- ECB: Report on a Digital Euro / Eurosystem report on the public consultation on a Digital Euro
- Bank of England: Just initiated a task force



Taler can serve as the foundation for a *bearer-based retail* CBDC.

- Taler replicates physical cash rather than bank deposits
- Taler has unique design principles and regulatory features that align with CBDC requirements
- ECB survey has identified privacy as a primary requirement of end users

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https://www.snb.ch/en/mmr/papers/id/working_paper_2021_03

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Requirements: Online vs. Offline CBDC

https://taler.net/papers/euro-bearer-online-2021.pdf

- Offline capabilities are often cited as a requirement for CBDC
- All implementations must either use restrictive hardware elements and/or introduce counterparty risk.

⇒ Permanent offline features weaken a CBDC solution (privacy, security)

⇒ Introduces unwarranted competition for physical cash (endangers emergency-preparedness).

We recommend a tiered approach:

1. Online-first, bearer-based CBDC
2. (Optional:) Limited offline mode for network outages
3. Physical cash for emergencies (power outage, catastrophic cyber incidents)

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.

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Limitations:

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

How does it work?

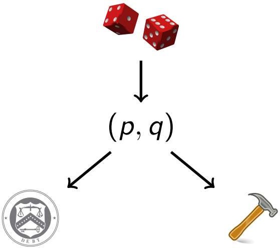
We use a few ancient constructions:

- Cryptographic hash function (1989)
- Blind signature (1983)
- Schnorr signature (1989)
- Diffie-Hellman key exchange (1976)
- Cut-and-choose zero-knowledge proof (1985)

But of course we use modern instantiations.

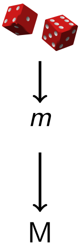
Exchange setup: Create a denomination key (RSA)

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



Merchant: Create a signing key (EdDSA)

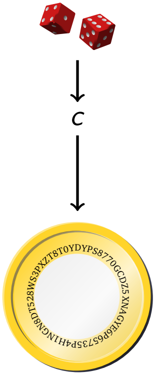
- pick random $m \mod o$ as private key
- $M = mG$ public key

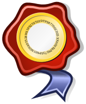


Capability: $m \Rightarrow$ 

Customer: Create a planchet (EdDSA)

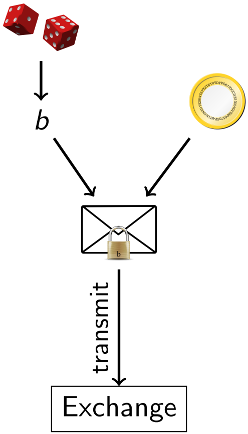
- Pick random $c \mod o$ private key
- $C = cG$ public key



Capability: $c \Rightarrow$ 

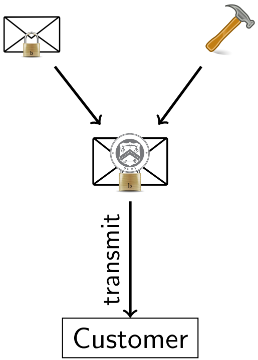
Customer: Blind planchet (RSA)

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



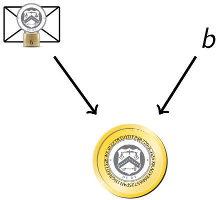
Exchange: Blind sign (RSA)

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

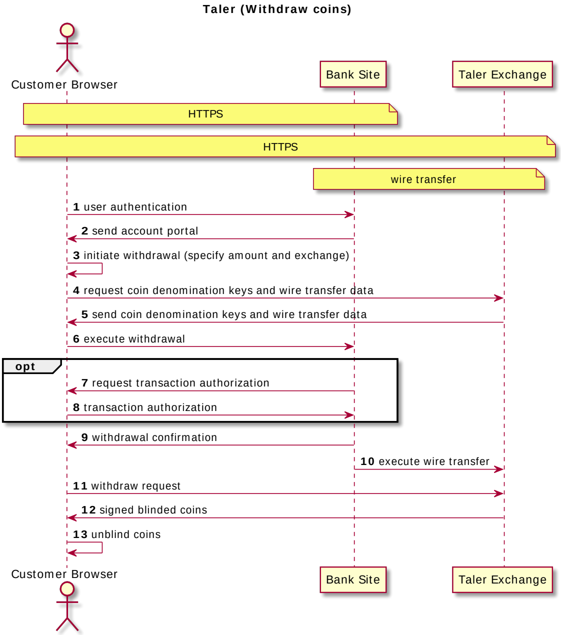


Customer: Unblind coin (RSA)

