Keep It Secret, Keep It Safe — ZK-Proofs in the EU Identity Wallet

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Why this is our problem

450 million citizens, one wallet model, every relying party in Europe

Identity primitives suddenly have to scale: pseudonymity, unlinkability, revocation

Get this wrong and we lock bad cryptography in for a decade, and lose citizens trust

Estonia has been here before: your e-ID story is now everyone’s

eIDAS 2.0: the road to a wallet

2014

eIDAS 1.0: qualified signatures, no wallet

Jun 2021

COM proposal for a European Digital Identity

May 2024

Reg. (EU) 2024/1183 enters into force

Nov 2024

ARF v1.4: first concrete cryptographic targets

By end of 2026

Each Member State must offer at least one wallet

EU DI Wallet

Three actors, one credential

Issuer: government, bank, university — signs an attestation

Holder: the citizen, with the wallet on a phone

Verifier: a relying party: airline, hotel, online shop

Trust:

verifier trusts issuer's signature

holder trusts the wallet to hide what isn't asked

Two privacy questions, not one

Privacy vs. the verifier: what can the relying party reconstruct after I show my credential?

Privacy vs. the issuer: what can the issuer learn about where, when, and to whom I presented?

The two are **independent**: a scheme can give one and silently break the other

Issuer-privacy is the hard one: the issuer is the state, and it never goes away

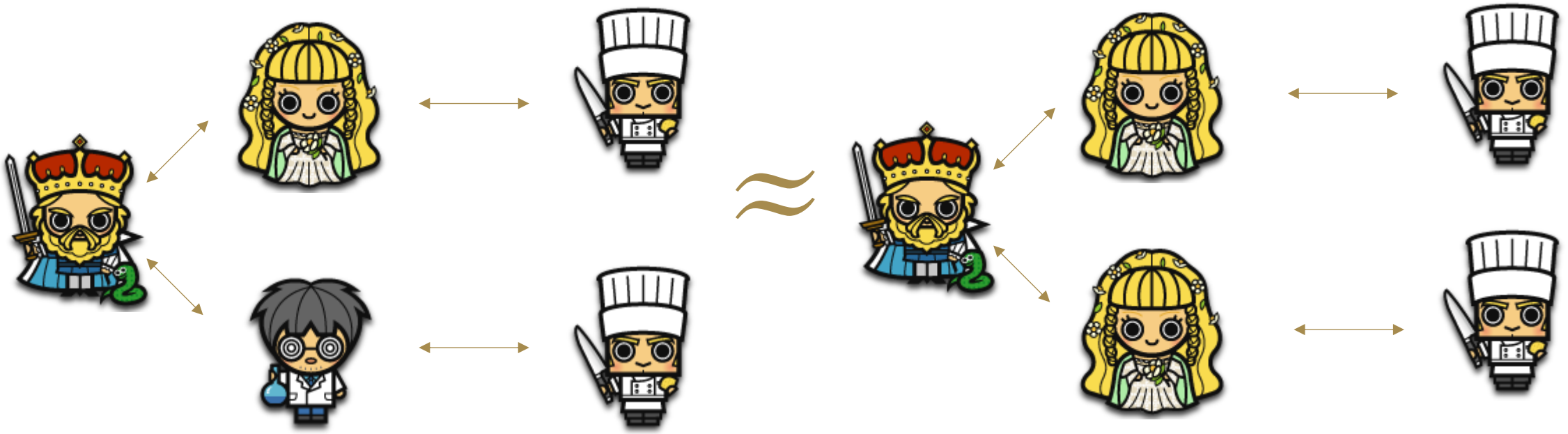
Every design choice in the wallet must be evaluated against both threat models

Privacy vs. the verifier

~~**Unlikeability**~~ **Unlinkability:** after seeing two credential presentations, no verifier should be able to infer whether they come from the same user

Privacy vs. the issuer

Unlinkability: after seeing two credentials it generated, the issuer should not be able to determine whether they come from the same user



Two credential formats, one wallet

SD-JWT VC

IETF draft, JSON-based

Salted-hash selective disclosure
Holder-binding via JWT key confirmation
Easiest path to web verifiers

mdoc / ISO 18013-5

Ratified ISO standard, CBOR-based

Mobile Security Object with hash digests
Optimised for proximity (Bluetooth / NFC)
Aligns with the mobile driving licence

