

Galxe Protocol [Draft] v0.1.2

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Abstract

In this paper, we present the Galxe Protocol—an innovative, verifiable credential protocol exemplifying a self-sovereign identity (SSI) service—designed with a vision for future adaptability and grounded in state-of-the-art zero-knowledge proof (ZKP) techniques. This permission-less protocol constitutes chain-agnostic components catering to all roles within the ecosystem, namely credential issuers, holders, and verifiers, featuring unique enhancements, e.g. no-code ZKP. It empowers issuers to generate revocable credentials and manage them on-chain. Holders can selectively disclose requisite information for specific verification instances under a deterministic pseudonymous identity. Verifiers have the ability to specify a programmable trust schema, and by using the built-in identity nullifiers, they can use the protocol for various applications requiring access control, both on-chain and off-chain. The

Galxe protocol further enhances verification efficiency by facilitating minting of soul-bound tokens (SBTs) based on typed credential and supporting no-code compositional verification without involving recursive proofs.

Introduction

The concept of self-sovereign identity (SSI), in which individuals have full control over their personal information used for verification purposes, has gained significant attention over the past decade, fueled by the advancements in blockchain technology and the pursuit of decentralization. In an era marked by ever-increasing digital identity inter-connectivity, the limitations of traditional models of identity management have become a critical concern. Methods that rely on centralized authorities and third-party intermediaries have faced significant challenges in terms of privacy, security, and sovereignty.

Over the past two years, galxe.com has emerged as the leading user growth community within the Web3 ecosystem, relying extensively on credential-based systems for hosting marketing campaigns. During this period, our platform has facilitated the issuing of over one hundred million credentials to more than ten million users. At its peak, Galxe conducted over one million verifications in a single day. Such extensive engagement has endowed us with firsthand experience and profound insights into the challenges associated with the existing solutions of verifiable credential and SSI, specifically regarding scalability, privacy, or the realization of self-sovereignty for users. While the [W3C Verifiable Credentials Data Model](#) has defined the structure of verifiable credentials and pioneers like [Iden3](#) and [Ethereum Attestation Service](#) have launched services in production, widespread adoption is still in its early stages and has not been fully realized.

In response to the challenges we faced on galxe.com, we have designed Galxe Protocol, a SSI service that utilizes verifiable credentials, powered by zero-knowledge proof mechanisms. The architecture of this protocol is meticulously crafted to be **privacy-first, user-friendly, scale-able, and future-proofing**. Galxe protocol allows credential holders to selectively reveal requisite information in form of zero-knowledge proofs, while maintaining their pseudonyms. Proofs can be generated within seconds by Galxe identity vault in browsers or mobile devices, and verifications can happen on-chain at affordable costs. The protocol uses a flexible identity commitment schema to address the issue of digital identity multiplicity, so that nullifiers of proofs are deterministic and can be utilized by verifiers without introducing an extra layer of trust. This design ensures the privacy and non-traceability of the underlying identity, even in scenarios where collusion between issuers and verifiers occurs and verification activities are publicly disclosed, e.g. on-chain verification. In addition to holders, issuers and verifiers can leverage our ease-of-use Software Development Kits (SDKs) to apply ZKP without the necessity of understanding ZKP. Moreover, the typed credential design allows most issuers to create new credentials in a no-code fashion, and the unique zkOAT mechanism further enhances verification efficiency by facilitating minting of a soul-bound token (SBT) for reduced cost verification in the future. Holders are not required to register for a global ID or reveal any commitment on-chain, and lazy registration is supported for issuers. The protocol promotes the use of non-revocable credentials with expiration for scalability, while also supporting and managing revocable credentials on-chain. In recognition of the rapid-evolving nature of ZKP technology, the protocol adopts a modular verification stack design, making it future-proofing. The initial implementation of the protocol is based on a Zero-Knowledge Succinct Non-Interactive Argument of Knowledge (zk-SNARK) system, but it can be seamlessly upgraded.

Overview

One of the most important functions of digital credentials is their verifiability through cryptographic methods. Although the verifier still needs to trust the credential issuer, this functionality obviates the necessity for verifiers to interact with the data sources. Moreover, it empowers the holder of credentials with the complete ownership of the data, thereby endowing them with the discretion to decide where, when, who and what to share.

The Galxe protocol defines the 'how'. The protocol provides a set of ease-of-use SDKs, smart contracts and identity vault applications, hoping to bring the state-of-art SSI service to millions of users. Before jumping into the technical details of the protocol, we will give an overview of preliminary concepts and explain the capabilities and responsibilities of each role of the ecosystem. At the end, we will give an example of leveraging the protocol to run an on-chain NFT drop for angel users, where the security of application and user privacies are both protected.

Concepts

In this section, we provide a comprehensive overview of preliminary concepts, with a particular emphasis on notations used by this paper. We assume that readers are familiar with cryptographic concepts, including hash functions, asymmetric cryptography, digital signatures, sparse merkle trees, and basic understanding of zero-knowledge proofs.

Digital identity multiplicity problem

The term *digital identity multiplicity* emphasizes the multidimensional nature of modern digital identities, that a person can have multiple different identities across different platforms. For example, it is not uncommon that a user uses different nicknames, handles, and cryptographic IDs (namely addresses) for different platforms. A user might be called `MightyKitty` on twitter, while being `BraveBarbie` on discord, or uses address `0x7f7f7...abc` on EVM-compatible blockchains.

The phenomenon introduces a subtle challenge for designing a credential protocol: under what identity, should the issuer credential to? The design must allow a user to connect all his owned identities in order to reveal or generate zero-knowledge proofs against a comprehensive profile, while not leaking any privacy, e.g., the connections of accounts, to any other party.

One straightforward solution is to issue credentials under the ID of the domain that the issuer controls. That is, a credential showing that the user `MightyKitty` has more than 1000 Twitter followers, should be issued to the `MightyKitty`. However, this implementation can hinder the interoperability of credentials. When using credentials outside of the issuer's domain, the user has to prove that he is the ID shown on the credential. This process can be done through a 3rd party, which introduces another layer of trust, or the user has to reveal his ID to the verifier, sacrificing privacy. Another choice is using a global identifier schema, where each user is assigned to a globally unique identifier and issuers shall create credentials to that identifier. However, when issuers collude, a unique identifier can be used to track down footprints of the user behind, by linking together different identities from different issuers.

Galxe protocol proposes an innovative schema that, by embedding identity commitments into credentials, allows a user to harness his credentials from different platforms, while preserving his privacy.

Nullifier

In the context of zero-knowledge proof cryptography, a nullifier is a value that prevents double-spending, without revealing which resource is being spent. Essentially, it is a value that 'nullifies' (voids) the underlying resource in a privacy-preserving way. It plays a critical role in the applicability of zero-knowledge proof methods to practical applications. The lack of the ability to generate nullifiers with proofs compromises the verifier's ability to ascertain if a proof has been previously utilized. To draw an analogy, one may envision a scenario where a huge group of people is permitted entry into a concert event, but using a single ticket meant for only one person.

Identity commitment

An identity commitment is a public value, hiding two secret values: a secret identity and an internal nullifier. Both secret values are known only by the credential holder, while identity commitment can be public. In Galxe protocol, conceptually, identity secrets will be used by holders to prove the ownership of credentials, and internal nullifiers will be used, together with external nullifiers, to generate deterministic nullifiers per each verification.

Similar to [Semaphore protocol](#), Galxe protocol constructs identity commitment in the same simple way. It is a Poseidon hash of two secrets. Note that the order of two secrets is fixed when used as the inputs to the hash function. The first one is the identity and the second one is the internal nullifier, so that nullifiers and secrets can be distinguished in a zero-knowledge proof.

