# NEXT GENERATION INTERNET

## Key management

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NGI 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?

## Part I: How can we protect confidentiality of private keys?

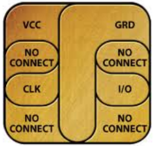
# Software based Personal Security Environments (PSE): PKCS#12

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

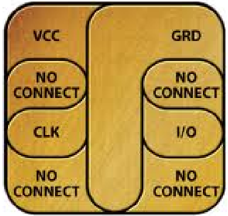
- PKCS#12 is a file container format used for storage and transport of private keys (and possibly certificates).
- Information is protected with a password-based symmetric key (e.g. a password).
- The security of a software PKCS#12 is based on the strength of the password protecting it.

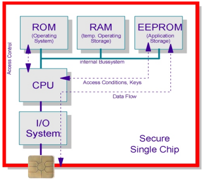
Problem: A PKCS#12 soft-token may be copied unnoticed.

# 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)

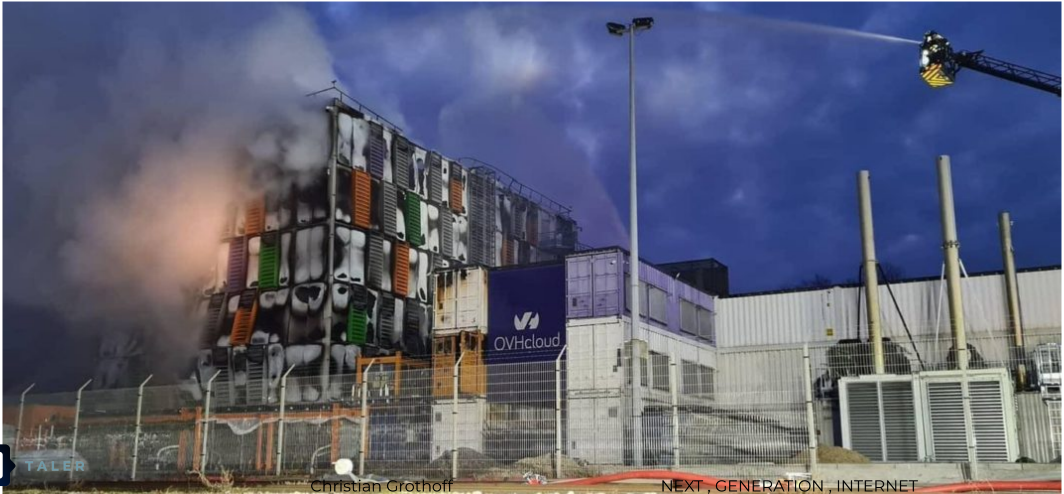
Common functionality:

- 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



## Part II: How does Shamir Secret Sharing work?

# Problem 1: Availability

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

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$\Rightarrow$ 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.

# Problem 3: Scalability

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

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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

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

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?

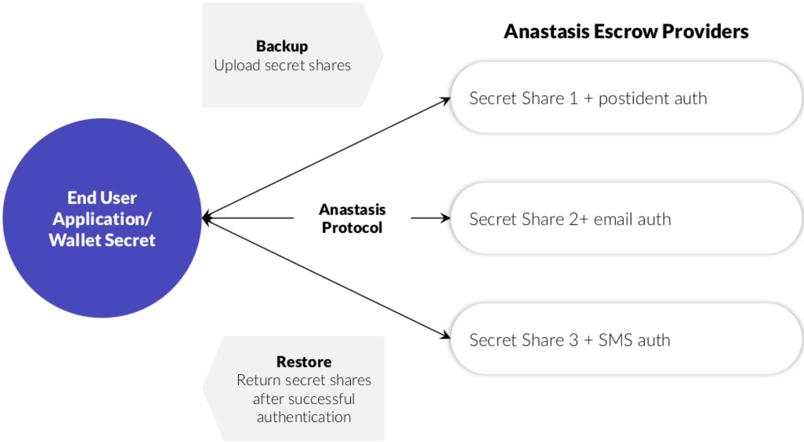
How many people realistically participate in recovery?

