One Password: An Encryption Scheme for Hiding Users’ Register Information

Bo Zhao†  Yu Zhou‡
† National Engineering Laboratory for Video Technology; School of Software & Microelectronics, Peaking University
‡ Ant-financial Light-Year Security Lab; School of Information Science Technology, East China Normal University
bozhao@pku.edu.cn, 51151211020@stu.ecnu.edu.cn

Abstract
In recent years, the attack which leverages register information (e.g. accounts and passwords) leaked from 3rd party applications to try other applications is popular and serious. We call this attack ”database collision”. Traditionally, people have to keep dozens of accounts and passwords for different applications to prevent this attack. In this paper, we propose a novel encryption scheme for hiding users’ register information and preventing this attack. Specifically, we first hash the register information using existing safe hash function. Then the hash string is hidden, instead a coefficient vector is stored for verification. Coefficient vectors of the same register information are generated randomly for different applications. Hence, the original information is hardly cracked by dictionary based attack or database collision in practice. Using our encryption scheme, each user only needs to keep one password for dozens of applications.

Introduction
In daily life, people have to sign up dozens of different applications, e.g. softwares and websites. When some application is hacked, the leaked register information (e.g. accounts and passwords) may be leveraged by hackers to try other applications. If the same account and password is used, it will be a serious threat. We call this attack ”database collision”. This attack is listed as Top 10 Security Risks for 2014 by ZD-NET (Blue 2014). It is recommended that people should use different accounts and passwords for different applications to prevent this attack. However, this solution brings people some troubles, especially, keeping many different passwords is really a complex and annoying task for many people.

Most applications hash users’ passwords or other important register information in order to avoid hackers’ leverage of these important information when their databases are hacked. However, some methods such as the rainbow table (Oechslin 2003) can efficiently crack password hashes. As most hash functions are open, different applications store the same hash string for the same input. This makes the dictionary based attack to hash functions easier. In some applications, the salt is introduced to the hash functions for generating different hash strings. The fact that the salt is fixed and the whole process is reversible makes this scheme not secure.

Similar to Biometric Cryptosystems (Uludag et al. 2005) (Zhou et al. 2015), we aim to protect the register information from leaking. In this paper, we propose a novel encryption scheme to hide users’ register information (illustrated in Fig. 1). Different from traditional schemes, we do not keep the hash string of register information (e.g. password) directly. Instead, we hide the hash string and keep a random coefficient vector for verification or encoding some key information. Specifically, in the registration phase, we hash the register information using existing safe hash function. Then we repeat the hash process for several times and convert these hash strings to big numbers. We concatenate these numbers to form a vector which can be viewed as a datapoint in the high-dimension space. We randomly generate some auxiliary datapoints in the space and guarantee that there exists only one hyperplane covering all these datapoints. The coefficient vector of the this hyperplane can be calculated using these datapoints. We store the coefficient vector instead of hash string for hiding original hash string. The hash hiding process is illustrated in Fig. 2. Some key information can be encoded in this hyperplane equation by setting the constant term. In the verification phase, the datapoint of the testing input is obtained using the aforementioned process. If the testing input is the same to register information, the testing datapoint locates on the hyperplane and the verification succeeds. Otherwise, the verification fails and the encoded information is not accessible. In our scheme, several pieces of different register information can be registered for separate use at the same time.

This paper has two main contributions: i) a novel encryption scheme is proposed, which is hardly cracked by dictionary based attack or database collision. ii) with our scheme, every user only needs to keep one register information (e.g. password) for all applications.

Proposed Method
Registration
In the registration process, one or several pieces of user’s register information are used to generate random coefficient vectors. p denotes a piece of register information which is a string. The string is first hashed using a safe hash function (e.g. SHA-256 (Gilbert and Handschuh 2003))

\[ h = H(p). \]

h is a fixed-length string with the length \( l. \)
We repeat the hash process for \( d \) times and obtain a set of strings \( \{h_1, h_2, ..., h_d\} \). Then these strings are converted to big numbers for obtaining a \( d \)-dim row vector \( \mathbf{v}_1 = (x_1, x_2, ..., x_d) \). If several pieces of register information are provided, we obtain several vectors \( \{\mathbf{v}_1, \mathbf{v}_2, ..., \mathbf{v}_n\} \), where \( n \) is the number of register strings and \( n < d \).

