NEXT GENERATION INTERNET

Key management

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TALER

Learning Objectives

How can we protect confidentiality of private keys?

How does Shamir Secret Sharing work?

Key escrow and recovery: From Shamir to Anastasis

What are threshold signatures?

What does key management look like in practice?

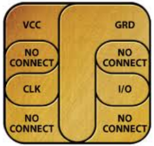
Software based Personal Security Environments (PSE): PKCS#12

PKCS#12 is the most common format for software PSEs:

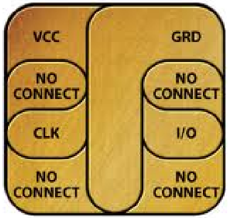
- PKCS#12 is a file container format used for storage and transport of private keys (and possibly certificates).
- Information is protected with a password-based symmetric key (e.g. a password).
- The security of a software PKCS#12 is based on the strength of the password protecting it.

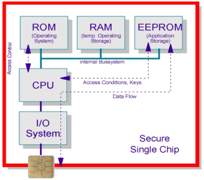
Problem: A PKCS#12 soft-token may be copied unnoticed.

Smartcards and Cryptotokens



Properties of Crypto-tokens/cards





- Crypto-cards have the ability of a secure container for secret data and have an executive platform for cryptographic algorithms.
- A Crypto-card looks like a “Black Box” from the outside, where some operations can only be used over a very restrictive hard- and software interface which is able to enforce specific security policies.
- Access to sensitive data areas (i.e. private keys) is physically “impossible” from the outside.

Example: Yubikey and Personal Identity Verification (PIV)

- Yubikey provides Smart Card functionality based on the Personal Identity Verification (PIV) interface specified in NIST SP 800-73.
- Yubikeys perform RSA or ECC sign/decrypt operations using a private key stored on the token, through common interfaces such as PKCS#11.
- Supported key sizes: RSA 2048 or ECC 256/384.
- The “universal smartcard minidriver” provides “standard smart” functionality and additional certificate and PIN management features.
- Special Yubikeys obtained FIPS 140-2 security level certification.

Hardware Security Modules (HSM)

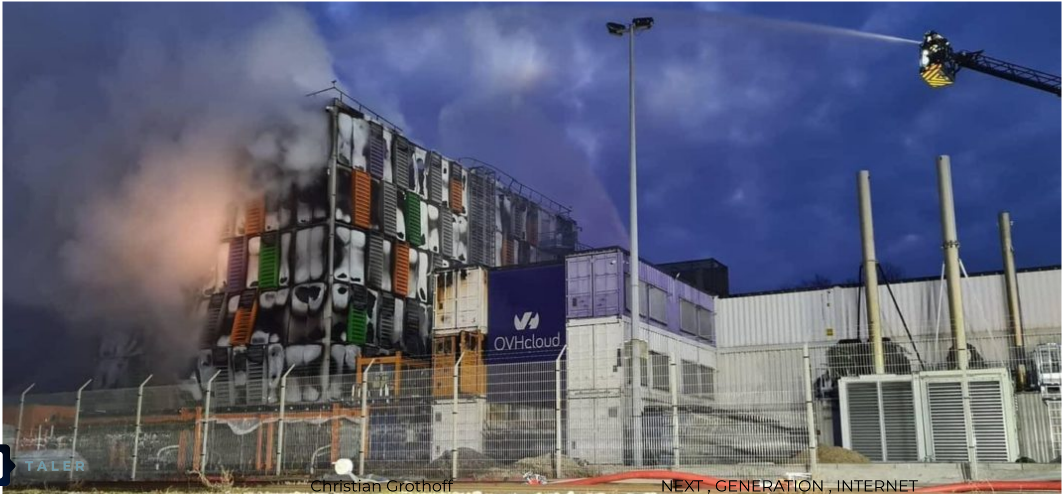
Common functionality:

- Secure storing and use of keys
- Random number generator
- Key pair generation
- Digital signing
- Key archiving
- Acceleration for crypto schemes

Should protect keys against:

- Mechanical & chemical attacks
- Temperature attacks
- Manipulation of voltage

Availability



Problem 1: Availability

If you give one person (or data center) a secret, it may get lost.

