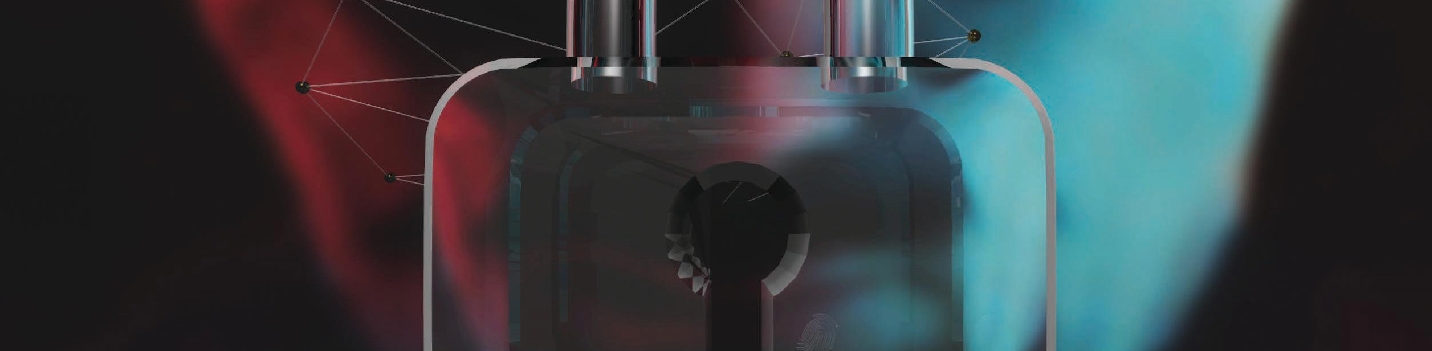
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**A First Look at Identity Management Schemes on the Blockchain**

### We introduce the emerging landscape of distributed ledger technology (DLT)-based identity management (IdM) and evaluate three representative proposals—uPort, ShoCard, and Sovrin—using the analytic lens of a seminal framework that characterizes the nature of successful IdM schemes.

wenty-four years have passed since Peter Steiner first showed the world that “on the Internet, nobody knows you’re a dog,” yet that famous drawing still stands to illustrate the challenge to identify indi- viduals online. Today, we are very far from the public directory vision of the inventors of public-key cryp- tography in the 1970s or the grand scheme of hierar- chical certification envisaged in the 1980s. Identity management (IdM) on the Internet still relies on what Cameron called a decade ago a “patchwork of identity one-offs,”1 comprising several types of IdM systems that are restricted to specific domains and do not interact much with one another. Centralized models of IdM cur- rently face challenges due to the increasing regularity of data breaches that lead to reputation damage; identity fraud; and above all, a loss of privacy for all concerned. ftese recurring events highlight a lack of control and ownership that end users experience with their digital

T

identities.2–4

fte investigation of alternative approaches to IdM is being led by initiatives that seek to expand the trust- worthiness and reach of digital forms of identity. fte United States’ National Strategy for Trusted Identities in Cyberspace (NSTIC) aims to accelerate the devel- opment of novel technologies that can increase trust

in online transactions.5 In addition, ID2020 seeks to leverage emerging digital technologies to expand the reach of legal identities (mirroring the United Nations’ goals to “provide [by 2030] legal identity for all, includ- ing birth registration”6). fte emergence of Bitcoin7 has also inspired fresh thinking about digital identity due to its underpinning distributed ledger technology (DLT) not requiring a central authority to validate transactions of its native cryptocurrency. ftus, a globally decentral- ized network is able to reach consensus on the current state of its book of transactions, the “ledger.” fte dis- tributed ledger itself is an append-only shared record of transactions that is maintained by entities on a peer-to- peer network, whereas the often-cited “blockchain” is a cryptographic data structure that is often instrumen- tal in DLTs and is constructed through cryptographic hashing of blocks of transactions.

Given that DLT is suited to ensuring consensus, transparency, and integrity of the transactions that it contains, a number of benefits of applying DLT to IdM have already been proposed:

* *Decentralized*—Identity information is referenced by a ledger that no single central authority owns or controls.

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* + *Tamper resistant*—Historical activities in the DLT cannot be tampered with and transparency is given to all changes to that data.
  + *Inclusive*—New ways to bootstrap user identity can be conceived that expand the reach of legal identities and reduce exclusion.
  + *Cost effective*—Shared identity information can lead to cost savings for relying parties along with the potential to reduce the volume of personal informa- tion that is replicated in databases.
  + *User control*—Users cannot lose control of their dig- ital identifiers if they lose access to the services of a particular identity provider/broker.