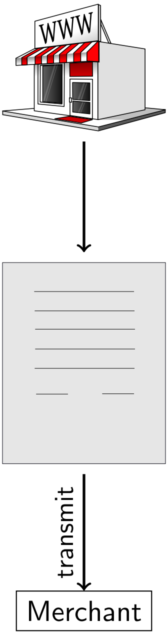
1. Receive s'.
2. Compute $s := s' b^{-1} \mod n$



Withdrawing coins on the Web

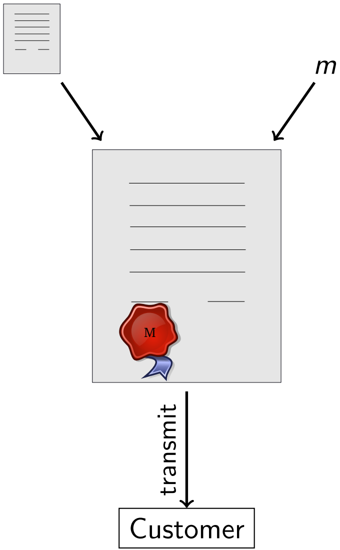


Customer: Build shopping cart



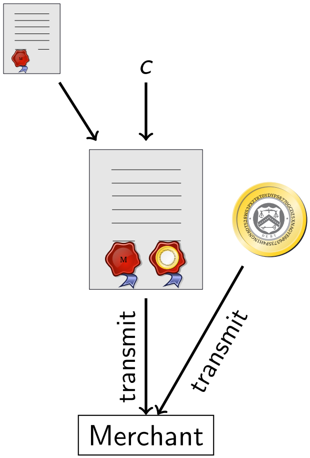
Merchant: Propose contract (EdDSA)

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



Customer: Spend coin (EdDSA)

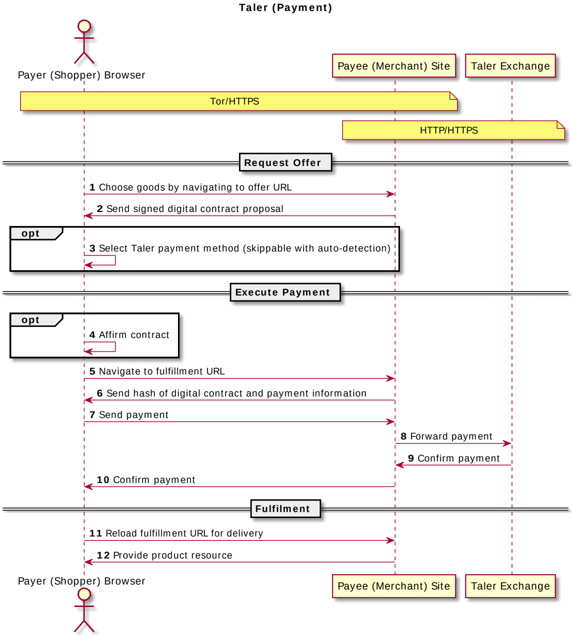
1. Receive proposal D, $EdDSA_m(D)$.
2. Send s, C, $EdDSA_c(D)$



Merchant and Exchange: Verify coin (RSA)

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

Payment processing with Taler



Warranting deposit safety

Exchange has *another* online signing key $W = wG$:

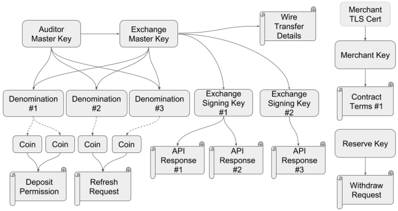
Sends $EdDSA_w(M, H(D), FDH(C))$ to the merchant.

This signature means that M was the *first* to deposit C and that the exchange thus must pay M.

Without this, an evil exchange could renege on the deposit confirmation and claim double-spending if a coin were deposited twice, and then not pay either merchant!

