Formalising Linked-Data based Verifiable Credentials for Selective Disclosure

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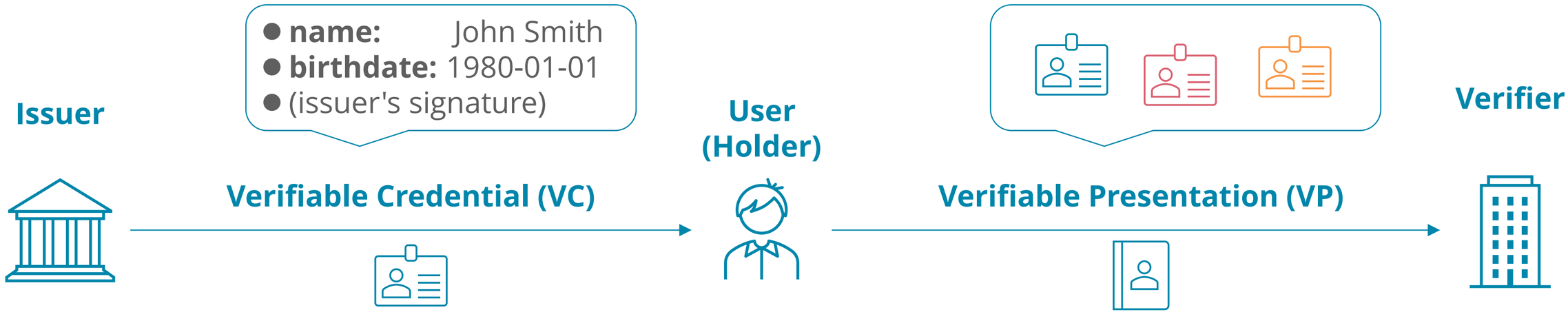
Verifiable Credentials

- **W3C Recommendation**: Verifiable Credentials Data Model (v1.1, March 2022)
- provides a mechanism to express digital credentials in a way that is **cryptographically secure**, **privacy respecting**, and **machine-verifiable**



- Examples: **SMART Health Cards** / IATA Travel Pass / Azure Active Directory Verifiable Credentials (in public preview)

SMART Health Cards

- Paper or digital versions of clinical information
- developed and standardized by VCI (Vaccination Credential Initiative)
- used in 15 nations: US, UK, Canada, Japan, ...

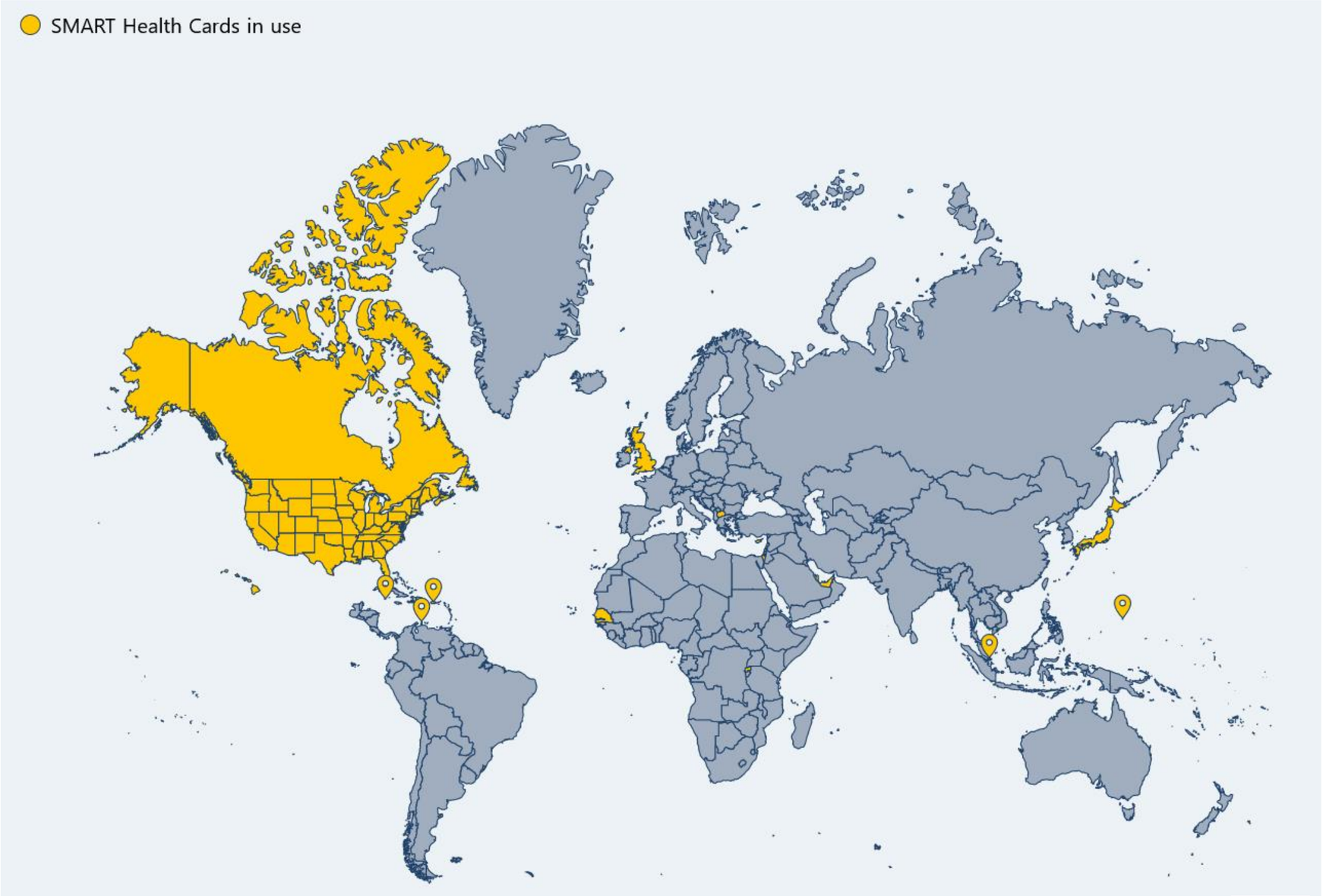
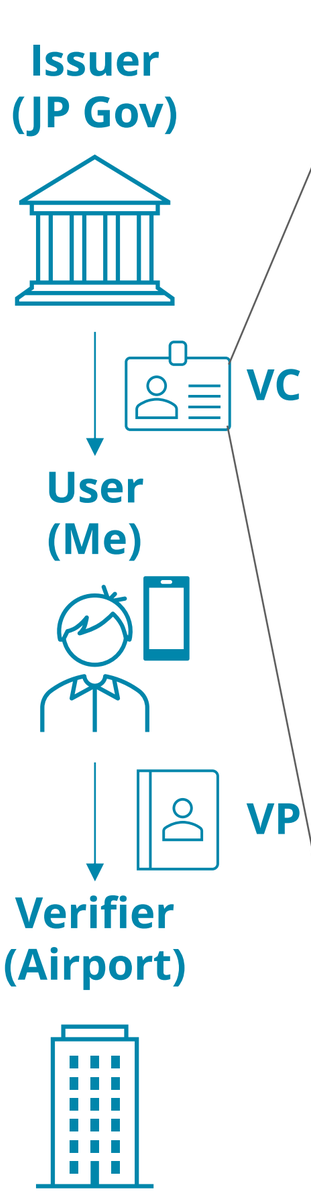


image: https://vci.org

SMART Health Cards



JWT

Header

```
{ "iss": "https://vc.vrs.digital.go.jp/issuer",
  "nbf": 1648956149.461584,  // ~= 2022-04-03
  "vc": {
    "type": ["https://smarthealth.cards#health-card",...],
    "credentialSubject": {
      "fhirVersion": "4.0.1",
      "fhirBundle": { ...,
        "entry": [
          { "fullUrl": "resource:0",
            "resource": {
              "resourceType": "Patient",
              "name": [ ... , {
                  "use": "official",
                  "given": [ "DAN" ], "family": "YAMAMOTO",
                }],
              "birthDate": "xxxx-xx-xx"
            } },
          { "fullUrl": "resource:1",
            "resource": {
              "resourceType": "Immunization",
              "status": "completed",
              "occurrenceDateTime": "2021-08-10",
              "vaccineCode": { "coding": [ {
                    "system": "http://hl7.org/fhir/sid/cvx",
                    "code": "207"
                  } ] },
              "patient": { "reference": "resource:0" },
              "lotNumber": "9999999" ...
```

Signature

SMART Health Cards

Issuer (JP Gov)

VC

User (Me)

VP

Verifier (Airport)