However, given these proposed benefits of incorpo- rating DLT into future IdM schemes, is the path to new forms of DLT-based IdM really “inevitable”?2

**Identity Management on the Blockchain?** IdM encompasses the processes and policies involved in managing the life cycle of attributes in identities for a particular domain.8 Most IdM schemes today are centralized where a single entity such as an orga- nization owns and controls the system. However, the identities themselves can have a scope that goes beyond single organizations, as when governments issue national identity cards for use with multiple organizations. In federated identity systems, users can use identity information established in one security domain to access another. Single sign-on schemes, such as Facebook Connect, can work this way. User-centric identity management places admin- istration and control of identity information directly into the hands of individuals. Examples include net- work anonymization tools (for example, Tor and I2P) that minimize disclosure of personal information and password managers (for example, 1Password and LessPass) that securely keep track of different website credentials.

Despite the different approaches, one function that

is fundamental to IdM is securely binding together an *identifier*—a value that unambiguously distinguishes one user from another in a particular domain—and *attributes* (sometimes called certifications or claims)— entitlements or properties of a user such as name, age, or credit rating. fte first steps taken to tailor the use of DLT for establishing secure and decentralized identifier– attribute mapping were in the design of Namecoin: the longest surviving software fork of Bitcoin. Namecoin provides a human-readable, decentralized, and secure namespace for the “.bit” web domain. ftis achievement contradicted conventional wisdom that a naming sys- tem exhibiting all three characteristics of human read- able, decentralized, and secure namespace could not

be designed.9 Blockstack4 has extended Namecoin’s scheme to create a decentralized public-key infrastruc- ture (PKI): it registers bindings between a public key and a human-readable identifier.

Recently, several decentralized identity schemes have emerged that extend beyond naming and aim to provide a more complete suite of IdM functions. However, until now, there has been no evaluation of these proposals. We were interested in whether DLT-based IdMs have the potential to go beyond pre- vious approaches or would simply create new “identity one-offs.”

## Approach

We started our inquiry by searching for blueprints of DLT-based IdM proposals that were technically scru- table (for instance, white papers and open source soft- ware). We excluded schemes that provided only naming and found that all fell into one of two categories:

* *Self-sovereign identity* is owned and controlled by a user without the need to rely on any external adminis- trative authority and without the possibility that this identity can be taken away. ftis can be enabled by an ecosystem that facilitates the acquisition and record- ing of attributes, and the propagation of trust among entities leveraging such identities. Examples include Sovrin, uPort, and OneName.
* *Decentralized trusted identity* is provided by a propri- etary service that performs identity proofing of users based on existing trusted credentials (for instance, a passport) and records identity attestations on a DLT for later validation by third parties. Examples include ShoCard, BitID, ID.me, and IDchainZ.

Inthisarticle, wefocusonthreeparticular DLT-based IdM schemes: uPort, ShoCard, and Sovrin. We chose these three schemes because, individually, they serve as key exemplars of the prevalent design decisions and challenges found in their respective genres, and together serve a similar purpose for the broader landscape of DLT-based IdM. In addition, they have provided the most technical detail of their scheme designs and are either underpinned by sizable online communities or have notable venture capital funding.

ftere is no definitive criterion to evaluate IdM schemes, so to generate early insights about individual schemes, we leveraged an evaluation framework known as the “laws of identity,”1 which serve to pinpoint the successes and failures of digital identity systems. It is a widely known framework and represents a full spec- trum of IdM concerns, encompassing security, privacy, and user experience. Furthermore, the laws provide an inherent flexibility, which is ideal for application to the

heterogeneous and early-stage DLT-based IdM schemes we considered. fte laws themselves are as follows:

1. *User control and consent*—Any information that identifies the user should be revealed only with that user’s consent.
2. *Minimal disclosure for a constrained use*—Identity information should be collected only on a “need-to- know” basis and kept on a “need-to-retain” basis.
3. *Justifiable parties*—Identity information should be shared only with parties that have a legitimate right to access identity information in a transaction.
4. *Directed identity*—Support should be provided for sharing identity information publicly or in a more discreet way.
5. *Design for a pluralism of operators and technology*—A solution must enable the interworking of different identity schemes and credentials.
6. *Human integration*—fte user experience must be consistent with user needs and expectations to enable users to understand the implications of their interactions with the system.
7. *Consistent experience across contexts*—Users must be able to count on a consistent experience across dif- ferent security contexts

and technology

an asymmetric key pair and sends a transaction to Ethe- reum that initiates the creation of a new controller that stores a reference to the public key. ften, a new proxy is created that contains a reference to the just-created con- troller contract; only the controller can invoke functions of the proxy, a constraint that is specified in the controller and enforced by the EVM. fte address of the proxy com- prises the unique *uPort identifier* (uPortID). A user is free to create multiple uPortIDs. Figure 1a provides an over- view of an interaction between a uPortID and the smart contract of a decentralized service on Ethereum.