Compared with digital signatures, the power of identity commitment is actually smaller. You cannot use it for authentication without using a zero-knowledge proof, and secret values will have to be the inputs to the prover, unlike signatures where only public keys and signatures are required. However, this disadvantage can help to limit impersonation and fake profiles. For a credential, identity secrets cannot be shared without permanently sharing the ownership, while signatures can be shared with limited costs: one can temporarily transfer or lease the ownership of a credential to someone else, until the signature expires.

Verification stack

A verification stack is a set of instantiations of cryptographic algorithms that will be applied during credential issuance, proof generation and verification. Because the domain of zero-knowledge proof technology is witnessing a meteoric rise, with innovative techniques being invented rapidly, alongside the consistent refinement of implementations, the protocol is designed with a vision for future adaptability. The design de-couples the signature and verification schema from the core protocol, allowing versatile use cases and smooth upgrades.

The initial version of Galxe protocol will come with one simple yet powerful verification stack called 'BabyZK'. It is a production-ready full-feature zero-knowledge tech stack that supports ultimate privacy protection, that can be used even publicly on blockchains, like Ethereum.

Credential schema

In Galxe protocol, credential schemas are defined by the two fields on credentials: **type** and **context**. Like types in programming languages, credential types are structs, specifying the list of typed claims. A type will be associated with a set of zero-knowledge circuits and verification parameters published on-chain. On the other hand, a credential context is used to construct a concrete instantiation from a credential type. Together, they form a credential schema, consisting of typed claims under a specific context. For example, assuming there is (there actually will be) a simple credential type with one unsigned integer field and we call this type 'scalar', different schemas can leverage this same type by linking different contexts, e.g., the number of loyalty points, the highest rank achieved in a game, or date of birthday expressed in UNIX timestamp. These credential schemas can all use the zero-knowledge circuits that have been created for the scalar type. This advantage allows issuers, holders, and verifiers to apply zero-knowledge proofs without writing any code.

zkOAT: a soul-bound NFT badge for zero-knowledge verification

For on-chain verifications, users can mint a soul-bound NFT that caches the revealed facts. For each pair of `(type, context)` and an issuer, there will be an NFT collection. Every NFT has a unique token id, which is the nullifier generated by the owner, and its properties represent some facts of the owner. The facts are automatically aggregated based on all past information revealed, during on-chain verification. Because fields are typed, aggregations are also type-aware. Taking an unsigned integer field as an example, its lower bound and upper bound that have been checked will be stored. For example, if there were two proofs that one says `height > 100 && height < 150`, and the other says `height < 123`, the NFT properties of height will be `lower_bound: 101` and `upper_bound: 122`. Note that the NFT will not leak any extra information about the owner, because when the verification happened, those facts have already been revealed publicly, at the owner's will. For revocable credentials, the root hash of sparse merkle tree of revoked credentials that has been used during proof will be cached.

This NFT offers the potential for future verification at a reduced computational cost. On Ethereum, a ZK-SNARK verification of Groth16 on BabyJubjub curve generally costs around 300k gas. In contrast, querying an NFT property necessitates only a few thousand units. Because activities under the same pseudonym of the zkOAT will be public, protocol leaves the freedom to choose between the highest level of privacy and gas efficiency to verifiers and holders.

Roles

The protocol incorporates four main roles, each contributing uniquely to the protocol's functioning. This section will give a brief introduction to their capabilities and responsibilities.

Holder

The Holder role is the centerpiece of the whole ecosystem: the individual possessing verifiable credentials. Holders do not need to register anything on-chain and the ownership of a credential is controlled by identity commitments constructed from secrets that are only known by their holders. In the Galxe protocol, holders maintain total control over their digital identity by storing credentials in Galxe identity vault, an open-source application that runs on holders' local devices, e.g. browser, and native applications. Holders use the vault to manage different identity commitments for different issuers, and generate zero-knowledge proofs for verification based on owned credentials. By using ZKP, holders have the ability to reveal only requisite data under a deterministic and pseudonymous identity.

Issuer

Issuers create verifiable credentials to holders by using digital signatures to endorse claims about the holder. In our design, issuers do not need to know any extra information of a holder, except for the identity commitment, which can be considered as a random number. Any identity can issue non-revocable credentials to others without on-chain registration. However, for revocable credentials, issuers must be registered on-chain to manage credential validity by publishing the root hash of sparse merkle tree of revoked credentials. Moreover, public keys used for signing need to be registered on-chain to be linked to their issuers.

Issuers can use built-in auxiliary contracts, such as Domain Name System Security Extensions (DNSSEC) verification and GAL staking contracts to enhance their perceived trustworthiness and credibility. Verifiers can leverage these records for setting up a dynamic trust schema. For example, instead of trusting credentials signed by a specific key, verifiers can program a policy that trusts a specific issuer, issuers with DNSSEC verification of a specific domain, or issuers with enough GAL staking.

Issuers must maintain a 1-to-1 mapping from users of the domain to identity commitments. The identity secret part can be changed with a zero-knowledge proof that the internal nullifier remains the same.

Verifier

The verifier is the role that has the least dependence with other roles of the ecosystem. They are usually applications of gated services, allowing access only if the identities meet some specific requirements, like bouncers at bars. To host a verification, verifiers need to pick issuers that they can trust via a programmable trust schema, and verification requirements of credentials to be checked. Verifiers can use the protocol SDK to generate verification requirements that holders can use for generating proofs. To verify a proof, verifiers need to fetch verification key based on the type of the credential from blockchain, and check revocation status if there is any proof of revocable credentials.

Credential type designer

In Galxe Protocol, credential designers propose new types of credentials to the community. These individuals, typically community contributors, actively participate in shaping the ecosystem of evolving needs and requirements, by introducing innovative and diverse credential types. Using SDK, the proposed credential type will have automatically generated zero-knowledge circuits, compiled from the type definition. Depending on the verification stack, type designer may need to hold a decentralized trust set up ceremony and publish the proof key to permanent storages.

Designers must also provide a detailed specification of in-depth description of the credential type, outlining its purpose, intended use cases, and the specific attributes and fields it contains. These specifications clarify the semantic meaning of each field, define any restrictions or requirements associated with the credential, and provide guidelines for issuing and verification. The specifications ensure a shared understanding among ecosystem participants regarding the purpose and usage of the proposed credential type.

Although it is a permission-less process to introduce new types to the ecosystem, the Galxe Protocol employs a governance framework to facilitate decision-making regarding inclusion of new credential types into official core types with long term support. The community, comprising users, developers, and other stakeholders, actively participates in the evaluation and acceptance process. Through transparent discussions and GAL voting mechanisms, the community collectively determines which proposed credential types are incorporated into the official type.

Case Study: On-chain NFT Drop for Angel Users Using Galxe Protocol

The Galxe protocol offers a solution for services that require identity-based access control, just like a bouncer at a club. To demonstrate its application, let's consider an on-chain NFT drop scenario.

Scenario:

A decentralized exchange (DEX) project on EVM chains, named *Alpha*, intends to reward its early supporters (angel users) with a unique on-chain NFT drop. The criteria for qualifying as an angel user are:

1. Following their official Twitter account (X) within the first 30 days post-launch. Given that Alpha launched on 01/01/2021, the cut-off date is 01/31/2021.
2. The user's nationality isn't on the disallowed list.
3. For every \$1000 trading volume, the user qualifies for one NFT drop.