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If you give one person (or data center) a secret, it may get lost.

$\Rightarrow$ So give it to more than one person (or data center)!

Problem 2: Confidentiality

If you give many entities a secret, it may get disclosed.

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If you give many entities a secret, it may get disclosed.

$\Rightarrow$ So give them only a key share!

Problem 3: Scalability

If you want k out of n entities to coordinate to recover a secret, there are

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \tag{1}$$

combinations to consider.

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combinations to consider.

$\Rightarrow$ Use polynominals!

Polynominals

A polynominal of degree $k-1$ is fully determined by k data points

$$(x_0, y_0), \ldots, (x_j, y_j), \ldots, (x_{k-1}, y_{k-1}),$$

where no two x_j may be identical.

Lagrange interpolation

The interpolation polynominal in the Lagrange form is:

$$L(x) := \sum_{j=0}^{k} y_j \ell_j(x)$$

where

$$\ell_j(x) := \prod_{\substack{0 \le m \le k \\ m \ne j}} \frac{x - x_m}{x_j - x_m} = \frac{(x - x_0)}{(x_j - x_0)} \cdots \frac{(x - x_{j-1})}{(x_j - x_{j-1})} \frac{(x - x_{j+1})}{(x_j - x_{j+1})} \cdots \frac{(x - x_k)}{(x_j - x_k)} \qquad (2)$$

for $0 \le j \le k$.

Practical considerations

- Our secrets will typically be integers. Calculations with floating points are *messy*.

$\Rightarrow$ Use finite field arithmetic, not $\mathbb{R}$.

Real world scalability

n / k	1	2	3	4	5	6
1	1	2	3	4	5	6
2		1	3	6	10	15
3			1	4	10	20
4				1	5	15
5					1	6
6						1

Other values:

- $\binom{10}{5} = 252$
- $\binom{20}{10} = 184756$
- $\binom{30}{15} = 155117520$

Do we have a scalability problem?

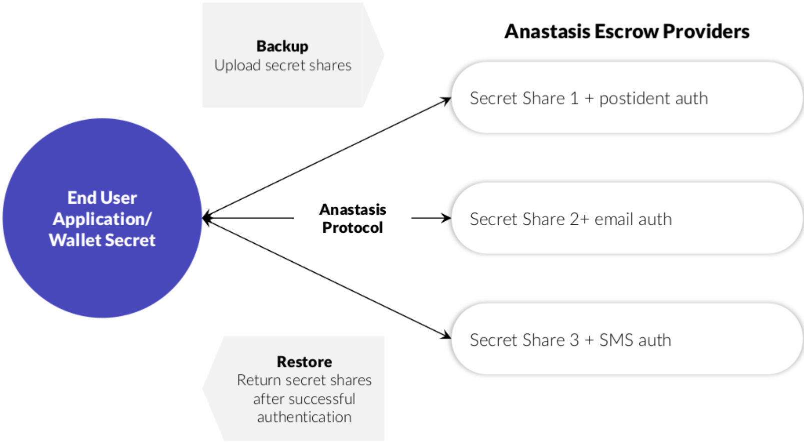
How many people do you have to share your secrets with?

How many people realistically participate in recovery?

What is GNU Anastasis? [2]

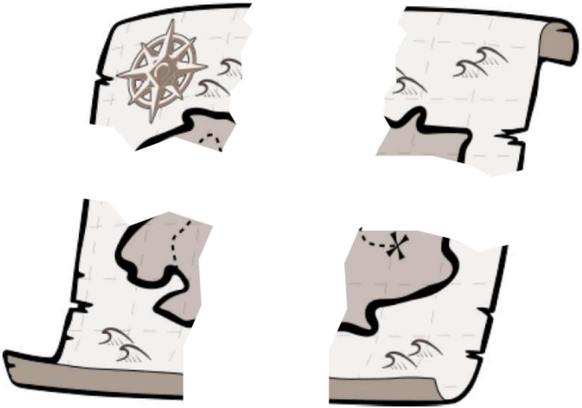
- Distributed key escrow and recovery service
- Users split their secret keys and distribute shares across multiple service providers
- Only the authorized user can recover the key by following standard authentication procedures
- Service providers learn nothing about the user, except possibly some details about how to authenticate the user

