# ZKLang – Implementation and Standardization

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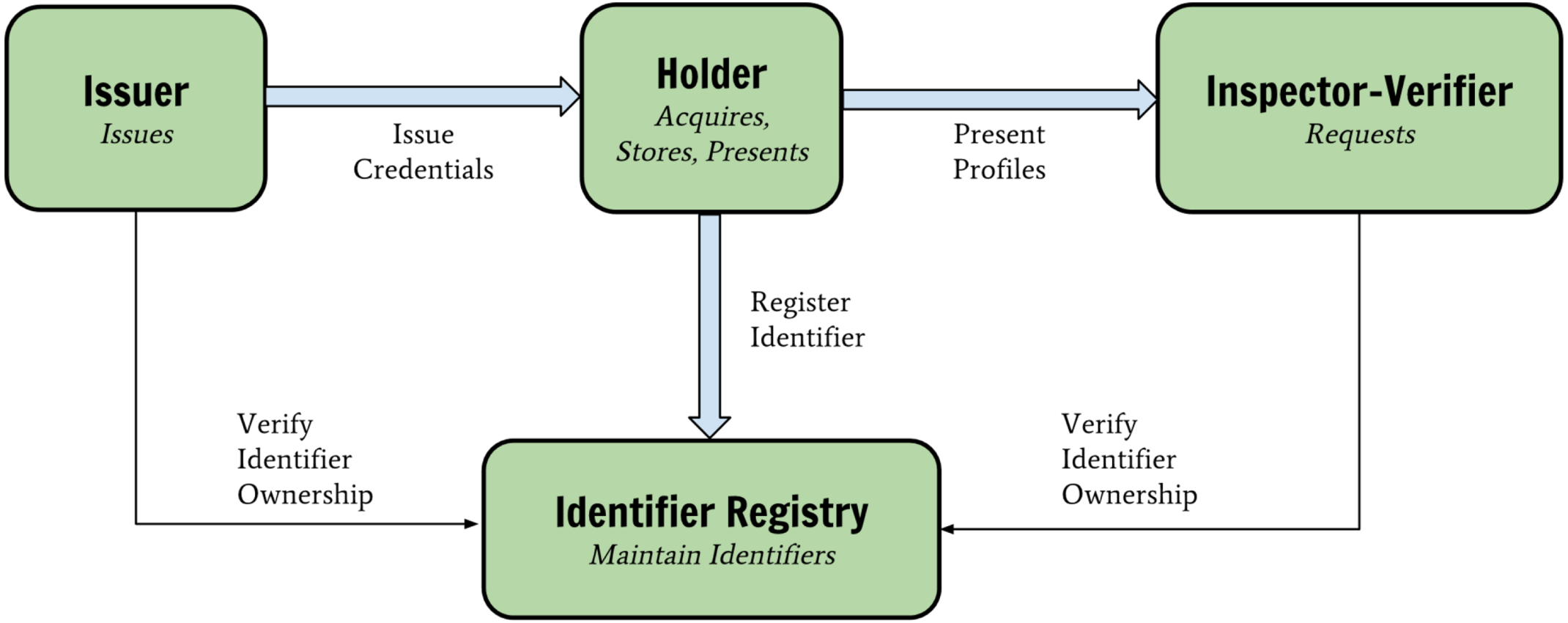
# W3C Verifiable Claims (VC)

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

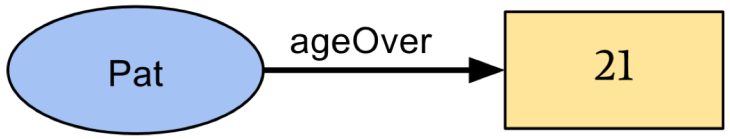
- A holder collects credentials from different issuers
- A verifiable credential reveals multiple claims about the holder to service providers
- A claim can reveal different attributes (e.g., email address) or just facts (e.g., Older18) about the holder
- Revocation and Inspection are supported