JWT

Header

```
{ "iss": "https://vc.vrs.digital.go.jp/issuer",
  "nbf": 1648956149.461584,  // ~= 2022-04-03
  "vc": {
                    "given": [ "DAN" ], "family": "YAMAMOTO",
                  }],
                "birthDate": "1980-05-03"
              } },
            { "fullUrl": "resource:1",
              "resource": {
                "resourceType": "Immunization",
                "status": "completed",
                "occurrenceDateTime": "2021-08-10",
                "vaccineCode": { "coding": [ {
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                      "code": "207"
                    } ] },
                "patient": { "reference": "resource:0" },
                "lotNumber": "9999999" ...
```

- ✓ issued by: **Japanese Government**
- ✓ issued on: **April 3, 2022**
- ✓ patient name: **Dan Yamamoto**
- ✓ got vaccinated on: **August 10, 2021**
- ✓ vaccine code: **207**
- ✓ lot number: **9999999**

Signature

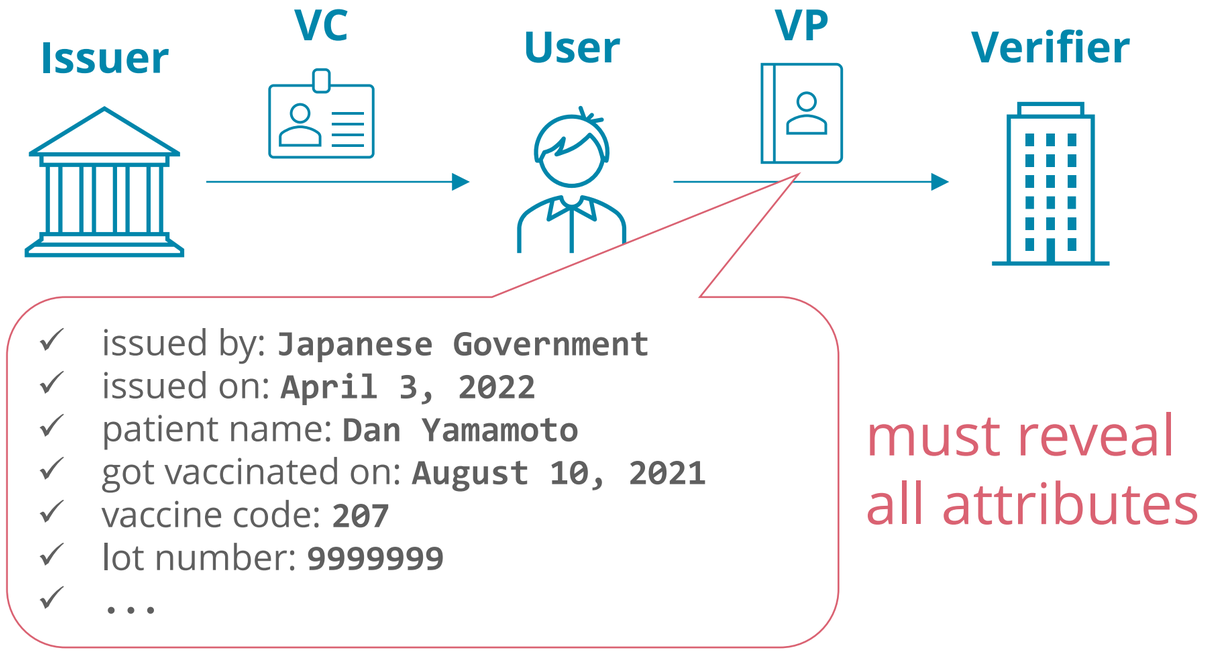
VC flavors

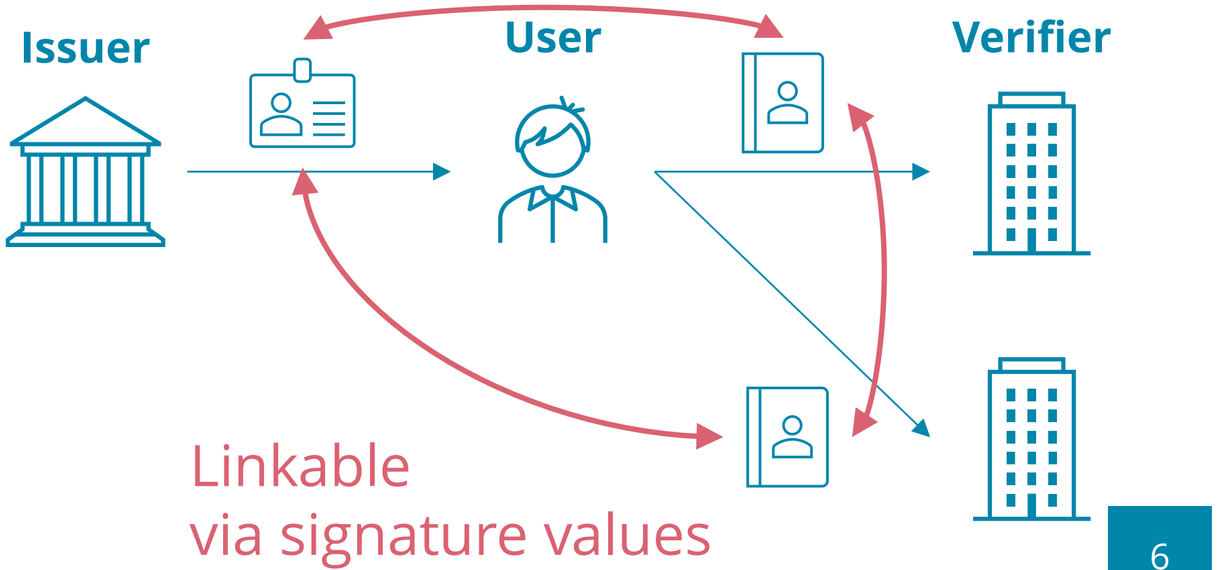
JWT-based VC
(e.g., SMART Health Cards)

doc format = **JSON**
proof format = **JWT**
sig scheme = **RSA, ECDSA, EdDSA, …**

- ✓ Simple, easy to develop
- ✓ Many real world instances
- ✗ No selective disclosure
- ✗ Presentations are linkable

Not privacy-preserving





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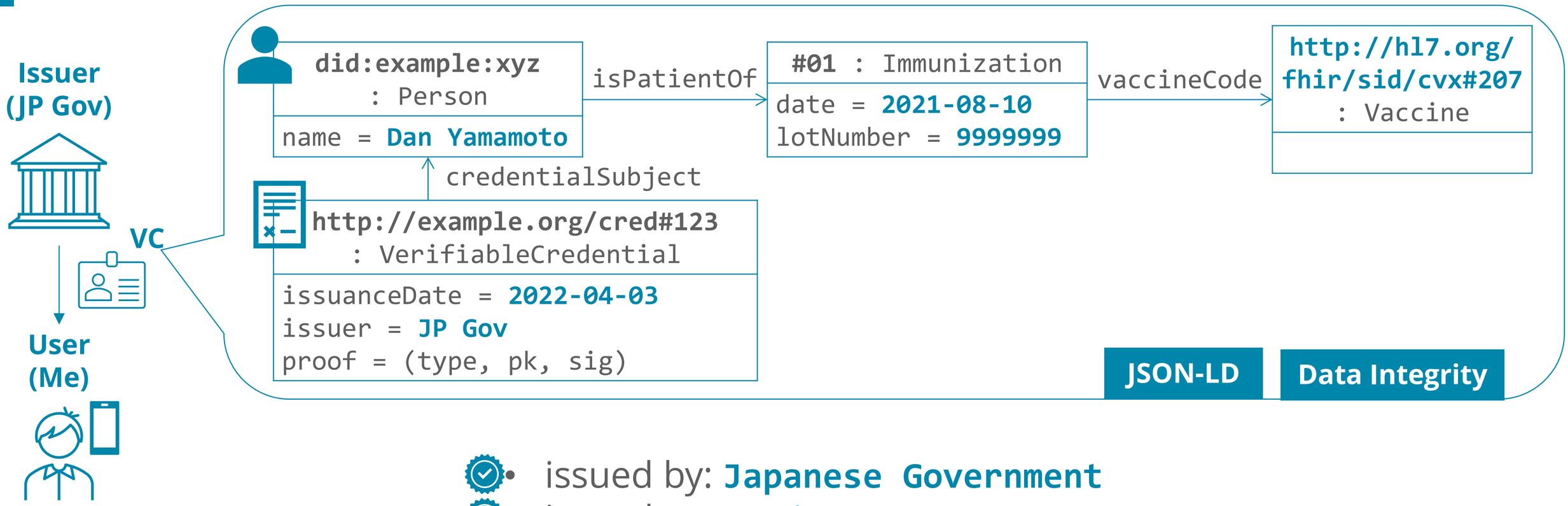
Linked-Data based VC
(LDP-BBS+)

doc format = **JSON-LD**
proof format = **Data Integrity** (LD Proof)
sig scheme = **BBS+**

- ✗ Relatively complicated
- ✗ Still work in progress
- ✓ Selective disclosure
- ✓ Unlinkable Presentations

LD-based Health Cards



Verifier
(Airport)