Instead of creating an application that mandates users to link their EVM address, Twitter, and undergo KYC (potentially compromising privacy), Alpha can utilize the Galxe Protocol for a privacy-centric approach:

1. **Issue trading volume credentials:** Alpha becomes a credential issuer, providing scalar-typed credentials under the context "Project Alpha trading volume" to its users. Users must submit an identity commitment to Alpha, either on-chain via a registry contract based on `msg.sender` or off-chain through ECDSA signatures, to receive the credential. Alpha ensures one EVM address corresponds to a single identity commitment, as required by Galxe protocol.
2. **Select 3rd-party credentials issuers:** Alpha collaborates with two reputable credential issuers to verify user's Twitter follows and user nationalities. We assume that Twitter follow credentials have two claims in its body: followed account ID and verification date, from issuer *deSocial*. As for nationality, we assume that the issuer, *DeKYC*, provides passport-type credentials which includes a claim about the holder's nationality.
3. **Deploy NFT drop smart contract:** Alpha deploys a smart contract that rewards NFTs based on trading volume to any address providing valid zero-knowledge proofs with unused nullifiers. The external nullifier is set to `0x18d...`, derived from the hash of "Alpha angel user NFT drop".

The smart contract checks the proofs against:

General requirements:

- The revealed identity specified in proof, backed by the fact that only the credential holder knows secrets of identity commitments, must match the `msg.sender`.
- The external nullifier is `0x18d...`.
- Nullifiers are either unused or associated with other addresses.

Credential-specific requirements:

1. **Twitter Follow:** The zero-knowledge proof must confirm the followed account is Alpha and the verification date is before 01/31/2021.
2. **Passport:** The proof should list countries that don't match the user's nationality, and the list is a super set to the Alpha's disallow list.
3. **Trading Volume:** The proof must show the lower bound of the trading volume, determining the number of NFTs a user can claim. To incentivize trading, unlike the above two credentials, this credential isn't voided but linked to an EVM address for future volume updates.

Credential	Type	Schema	Public inputs	On-chain verifications	Post-verification actions
Twitter follow	Custom, two claims: 1. Followed account ID. 2. Verification date.	Simple non-revocable twitter follow credentials with verification date.	1. Equality of followed account ID v.s. "Alpha". 2. Upper bound of verification date. 3. External nullifier and nullifier <code>A</code> 4. Revealing identity is X.	1. Equality is true. 2. Upper bound is before 01/31/2021. 3. External nullifier is <code>0x18d...</code> 4. X is <code>msg.sender</code> 5. <code>A</code> has not been marked as used.	Mark nullifier <code>A</code> as used for twitter credentials.
Passport	Custom, containing a claim of nationality.	DeKYC's AI-power KYC solution.	1. Equalities of nationality v.s. a list of countries. 2. External nullifier and nullifier <code>B</code> 3. Revealing identity is X.	1. Equalities are all false, and the list of countries is a super set to of the disallow list. 2. External nullifier is <code>0x18d...</code> 3. X is <code>msg.sender</code> 4. <code>B</code> has not been marked as used.	Mark nullifier <code>B</code> as used for passport credentials.
Trading volume	Scalar (a basic credential type shipped)	Project Alpha trading volume	1. Lower bound of trading volume. 2. External nullifier and nullifier <code>C</code> 3. Revealing identity is X.	1. External nullifier is <code>0x18d...</code> 2. X is <code>msg.sender</code> 3. <code>C</code> has not been binded yet, or binded with <code>msg.sender</code>	Bind <code>C</code> with <code>msg.sender</code> , as used for trading volume credentials, and set the number of available NFTs to mint to be <code>lower_bound_volume / 1000</code>

Once preparations for Project Alpha are complete, we can focus on the user experience. The user workflow is streamlined: collecting credentials and generating proofs for verification. All these steps can be effortlessly executed using the **Galxe Identity Vault**, a local application compatible with both browsers and mobile devices.

1. **Credential Collection:** Users are required to gather three distinct credentials from separate issuers. If a user has not previously requested credentials from these issuers, they would need to set up three unique identity commitments. The Galxe Identity Vault automates this process, ensuring that all confidential information remains safeguarded by the user's password.
 - a. **Twitter follow:** Visit *DeSocial's* website or app, connect with Galxe Identity Vault, and potentially do an OAuth login with your twitter account to verify the follow status. Then *DeSocial* will request a identity commitment from the connected Galxe identity vault, and delivery the credential directly to the vault.
 - b. **Passport:** By accessing *DeKYC's* platform, users may pay a service fee for KYC verification and credential issuance, then DeKYC will follow a process analogous to the one mentioned above.
 - c. **Trading Volume:** Within Project Alpha's application, users can directly request a trading volume credential, again following a similar procedure.
2. **Proof Generation:** With the three credentials secured, users can effortlessly produce zero-knowledge proofs using the Galxe identity vault. The intricate technical details of generating these proofs remain hidden from users. Instead, Project Alpha

forwards statements to be proved directly to the vault. The vault then displays the information set to be disclosed, such as "your nationality differs from countries A, B, C..." or "Your trading volume exceeds XXX", seeking user confirmation. Upon approval, the proofs are generated and sent to the smart contract for NFT minting.

It's worth noting that while this process is hosted on-chain, it can also be executed off-chain in a centralized manner.

Security Analysis:

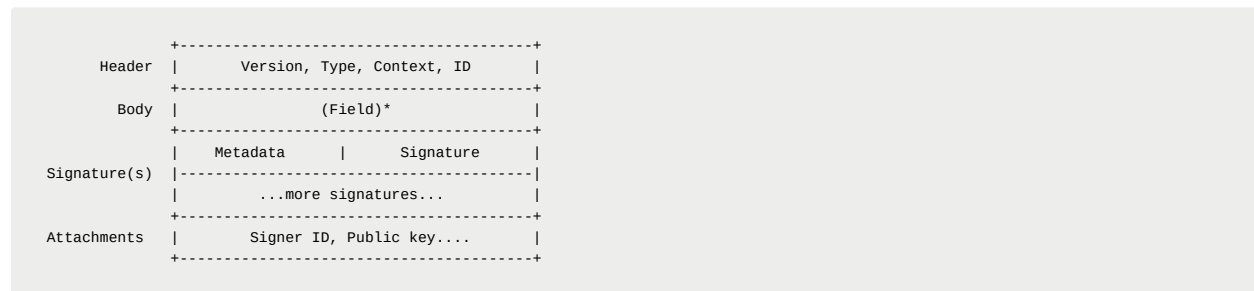
1. **Identity Linkage Protection:** The protocol ensures that users' identities across various platforms remain concealed. These identities are interconnected using different identity commitments and the revealed identity. Importantly, even if multiple issuers were to collude, they will not be able to correlate a user's identity across different platforms, as long as users follow the best practice of using different identity commitments for each issuer.
2. **Pseudonymous Claims:** Users have the flexibility to claim NFTs under a pseudonym. This ensures that their trading address on the DEX remains separate from their NFT ownership, bolstering privacy. As a practical implication, a user can sell their NFTs on a KYC-mandated marketplace without the fear of their KYC data being associated with their trading activities on the DEX.
3. **Double-spending Prevention:** Nullifiers ensure credentials cannot be used more than once. This ensures that each angel user can only claim their rightful amount of NFTs.
4. **Minimal Data Exposure:** The protocol is designed to disclose only the bare minimum data, thereby reducing the risk of privacy breaches, such as birthday attacks. For instance:
 - For the Twitter follow date, users disclose the an upper bound of verification date, instead of a precise date. All angel users can standardize it to 01/31/2021.
 - Regarding nationality, the protocol doesn't directly reveal the country. Instead, it provides a list of countries that don't match the user's nationality, which is theoretically the least revealing method.
 - For trading volume, a lower bound is used in place of the precise volume, which can be easily used to identity an user. The lower bound can be adjusted to any legit $N * 1000$, based on the number of NFTs a user could and intend to mint.