Online keys

- The exchange needs d and w to be available for online signing.
- The corresponding public keys W and (e, n) are certified using Taler's public key infrastructure (which uses offline-only keys).

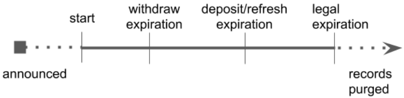


What happens if those private keys are compromised?

Denomination key (e, n) compromise

- An attacker who learns d can sign an arbitrary number of illicit coins into existence and deposit them.
- Auditor and exchange can detect this once the total number of deposits (illicit and legitimate) exceeds the number of legitimate coins the exchange created.
- At this point, (e, n) is *revoked*. Users of *unspent* legitimate coins reveal b from their withdrawal operation and obtain a *refund*.
- The financial loss of the exchange is *bounded* by the number of legitimate coins signed with d.

⇒ Taler frequently rotates denomination signing keys and deletes d after the signing period of the respective key expires.



Online signing key W compromise

- An attacker who learns w can sign deposit confirmations.
- Attacker sets up two (or more) merchants and customer(s) which double-spend legitimate coins at both merchants.
- The merchants only deposit each coin once at the exchange and get paid once.
- The attacker then uses w to fake deposit confirmations for the double-spent transactions.
- The attacker uses the faked deposit confirmations to complain to the auditor that the exchange did not honor the (faked) deposit confirmations.

The auditor can then detect the double-spending, but cannot tell who is to blame, and (likely) would presume an evil exchange, forcing it to pay both merchants.

Break

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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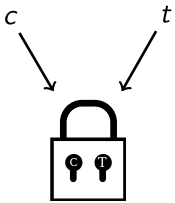
Method:

- 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 $cT = c(tG) = t(cG) = tC$

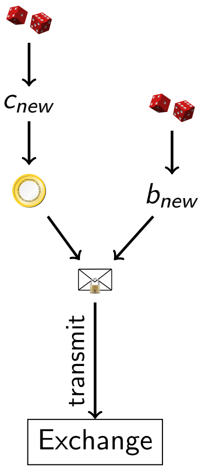


Strawman solution

Given partially spent private coin key c_{old}:

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

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



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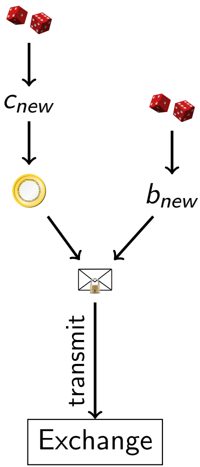
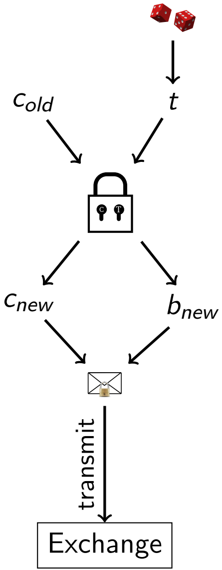


Problem: Owner of c_{new} may differ from owner of c_{old}!

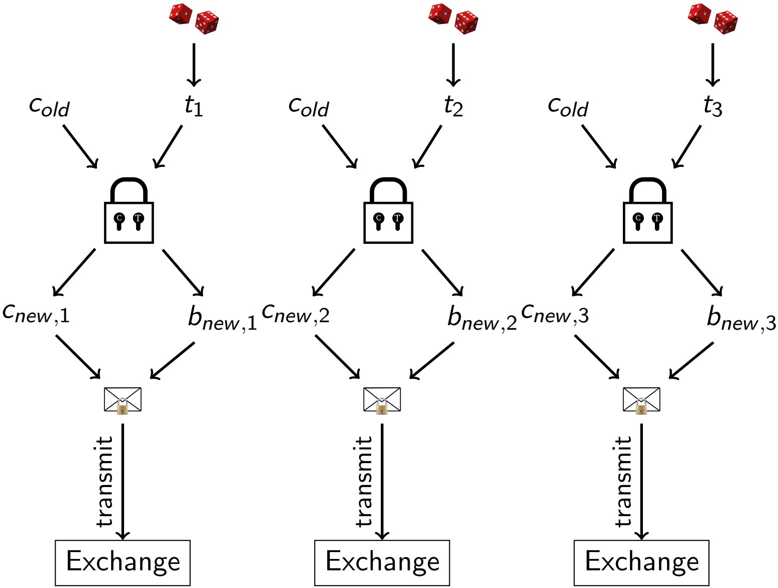
Customer: Transfer key setup (ECDH)