- issued by: **Japanese Government**
- issued on: **April 3, 2022**
- patient name: **Dan Yamamoto**
- got vaccinated on: **August 10, 2021**
- vaccine code: **207**
- lot number: **9999999**

Selective Disclosure & Unlinkable Presentations

Issuer
(JP Gov)

VC

User
(Me)

VP

Verifier
(Airport)

did:example:xyz
: Person

name = **Dan Yamamoto**

isPatientOf

#01 : Immunization

date = **2021-08-10**
lotNumber = **9999999**

vaccineCode

http://hl7.org/fhir/sid/cvx#207
: Vaccine

credentialSubject

http://example.org/cred#123
: VerifiableCredential

issuanceDate = **2022-04-03**
issuer = **JP Gov**
proof = (type, pk, sig)

did:example:xyz
: Person

****

isPatientOf

#01 : Immunization

date = **2021-08-10**
****

vaccineCode

http://hl7.org/fhir/sid/cvx#207
: Vaccine

credentialSubject

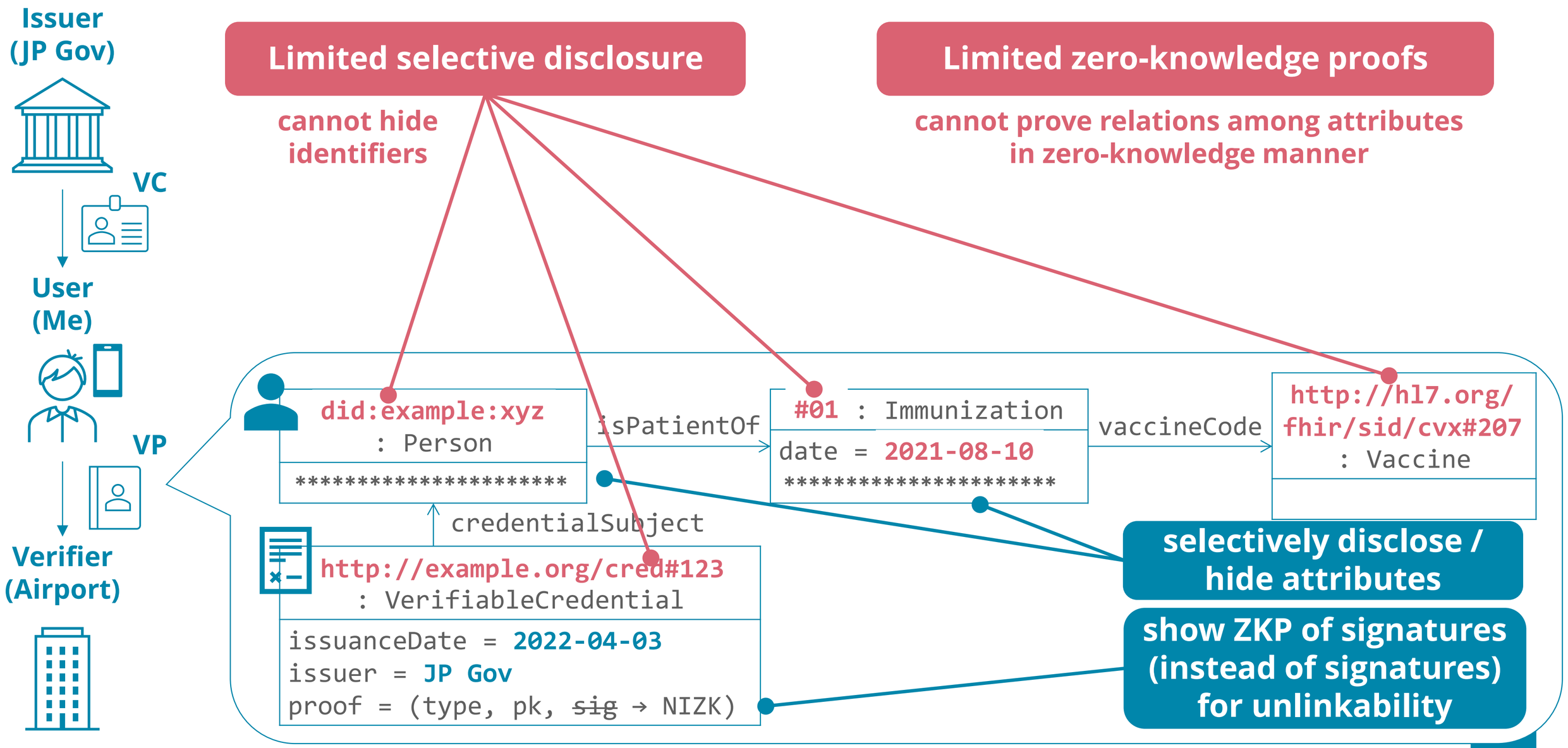
http://example.org/cred#123
: VerifiableCredential

issuanceDate = **2022-04-03**
issuer = **JP Gov**
proof = (type, pk, ~~**sig**~~ → **NIZK**)