fte private key associated with a uPortID is stored only on the user’s mobile device. fterefore, an impor- tant aspect of uPort usability is its key recovery protocol in the event of loss or theft of the user’s mobile device. For key recovery, users must nominate trustees, who can trigger a vote to set a new public key via the controller; once a quorum is reached, the controller replaces the lost public key with a new nominated key by invoking a dedicated function of the proxy. ftis process enables the user to maintain a persistent uPortID even after the loss of cryptographic keys.

A final aspect of the uPort scheme is its support for securely mapping identity attributes to a particular

uPortID. fte uPort *registry*

is a smart contract

platforms.

In the text that fol- lows, where we refer to a specific law, we use bracket nota- tion to reference the

law number (for instance,

# If an attacker can compromise a uPort application and replace trustees unnoticed

**via the controller, the uPortID compromised permanently.**

that stores the global mapping of uPortIDs to identity attributes. Any entity can query the registry; however, only the owner of a specific uPortID can

modify its respective attri-

**is**

(1) or (5)).

# uPort

uPort is an open source decentralized identity frame- work that aims to provide “decentralized identity for all.”3 Its use case is IdM for next-generation decentralized applications on the Ethereum DLT and for traditional centralized applications such as email and banking.

## Design

A uPort identity is underpinned by the interactions between Ethereum *smart contracts*: bespoke code that can regulate the movement of data and ether (the native cryp- tocurrency) on Ethereum. Smart contracts are uniquely addressed by 160-bit hexadecimal identifiers and, when invoked, are executed by the Ethereum Virtual Machine (EVM) installed on every Ethereum node. Two smart contract templates designed by uPort’s creators com- prise each uPort identity: *controller* and *proxy*. To create a new identity, a user’s uPort mobile application creates

butes. Due to the cost of storing large volumes of data in a smart contract, only the hash of the JSON attribute structure is proposed to be stored in the registry. fte data itself is stored on IPFS: a distributed file system where a file can be retrieved by its cryptographic hash.

## Analysis

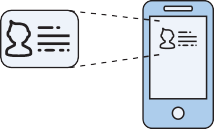
uPort has no central server and does not authenticate the owner of a uPortID; this passes the risk of unauthorized access to the local authentication methods on the user’s mobile device. While the social recovery protocol pro- vides one method to recover ownership of a lost or com- promised uPortID, the trustees themselves could be one vector of attack because their own uPortIDs are openly linked to the user’s uPortID; this transparency provides opportunities for collusion against a specific uPort user. If an attacker can compromise a uPort application and replace trustees unnoticed via the controller, the uPortID is compromised permanently. So while uPort does place more control over uPortIDs in the hands of its users—a

**(c)**

**(b)**

**(a)**

**Figure 1.** An overview of the key components of the (a) uPort, (b) Sovrin, and (c) ShoCard systems. In uPort, when interacting with a service hosted on the Ethereum network, the proxy can update the user data stored on a file system external to Ethereum, while the service used may read from it. At the base of Sovrin is a permissioned ledger. Only stewards that legally abide by the Sovrin Trust Framework can write to the ledger. Users can interact with the network through a client app. To be always accessible, users and organizations on Sovrin rely on agents that are addressable network points. Identifiers, keys, and endpoint addresses are stored on the ledger while attributes are stored off the ledger.



ShoCard store

Additional data

**Bitcoin blockchain**

Envelope

Trans. #

Trans. # Certification record

Seal

Trans. #

Link

Link

Certification record

Seal

Retrieve envelope

Certifier

Photo

Verifier

Envelope reference + Plain text data

ShoCard uses the Bitcoin blockchain to store and link together signed cryptographic hashes of identity data. The plaintext data is stored on a dedicated server in encrypted form.

plus for (1)—a layer of added complexity and responsi- bility is inevitably handed to users.