Protocol specification

The protocol specification covers the format of credentials, components and standard workflows throughout the lifecycle of credentials. Designed to be minimalism and future-proofing, Galxe protocol isolates rapid-changing zero-knowledge proof technology from the core elements of a credential, using the modular verification stack design. For implementations that are specified by the chosen verification stack, we use BabyZK stack as an example for illustration.

Credential format

A credential is made from header, body, an array of signatures and attachments. This design allows a credential to be endorsed by multiple signatures from different issuers, or using different verification stacks. Credentials are primarily stored and presented to holders in JSON format, for readability, while other formats like YAML, XML can also be supported. Note the formats of storing and showing the credential are not related to how the digest (i.e., the hash value) is computed, and will not affect zero-knowledge proof generation. The digest algorithm is determined by the verification stack and it can evolve without upgrading the main protocol.



Header

Header contains the common fields that all every credential must have.

- **Version** (uint8) : The version of protocol. Currently, the only supported version is 1.
- **Type** (uint160) : The type ID this credential, specifying the order and type of the claims in the body.
- **Context** (uint160) : The context ID created of the credential. This context ID needs to be registered on-chain before issuing. Context IDs are computed by taking the 160 least significant bits of the keccak256 hash of the context string. Optionally, the issue can attach the original context string in the attachments section for better readability.
- **ID** (uint248) : An identifier of holder. This value does not needs to be registered on-chain. For example, EVM address, twitter handle, or Discord handle. If the original identity is a string, issuer must convert it to an integer value, by taking the 160 least significant bits of output of a collision-resistant hash function, or ways that can guarantee the 1-to-1 mapping from the original handle to the ID. For 160-bit EVM addresses, they can be directly used as IDs.

For example, to create a credential for [Galxe.com](https://galxe.com) users, about the loyalty points that they earned in the Galxe space, assume that we have registered the context "Galxe.com loyalty points" on-chain and the context ID is `0xff`, when the user's Galxe ID is `123123`, Here is an example header.

```
"header": {
  "version": "1",
  "type": "2",
  "context": "0xff",
  "id": "123123"
}
```

Body

The body part of a credential comprises an ordered list of fields, each representing a typed claim about the holder. The structure of body is defined by the credential type, specified in the header, crafted by credential type designers.

The protocol defines the supported field types and their respective operations, which are summarized in the following table. Under Protocol Version 1, we support five types of claims (fields):

1. **Boolean**: This simple type can only choose to or not to reveal its value within a proof. This is due to its inherent limitation of equality check operation, which, when executed, inevitably discloses the value.
2. **String (Property Type)**: Referred to as the "property type" in this document, this type is primarily designed for representing innumerable properties, such as "name". However, it can also be applied to enumerations.
3. **Scalars**: Representing unsigned integers with bit-lengths spanning from 8 to 256, scalars are equipped to support range checks.
4. **Reference**: This type's primary function is to store the hash of another credential it references.
5. **Fixed-length array**: This type encapsulates arrays of the previously mentioned types. Operations specific to the underlying type can be executed on either an individual element or the entire array, facilitated by the `one_of` and `all_of` operators. Note that the `any_of` operator is redundant, as during the proving phase, the holder is aware of which element is the desired value.

The implementation, including how these fields will be digested and mapped to the underlying signals, will be decided by the verification stack. Verification stack might put on additional constraints on the types. On the protocol level, there is no limitation of the number of fields or the size of the body part, but verification stack may limit the number of fields based on its limitations.

Name	Description	Supported operation	Output	BabyZK implementation
boolean	A boolean value	==, ≠	Revealed value, or Not available	1-to-1 mapped to a signal, where 1 is true, 0 is false.
prop<width, hash_algorithm>	A string representing some property of the holder, designed for innumerable properties. The big-length of property and the hash algorithm that maps the string to an unsigned integer which fits the width must be provided.	==, ≠	(1) True or false, representing if the value equals any of the (2) checked values.	A field contains the hash value of the string.

Name	Description	Supported operation	Output	BabyZK implementation
uint<8>, uint<16>, uint<32>... uint<248>, uint<256>	Scalar values	\leq, \geq	(1) Lower bound and (2) Upper bound of the value, both inclusive.	For uint<8>, uint<16>, ... uint<248>, the value will be 1-to-1 mapped to a signal. For uint256, in BabyZK's implementation, it will be mapped to two signals, lower 128 and higher 128 bits.
ref	A Uint256 value representing the hash of other credential.	$==, \neq$	1. Equality 2. Checked Value	In BabyZK, the width of reference is limited to 248bit.
T[N]	An fixed-length array of other values.	1. oneOf(A, OP, I) 2. allOf(A, OP, I) rhs)	Underlying type output	array of T's underlying

```
"body": {
  "first_name": "John",
  "last_name": "Doe",
  "birthday": 1000,
  "nationality": 99,
  "gender": 1,
  "document_number": "vendor-ref-123456789",
  "country_code": 77,
  "id_type": 2,
  "id_number": "ABC123"
},
```

Basic credential types

There are some build-in credential types. Issuers can start to issue credentials of those basic types without going through the type creation process. Based on Galxe's experience, these types should cover a large portion of common use cases.

Type ID	Name	Description	Fields	Example
1	Boolean	The simplest credential type that does not contains any field. Owning a boolean credential means that the owner, indicated by the ID in header, satisfies the context.	N/A	1. Have you been followed by Elon Musk. 2. Have you ever made donation to Wikipedia. 3. Have you ever lived in Japan.
2	Scalar	A credential with an unsigned integer field.	a 256-bit unsigned integer	1. Holder's loyalty points of some brand. 2. UNIX Timestamp of the holder's first transaction on Ethereum. 3. User's ERC20 token balance on height 1000.
3	Property	A credential with a string field.	a string field representing a property that the holder has.	1. Name of holder's first pet. 2. Holder's first name on passport.

Signature(s)

The signature part of a credential is an array of pairs of metadata and signature, allowing one credential to have multiple signatures. Although the format of a signature is specified by the verification stack used by the issuer, all signatures shares a common metadata structure.

Signature metadata

- **verification_stack_id** (uint8): an ID of verification stack used for this credential.
- **chain_id** (uint64): the primary chain that will be used to manage the revocable credential. Value should be 0 if non-revocable. Note that although chain id may a 256-bit value, we do not support chain id larger than uint64_max.

- **signature_id** (uint248): the id of this signature that will be used to manage revocation. This value will never be exported as a public value for user's privacy. It will only be used in the circuit when proving that the credential is not revoked, if required.
- **expiration** (uint64): the UNIX timestamp of when the credential will be expired. This field is mandatory and you can fill-in UINT64_MAX if the credential never expires.
- **identity_commitment** (uint256): a field serves as the identity commitment for zero-knowledge proofs. The algorithm of computing the value is depending the chosen verification stack.

Identity commitment will be used as the key to the power of creating a link from ID to another ID, e.g. EVM. At verification, a holder must generate a proof that he is the actual owner of the credential, by showing that he knows the secrets behind the commitment, and output a number representing the pseudonymous identity the verifier will see. In this way, verifier knows that the verification is generated by the holder and he is the identity talking to the verifier in that session.