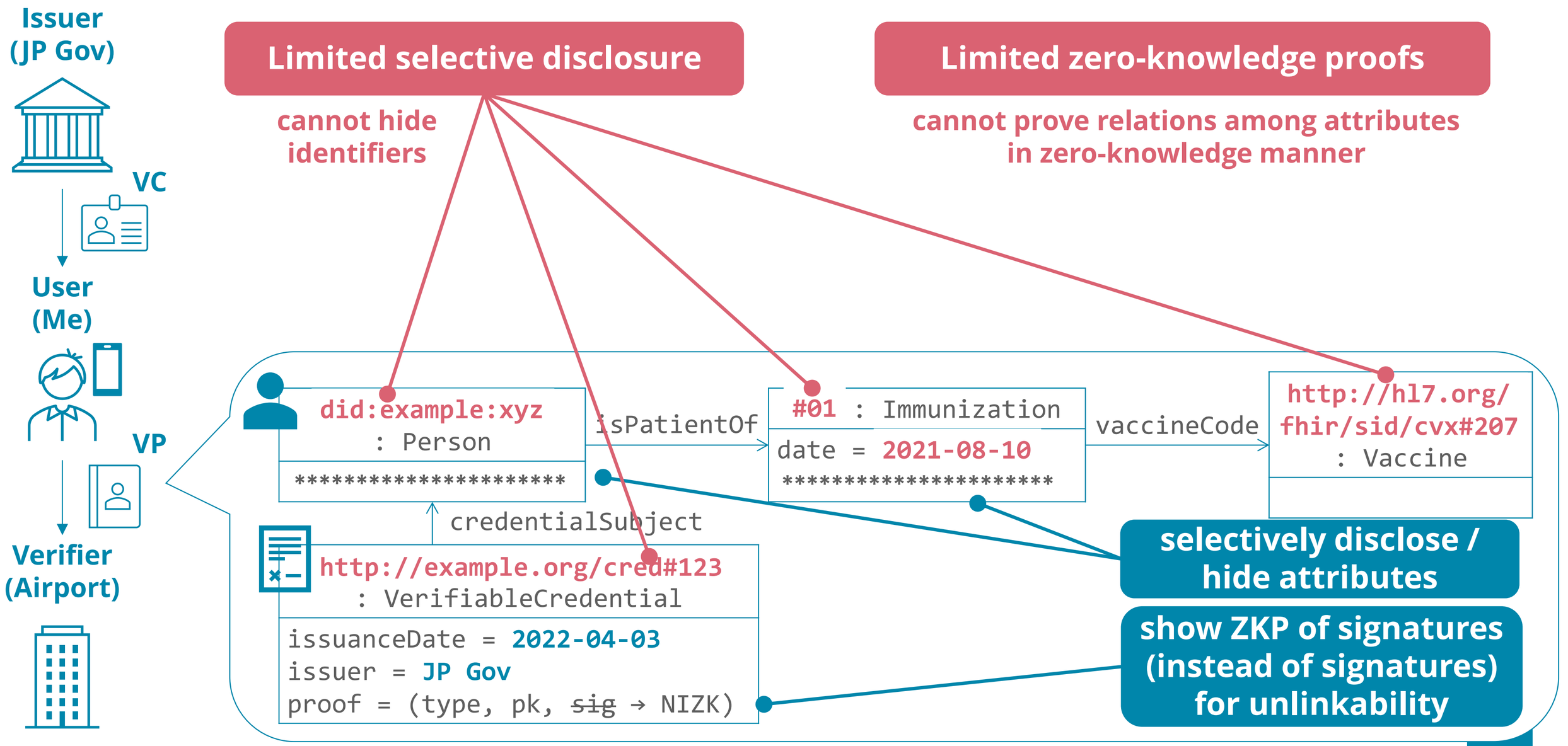
selectively disclose / hide attributes

show ZKP of signatures (instead of signatures) for unlinkability

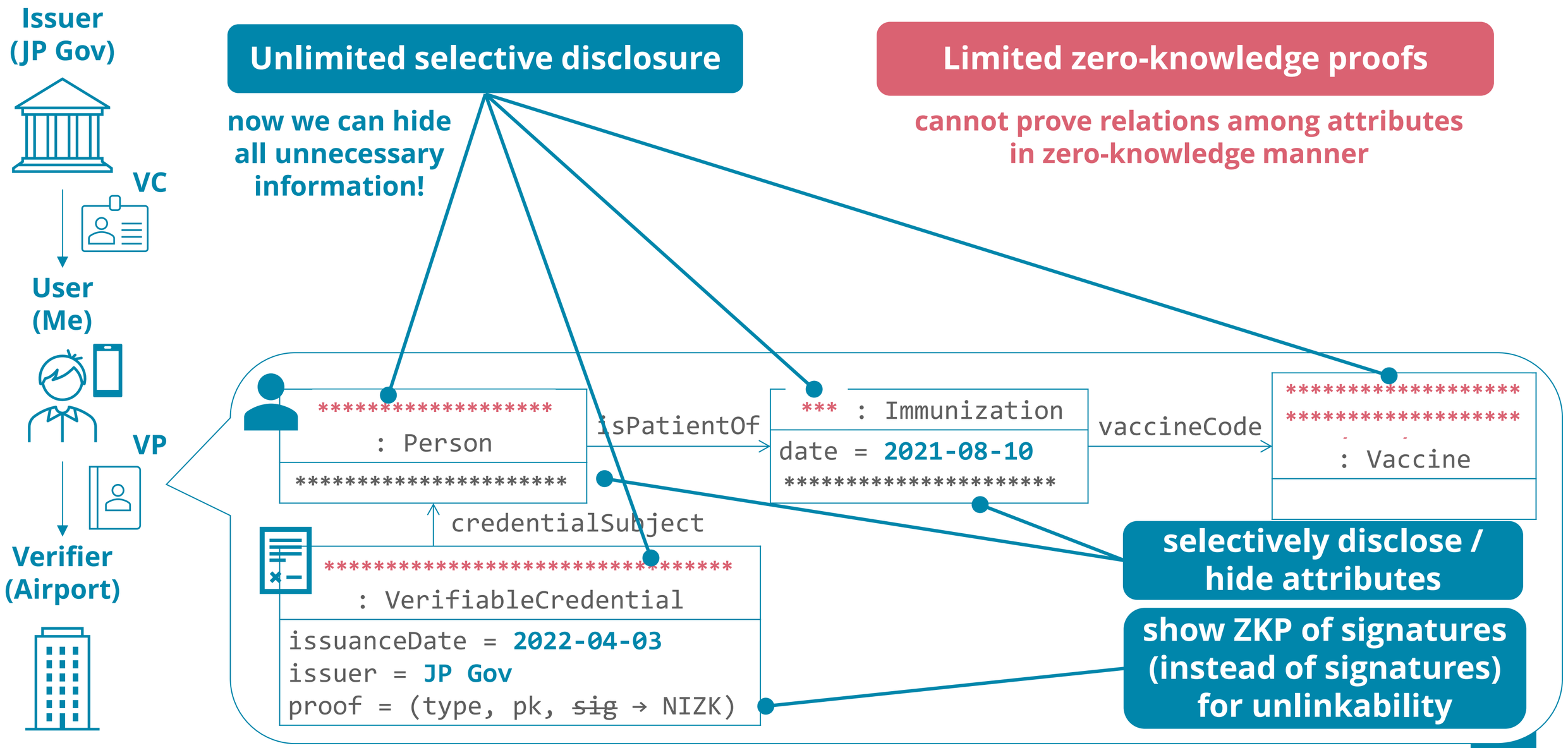
Limitations of Existing Construction (LDP-BBS+)



