ZKLang – Implementation and Standardization

Jan Camenisch[1], Manu Drijvers[1], Maria Dubovitskaya [1],

Nathan George[2], Lovesh Harchandani[2], Jason Law[2]

[1] IBM Research – Zurich

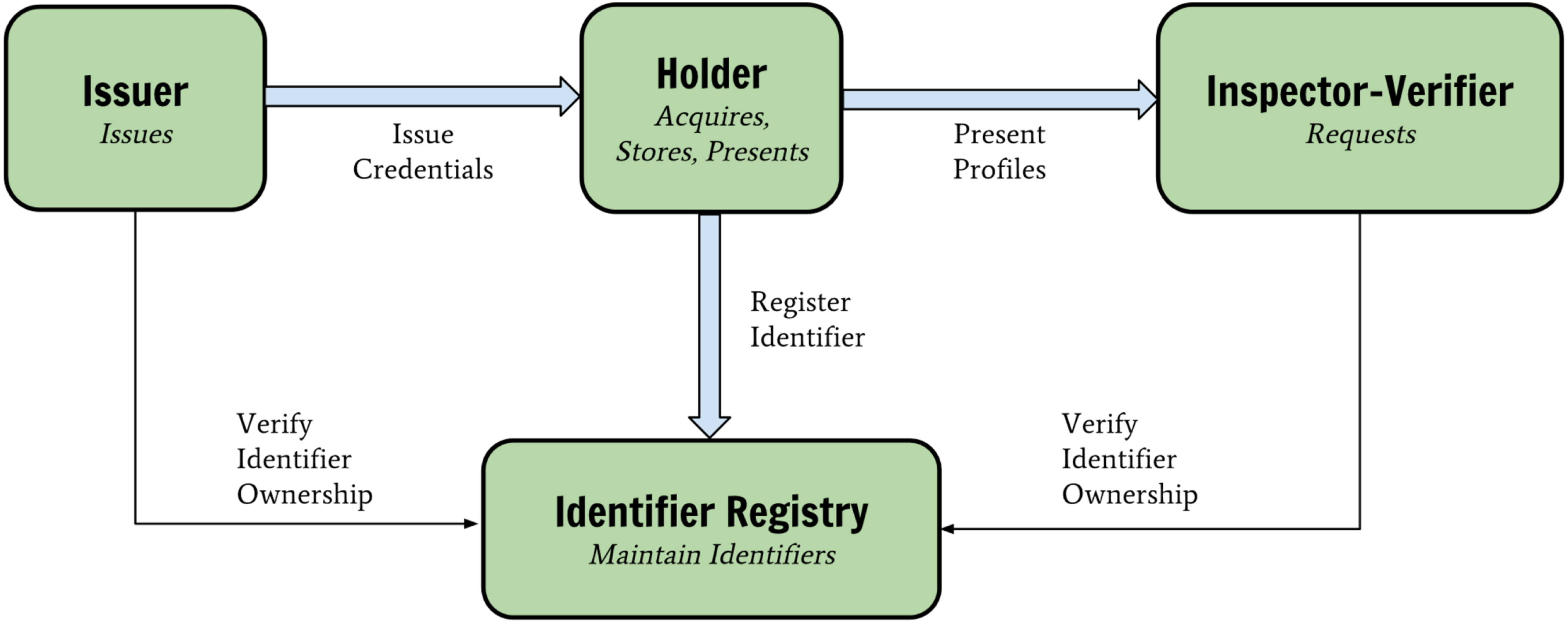
[2] Evernym

W3C Verifiable Claims (VC)

- An effort for standardizing protocols and languages for authentication and identity management
- Supports different levels of privacy preservation

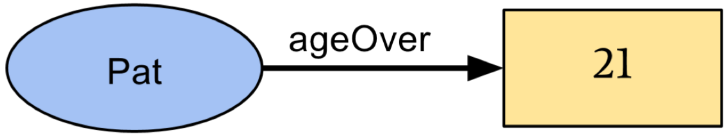
- A holder collects credentials from different issuers
- A verifiable credential reveals multiple claims about the holder to service providers
- A claim can reveal different attributes (e.g., email address) or just facts (e.g., Older18) about the holder
- Revocation and Inspection are supported