Overview

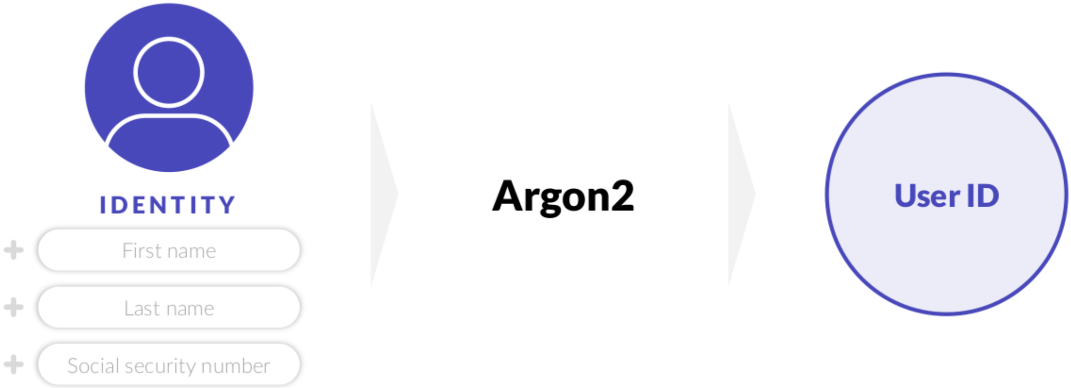

Backup
Upload secret shares
Anastasis Escrow Providers
Secret Share 1 + postident auth
End User
Application/
Wallet Secret
Anastasis
Protocol
Secret Share 2+ email auth
Secret Share 3 + SMS auth
Restore
Return secret shares
after successful
authentication