Endpoint

Endpoint

Endpoint

Endpoint

Service

Has access to

Proxy

Owns

Controller

Read/write

Registry

**Ethereum blockchain**

Read/write

Read/write

Controls

IPFS data store

uPort app

Read/write

~~Stewards~~

**Sovrin ledger**

IDs, keys, end-point addresses

Service provider (S) agent Data vault Policy & keys

Ledger client

User (U) agent

Data vault Policy & keys

Ledger client

Service endpoints

User endpoints

Controls

Direct

communication

*EPS*

*EPU*

User client app

uPort does not require personal data disclosures to bootstrap a uPortID for a constrained use and also respects privacy in terms of the lack of inherent link- ability between uPortIDs (2). However, the registry (if used) represents a point of centralization that can be probed for information. So while specific attributes within the attribute data structure can be individually encrypted, the overall JSON data structure is still vis- ible, which could leak metadata about specific attributes

or relationships with identity providers or relying par- ties. ftus there is a chance that over-reliance on the reg- istry can compromise privacy (3).

A commerce application can widely advertise its uPortID, but uPort provides no public directory to look up uPortIDs from arbitrary search criteria. Discreet dis- closure of a uPortID is possible if a user creates new uPortIDs for each new relying party that they encoun- ter (4). However, because a uPortID equates to a smart contract, an honest but curious Ethereum node could dis- cover even nondisclosed uPortIDs through analysis of the

smart contract code stored at a given address to determine if it is a uPort template. More work is needed to discover whether nondisclosed uPortIDs are private in practice.

uPort does not perform any identity proofing but instead provides a framework for users to gather attri- butes from an ecosystem of identity providers; uPort simply specifies the format of attributes that are stored in its registry. But as a consequence of the uPortID owner alone having write access to their own respective part of the registry, a user can selectively discard neg- ative attributes that they are given, for example, a low credit score, a criminal conviction, and so on (5).

fte mobile application of uPort provides a consis- tent user experience across all usage contexts (7) due to the scanning of a QR code being relied on to initiate interactions with a relying party. However, the in-app education does not convey privacy implications of stor- ing representations of personally identifiable informa- tion on a blockchain (6). fte area of user education will become pressing in this context as legislation such as the European General Data Protection Regulation (GDPR) come into force.

# Sovrin

fte Sovrin architecture can be summarized by the components as shown in Figure 1b. fte key element is the Sovrin ledger. ftis contains identity transactions associated to a particular identifier and is written, dis- tributed, and replicated among the *steward nodes*, which run an enhanced version of the redundant Byzantine fault-tolerant protocol of Aublin and colleagues,10 called Plenum, for consensus.

ftere are two important consequences to the choice of permissioned ledger in Sovrin’s design. First, no expensive proof-of-work computation is required to reach consensus on the state of the ledger, significantly reducing the energy cost of running a node and dramat- ically improving transaction throughput. Second, trust on Sovrin relies on both people and code. Trust starts from the common root of trust formed by the globally distributed ledger, but as new organizations and users join the network, they can become *trust anchors* (that is, allowed to add more users and organizations); a “web of trust” is expected to evolve to support this decentralized network growth.

Users interact with Sovrin through a mobile applica- tion and control software *agents* acting on their behalf

to facilitate interactions with

Sovrin is an open source identity

network built on permissioned DLT that stores identity records.2 Sovrin is public, but only trusted institutions, called

*stewards*—which could

# Users must rely on agencies that will act on their behalf in the Sovrin network and on the stewards maintaining the distributed ledger.

**Depending on the choice of agent and its implementation, a lot of information could potentially be in the hands of the agency.**

other agents on the net- work. Agents are net- work endpoints that are always addressable and accessible. Users could run their agents on their own servers, but more likely, they will ask spe- cialized intermediaries,

*agencies*, to do that for them,

be banks, universities, governments, and so on—can run nodes that take part in consensus protocols; thus, the ledger is *permissioned*. fte nonprofit Sovrin Foun- dation ensures the proper governance of the stewards and their respect of a legal agreement called the Sovrin Trust Framework. Sovrin provides the code base to the Hyperledger Indy project.

## Design

Sovrin enables a user to generate as many identifiers as needed to keep contextual separation of identities for privacy purposes; each identifier is unlinkable and con- trolled by a different asymmetric key pair. Sovrin identi- fiers are managed by the user or an appointed guardian service and follow the Decentralized Identifier (DID) specification currently seeking Internet Engineering Task Force (IETF) standardization. A DID is a data structure containing the user identifier, cryptographic public key, and other metadata necessary to transact with that identifier.

like email systems. Agents also provide backup service and encrypted storage of attribute credentials. fte for- mat of these attribute credentials align with the emerg- ing W3C Verifiable Claims standard for credentials verified by third parties.

fte mobile application also helps users manage cryptographic keys, which are stored on the users’ mobile device. As in uPort, Sovrin offers a mechanism for key recovery that relies on the user selecting a set of trustees. When requested to do so by the user, a speci- fied quorum of trustees must sign a new identity record transaction that stewards must verify.