W3C Verifiable Credentials: Entities

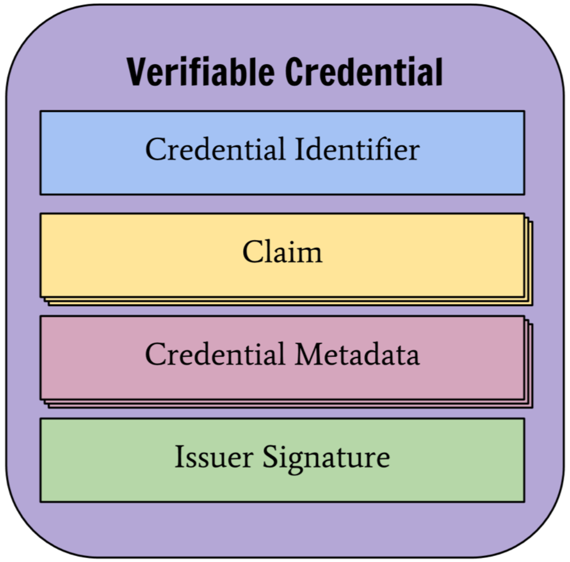


W3C Verifiable Credentials: Data Model

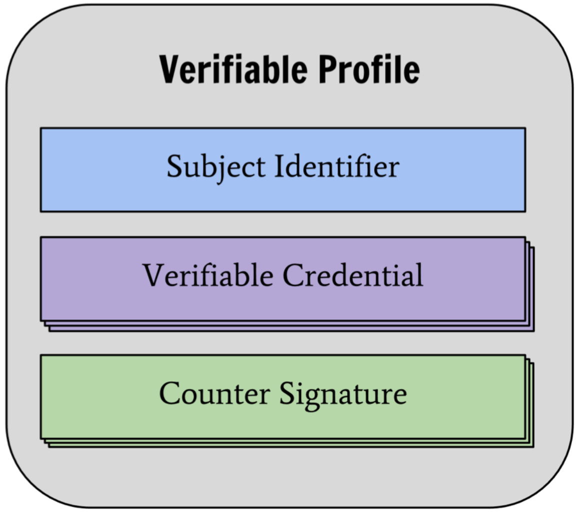
- Claim



- Verifiable Credential



- Verifiable Profile



Cryptographic Protocols to Realize VC

- We can use advanced crypto to get privacy-friendly VC

- Issuer signs subject’s attributes using special type of signature (CL signature)
- Non-Interactive Zero-Knowledge Proofs (NIZK) to generate verifiable credentials/profiles
- Verifiable Encryption to conditionally reveal attributes only to certain entities (revocation/auditability)

Example: Proving Knowledge of BBS+ Signature

PoK of Signature (A, e, s) on message m w.r.t. issuer public key $y = {g'}^x$

- $A' \leftarrow A^r$
- $\bar{A} \leftarrow {A'}^{-e} \cdot (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \qquad (= {A'}^x)$
- $d \leftarrow (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \cdot {h_0}^{r'}$

$$SPK\left\{(m, e, s', r, r', r''): \frac{\bar{A}}{d} = {A'}^{-e} \cdot \ {h_0}^{r'} \quad \wedge \quad g_1 = d^{r''} \cdot h_0^{-s'} \cdot h_1^{-m}\right\}$$

Implementing even a simple verifiable claim results in a complicated NIZK statement and requires orchestration of different cryptographic building blocks

Problem: Gap Between high-level W3C VC language and Complex Cryptographic Algorithms

EXAMPLE 2: Usage of signature property

```
{
  "id": "http://example.gov/credentials/3732",
  "type": ["Credential", "ProofOfAgeCredential"],
  "issuer": "https://dmv.example.gov",
  "issued": "2010-01-01",
  "claim": {
    "id": "did:example:ebfeb1f712ebc6f1c276e12ec21",
    "ageOver": 21
  },
  "signature": {
    "type": "LinkedDataSignature2017",
    "created": "2017-06-18T21:19:10Z",
    "creator": "https://example.com/jdoe/keys/1",
    "nonce": "c0ae1c8e-c7e7-469f-b252-86e6a0e7387e",
    "signatureValue": "BavEll0/I1zpYw8XNi1bgVg/sCneO4Jugez8RwDg/+
    MCRVpjOboDoe4SxxKjkCOvKiCHGDvc4krqi6Z1n0UfqzxGfmatCuFibcC1wps
    PRdW+gGsutPTLzvueMWmFhwYmfIFpbBu95t501+rSLHIEuujM/+PXr9Cky6Ed
    +W3JT24="
  }
}
```

?