# W3C Verifiable Claims: Entities

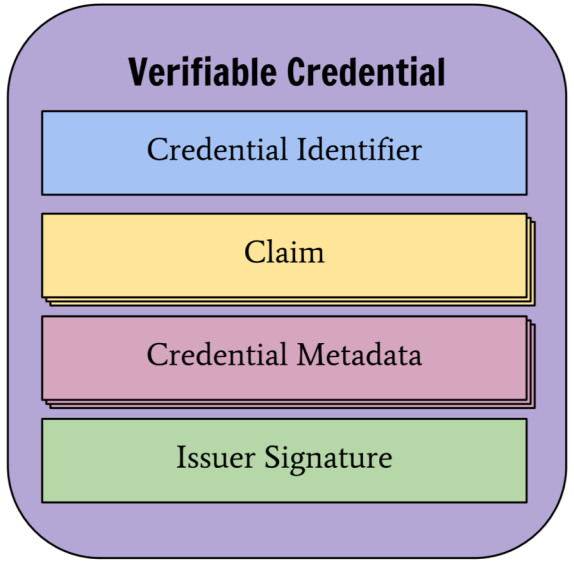


# W3C Verifiable Claims: Data Model

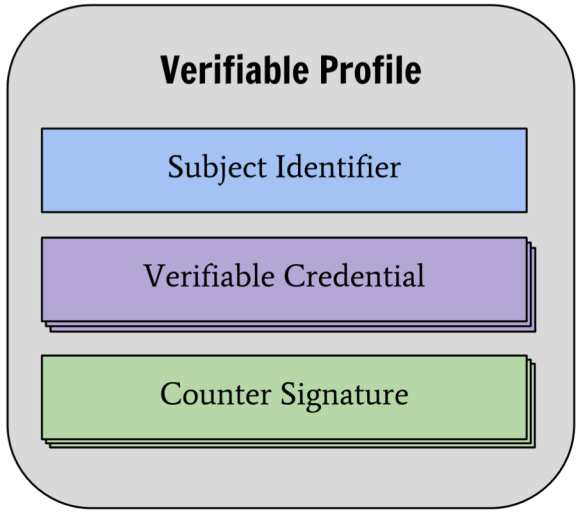
- Claim




- 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 $y = g'^{x}$

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

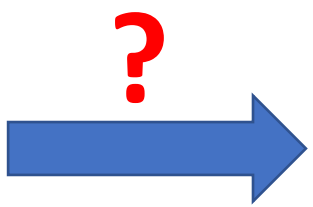
$$SPK\left\{(m, e, s', r, r', r''): \frac{\bar{A}}{d} = A'^{-e} \cdot {h_0}^{r'} \;\wedge\; g_1 = d^{r''} \cdot h_0^{-s'} \cdot h_1^{-m}\right\}$$