Next, we randomly generate \( d - n \) auxiliary vectors (e.g., auxiliary datapoints) with the same dimensionality and span, namely, \( \{\mathbf{v}_{n+1}, \mathbf{v}_{n+2}, ..., \mathbf{v}_d\} \). We guarantee that the determinant of the square matrix \( \mathbf{V} = (\mathbf{v}_1; \mathbf{v}_2; ...; \mathbf{v}_d) \) which is formed by these \( d \) datapoints does not equal zero, so that these \( d \) datapoints can span the only one \( d - 1 \)-dim hyperplane in the \( d \)-dim ambient space. We denote the hyperplane using the following linear equation,

\[
\alpha_1 x_1 + ... + \alpha_d x_d = c. \tag{1}
\]

Hence, we can calculate the coefficients of the hyperplane function using these \( d \) datapoints. It can be easily solved by calculating the inverse matrix, i.e. \( \mathbf{\alpha} = \mathbf{V}^{-1} \mathbf{c} \), \( \mathbf{c} = (c; c; ...; c) \) and \( \mathbf{\alpha} = (\alpha_1; \alpha_2; ...; \alpha_d) \) are two \( d \)-dim column vectors. The number \( c \) can be simply set to be 1 for verification. For encoding key string \( s \), we can convert \( s \) to \( c \). In our scheme, each application stores the randomly generated coefficient vector \( \mathbf{\alpha} \).

**Verification**

Considering the testing input \( \hat{p} \), we first calculate the testing datapoint \( \hat{\mathbf{v}} = (\hat{x}_1, \hat{x}_2, ..., \hat{x}_d) \) using aforementioned process. The testing number \( \hat{c} \) is calculated by the dot product of coefficients and the testing datapoint, i.e. \( \hat{c} = \mathbf{\alpha} \cdot \hat{\mathbf{v}} \). If the datapoint \( \hat{\mathbf{v}} \) satisfies the hyperplane equation \( \mathbf{\alpha} \cdot \hat{\mathbf{v}} = c \) and "True" is returned. Otherwise, "False" is returned. In addition, for decoding purpose, the key string \( s \) is obtained by decoding \( \hat{c} \).

Figure 1: Illustration of the proposed encryption scheme.

Figure 2: Illustration of hash hiding process. For simplification, we illustrate the hiding process in a 3-dim space. Given the authentic datapoint and two random datapoints, a plane equation can be calculated for one application. We store coefficients of the plane equation, while the authentic datapoint is hidden. The intersection of two different planes (database collision) can shrink the range which contains the authentic datapoint (shown as the green line in the figure). We increase the dimension and guarantee the dimension is greater than the number of registered applications.
Security Analysis

Brute Force Attack

There are two possible ways to implement brute force attack. First, all possible input strings are tried. In this way, the security of our scheme is guaranteed by the hash function and the length of user’s register information. In our scheme, we use existing safe hash functions. In addition, if each user only needs to remember one password, he/she can keep one long password. Hence, it will be more difficult to implement this type of brute force attack to our encryption scheme.

Second, someone may try all possible datapoints in the ambient space. Although many fake keys (those datapoints located on the hyperplane) to our scheme are generated, the whole space is also exponentially expanded. For simplification, we assume that the hash string includes \( l \) hex characters, where \( l \geq 128 \). Hence, the value range of each dimension \( x_i \) is \([0, 16^l - 1]\). As the ambient space is one dimension higher than the hyperplane, we can guess the intersection point (i.e. an 1-dim variable) of the hyperplane and an arbitrary axis. The possibility of a successful guess that satisfies the hyperplane equation is \( \frac{1}{16^l} \), where \( l \geq 128 \). This possibility is extremely low.

Dictionary based Attack

Our encryption scheme is hardly cracked by dictionary based attack. The requirements of dictionary based attack include 1) the hash process is kept the same, 2) the data pair of original input and corresponding hash string are known. In our scheme, the coefficient vectors are generated randomly every time and different applications store different coefficient vectors. The hash string of user’s register information is not accessible even the database is cracked. Therefore, the recording of leaked coefficient vectors is meaningless and the dictionary attack is not a threat.

Database Collision

Compared to existing hash based encryption schemes, our method is highly resistant to database collision. For each application, a new hyperplane is randomly generated. When a database is hacked and coefficient vectors are leaked, the risk is that one dimension will be associated to others and the range that contains authentic datapoint shrinks. In other words, if two hyperplanes intersect, the free dimension of points on the intersection will reduce by 1-dim (illustrated in Fig. 2). The authentic datapoint must be on the intersection, so the search range shrinks. Only if at least \( d \) hyperplanes intersect, i.e. \( d \) different applications that contain the same register information are hacked, the original hash string \( h \) of user’s register information can be discovered. For preventing this attack, we can simply increase \( d \). For example, if \( d > 100 \), it is enough to guarantee the security of most users’ register information.

Experiments

We implement our method in Python and release the code on Github[^1]. In our experiment, \( d \) is set to be 100, and \( \text{SHA-256} \) is used as the hash function. Experiments show that our method can effectively register and verify user’s information.

Conclusion

In this paper, a novel encryption scheme is proposed to prevent the attack of database collision. We store coefficient vectors which is randomly generated, instead of keeping original hash string of register information. Hence, the dictionary based attack and database collision can be effectively prevented. Using our scheme, every user only needs to keep one register information (e.g. one account and password) for all applications.

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[^1]: https://github.com/PatrickZH/One-Password