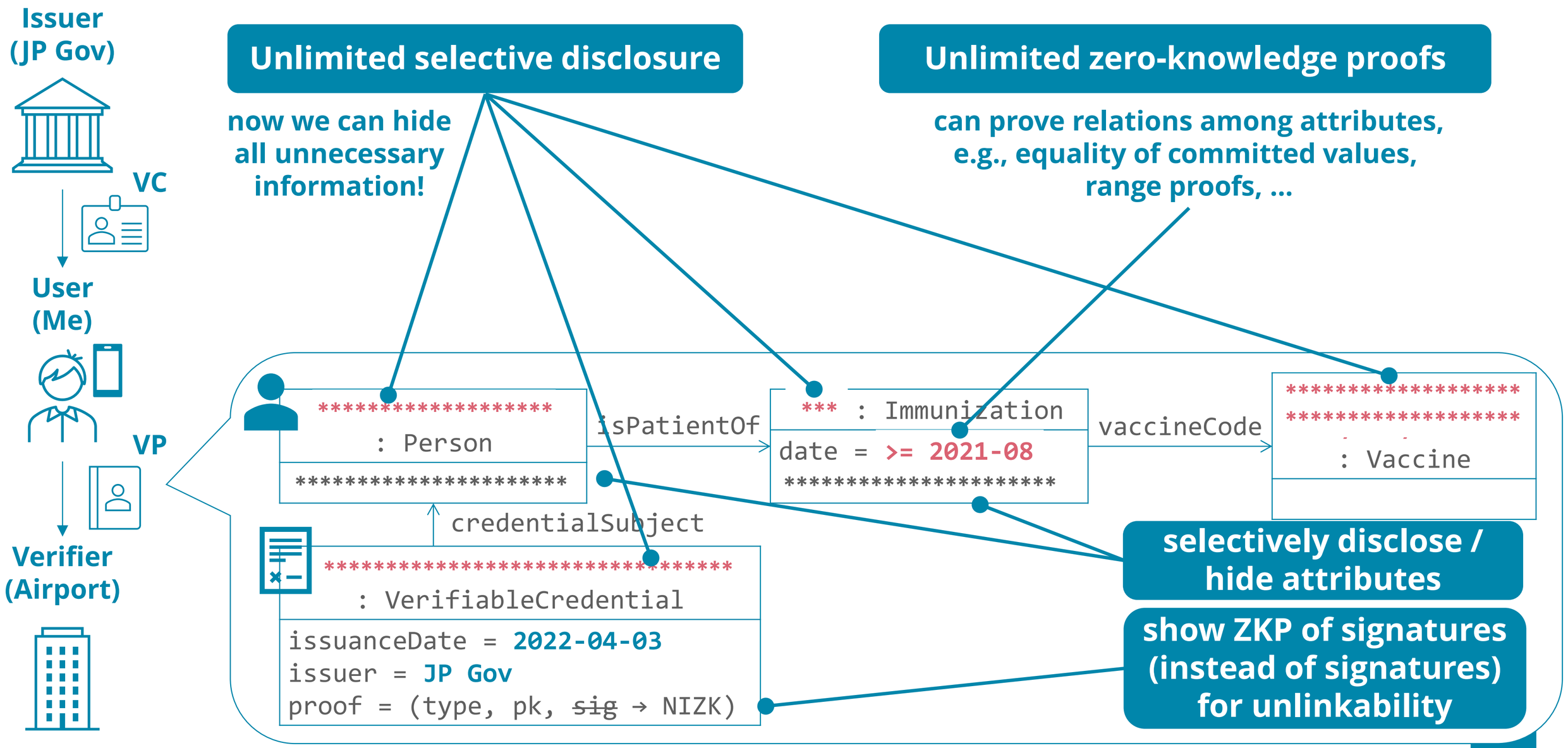
Our Contribution



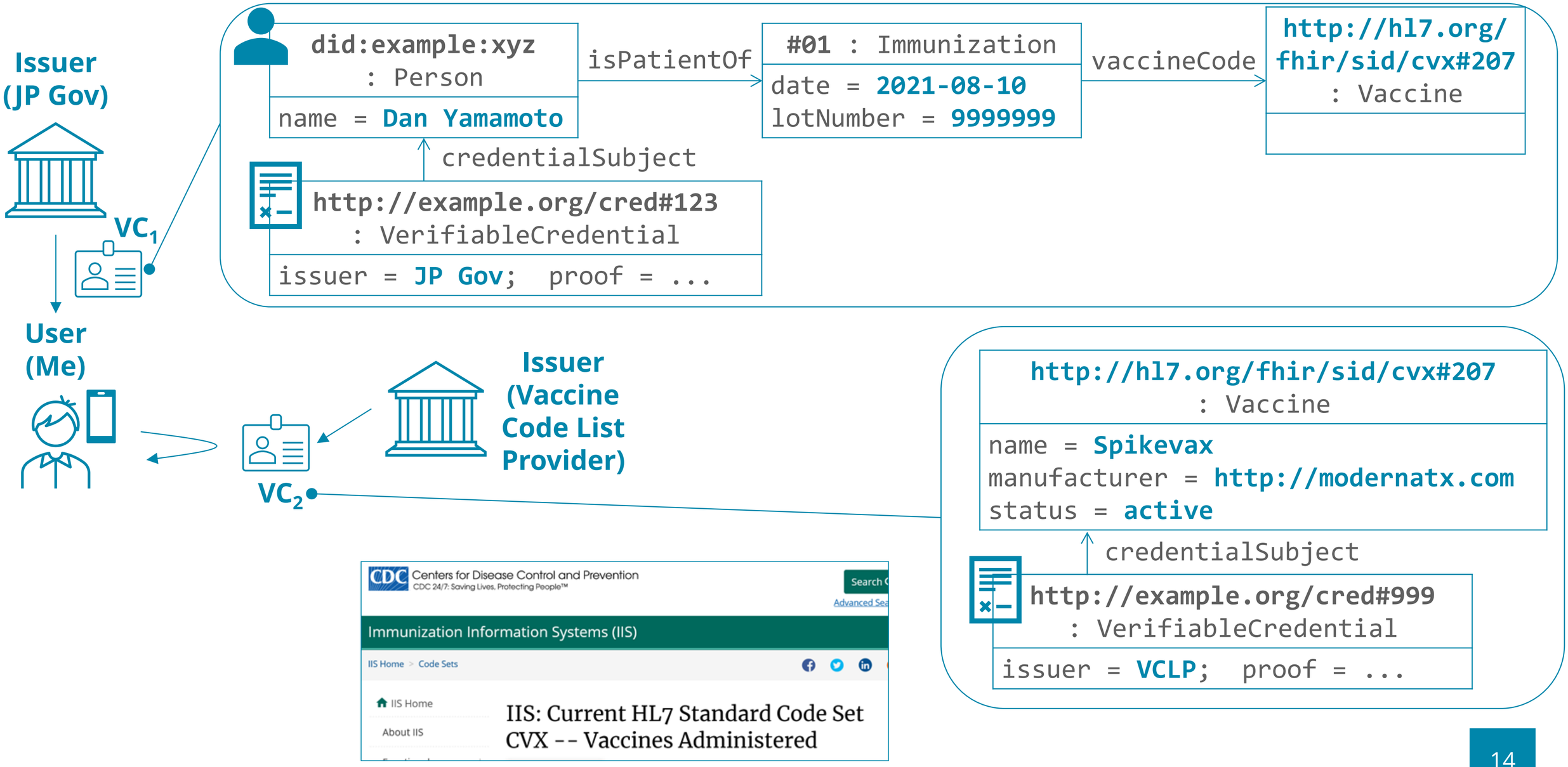
Our Contribution



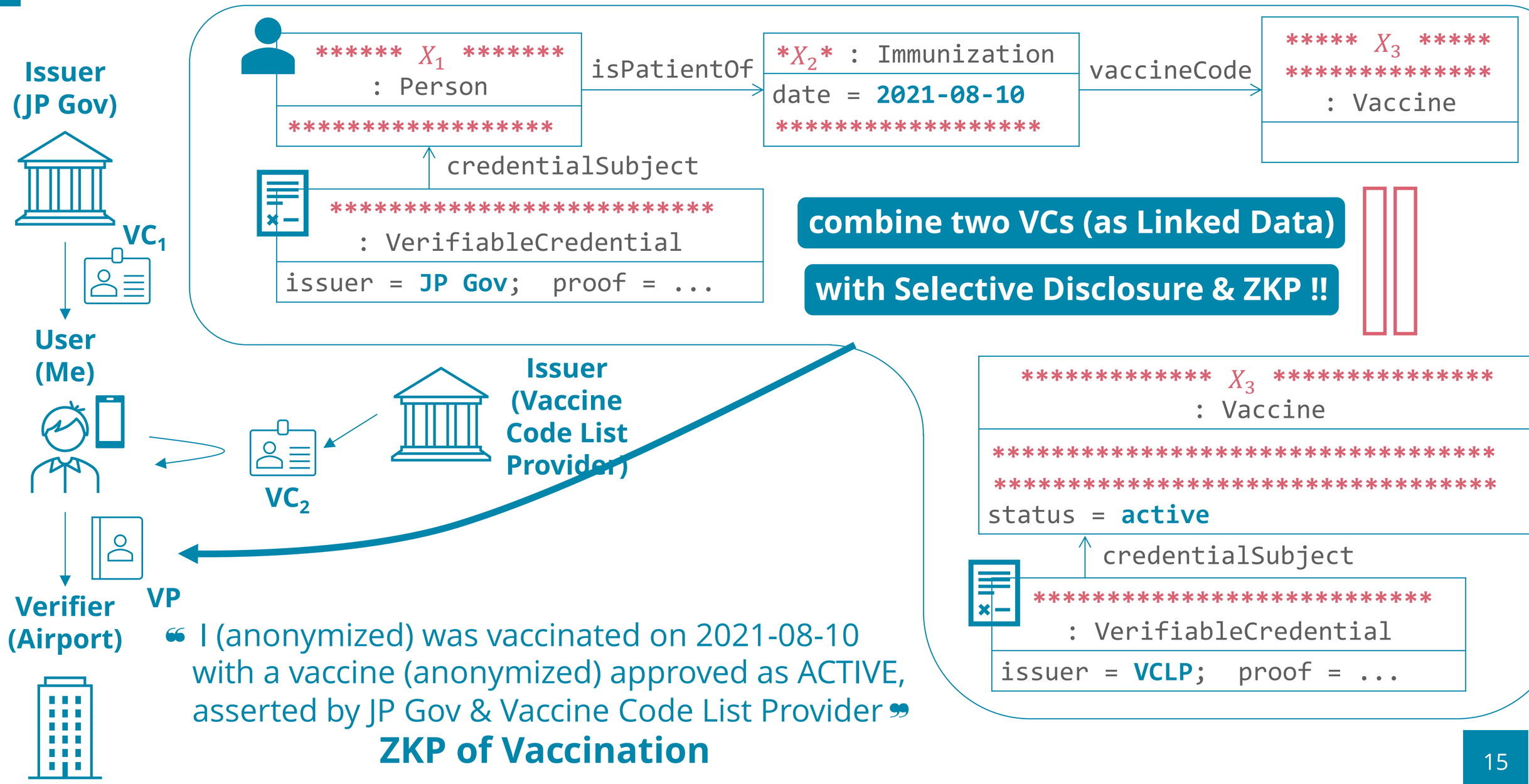
Our Contribution



Possible Future Use Cases



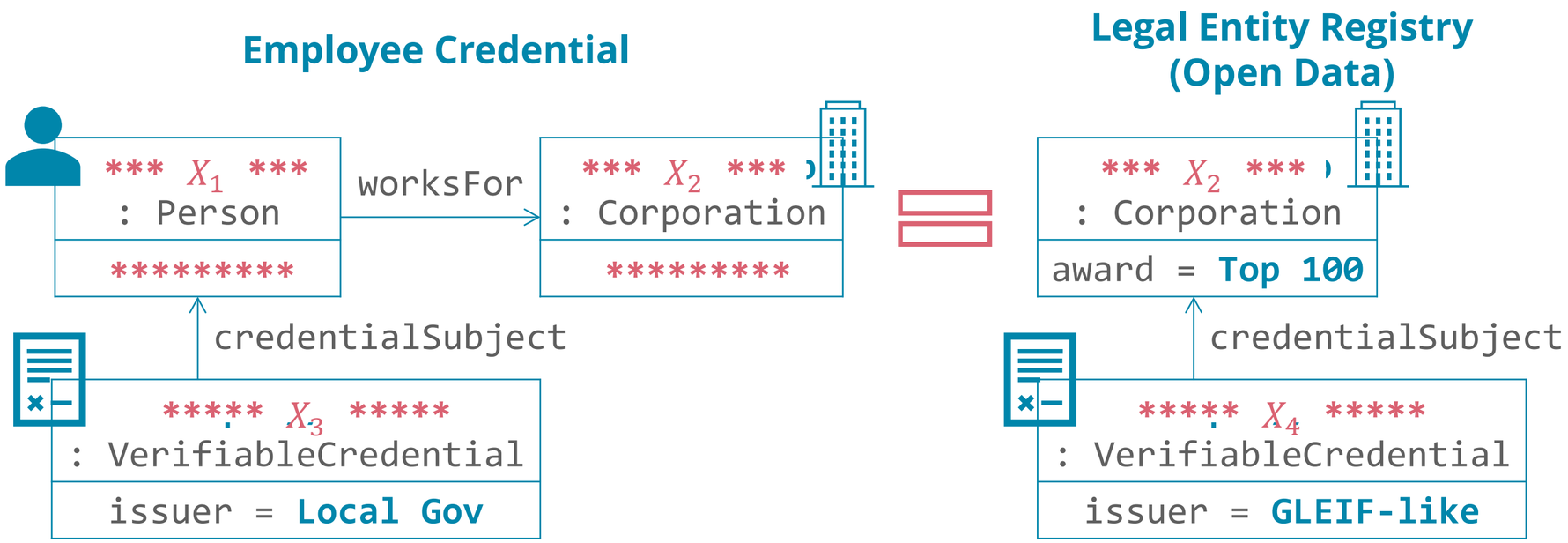
Possible Future Use Cases



❝ I (anonymized) was vaccinated on 2021-08-10 with a vaccine (anonymized) approved as ACTIVE, asserted by JP Gov & Vaccine Code List Provider ❞