The unlinkability problem

Two presentations of the same SD-JWT carry the same JWT signature

Two verifiers can **collude**: or one verifier across two visits
→ “Same wallet” is provable from the signature alone

mdoc has the same property: MSO is a stable, signed object
“Selective disclosure” ≠ “private”: this is where ZK enters

Why a stable issuer signature kills issuer-privacy

Two presentations of the same SD-JWT carry the same issuer signature σ

Scenario: Alice shows her credential at 09:14 at an airport, then at 14:02 at a pharmacy

If the issuer ever sees the presentations *through a revocation check, an audit log, or a court order* it sees the same σ both times

No collusion between verifiers required: the issuer alone correlates the two visits

The stable signature is an identifier across the issuer's view of the world too

This is what BBS **removes**: every presentation is a **fresh**, **re-randomised** σ' that even the signer cannot recognise

Batch issuance: the tempting shortcut

Idea: issue N one-shot credentials at once; the holder uses each only once

Easy to deploy: reuses existing SD-JWT / mdoc machinery, no new crypto primitives

Gives a wallet-level "**unlinkability**" at presentation time: each token looks fresh

Many real deployments are heading this way: it ships fast, it demos well

Worth taking seriously before we explain why it is a dead-end

Why batch issuance is a **bad** first solution

Issuer-privacy is GONE: the issuer can predict every future presentation

Tokens are not bound to a verifier: a relying party can reuse, pool, or trade them across users

Refill problem: when the holder runs out, they contact the issuer again (issuer learns presentation patterns)

Cryptographic **dead-end**: once shipped, migrating to BBS or anon-creds is politically very hard

Easy to deploy, easy to regret: exactly the lock-in we should avoid for 10+ years

Zero-knowledge proofs

Goal: convince a **verifier** that a statement is true (without revealing why)

Three properties: **completeness** (true statements convince), **soundness** (false ones don't), **zero-knowledge** (proof reveals nothing else)

Examples: "I know x such that H(x) = y", "I am over 18", "I hold a valid issuer signature"

Non-interactive via Fiat–Shamir: a single message replaces a multi-round protocol

Concrete schemes: Σ-protocols, Bulletproofs, Groth16, Plonk, Halo2, STARKs: different cost / setup trade-offs

How ZK fits the EU Identity Wallet

Anonymous credentials: prove “I hold a valid issuer signature” without revealing it: restores verifier- and issuer-**unlinkability**

Selective disclosure with **unlinkability**: everything hash-SD does, plus **no stable identifier**

Predicate proofs: “over 18”, “EU resident”, “earns under €X” without disclosure

Membership / revocation: prove “I am not on the revocation list”

Composability: chain proofs into complex policies without re-issuing

BBS signatures, briefly

Pairing-based signature on a list (m_1, …, m_n) of messages

Standardised by IRTF: “BBS over BLS12-381”
Verification: two pairings
Signing: one exponentiation per message

Killer feature: prover can derive a randomised proof-of-knowledge of σ
Selective disclosure becomes a **free** corollary

More flexibility is better for adoption

Locking into a single verification circuit narrows the set of supported use cases

ZK-proofs enable complex policies, e.g.:

lives in Paris surburbs AND (under 18 **OR** (between 16 and 25 **AND** Studying) **OR** (more than 62 **AND** Retired) **OR** civil servant **OR** social worker **OR** welfare recipient (**in** {RSA,ASS,CSS,AME, AAH,AEEH}) **OR** welfare card holder (**in** {CI, CMI}) **OR** Veteran **OR** Travel Pass holder (**in** {Imagine R, Améthyste, TST, Navigo Senior}) **OR** member of car-pooling service (**in** {Citiz, Clem', Communauto}))

(*simplified* Veligo (Parisian bike rental) reduction rules)

Policies should be expressive, and adaptable to any use case on the fly, without re-issuance or heavy recomputations.

Framing proofs around "positive" use cases (discounts, eligibility) also helps public acceptance.

Take-aways

01

SD ≠ private

Batch issuance ≠ private

02

BBS is the bet

03

Predicates are the next frontier

04

PQ is wide open

05

Revocation needs ZK too

06

Crypto won't fix law


Merci
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