# Part III: Key escrow and recovery: From Shamir to Anastasis

# What is GNU Anastasis? [2]

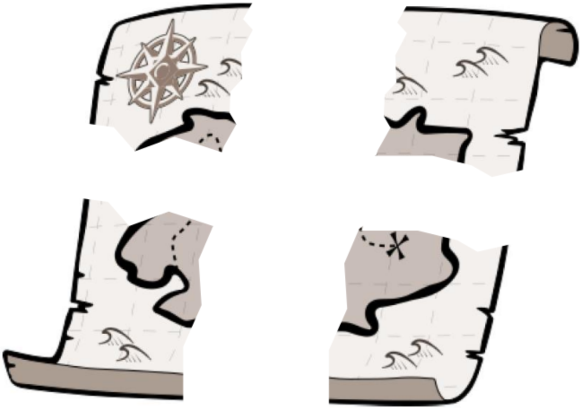
- Distributed key escrow and recovery service
- Users split their secret keys and distribute shares across multiple service providers
- Only the authorized user can recover the key by following standard authentication procedures
- Service providers learn nothing about the user, except possibly some details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

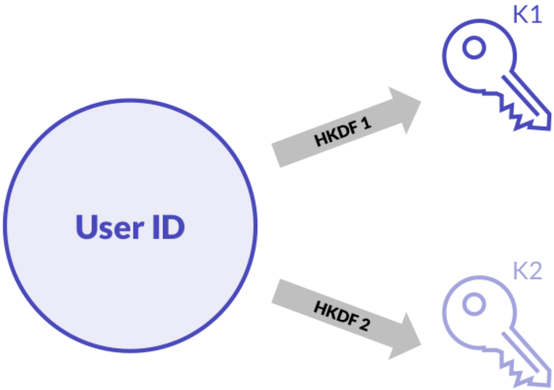
# Step 1: Enter secret information

# Step 2: Split information

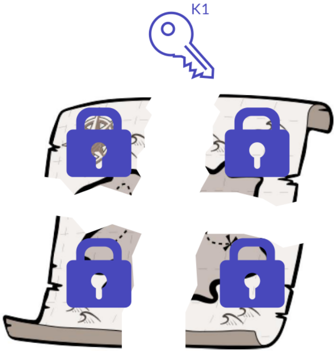


# Step 3: Hash user identification

# Step 4: Key derivation



# Step 5: Encrypt parts



# Step 6: Add truth

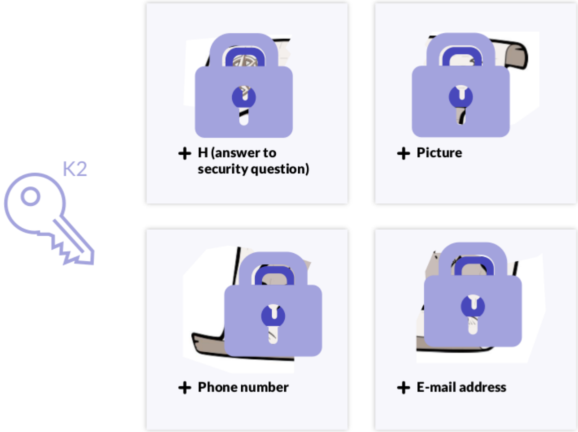
+ H (answer to security question)