Signature (A, e, s)

- $A' \leftarrow A^r$
- $\bar{A} \leftarrow A'^{-e} \cdot (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \quad (= A'^x)$
- $d \leftarrow (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \cdot {h_0}^{r'}$

$$SPK\left\{(m, e, s', r, r', r''): \frac{\bar{A}}{d} = A'^{-e} \cdot {h_0}^{r'} \;\wedge\; g_1 = d^{r''} \cdot h_0^{-s'} \cdot h_1^{-m}\right\}$$

Solution: ZKLang

EXAMPLE 2: Usage of signature property

```json
{
  "id": "http://example.gov/credentials/3732",
  "type": ["Credential", "ProofOfAgeCredential"],
  "issuer": "https://dmv.example.gov",
  "issued": "2010-01-01",
  "claim": {
    "id": "did:example:ebfeb1f712ebc6f1c276e12ec21",
    "ageOver": 21
  },
  "signature": {
    "type": "LinkedDataSignature2017",
    "created": "2017-06-18T21:19:10Z",
    "creator": "https://example.com/jdoe/keys/1",
    "nonce": "c0ae1c8e-c7e7-469f-b252-86e6a0e7387e",
    "signatureValue": "BavEll0/I1zpYw8XNi1bgVg/sCneO4Jugez8RwDg/+
    MCRVpjOboDoe4SxxKjkCOvKiCHGDvc4krqi6Z1n0UfqzxGfmatCuFibcC1wps
    PRdW+gGsutPTLzvueMWmFhwYmfIFpbBu95t501+rSLHIEuujM/+PXr9Cky6Ed
    +W3JT24="
  }
}
```

ZKLang

Signature (A, e, s)

- $A' \leftarrow A^r$
- $\bar{A} \leftarrow A'^{-e} \cdot (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \qquad (= A'^x)$
- $d \leftarrow (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \cdot {h_0}^{r'}$

$$SPK\left\{(m, e, s', r, r', r''): \frac{\bar{A}}{d} = A'^{-e} \cdot {h_0}^{r'} \ \wedge \ g_1 = d^{r''} \cdot h_0^{-s'} \cdot h_1^{-m}\right\}$$

Overview and Goal

- ZKLang: language onto which W3C verifiable credentials can be mapped and then be used to orchestrate the underlying cryptographic algorithms
  - Prove claims in a privacy-preserving way (using Zero knowledge proofs)
  - Abstracts cryptographic algorithms
    - (mapping to crypto algorithms needs to be specified)
  - Translates verifiable claims
    - (mapping between verifiable claims and ZKLang needs to be specified)
- Goal: define and implement ZKLang

ZKLang: Notation and Examples

Non Interactive Zero-knowledge proof of Knowledge (NIZK) statements:

- `NIZK{(m`$_1$`,m`$_2$`,m`$_3$`)[m`$_4$`]: Credential(PK`$_{issuer}$`, m`$_1$`,m`$_2$`,m`$_3$`,m`$_4$`)}` – possession of a credential
    - `(m`$_1$`, m`$_2$`, …)` are hidden messages (encoded as integers);
    - `[m`$_4$`]` are messages (attributes) that are revealed
- `NIZK{(m`$_2$`): Smaller/Larger(m`$_2$`, constant)}` – range proof
- `NIZK{(m`$_3$`): Enc(PK`$_{auditor}$`, ciphertext,m`$_3$`)}` – verifiable encryption for auditing

Terms can be combined

- `NIZK{(m`$_1$`,m`$_2$`,m`$_3$`)[m`$_4$`]: Credential(PK`$_{issuer}$`, m`$_1$`,m`$_2$`,m`$_3$`,m`$_4$`) AND`
  `Enc(PK`$_{auditor}$`, ciphertext, m`$_3$`)}`

- prove possession of a credential with four attributes issued by an issuer with Pk_{issuer},
- reveal attribute #4,
- verifiably encrypt attribute #3 under auditor's key $PK_{auditor}$