Attachments

The "attachments" section houses values that are external to the main body of the credential. It means that these values are not authenticated (or *signed*) by the issuer. Two fields are mandatory: `issuer_id` and `public_key`. They do not require explicit signing, because the issuer's signature inherently implies those values. Issuers have the flexibility to introduce any arbitrary fields to this section. For instance, an issuer could provide a passport credential accompanied by a PNG photo. In such a case, issuer can place the hash of the photo in the credential body, while the actual binary data of the image would reside in the attachments.

- **issuer_id** (uint248): Represents the unique identifier of the issuer.
- **public_key** (specific to the verification stack): Contains public keys essential for signature validation.
- Additional fields as deemed necessary by the issuer.

Technical components

This section describes all the components implemented by the protocol.

Verification stack: BabyZK

The initial zero-knowledge verification stack we have integrated is named "BabyZK". This stack employs the subsequent algorithms and parameters:

- **Curve**: BN254. All the following algorithms are using this curve.
- **Hash**: Poseidon.
- **Digest**: The digest is derived from the Poseidon hash of `poseidon(header, signature metadata)` and `poseidon(body)`. Initially, the header and signature metadata are cohesively hashed, according to the canonical sequence of header fields followed by signature metadata fields. Subsequently, the fields within the body are hashed in the type definition order. Finally we take the Poseidon hash of the two hash values.
- **Signature**: EdDSA Poseidon
- **Identity commitment schema**: a 2-input poseidon hash of BN254 curve of two fields: `identity secret` and `internal nullifier`, in this specified order.
- **Circuit language**: Circom
- **Proof system**: Groth16, powered by SnarkJS
- **Limits**: The total number of signals of fields in the body must be less than 256. For body types encompassing more than 16 signals—such as 9 `uint256` fields or 20 `bool`—the fields are segmented into groups of 16 and individually hashed. The final step is hashing results from these group hashes. This approach is necessitated by Poseidon's constraint of 16 signals. Given the further restriction that there can't exceed 256 fields, this hashing methodology can be implemented through a two-layer hashing structure.

Smart contracts

Smart contracts in the protocol serve two primary functions:

- **Metadata Storage**:

- Issuer details
- Type definitions
- Verification keys
- Status of revocable credentials
- Trust schemas
- **On-chain Verification:**
 - Verifier
 - zkOAT (zero-knowledge On-chain Achievement Token)

The Galxe protocol is crafted to be chain-agnostic, with plans to deploy these smart contracts across various EVM-compatible chains, including Ethereum, BSC, Polygon, and several Layer 2 solutions.

Credential Type Registry

Credential types must store related materials on-chain for reference during verification. These informations are immutable once published. Credential designers can utilize this contract to introduce new types into the Galxe protocol.

- User input:
 - Creator
 - Name
 - Definition in string format. For example, `age:uint<256>;wealth:uint<8>;name:prop<64,p>;followed:bool;`
 - Description
- Derived:
 - Type ID: a 160-bit unsigned integer derived from the lower 160 bits of keccak256 hash of the creator's address and type name.

Issuer registry

This contract empowers issuers to register and authenticate their identities on-chain and manage the status of public keys and state of revocable credentials.

- **Issuer Metadata:**
 - **Issuer ID:** Crafted to be chain-agnostic and deterministic, the issuer's EVM address is directly adopted as their Issuer ID. For chains not based on EVM, addresses can still be utilized, albeit truncated to 160 bits.
 - **Name:** Issuer can specify their name.
 - **Identity Verification** (built in separate contracts):
 - **DNSSEC:** Issuers can use DNSSEC records to validate their ownership of web2 domains.
 - **GAL Staking:** Issuers can manifest their commitment by staking GAL tokens.
 - **ENS/SpaceID & Other Bindings:** This facilitates the association of issuers with a web3 identity.
- **Issuer State:**
 - **Public Key Manager:** This contract caters to various verification stacks and is structured as a mapping from `(issuer_id, verification_stack, key_id)` to the key's status. The key ID is derived from the hash of the public key, with the hashing algorithm contingent on the selected verification stack. Key statuses are bifurcated into:
 - **Active:** Denotes keys currently in use.
 - **Revoked:** Signifies that all credentials signed with these keys are invalidated.
 - **Signature State Manager:** For credentials that can be revoked, this contract provision allows issuers to regulate the revocation status for each combination of credential type and context. This is achieved by uploading the hash root of the

sparse merkle tree containing signature IDs of the revoked credentials. Issuers need to publish the whole tree to a permanent storage for holders to access.

- URI to the sparse merkle tree.
- Root hash.

Credential context registry

A context is a string that, when paired with a credential type, forms a credential schema. This contract facilitates issuers in registering contexts, ensuring the meanings of credentials are publically accessible.

- Issuers can introduce a new context by submitting a string to the contract. The Context ID is derived from the keccak256 hash of this string, truncated to the lower 248 bits.
- Contexts are designed to be universal, instead of binded to a credential type. While it might seem unconventional to associate a boolean-typed credential with the context "Trading volume," we entrust this decision to the issuer.

Trust Schema Manager

This smart contract empowers verifiers to establish trust schemas tailored to specific verification scenarios. A straightforward example might involve enumerating a list of approved credential issuers. More intricate configurations could involve placing trust in issuers with active GAL staking, those operating under delegated trust, or issuers with a valid DNSSEC verification tied to some web2 domains. This contract transforms the trust establishment process into a communal activity, allowing trust schemas to be shared, voted upon, and dynamically adjusted.

Verifiers have the capability to introduce a new trust schema by supplying the address of a callback function. This function must be designated as a view function. The trust schema ID is then derived using a combination of the verifier's address and a nonce.

Verifier(s)

The Galxe protocol leverages zk-SNARK proofs, enabling affordable on-chain proof verification. For chains compatible with EVM, these proofs can be authenticated using the elliptic curve alt_bn128, as detailed in [EIP-197](#). The modular architecture of the verification stack ensures that the specific zero-knowledge proof technology can be updated without necessitating modifications to the core protocol. A verification stack must implement `verifier` interface and only trust **credential type registry contract** for adding parameters of new types. Each verification stack has its own verifier.

- Verifiers must implement the following interfaces
 - **On-chain zk-SNARK Proof Verification:** `function verifyProof(uint typeId, uint[] publicSignals, uint[] proof) public view returns (bool)`
 - **Verification key retrieval:** `function getVerificationKey(uint typeId) public view returns (uint[])`
 - **Type update:** `function setVerificationKey(uint typeId, uint[] verificationKey) external`

zkOAT NFT

The zkOAT NFT collection is an ERC-721 contract, acting as a cache for the revealed data associated with the pseudonymous identity, which is the address owning the NFT. This data is aggregated during each proof verification. The contract can be conceptualized as a decorator class, which proxies verification requests to the whitelisted `verifyProof` function of the chosen stack. Upon a successful return of `true`, an NFT is either minted or updated. The unique identifier for these NFTs is structured as a tuple: `(verifier, type, context, issuer)`.

For credentials that can be revoked, prior to utilizing this NFT, two verifications are essential:

- The `block.timestamp` should be earlier than the disclosed lower limit of the expiration date.
- The result of `getRevokeRoot(issuer, type, context)` should match the verified hash. This hash corresponds to the root of the revocation Sparse Merkle Tree (SMT) used in the proof.