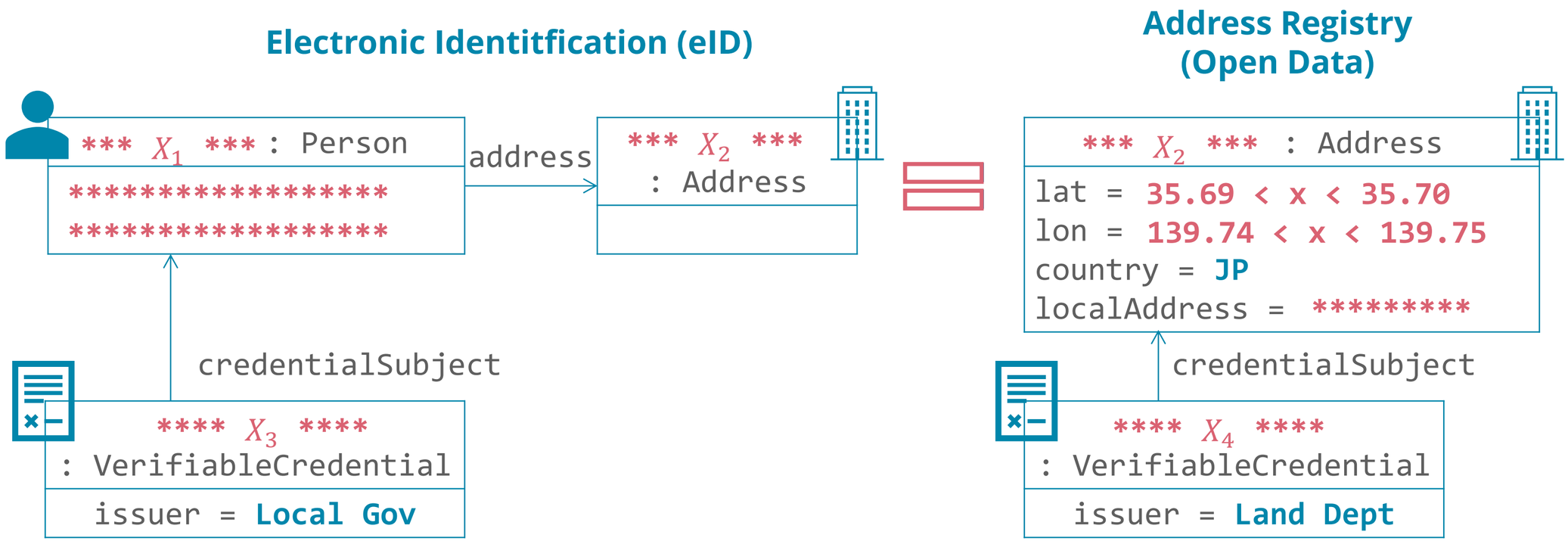
ZKP of Vaccination

Other Use Cases: ZKP of Employer



❝ I (anonymized) work for
a company (anonymized) that received the Top 100 award,
asserted by Local Gov & GLEIF-like organization ❞

Other Use Cases: ZKP of Residence



❝ I (anonymized) live in a place (anonymized)
that is geographically located in (35.69, 139.74) --- (35.70, 139.75),
asserted by Local Gov & Land Department ❞

Related Standardization Efforts

JSON-LD, RDF, ...

Verifiable Credentials Data Model
W3C Recommendation

Data Integrity
W3C Draft Community Group Report (in Progress)

BBS+ Signatures 2020 (LDP-BBS+)
W3C Draft Community Group Report (in Progress)

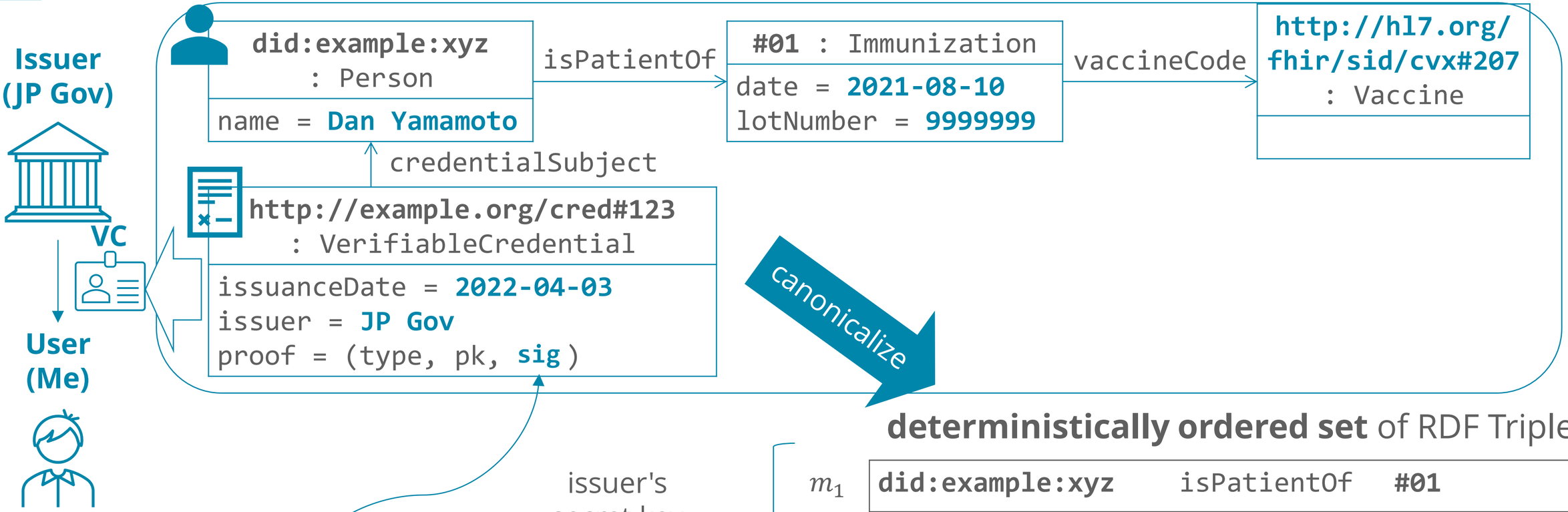
OpenID Connect for SSI
(in Progress)

The BBS Signature Scheme
(in Progress)

Ours: LDP-BBS++?
(not on any standardization process yet)

*this work formalizes security & privacy notions for future standardization

Existing Construction (LDP-BBS+)



deterministically ordered set of RDF Triples

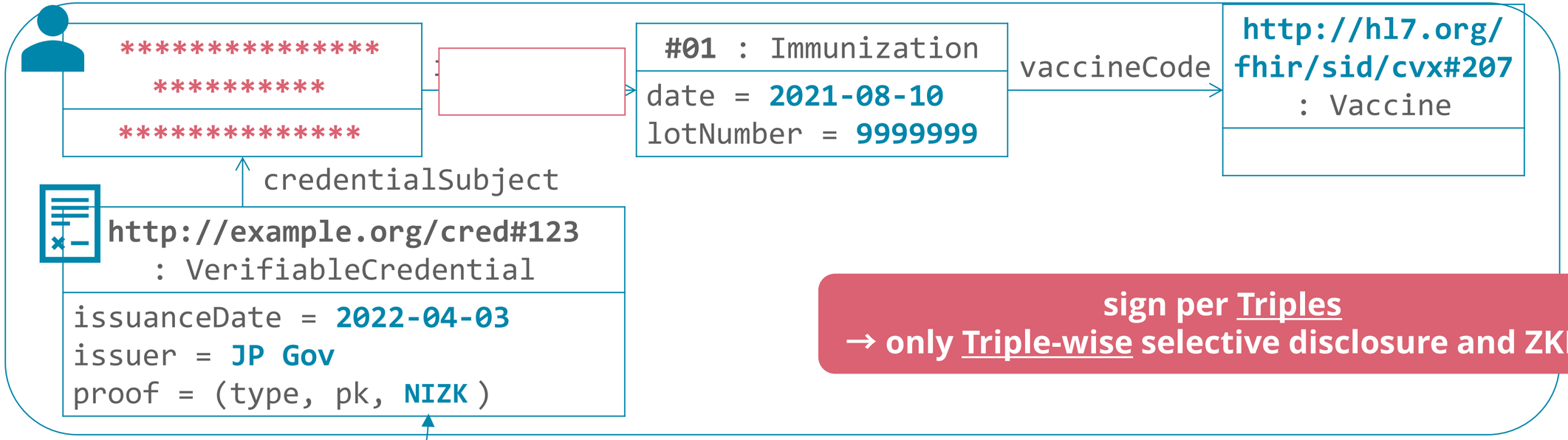
m_1	**did:example:xyz**	isPatientOf	**#01**
m_2	**did:example:xyz**	name	**Dan Yamamoto**
m_3	**did:example:xyz**	type	Person
m_4	**http://hl7...#207**	type	Vaccine
m_5	http://...#123	issuanceDate	2022-04-03
⋮		⋮	

issuer's
secret key

**BBS+.
sign**

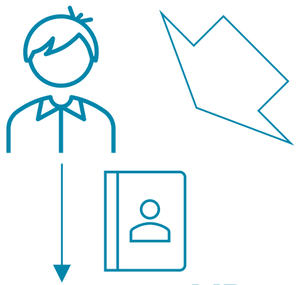
signature

Existing Construction (LDP-BBS+) = **Triple-wise** Encoding



sign per Triples
→ only Triple-wise selective disclosure and ZKPs

User (Me)