ZKLang: JSON Example

ZKL-ProofSpec:

```
{
"amountAttributes": 10, // the amount of attributes involved  numbered 0, …, amountAttributes-1

  "disclosed": [{
        "index": 3, // attribute 3 has value 500
        "value": 500
  }, {
        "index": 9, // attribute 9 has value 20
        "value": 20
  }],
  "clauses": [{
        ”type": "Credential",
        "clauseData": {
              "pk": "<ipk1>",
              "attrs": [0, 1, 2, 3]
        }
  }, {
        "type": "Credential",
        "clauseData": {
              "pk": "<ipk2>",
              "attrs": [0, 4, 5, 6, 7, 8, 9]
        }
  }, {
        "type": "Interval",
        "clauseData": {
        "attrs": [2],
        "min": 6,
        "max": 10,
        "pk": "<ipk1>”
        }
  },
{
        "type": "Enc",
        "clauseData": {
              "attrs": [0],
              "cryptoval": "<ciphertext>",
              "pk": "<epk>"
        }
  }, {
        "type": "Nym",
        "clauseData": {
              "attrs": [0],
              "cryptoval": "<nym>"
        }
  }, {
        "type": "ScopeNym",
        "clauseData": {
              "attrs": [0],
              "cryptoval": "<snym>",
              "scope": "<scope>"
        }
  }]
}
```

Mapping to Verifiable Credentials

- Map Issuer name to issuer public key ($\mathtt{PK}_{\mathtt{issuer}}$)
- Map higher level data format (strings, dates, names, etc) to integers
- Translate predicates such as `Over18` into $\mathtt{Larger(today-m_2,18)}$
  - $\mathtt{m}_2$ is an attribute that encodes the year of birth

Mapping to Cryptographic algorithms

- Multiple options possible (RSA, ECC, DL)
  - Different cryptographic assumptions
  - Different implementations
- Different building blocks are realized in different groups
- Need to be carefully defined to allow for interoperability

- Signatures:
  - CL-signatures (RSA/ECC), U-Prove (Brands) signatures
- Range proofs:
  - `Smaller/Larger` can be realized in RSA groups

Backup slides

W3C Verifiable Claims: Examples

EXAMPLE 6: A simple entity profile

```
{
  "@context": "https://w3id.org/identity/v1",
  "id": "did:example:ebfeb1f712ebc6f1c276e12ec21",
  "type": ["Entity", "Person"],
  "name": "Alice Bobman",
  "email": "alice@example.com",
  "birthDate": "1985-12-14",
  "telephone": "12345678910"
}
```

EXAMPLE 7: A simple claim

```
{
  "@context": "https://w3id.org/identity/v1",
  "id": "http://example.gov/credentials/3732",
  "type": ["Credential", "ProofOfAgeCredential"],
  "issuer": "https://dmv.example.gov",
  "issued": "2010-01-01",
  "claim": {
    "id": "did:example:ebfeb1f712ebc6f1c276e12ec21",
    "ageOver": 21
  }
}
```

W3C Verifiable Claims: Examples

EXAMPLE 8: A simple verifiable claim


```
{
  "@context": [
    "https://w3id.org/identity/v1",
    "https://w3id.org/security/v1"
  ],
  "id": "http://example.gov/credentials/3732",
  "type": ["Credential", "ProofOfAgeCredential"],
  "issuer": "https://dmv.example.gov",
  "issued": "2010-01-01",
  "claim": {
    "id": "did:example:ebfeb1f712ebc6f1c276e12ec21",
    "ageOver": 21
  },
  "signature": {
    "type": "LinkedDataSignature2015",
    "created": "2016-06-18T21:10:38Z",
    "creator": "https://example.com/jdoe/keys/1",
    "domain": "json-ld.org",
    "nonce": "6165d7e8",
    "signatureValue": "g4j9UrpHM4/uu32NlTw0HDaSaYF2sykskfuByD
7UbuqEcJIKa+IoLJLrLjqDnMz0adwpBCHWaqqpnd47r0NKZbnJarGYrBFcRTw
PQSeqGwac8E2SqjylTBbSGwKZkprEXTywyV7gILlC8a+naA7lBRi4y29FtcUJ
BTFQq4R5XzI="
  }
}
```