SDK

The protocol provides an open source implementation of SDKs that allows developers to build application on Galxe protocol. The SDK provides:

1. Credential maker function: generate a credential based on its type.

2. BabyZK verification stack

- a. circuit generator: generate circom code based on type definition.
- b. signer: Sign a credential with private key.
- c. proof generator: Generate a proof based on the type and conditions.
- d. proof verifier: Based on the credential type, query verification key from blockchain and return the verification result.

Hosted service

Galxe BabyZK trust setup MPC node

This is a hosted service that can participate in phase 2 trust setups for BabyZK's Groth16 circuits. The service is not a necessity for protocol, but it can improve the user experience of credential type designer and its users. They do not need to worry about the trust setup when a new type is newly invented. The Galxe's MPC node will make sure to add secrets into the result, seal and publish the proving and verification keys to decentralized storage and corresponding verifier.

Application: Galxe identity vault

At the core of Galxe protocol's philosophy lies a deep commitment to the idea of self-sovereign identity. In pursuit of ultimate sovereignty, we developed the **Galxe identity vault**, a local storage solution for identity data, with embedded zero-knowledge provers, that gives users

1. **self-evident privacy safeguard**: given that data is stored locally, users can ensure that their personal information is kept private. Data does not need to pass through or be stored on any external servers where it could potentially be accessed by unauthorized parties.
2. **total access control**: Local storage gives users full control over their own data. They can decide what to do with it, when to share it, how to share it, and who to share it with. This is in contrast to storing data with centralized authorities or intermediaries, where users must trust those authorities will handle their data appropriately, and hope their services are live when needed. With local storage, users can ensure that their data is stored in their own jurisdiction, avoiding potential legal and regulatory complications.
3. **no-code ZKP**: It allows credential type designer, issuer, verifier, and holder to run all the workflow without any coding.

The Galxe identity vault will be developed as an open-source reference implementation, and any party can build their own vaults as long as it follows the specification. The reference implementation of Galxe identity vault will be available as browser extensions and native Apps. Once installed, the user can start to collect verifiable credentials to build his self-sovereign identity.

By using zero-knowledge proof technologies, users will be able to practice data minimization, down to the least required. In practice, all computation on the credentials will happen on user's local device via embedded zk-circuits, and only the public input and output will be shared with verifiers.

The wallet app must support:

- all the workflows defined below and
- generating a key pair on Baby Jubjub curve, which will be used for signing.
- sync and fetch credentials from issuers.
- checking on-chain state of revocable credentials.
- issuing credentials to any other identity

Storage add-on(s)

The protocol can work with decentralized permanent storages to improve its user experiences, by storing these information:

1. Proving keys, which is required for holders to generate zero-knowledge proofs. The size of these keys range from one megabytes to even hundreds of megabytes, depending on the number of constraints of the circuit.
2. Sparse merkle tree of revoked credentials. Without the SMT data, holders cannot prove the validity of revocable credentials.

Workflow

Most workflows are depending the chosen verification stack. For demonstration, we will explain them of BabyZK.

Type designer: create and publish a new credential type

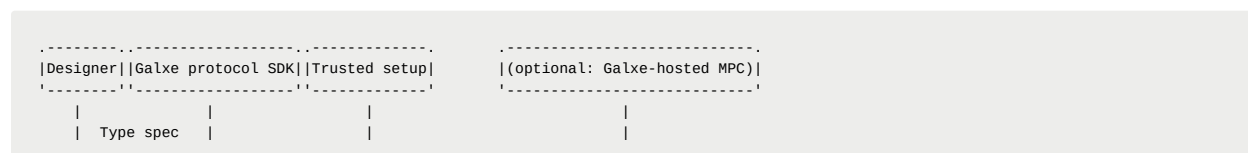
Adding a new type to the protocol is a permission-less process. Type designer can use Galxe protocol SDK programmatically, or he can use Galxe identity vault for the no-code solution.

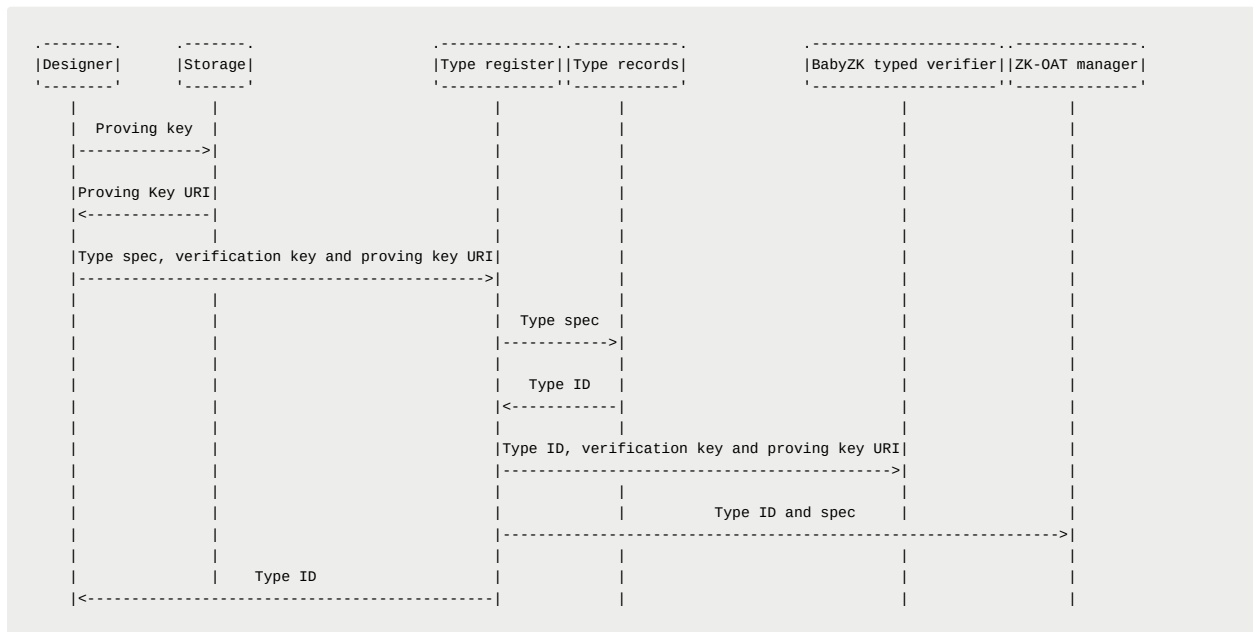
To introduce an official type, which will have long-term support of verification stacks, Galxe protocol employs a governance framework to facilitate decision-making regarding the acceptance and inclusion of new official credential types proposed by credential designers. The community, comprising users, developers, and other stakeholders, actively participates in the evaluation and acceptance process. Through transparent discussions and GAL voting mechanisms, the community collectively determines which proposed credential types are incorporated into the protocol.

The common workflow is:

1. **Idea and Proposal:** An individual or a group comes up with a new credential type. They draft a proposal document explaining the concept, its benefits, and technical specifications, including name and type of the fields, supported verification stack, zero-knowledge proof circuits, and details of the trust setup ceremony if required.
2. **Community Feedback:** The proposal is shared with the community for review and feedback. This can be done through forums, mailing lists, social media, or dedicated development channels like the official Galxe protocol github repository.
3. **Type Number Assignment:** If the proposal gains support and consensus within the community, an type number is assigned to it. The community uses these numbers to refer to specific proposals.
4. **Audit and Security:** Depending on the complexity and potential impact, an external security audit might be conducted to identify vulnerabilities or weaknesses in the proposal: (1) whether the wire format might be ambiguous, (2) if circuits were under-constrained or over-constrained, and (3) security level of the trust setup ceremony.
5. **Voting and Adoption:** Once the implementation passes security audits and testing and passes GAL voting process, it can be deployed to the Galxe protocol as a new official type.