Verifier (Airport)

VP

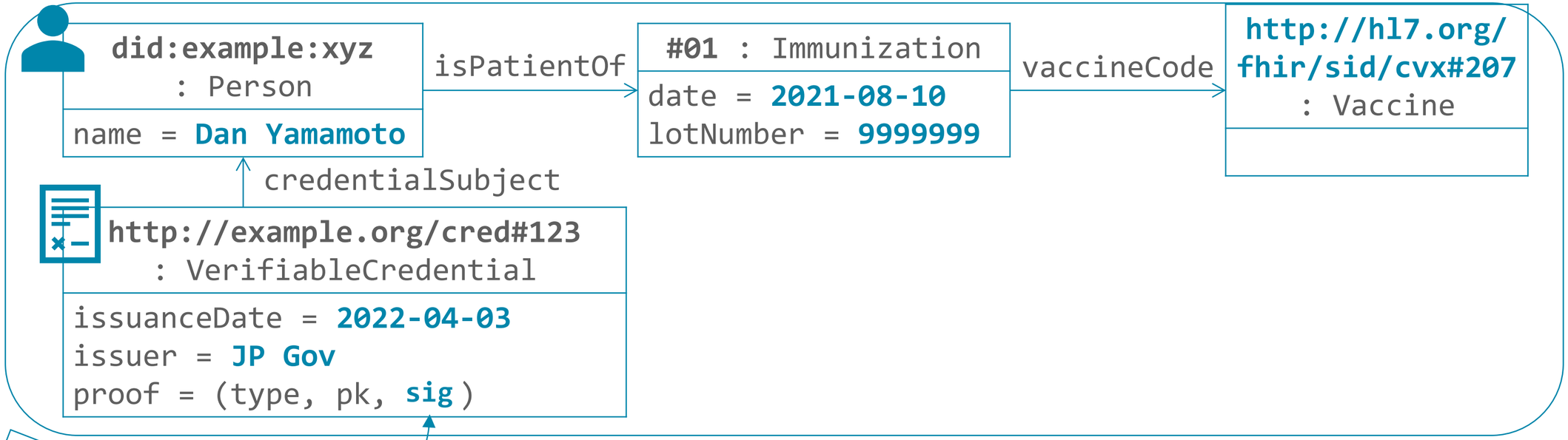
"hide m_2"

NIZK proof

BBS+. show

m_1	**********
m_2	**********
m_3	**********
m_4	http://hl7...#207 type Vaccine
m_5	http://...#123 issuanceDate 2022-04-03
⋮	⋮

Our Construction = **Term-wise** Encoding



VC
(JSON-LD)

issuer's
secret key

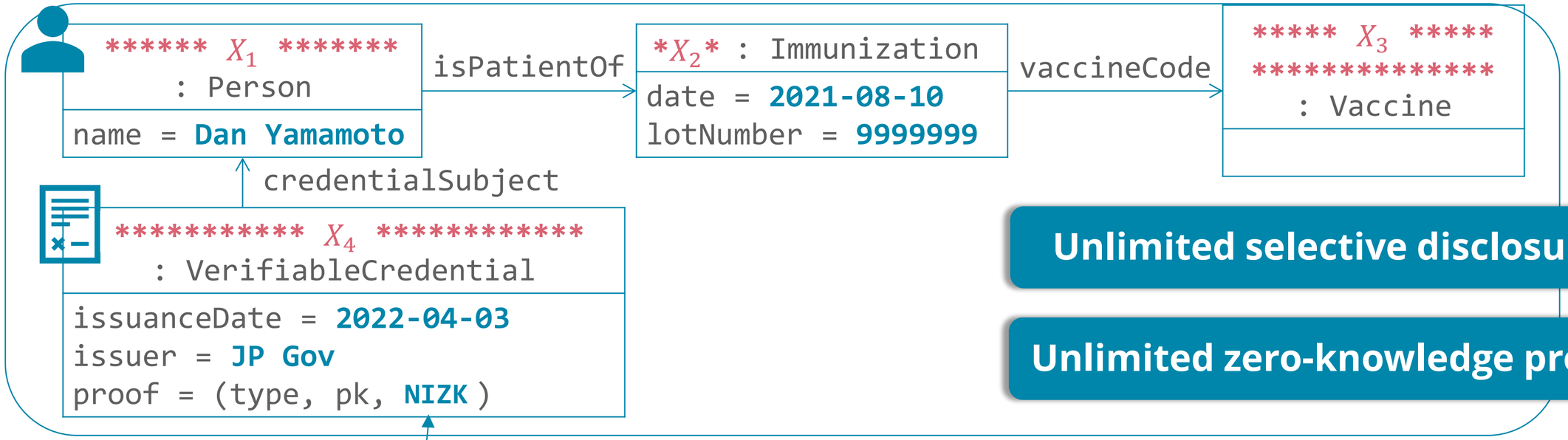
BBS+.
sign

signature

m_1	did:example:xyz	m_2	isPatientOf	m_3	#01
m_4	did:example:xyz	m_5	name	m_6	Dan Yamamoto
m_7	did:example:xyz	m_8	type	m_9	Person
m_{10}	http://hl7...#207	m_{11}	type	m_{12}	Vaccine
m_{13}	http://...#123	m_{14}	issuanceDate	m_{15}	2022-04-03
⋮	⋮	⋮	⋮	⋮	⋮

sign per Terms
→ Term-wise selective disclosure and ZKPs

Our Construction = **Term-wise** Encoding



Unlimited selective disclosure

Unlimited zero-knowledge proof

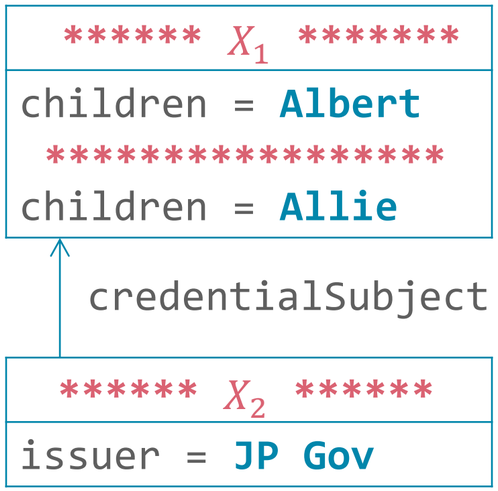
NIZK proof ← **BBS+. show**

m_1	****** X_1 *******	m_2	isPatientOf	m_3	#01
m_4	****** X_1 *******	m_5	name	m_6	Dan Yamamoto
m_7	****** X_1 *******	m_8	type	m_9	Person
m_{10}	****** X_3 *******	m_{11}	type	m_{12}	Vaccine
m_{13}	****** X_4 *******	m_{14}	issuanceDate	m_{15}	≥2022-01-01
⋮	⋮	⋮	⋮	⋮	⋮