## Analysis

Sovrin aims to equip users to fully control all aspects of their identity. Each user can selectively disclose attribute credentials that they hold to meet the identity validation requirements of a relying party (1). Also, the privacy that can be achieved in this process can be enhanced through the use of anonymous credential technology.

Although users can choose to store those attributes on the ledger, in general, they will prefer to use the storage capabilities of their mobile phone or their agent to trans- mit attributes to other parties through secure communi- cation channels and use the ledger to identify the correct network endpoint to use. fte use of attribute-based credentials allows users to reveal only information that is necessary (2). Verifying the party with whom data is shared remains a challenge, which is partly addressed through the web of trust, the governance of the Sovrin Foundation, and the reputation of the stewards.

Although there are no trusted third parties in the PKI sense on Sovrin, users must rely on agencies that will act on their behalf in the Sovrin network and on the stewards maintaining the distributed ledger. Depending on the choice of agent and its implementation, a lot of information could potentially be in the hands of the agency. However, as agencies are acting on behalf of the user, they have a “necessary and justifiable place” in the identity relationship (3).

Sovrin supports both omnidirectional and unidirec- tional identifiers (4): public organizations can decide to publish their full identity on

the network, while

# ShoCard

ShoCard is a digital identity card on a mobile device that binds a user identifier, an existing trusted creden- tial (for instance, passport or driver’s license), and addi- tional identity attributes together via cryptographic hashes stored in Bitcoin transactions.11 ShoCard’s pri- mary use cases are verification of identity in face-to-face and online interactions.

## Design

ShoCard uses Bitcoin as a timestamping service for signed cryptographic hashes of the user’s identity infor- mation, which are mined into the Bitcoin blockchain. ShoCard incorporates a fixed central server as an essential part of its scheme; this server intermediates the exchange of encrypted identity information between a user and a relying party. fte scheme relies on three phases: *boot- strapping*, *certification*, and *validation*. Figure 1c schema- tizes those phases.

Bootstrapping occurs at the creation of a new ShoCard. fte ShoCard mobile application generates an asymmetric key pair for the user and scans their

identity credentials using the device’s camera.

users may choose to publish only identifi- ers and to use different identifiers and cryp- tographic key pairs with each party they interact with, avoiding emitting “correlation handles.”

Today, Sovrin depends

# ShoCard’s intermediary role does create uncertainty about the longitudinal existence of a ShoCardID; if the company ceased to exist, users of ShoCard would be unable to use the system with the certifications they had acquired.

fte scan and the corresponding data are encrypted and stored on the mobile device; the signed hash of this data is also embedded into a Bitcoin transaction for later data valida-

tion purposes. fte result-

on a very small number of operators sharing the same implementation. As the systems gets traction, new agencies, and new stewards, will join. fte Sovrin Foundation expects in particular to build a market of agencies that will compete on the features they offer, for instance, interfaces with other (existing) identity systems (5).

An important issue not yet addressed by the Sovrin developers is the user experience. fte his- tory of security offers several examples of smart cryp- tographic systems, which have never been deployed widely because users found it too cumbersome or dif- ficult to understand—email encryption using PGP is a seminal example. So, human integration remains a big open question for Sovrin. Considering that Sovrin is still in the early development phase, evaluating it against laws (6) and (7) is tricky, but it is illustrative that much work has considered the scheme architec- ture design, but hardly any has considered the user experience.

ing Bitcoin transaction number constitutes the user’s ShoCardID and is retained in the mobile application as a pointer to the ShoCard *seal*.

Once a ShoCard is bootstrapped, the user can interact with service providers to gather additional attributes that rely on the seal in a process called certification. To associ- ate certificates to a ShoCardID, an identity provider must first verify that the user knows both the data hashed to create the seal and the cryptographic key used to create its signature. In a face-to-face context, this can be achieved by the user providing the original identity data forming the seal from their mobile device, a digitally signed chal- lenge, and the original trusted credential. fte certificate takes the form of a signed hash of new attributes (and its associated ShoCardID) in a Bitcoin transaction cre- ated by the provider. fte provider must share the Bitcoin transaction number, along with a signed plaintext of the new attributes, directly with the user. Because the user will later need to provide the attributes to relying par- ties and may not want to lose them if the mobile device

is lost, a ShoCard server offers storage for symmetrically encrypted certifications (known as envelopes). ShoCard never learns the encryption key, which enables the user to share certifications only with selected parties.