	Role (who's doing it)	What	Input	Outcome	Modules
1. Create credential type	Credential designer	Design a new credential type.	Credential type specification string	Circom circuit	SDK, circuit generator
2. Phase2 trusted setup for the type and circuit.	Credential designer + other parties (Galxe)	Phase2 setup for zk-related, specifically for babyzk stack's proof system: Groth16	Circom circuit	1. proving key 2. verification key	The type designer needs to host a trusted setup ceremony for the circuit. Galxe protocol will provide an optional MPC node for participating the ceremony.
3. Publish credential type	Credential designer	Type specification will be published on-chain, and a deterministic Type ID will be generated. For babyzk, verification key parameters must be updated to the verifier contract.	1. proving key 2. verification key	1. Type ID. 2. add the verification key to the verifier. 3. proving key will be stored on decentralized storage.	contract: 1. Credential type registry. 2. BabyZK, typed verifier. 3. zkOAT contract. Storage: 1. decentralized permanent storage.

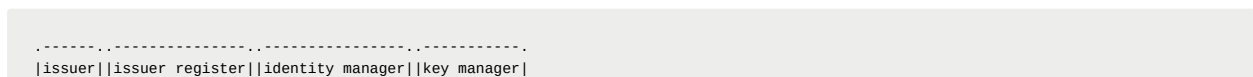


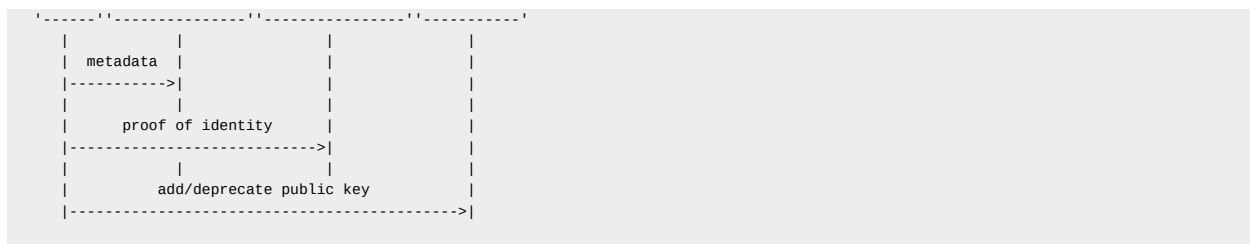


Issuer: register and issue credentials

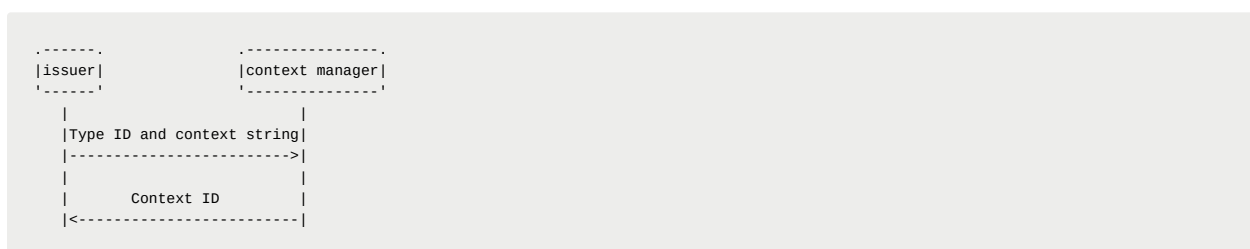
	Role (who's doing it)	What	Input	Outcome	Modules
4. Register as an issuer	Issuer	Register to become an issuer.	1. metadata 2. public keys 3. proof of identities.	issuer ID	Issuer registry + pubkey manager for different verification stack
5. Register a new credential context	Issuer	Add a new context on-chain.	1. CredType ID. 2. Context string	context ID	contract: context registry Context ID: hash of context string cut to 160 bits, from LSB.
6. Issue a new credential	Issuer \leftrightarrow owner	Sign a new credential to user.	1. credential header 2. body. 3. user's identity commitment 4. signature	a credential JSON string	Credential maker SDK. Babyzk verification stack SDK.

To become an issuer, one can register on-chain. The issuer ID is computed deterministically based on the caller's address. Issuers can add proofs of identity to show his accountability, e.g., DNSSEC verification, and GAL staking. It is recommended to use a smart contract wallet, e.g. ERC-4337 wallet, to register the issuer, for permission management.





Before issuing a credential, issuer must decide the credential schema, which is the type and context of credential. The context is a string that describes the content of the credential. For example, for a credential that proves a user's total USD value of financial assets, issuer can use the basic credential type 'scalar', and its context can be a string of "total USD value of financial assets". The separation of context and type in a the credential schema allows users to reuse the pre-compiled zero-knowledge proof circuits. Note that credential schema is universal, meaning that you can use a schema that is created by some other issuers. This can also be useful during verification: a verifier can program the logic of which schema to accept, from a simple list of schema IDs to dynamic logic programmed on-chain.



One important benefit of Galxe protocol is that, credential issuance can happen completely off-chain. The issuing process requires holder to provide an identity commitment to the issuer. An issuer must maintain a strict 1-to-1 mapping from the unique ID of the under the application to the identity commitment. In another word, a user must use the same commitment for an issuer. If the issuer failed to do so, the holder can create multiple proofs of different nullifiers, which allow him to 'double-spend' the credential.

Note that this interactive process can be improved by using [PLUME](#), if the ID is a public key. However, due to the high cost (over 2M constraints) under BabyZK stack, it is currently not supported.



After issuing credentials, issuers can still manage their validity on-chain, if they are revocable. Galxe protocol provides different ways to do it

1. Signing key management. Signing keys can be marked as active or deprecated. Verifiers should never trust any credential that is signed by a deprecated key.
2. Expiration date embedded in the signature.
3. Revocable credentials: sparse merkle tree (SMT) of signature IDs.

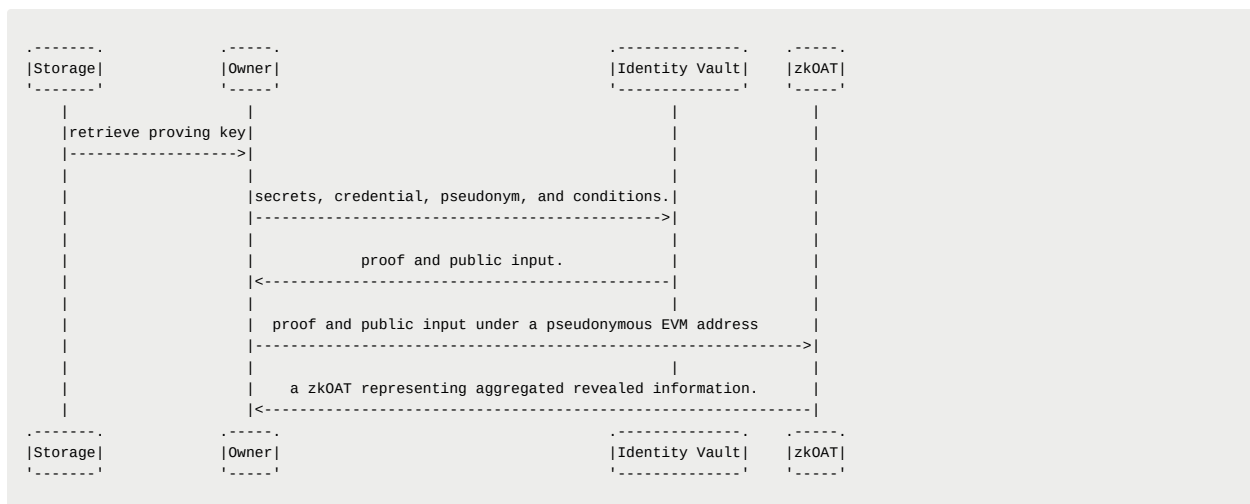
	Role (who's doing it)	What	Input	Outcome	Modules
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	Role (who's doing it)	What	Input	Outcome	Modules
6.1 Credential revocation	issuer	Issuers can management the 'signatures' they issued on credentials.	1. expiration. 2. signature ID via SMT. 3. explicitly seal the credential.	Credential will be revoked, holder cannot generate proofs that satisfy the goal.	Signature state smart contract.