Security and Privacy

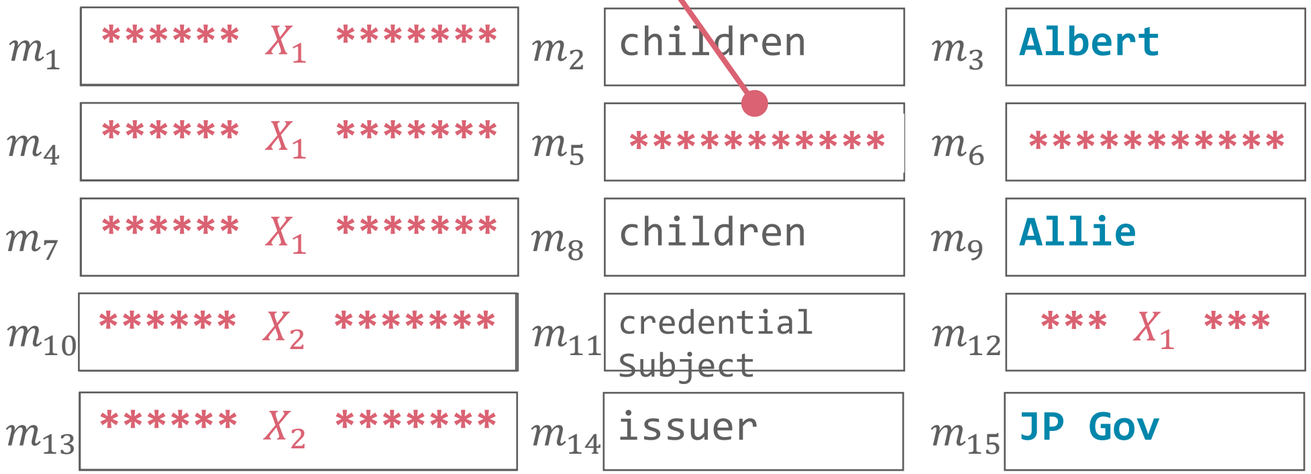
- We defined game-based notions of **unforgeability** and **anonymity** based on Sanders' definition (@ PKC '20)
- and proved:
  - Our construction is **unforgeable**
    if the underlying anonymous credential (e.g., BBS+) is unforgeable
  - Our construction is **weakly anonymous**
    if the underlying anonymous credential (e.g., BBS+) is anonymous

Anonymity vs. Weak Anonymity



canonicalize

Adversary knows:
m_5 must be lexicographically larger than m_2
(if lexicographically sort is used for canonicalization)



VP

NIZK proof

BBS+. show

Anonymous presentation only leaks:
- attributes selectively disclosed by user
- issuer's public key

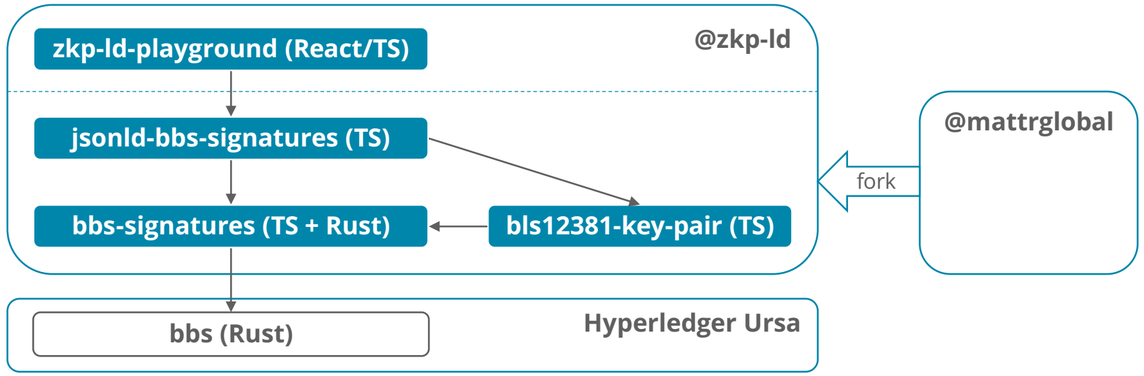
Weakly anonymous presentation additionally leaks:
- total number of attributes: $|\{m_i\}| = 15$
- index i of canonicalized attributes $\{m_i\}$

workarounds:
add dummy attributes
& random permutations

Implementations and Demo

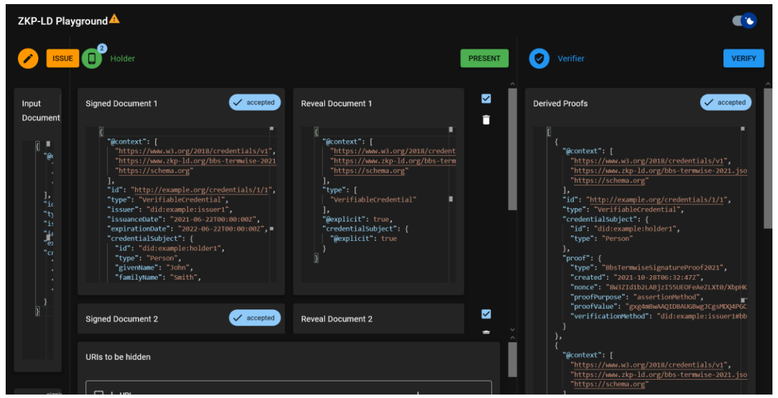
Implementations (published on Github and npm)

- @zkp-ld/jsonld-signatures-bbs
- @zkp-ld/bls12381-key-pair
- @zkp-ld/bbs-signatures



ZKP-LD Playground <https://playground.zkp-ld.org>

- a playground for developers
- you can sign & verify LD-based credential and show & verify presentations on browser

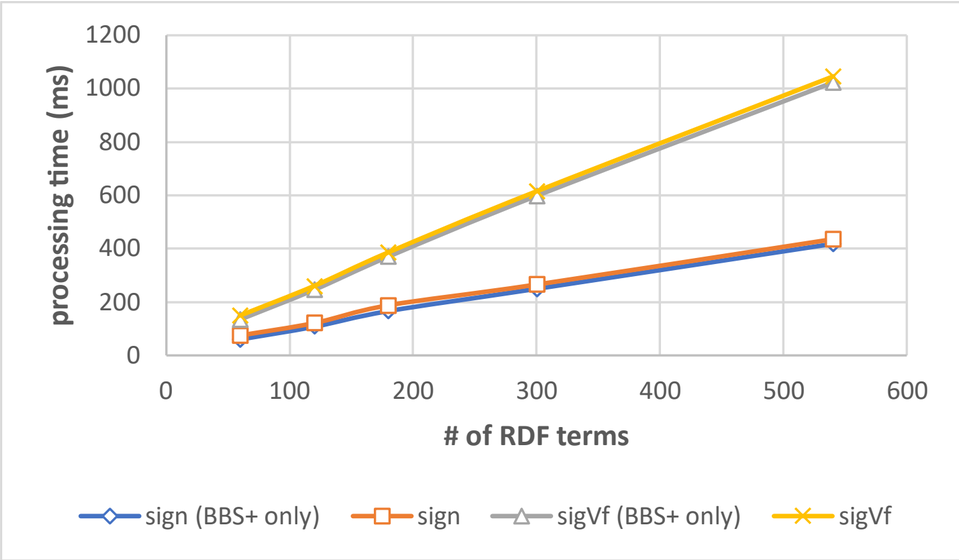


Performance Evaluation

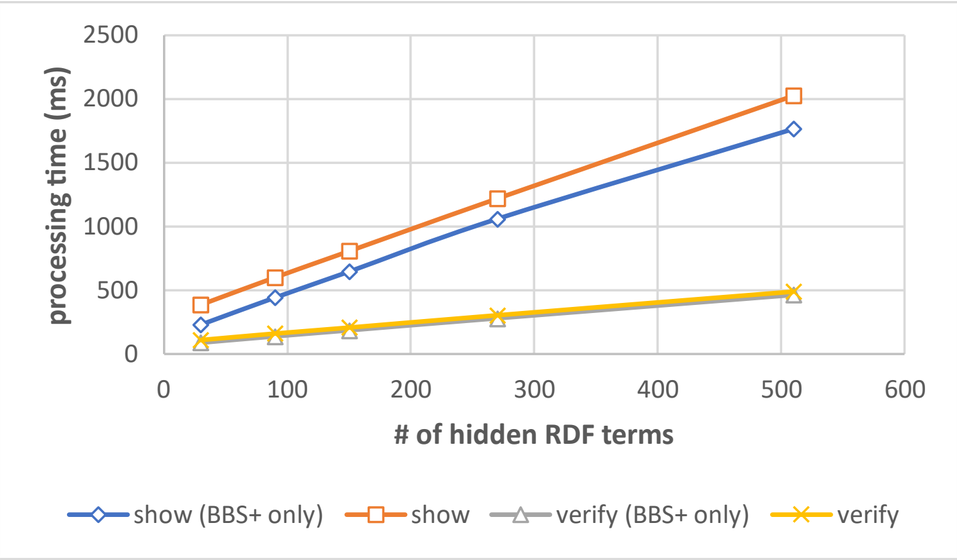
size (bits)	
secret key	256
public key	768
signature	896
proof	$2944 + 256\,n$

(n : # of hidden terms)

VC: sign / sigVf



VP: show / verify



- i7-10750H (6 cores 12 threads) CPU, 32GB RAM, Google Chrome
- takes at most 1 sec to handle < 200 RDF terms
- (the issuance of bound credentials has not yet been implemented & evaluated)

Conclusions

1. Constructed a LD-based VC scheme with fully selective disclosure
2. Proposed novel use cases using LD-based VCs with ZKP
3. Formalized LD-based VC and its security and privacy notion
4. Proved the security and privacy of our construction
5. Provided OSS implementations and Web-based demo

Future Work

- Fully anonymous construction
- Revocation, Delegation, Pseudonyms, Issuer-Hiding
- Constant proof sizes and verification times