Step 1: Enter secret information

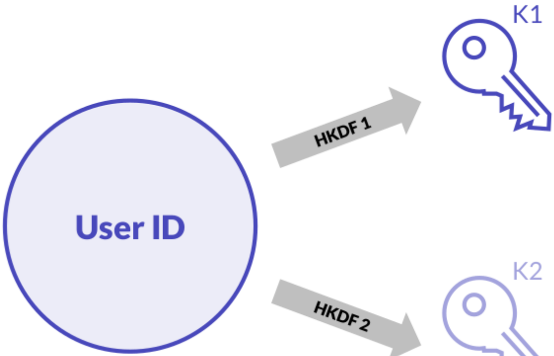
Step 2: Split information



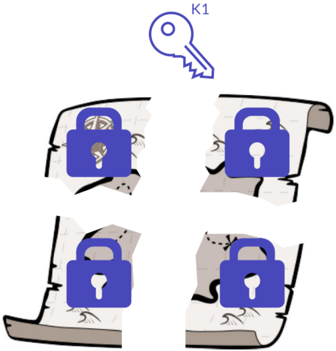
Step 3: Hash user identification



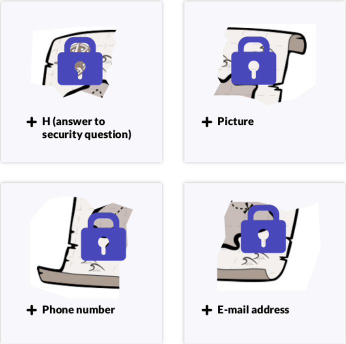
Step 4: Key derivation



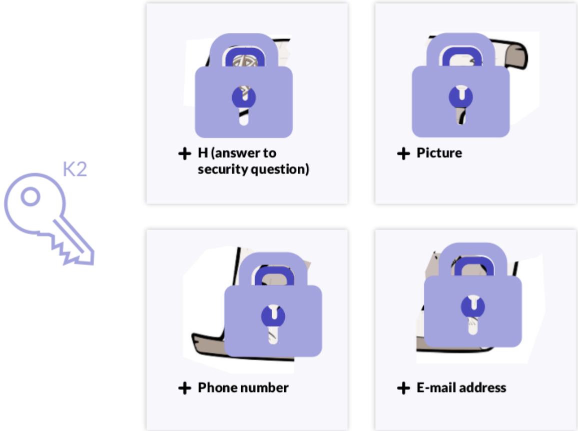
Step 5: Encrypt parts



Step 6: Add truth

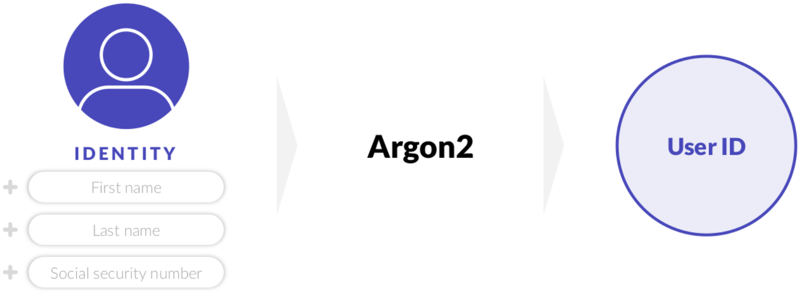


Step 7: Encrypt truth

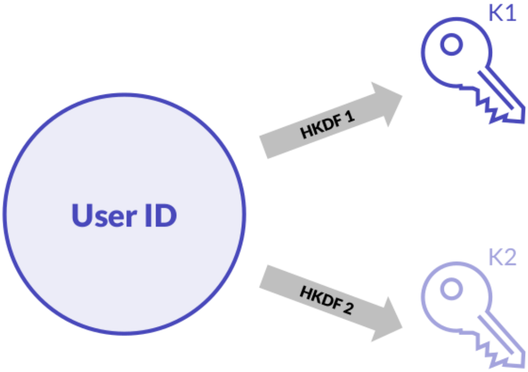


Step 8: Store data

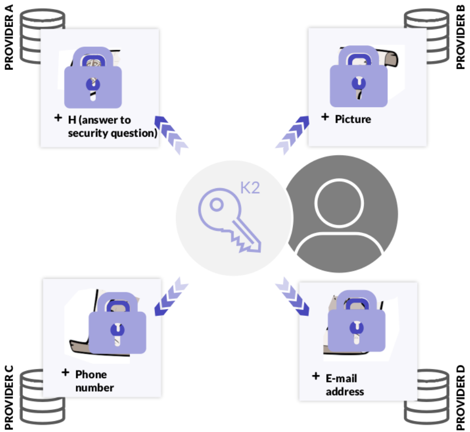
Step 9: User identification



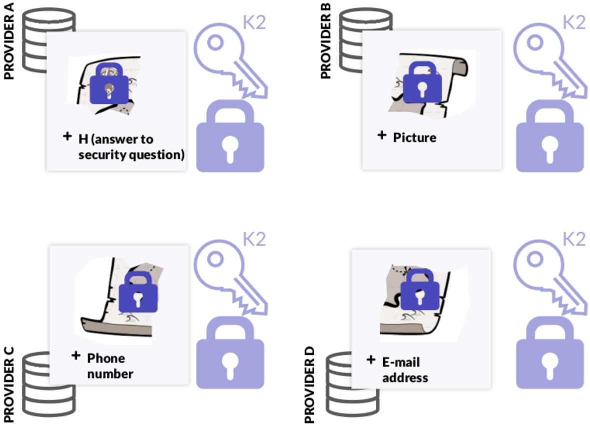
Step 10: Key derivation



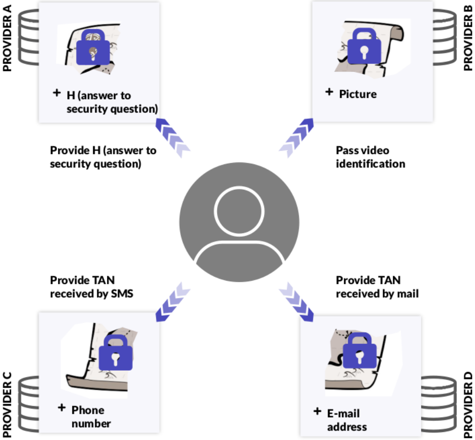
Step 11: Provide key



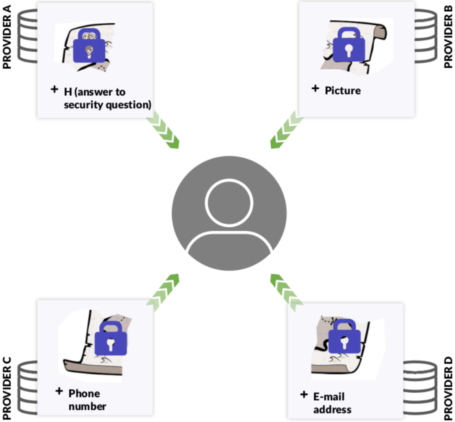
Step 12: Decrypt truth



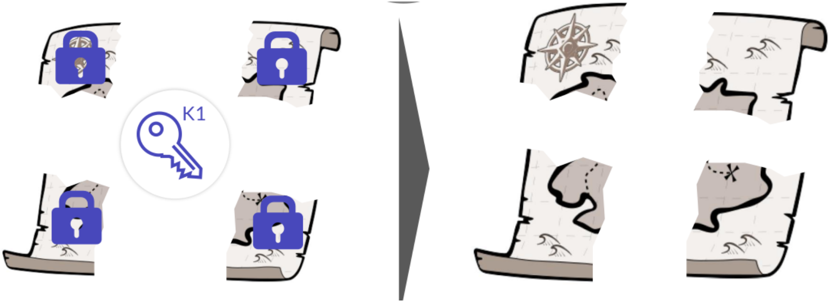
Step 13: Authenticate



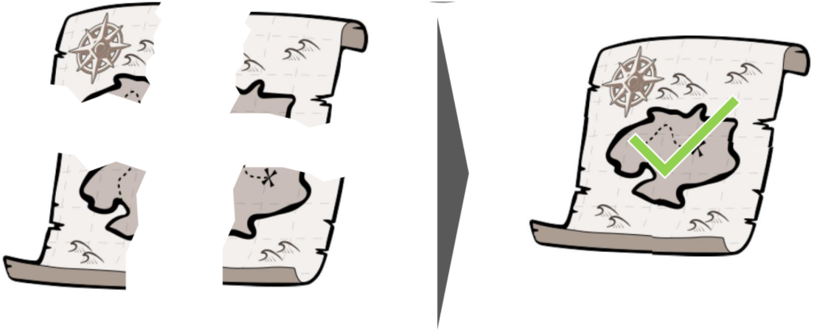