Owner: proof generation and identity management

	Role (who's doing it)	What	Input	Outcome	Modules
7. zk-proof generation	owner	Credential holder can generate a proof against a set of conditions.	1. credential. 2. conditions. 3. proving key. 4. external nullifier	1. proof 2. public data	Galxe identity value
7.1 zkOAT minting	owner	Owner can optionally mint a zkOAT	1. proof 2. public data	1. an zkOAT NFT representing the aggregated revealed information.	zkOAT

Owners can generate proofs that they hold a credential satisfying some constraints. This is done by using the circuit generated from compiled for the credential type. Using the credential and the conditions that will be checked as input, user can generate a succinct proof showing that the holder has a credential satisfying conditions. The proof will also contains an ID that is endorsed to be used for the verification. For on-chain verifications, this ID must be the EVM address that submits the transaction.

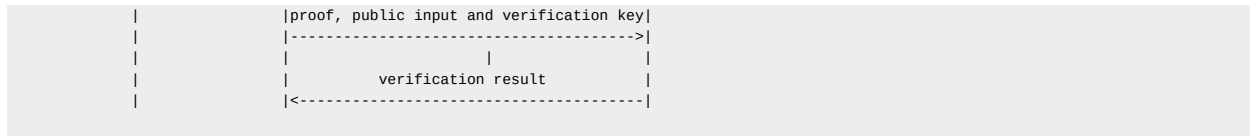


Verifier: verify proofs

Verifiers will fetch verification key from the contract and check the proof submitted by the holder.

	Role (who's doing it)	What	Input	Outcome	Modules
9. zk-based credential verification	verifier	Owner submit a proof to verifier which he possess a proof that he that satisfies some conditions.	1. proof.json 2. public.json	accept/reject	Signature state smart contract. onchain: verifier contract





Use Cases

Sybil Prevention

Sybil attack is one of the most prominent attack vectors in the digital space. Currently there is no foolproof solution to prevent sybil attacks. However, the greater amount of identity related data one can access, the easier it becomes to protect sybil attacks.

One solution to protect sybil attacks is through the implementation of KYC (know-your-customer) mechanisms. However, current KYC solutions raise privacy concerns as centralized entities collect and store users' personal identity information such as address, nationality, name, etc. Galxe Protocol offers a solution to solve this issue by allowing users to have ownership and control over their sensitive identity information. With the Galxe Protocol, users can securely share their data with third parties in a privacy-preserving way using zero-knowledge-proof verification stacks. By empowering users with control over their sensitive information, Galxe Protocol enhances privacy while addressing the need for identity verification in preventing sybil attacks.

Other solutions such as Gitcoin Passport are also effective approaches to tackle sybil attacks. These solutions request and utilize multi-dimension behavior and social data from users to estimate the likelihood of them being real humans and provide quantitative results. However, solutions like Gitcoin Passport typically require each vendor to collect a vast amount of data from users through centralized authentication processes. In contrast, with Galxe Protocol, users' credentials are aggregated and controlled by the users by default. All developers can thus build such scoring systems without the need to collect additional information from the users.

Reputation System

Traditional reputation systems often operate independently, resulting in data silos where reputation information is fragmented and not easily portable or shareable between different platforms or services. This lack of interoperability can limit the effectiveness and potential of reputation systems.

Galxe Protocol provides the opportunity to build a decentralized reputation system that can aggregate an individual's reputation. By utilizing the Galxe Protocol, it becomes possible to create a reputation system that is decentralized, transparent, and secure, enabling reputation to be collected and shared across various platforms or applications. This decentralized approach can enhance the trustworthiness and usability of reputation systems in a more interconnected manner.

Credit System

Current credit systems often rely on private data, which can raise concerns about data security and privacy. Centralized credit systems typically require access to personal and sensitive information, creating a risk of data breaches or unauthorized access. Additionally, these systems are often permissioned, meaning only certain entities have control over the data and how it is used.

Implementing a permissionless credential protocol can offer several advantages for building a credit system. By leveraging Galxe Protocol, it becomes possible to access a fuller and more diverse dataset for verifying and evaluating creditworthiness. This protocol can enable the integration of data from various sources, allowing for better accuracy and a more comprehensive understanding of an individual's creditworthiness.

Achievement System

Existing achievement systems often operate independently within specific applications or platforms. This creates data silos where the achievements earned in one application cannot be easily utilized or recognized in other applications. As a result, the value and impact of achievements are limited within their respective ecosystems.

An ideal scenario would be the ability to use achievements across different applications to unlock benefits or gain recognition. If achievements were transferable and recognized across various platforms or applications, it would enhance their value and provide users with tangible benefits beyond individual ecosystems. This would incentivize users to pursue and showcase achievements more actively, fostering a sense of accomplishment and motivation.

Personal Data Market

In the present scenario, application owners typically have control over users' personal data. They own, share, and may even monetize this information without direct user consent or control. This lack of control raises critical privacy concerns, while depriving users of the opportunities for monetization, and this could even be deemed as a deprivation of users' assets.

The Galxe Protocol offers a paradigm shift by allowing individuals to regain control over their identity data. With the Galxe Protocol, users can have ownership and agency over their personal credentials. They can decide how their data is used and shared, including the option to exchange data for improved services or monetary incentives. The privacy-enabled verification stack of the Galxe Protocol ensures that users' privacy is protected while engaging in these data transactions.

Identity Verification

Traditional methods of identity verification, such as presenting physical documents or IDs, are prone to fraud. Methods like photoshopping IDs or faking credentials like education degrees or drivers' licenses have become increasingly common. These fraudulent practices undermine the reliability and trustworthiness of the verification process.

Issuing digital verifiable credentials can help address these identity fraud concerns. Verifiable credentials are digitally signed pieces of information that are tamper-proof and can be easily verified by relying parties. By issuing these credentials, individuals can securely and conveniently present their verified identity information without the risk of forgery or manipulation.

Privacy-Enabled Access Control

Many existing access control systems require individuals to disclose private information in order to gain access to certain privileges or events. This can include revealing specific holdings like NFT collections and disclosing personal addresses. These requirements can potentially compromise privacy and expose individuals to risks associated with sharing sensitive information.

By leveraging privacy-enabled verification stacks, it becomes possible to ensure privacy for all kinds of access control systems.

Decentralized Review System

Credentials in Galxe Protocol go beyond personal identity data and can also include review-like credentials for other individuals or entities such as restaurants, clothing brands, and more. By aggregating reviews for all the entities within the network, developers can build decentralized review systems such as a decentralized version of Yelp. Moreover, the reputation scores built using the protocol can be utilized to weight the review aggregations, resulting in more robust and trustworthy review results.