fte validation phase occurs when a relying party must verify a certification to determine whether a user is entitled to access a service. To validate the envelope, the user must first provide the relying party with the envelope reference and its encryption key. After retriev- ing the envelope from the ShoCard servers, the relying party checks that:

* the envelope signature was produced with the same private key that signed the seal;
* the certification signature was created by a trusted entity and the plaintext certification corresponds to the one hashed and signed in the blockchain; and
* the textual details presented by the user in the pend- ing transaction match those embedded in the seal.

## Analysis

ShoCard supports only unidirectional identifiers and does not support a public registry of ShoCardIDs. Omnidirectional identifiers may be needed in the future to realize its vision of an ecosystem of reusable certifications (4).

ShoCard does support a multitude of different iden- tity providers through its certification functionality, but those providers must create bespoke integration with ShoCard’s own web services in addition to Bit- coin, which could be a barrier to uptake. fte decision to leverage ShoCard in future applications can only be driven by positive perceptions of the trustworthiness of ShoCard’s identity proofing of its users, and the result- ing value of a ShoCard (5).

fte scanning of identity documents and QR codes is a dominant interaction paradigm in the ShoCard user experience: it is simple and consistent (7). How- ever, it is unclear what the user motivations would be to adopt this new type of digital identity and how users

would be educated about the implications of

fte ShoCard central server functions as an intermediary to manage the distribu- tion of encrypted cer- tifications between ShoCard users and relying parties. In this way, ShoCard bears

less risk than if it stored and

# While DLT applications often target the removal of the “middle man,” this may not be a realistic goal in IdM applications due to the context of identity maintaining a profound need for trust.

referencing identity data on a blockchain (6). Users are also not supported with cryptographic key management.

One final point concerns the over- all deployability of

ShoCard. Bitcoin transac-

distributed plaintext identity data. Secure storage of identity information and appropriate sharing with rely- ing parties is controlled by the end user (1). However, ShoCard’s intermediary role does create uncertainty about the longitudinal existence of a ShoCardID; if the company ceased to exist, users of ShoCard would be unable to use the system with the certifications they had acquired. ftis makes ShoCard more centralized in practice than its open reliance on DLT might suggest.

Each ShoCard identity must be bootstrapped with an existing trusted credential, such as a passport or driv- er’s license. Such an approach requires users to provide personal information from the outset in order to create a ShoCard seal. ftis may make ShoCard less attractive for low-value online accounts (2).

Because the user is in control of initiating sharing activities, and because ShoCard stores only encrypted data, there can be some confidence that only justifiable parties are involved in the identity data–sharing transac- tion. However, the ShoCard server may be able to asso- ciate a particular ShoCardID with requests made by relying parties, since envelopes must be retrieved from the ShoCard server by the relying party (3).

tions take on average 10 minutes to be mined into the blockchain, and waiting for six additional blocks to be mined is recommended before assuming the settle- ment of a transaction. ftis could bring the waiting time for settlement to one hour on average. In a context that requires real-time settlement of certifications, this speed could create challenges for the user experience and those who wish to build applications that leverage ShoCard.

# Discussion

Table 1 summarizes each scheme that we evaluated with respect to each law of identity. An unshaded table cell indicates that we found evidence that a scheme com- plied with a specific law, and a shaded cell indicates that we currently see no evidence that a scheme complies with a specific law. We include a summary of Facebook Connect to provide contrast.

## Decentralization That Relies on Centralization and Intermediaries

DLT is often seen as a remedy for system architectures dominated by central authorities and intermediaries. But while each DLT-based IdM scheme we looked at