+ Picture

+ Phone number

+ E-mail address

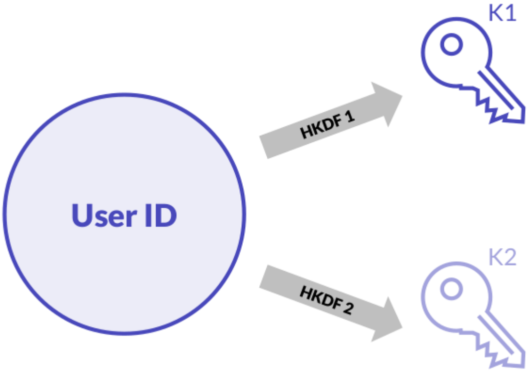
# Step 7: Encrypt truth



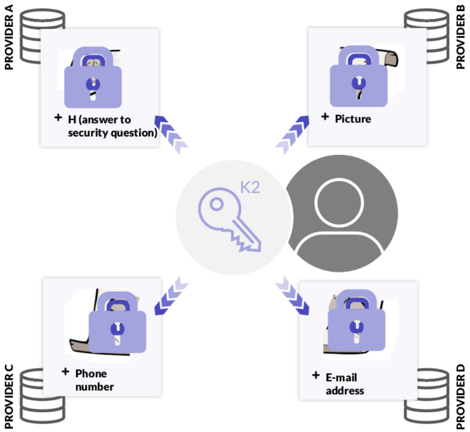
# Step 8: Store data

# Step 9: User identification

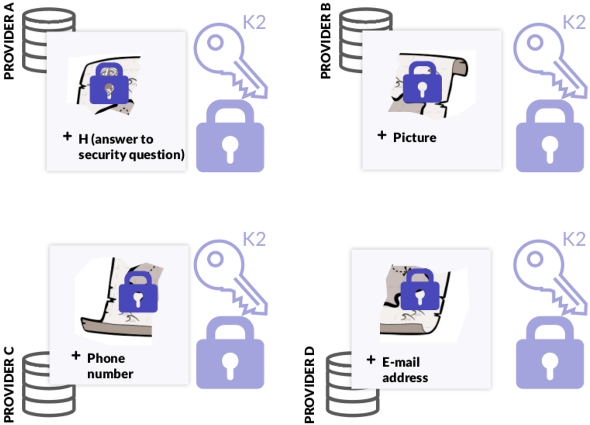
# Step 10: Key derivation



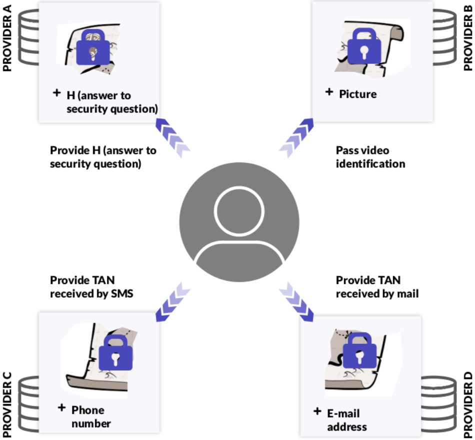
# Step 11: Provide key



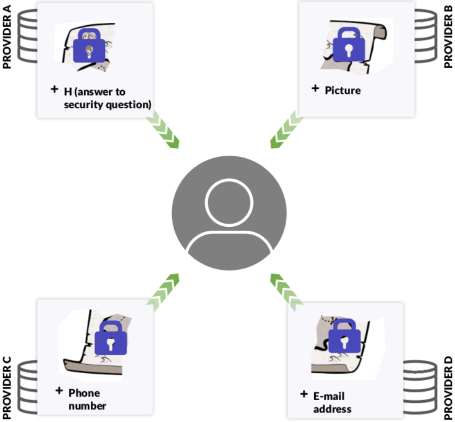
# Step 12: Decrypt truth



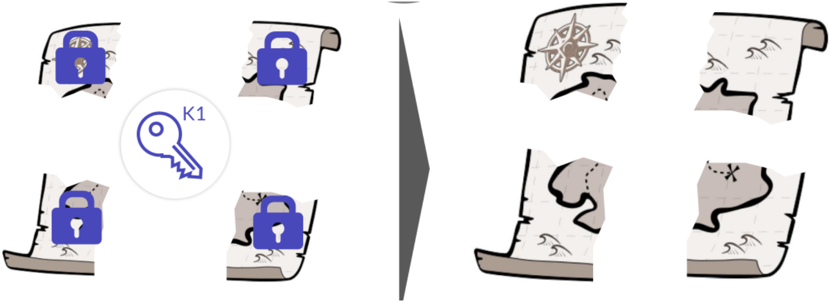
# Step 13: Authenticate



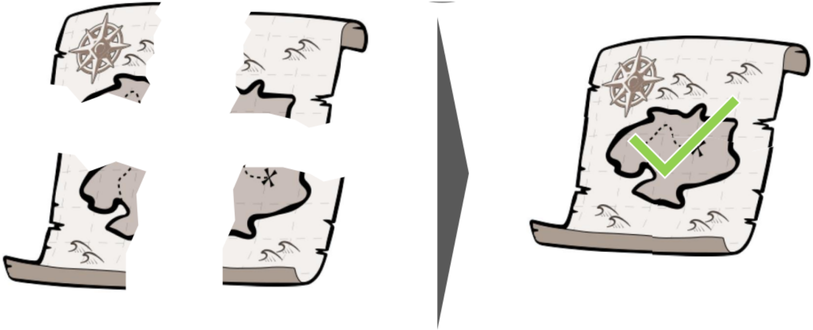
# Step 14: Receive parts



# 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

# Part IV: What are threshold signatures?

# 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:

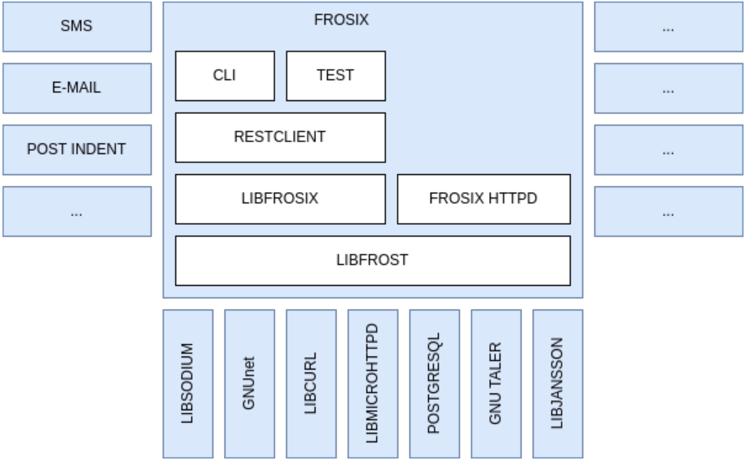
- Distributed key generation protocol can be used to ensure private key is never stored on a single device
- $t$ providers required to collaborate to create digital signature

# 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:

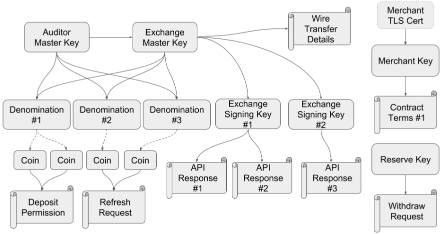
- Support additional signature schemes beyond EdDSA
- Pay signature service providers for their service
- Graphical user interfaces (Gtk+, WebUI, ...)

# Part V: What does key management look like in practice?

# Key management in GNU Taler

GNU Taler has many types of keys:

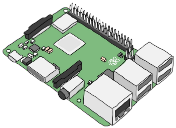
- Coin keys (EdDSA + ECDHE)
- Denomination keys (blind)
- Online message signing keys
- Offline key signing keys
- Merchant keys
- Auditor key
- Security module keys
- Transfer keys (ECDHE)
- Wallet keys
- *TLS keys, DNSSEC keys*



# 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!

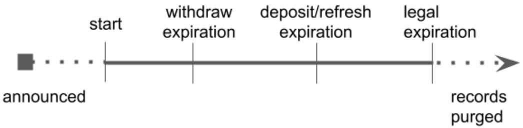
# Online keys

**What happens if private keys are disclosed or lost?**

# Private key disclosure

- Auditor and exchange can detect this once the total number of deposits exceeds the amount of digital cash put into circulation.
- At this point, signing keys are *revoked*. Users of *unspent* legitimate coins obtain a *refund*.
- The financial loss of the exchange is *bounded* by the number of legitimate coins signed with the private key.

⇒ Taler frequently rotates denomination signing keys and deletes a private key after the signing period of the respective key is over.



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