*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


```
{
  "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 $(A, e, s)$

- $A' \leftarrow A^r$
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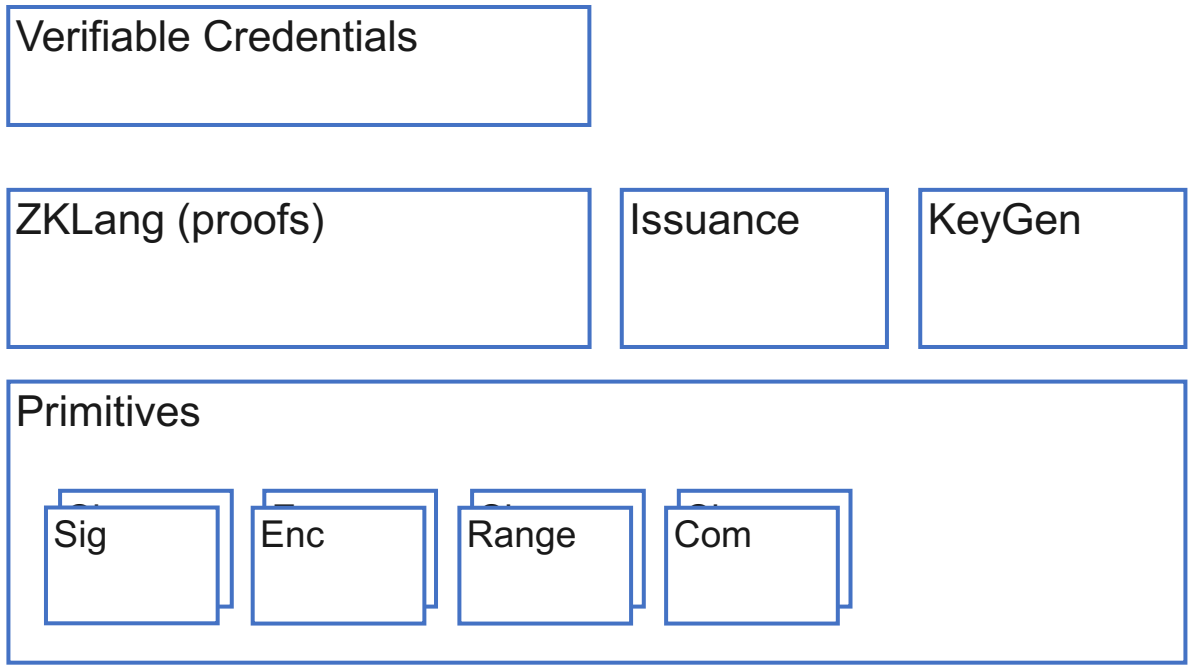
- $d \leftarrow (g_1 \cdot {h_0}^s \cdot {h_1}^m)^r \cdot {h_0}^{r'}$

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

# Overview and Goal

- ZKLang: language mapping W3C verifiable claims to cryptographic algorithms
  - Prove claims in a privacy-preserving way (using ZKP)
  - 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

# Overview and Goal



# ZKLang: Notation and Examples

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

- NIZK{$(m_1,m_2,m_3)[m_4]$: Statement(constants, $m_1,m_2,m_3,m_4$)}
  - $(m_1, m_2, \ldots)$ are hidden messages (encoded as integers);
  - $[m_4]$ are messages (attributes) that are revealed

- NIZK{$(m_1,m_2,m_3)[m_4]$: Credential($PK_{issuer}$, $m_1,m_2,m_3,m_4$)} – possession of a credential
- NIZK{$(m_2)$: Interval($m_2$, constant, constant)} – range proof
- NIZK{$(m_3)$: Enc($PK_{auditor}$, ciphertext,$m_3$)} – verifiable encryption for auditing
- NIZK{(): Nym(PPK)} – pseudonymous user public key
- NIZK{(): ScopeNym(PPK,scope)} – nym, but unique per scope
- NIZK{$(m_1,m_2,m_3)$: Polyrel($m_1$= $m_1$ – $4m_2$ + constant)} – linear relations

# ZKLang: Notation and Examples

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, $m_3$) AND