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 1. A summary of uPort, ShoCard, Sovrin, and their relation to Cameron’s laws of identity.\*** | | | | |
| **Law** | **uPort** | **ShoCard** | **Sovrin** | **Facebook Connect** |
| **1—User control and** | User controls creation | User controls creation and | By design, users can choose | Today, when using |
| **consent** | and disclosure of | disclosure of ShoCardIDs. | which DIDs are used | Facebook to log on to |
|  | uPortIDs and can prove | Attributes are accessible | and which attributes are | a service, the user can |
|  | ownership of uPortID | to a relying party only by | revealed. A web of trust | choose which data will be |
|  | without a central | invitation of ShoCardID | that could be reinforced | shared by Facebook with |
|  | authority. But attributes | owner. But ShoCard servers | by a reputation system | the relying party. |
|  | stored in registry may | are necessary part of attribute | helps protect users against |  |
|  | leak information. | validation protocol. | deception. |  |
| **2—Minimal** | Users do not need to | ShoCardIDs are bootstrapped | Support of anonymous | A user can create an empty |
| **disclosure for a** | disclose personal data | with a trusted identity | credentials based on | Facebook profile and |
| **constrained use** | in order to create uPort | document (for example, a | zero-knowledge proofs | progressively add identity |
|  | identifiers for low-value | government ID). | allows users to share the | information as needed. |
|  | accounts. |  | information “least likely |  |
|  |  |  | to identity [them] across |  |
|  |  |  | multiple contexts.”1 |  |
| **3—Justifiable parties** | The JSON structure of | ShoCardID is revealed to | Attributes are accessible | Facebook always has access |
|  | attributes in the registry | a relying party only at the | only to relying parties that | to the data stored on a |
|  | is visible to all, which | invitation of the ShoCardID | the user chooses, and to | user’s Facebook profile |
|  | may leak information to | owner. ShoCard servers | the agencies entrusted to | whether the data is public |
|  | an honest-but-curious | may learn identity of relying | act on their behalf. | or private. Facebook also |
|  | attacker—even if | parties. |  | creates and processes |
|  | encrypted. |  |  | its own attributes, for |
|  |  |  |  | instance, relationships with |
|  |  |  |  | friends. |
| **4—Directed identity** | Supports unidirectional | Supports unidirectional | Omnidirectional identifiers | Omnidirectional identifiers |
|  | sharing of identifiers | sharing of identifiers between | are supported. | are supported. A user’s |
|  | between parties, but | parties, but does not prevent |  | Facebook profile can be |
|  | does not prevent entities | entities broadcasting |  | made public or private, and |
|  | broadcasting identifiers | identifiers out of band. |  | profiles can be searched. |
|  | out of band, for instance, |  |  |  |
|  | on websites. |  |  |  |
| **5—Design for** | Agnostic to the types of | Supports parsing of existing | Expects to build a | Only one identity provider: |
| **a pluralism of** | attributes that third party | trusted credentials, but | market for intermediaries | Facebook. Uses a bespoke |
| **operators and** | identity providers create, | relying parties must create | (agencies) between users | method for authorization |
| **technology** | yet use of a specific data | bespoke integrations with | and the Sovrin network. | to applications. But |
|  | format is encouraged in | ShoCard centralized servers | Some could be interfaces | Facebook has nearly |
|  | the registry. | for attribute validation. | with other identity systems. | 2 billion users. |
| **6—Human** | Provides a mobile | Provides a mobile application. | Implementation has been | Facebook is well known |
| **integration** | application. Social | The digital ID card metaphor | targeted so far toward the | to users and usable |
|  | cryptographic key | is easy to understand. | underlying technology, | interface to single sign-on |
|  | recovery function | Unclear usability and user | not the user experience. | is provided. However, users |
|  | shows promise. Unclear | understanding of ShoCard | Unclear usability and user | may be unaware of privacy |
|  | usability and user | privacy implications. | understanding of privacy. | implications of Facebook |
|  | understanding of uPort |  |  | Connect. |
|  | privacy implications. |  |  |  |
| **7—Consistent** | User interaction | User interaction driven by | Not clear. This will highly | Consistent experience via |
| **experience across** | driven by the mobile | the mobile application. | depend on the market of | the “login with Facebook” |
| **contexts** | application. Consistently | Consistently follows a QR | implementations of mobile | button. |
|  | follows a QR code– | code–scanning paradigm for | device clients for the Sovrin |  |
|  | scanning paradigm for | all uses. | network. |  |
|  | all uses. |  |  |  |

* *Facebook Connect is provided for comparison. An unshaded table cell indicates that we found evidence that a scheme complied with a specific law, and a shaded cell indicates that we currently see no evidence that a scheme complies with a specific law.*

leverages techniques of decentralization to different degrees, this served mainly to reshape the role of cen- tralization and intermediaries rather than eradicate them. For example, uPort’s registry stores a secure map- ping between uPortID and its attributes and also relies on central authorities as trusted attribute providers. fte ShoCard central server is an intermediary that stores encrypted identity attributes and mediates between end users and relying parties. Sovrin on the other hand embraces an open ecosystem of intermediaries (for example, agencies and trust anchors).