Step 14: Receive parts



Step 15: Decrypt parts



Step 16: Reassembly



Reality is more complex

- 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

Everything is Broken

Alice wants to create a cryptographic signature, but:

- No single piece of hardware is trusted
- No single service provider is trusted

But: Using t independent signature service providers might be ok!

If we need t providers, we probably should initially sign up with n providers so that we can still create signatures if only t/n are available...

FROST [1]

Flexible Round-Optimized Schnorr Threshold (FROST) is a t-out-of-n threshold signature scheme:

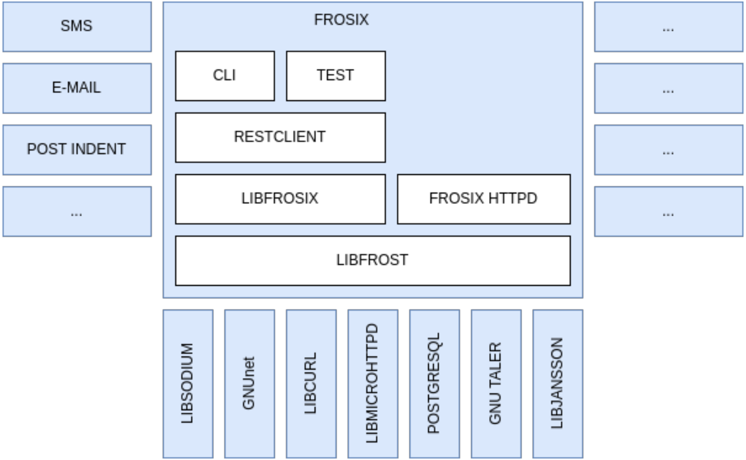
- Distributed key generation protocol can be used to ensure private key is never stored on a single device
- t providers required to collaborate to create digital signature