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 $T := tG$
4. Compute $X := c_{old}(tG) = t(c_{old} G) = tC_{old}$
5. Derive c_{new} and b_{new} from X
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



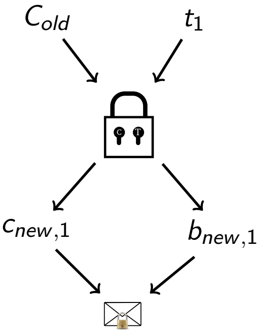
Exchange: Choose!

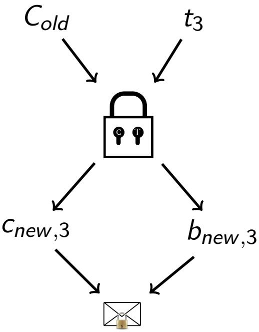
Exchange sends back random $\gamma \in \{1, 2, 3\}$ to the customer.

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

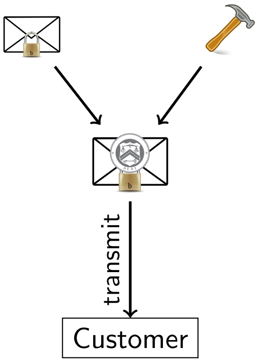
Exchange: Verify ($\gamma = 2$)





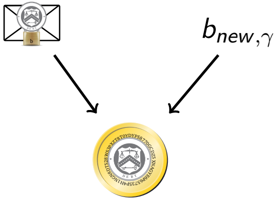
Exchange: Blind sign change (RSA)

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



Customer: Unblind change (RSA)

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

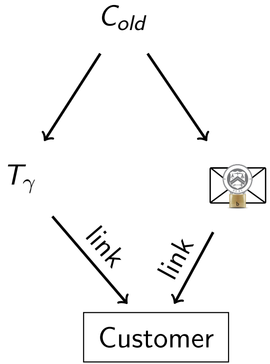


Exchange: Allow linking change

Given C_{old}

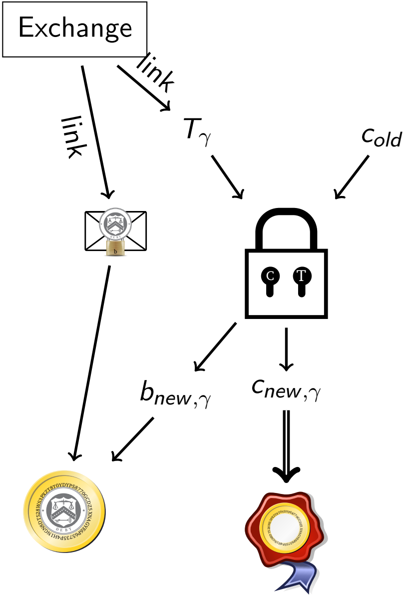
return T_γ and

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



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

⇒ New coins are owned by the same entity!

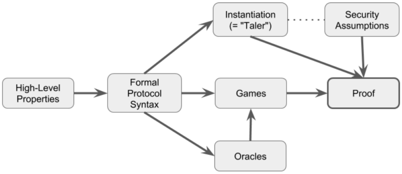
Thus, the refresh protocol allows:

- 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.

Summary

- We can design protocols that fail *soft*.
- GNU Taler's design limits financial damage even in the case private keys are compromised.
- GNU Taler does:
  - Gives change, can provide refunds
  - Integrates nicely with HTTP, handles network failures
  - High performance
  - Free Software
  - Formal security proofs



GNU Taler: Next Steps

- Implementation still needs:
  - Demonstration Taler can sustain 100k transactions/second
  - Wallet-to-wallet payments
  - Payments with zero-knowledge age verification
  - Payments via smart watch
  - Improved design and usability for illiterate and innumerate users
  - Internationalization ⇒ `https://weblate.taler.net/`
  - Porting to more platforms (Web shops, iOS, ...)
- Regulatory approval (withdraw and deposit limits, KYC/AML process validation)

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