  Interall (today-$m_2$,0,18*365) AND
  Nym(PPK)}

- 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 $PK_{auditor}$

# Mapping Verifiable Claims to ZKLang

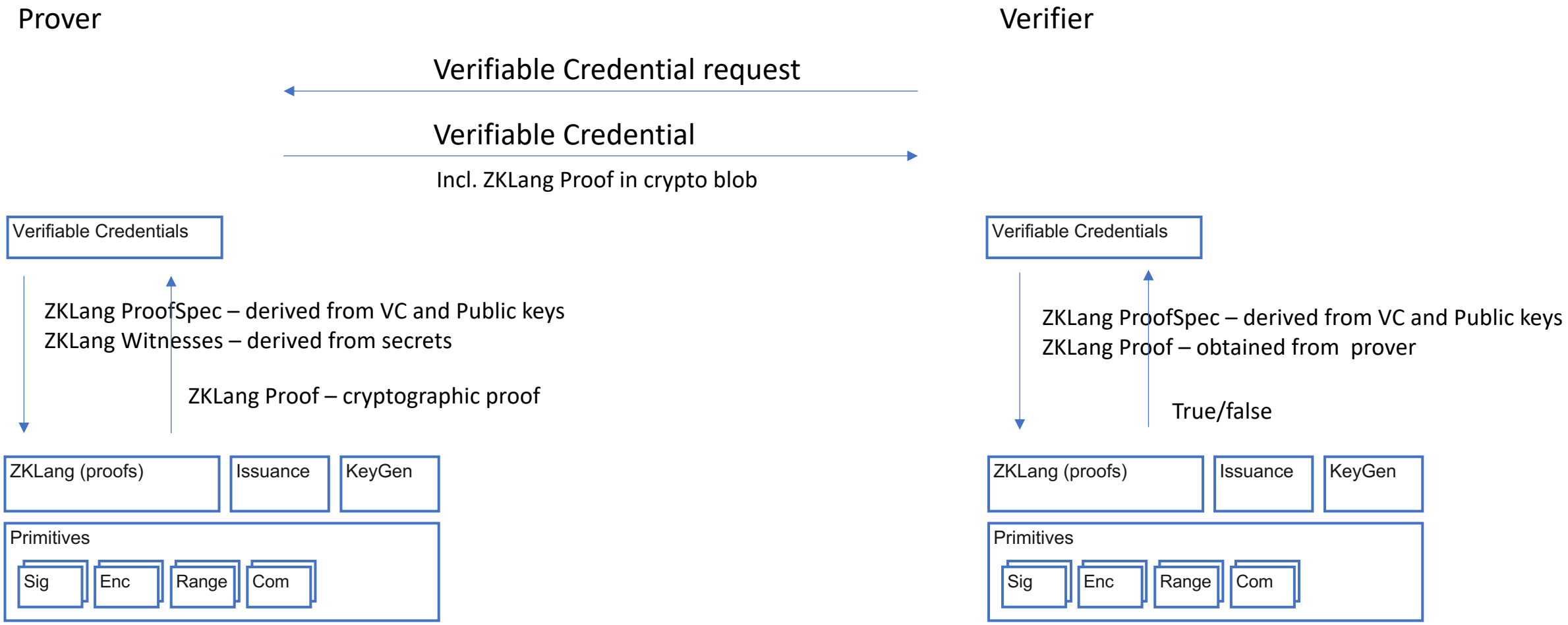
- Map Issuer name to issuer public key ($PK_{issuer}$)
- Map higher level data format (strings, dates, names, etc) to integers
- Translate predicates such as `Over18` into `Larger(today-`$m_2$`,18)`
  - $m_2$ is an attribute that encodes the year of birth

# 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

# ZKLang Objects



# JSON Objects for ZKLang (somewhat misformated)

**ZKL-ProofSpec:**{

```
"attributeCount": 10,
"disclosed": [{ "index": 3, "value": 500}, {"index": 9, "value": 20}],
"clauses": [  {"type": "Credential", "dataclauseData": { "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": "<rpk>}] }
```

**ZKL-Witness**:{

```
"attributeValues": ["av0","av1","av2","av3","av4","av5","av6","av7","av8"],
"clauseSecrets": [ "<cred1>",  "<cred2>", "<enc randomness>", "<nym randomness>", null ] }
```

**ZKL-Proof:**{

```
"chal": "<c>",  "s": [s0, s1, s2, s4, s5, s6, s7, s8],
"clauseOut": ["<out0>", "<out1>",  "<out2>", "<out3>", "<out4>",  "<out5>" ],
"clauseProof": [ "<proof0>",  "<proof1>",  "<proof2>", "<proof3>",  "<proof4>", "<proof5>" ]}
```

# Next Steps

- Finishing ZKLang Spec
- Specify mapping to crypto
- Specify crypto algorithms
- Implement it…