FROSIX

Free Software implementation for threshold signatures using FROST with:

- RESTful API to interact between signer and signing services
- Configurable authentication methods to authorize creation of signature
- Client should still use multiple devices (for authorization and to check distributed key generation) to avoid single point of failure
- Command-line tool to interact with FROSIX service providers

System components overview



FROSIX: Future Work

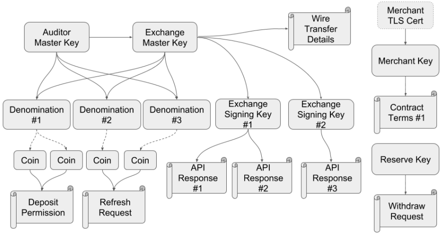
Open issues:

- Support additional signature schemes beyond EdDSA
- Pay signature service providers for their service
- Graphical user interfaces (Gtk+, WebUI, ...)

Key management in GNU Taler

GNU Taler has many types of keys:

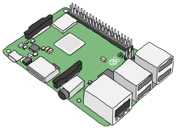
- Coin keys (EdDSA + ECDHE)
- Denomination keys (blind)
- Online message signing keys
- Offline key signing keys
- Merchant keys
- Auditor key
- Security module keys
- Transfer keys (ECDHE)
- Wallet keys
- *TLS keys, DNSSEC keys*



Offline keys

Both exchange and auditor use offline keys.

- Those keys must be backed up and remain highly confidential!
- We recommend that computers that have ever had access to those keys to NEVER again go online.
- We recommend using a Raspberry Pi for offline key operations. Store it in a safe under multiple locks and keys.
- Apply full-disk encryption on offline-key signing systems.
- Have 3–5 full-disk backups of offline-key signing systems.



Online keys

The exchange needs RSA and EdDSA keys to be available for online signing.

- Knowledge of these private keys will allow an adversary to mint digital cash, possibly resulting in huge financial losses.
- The corresponding public keys are certified using Taler's public key infrastructure (which uses offline-only keys).

`taler-exchange-offline` can be used to **revoke** the online signing keys, if we find they have been compromised.

Protecting online keys

The exchange needs RSA and EdDSA keys to be available for online signing.

- `taler-exchange-secmod-*` are the only processes that must have access to the private keys. These secmod processes should run under a different UID, but share the same GID with the exchange.
- The secmods generate the keys, allow `taler-exchange-httpd` to sign with them, and eventually delete the private keys.
- Communication between secmods and `taler-exchange-httpd` is via a UNIX domain socket.
- Online private keys are stored on disk (not in database!) and should NOT be backed up (RAID should suffice). If disk is lost, we can always create fresh replacement keys!

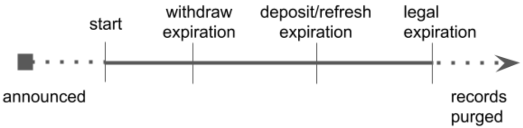
Online keys

What happens if private keys are disclosed or lost?

Denomination key (d, n) disclosure

- Auditor and exchange can detect this once the total number of deposits exceeds the number of legitimate coins.
- 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.

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



References I

- Deirdre Connolly, Chelsea Komlo, Ian Goldberg, and Christopher A. Wood.
  Two-round threshold schnorr signatures with frost.
  Technical report, IRTF, 2023.
  https://datatracker.ietf.org/doc/draft-irtf-cfrg-frost/.

- Dominik Samuel Meister and Dennis Neufeld.
  Anastasis: Password-less key recovery via multi-factor multi-party authentication.
  Master's thesis, Bern University of Applied Sciences, June 2020.

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