So, while DLT applications often target the removal of the “middle man,” this may not be a realistic goal in IdM applications due to the context of identity maintain- ing a profound need for trust. Of course, this need for centralization and intermediaries is not necessarily a bad thing: there are numerous

examples of central-

can certify attributes of an identifier; uPort and Sovrin support both self-attestation of attributes and those assigned by other entities.

Designing for reusable identity attributes aims to improve the granularity at which users can disclose iden- tity information and promotes reuse of attributes. How- ever, due to the lack of a central authority, trust of these attributes currently relies on ad hoc trust establishment and integration between organizations. ShoCard and Sovrin propose a “web of trust” as the means by which attributes can be trusted. However, the challenges to design a web of trust are widely known where the net- work size is unbounded: difficulty to quantify trust beyond a first-degree relationship especially if any entity can vouch for any other, poor density of trust anchors on the network, lost or expired private keys, slow prop-

agation of endorsement between users, and

ization and intermedi- aries serving essential functions in an indus- try (see, for example, SWIFT). Elements of needed centralization or intermediation in a decentralized IdM may comprise:

# There appears to be a widespread

**assumption that users are equipped to conduct effective cryptographic key management and would intuitively understand the implications of referencing identity attributes in a DLT.**

so on. DLT does not address any of those challenges, but future research could focus on methods to achieve the building of trust and reputa- tion between entities in the context of DLT

* + capturing additional authentication factors from end users;
  + backing up and recovering cryptographic keys;
  + providing a secure namespace to facilitate lookup of entities and services;
  + securely storing the information hash pre-images needed to validate digital signatures; and
  + recovering compromised DLT-based identities.

fte case of “fte DAO” stands as an example of the risks of pursuing too much decentralization in a system design. fte DAO was designed as an Ethereum smart contract–based autonomous venture capital company, but a flaw in its underlying code enabled an attacker to steal $50 million of the funding that it collected.12 fte research challenge for DLT applications in IdM is therefore to explore the balance between centraliza- tion and decentralization to create interoperable and privacy-respecting IdM that mitigates the risk of placing too much trust in any single authority.

## Ecosystems of Shareable Identity Attributes— But Ad Hoc Trust

Support for the creation and sharing of identity attri- butes certified by third parties is a design feature of each scheme we evaluated. In ShoCard, third parties

identity attributes. ftis could be one way that DLT-based IdM responds to NSTIC5 and delivers new interoperabil- ity in IdM.

## If It Isn’t Usable, It Isn’t Secure

Dhamija explains in her “Seven Flaws of Identity Man- agement” article that for users “identity management is not a primary goal.”13 ftis has been reflected in the shrug that users have largely given to single sign-on solutions—the user-facing proposition of IdM. ftis suggests that future IdM schemes with a novel tech- nological underpinning but developed with the same blueprint of end user interaction are unlikely to cre- ate widespread uptake. A principal tenet of human– computer interaction is to design systems that respond to empirical evidence of challenges faced by end users. So far, we have seen that none of the schemes we evalu- ated are accompanied by a novel evidence-based vision of user interaction; furthermore, the perennial challenge to provide usable end user key management14 is largely unaddressed. Recent research has suggested that key management remains a principal source of concern for users of Bitcoin.15 While the promising concept of key recovery was proposed in uPort and Sovrin, approaches to digital identity that remove central authorities and depend on effective key management strategies from their users create the risk that nontechnical users will be

alienated by the technology, and when things go wrong, those users will be unable to recover resources or repu- tation attached to lost keys.

istributed ledger technology is not a silver bullet solution for identity management. Our applica-

D

tion of Cameron’s evaluative framework provides an early glimpse of the current strengths and limitations of applying DLT to IdM. Future work in this nascent research area faces two particular hurdles.

First, there is a noticeable lack of contextual under- standing relating to the user experience elements of the schemes we encountered. Usability is a particularly pressing unknown because there appears to be a wide- spread assumption that users are equipped to conduct effective cryptographic key management and would intuitively understand the implications of referencing

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identity attributes in a DLT.

Second, there is a tightening regulatory landscape for storing and processing personal data. For example, the GDPR grants end users new powers over personal dataand places new obligations on data controllers and processors. ftis creates a challenge for the design of identity-focused immutable ledgers that reference personal data and that provide inherent transparency to data that they store.

Delaying the advance of new approaches to secure and trusted identities on the Internet is said to be an unacceptable course of action by the United States’ NSTIC strategy.5 ftis might be due to the concern that the online adage that “on the blockchain, nobody knows you’re a fridge” may soon replace the prescience of Steiner’s original cartoon.

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