

Prompted User Retrieval of Secret Entropy: The Passmaze Protocol

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Abstract

A prompting protocol permits users to securely retrieve secrets with greater entropy than passwords. The retrieved user secrets can have enough entropy to be used to derive cryptographic keys.

1 Introduction

Users are generally treated as the weakest link in the information security chain. One of users' main contribution to security is low-entropy passwords. Users' long-term keys, if any, are generally stored in a device, encrypted with passwords. The entropy of a user's password, say 20 bits, represents the relative cost for an adversary to extract the key from its password-encrypted form, which would be approximately 2^{20} password-decryptations in this example. Access to the stored password-encrypted user key should therefore be limited.

Passwords may provide adequate security in many applications. However, the low-entropy nature of passwords is not intrinsic to human nature, but rather to the computer user interface. Human memory, including memory of individual secrets, has a capacity far greater than what is needed for a secure cryptographic key. Unfortunately, keyboard entry of passwords (or passphrases) has relative low entropy input rate per character stroke, and as the number of character strokes increases, so does user inconvenience and chance of user error. With proper prompting however, the entropy rate input per character stroke (or mouse click) can be considerably increased. This may be useful in certain applications.

A prompting protocol described in this paper provides a secure and reliable method for users to input high-entropy secrets. Its name, *passmaze*, is derived from *passphrase* and indicates the fact that the user must navigate a maze of challenges and responses. Many systems have been proposed to mitigate the various deficiencies of using passwords (see references section), but the passmaze protocol is intended to replace passwords with something potentially more secure.

2 The Passmaze Protocol

This section describes the protocol. First, the user interface is described. Second, the underlying cryptographic operations are described.

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2.1 User Interface

An example of a user interface to the passmaze protocol is shown in Figure 1. A *render* function, computed by the client device, converts cryptographic value, computed by the client and server, into a prompt r_{j-1} . The example interface renders the prompt r_{j-1} as a list of English words from a fixed dictionary. The user input is a choice c_j of one word from the prompt r_{j-1} . The client device converts the user input into a cryptographic value, which is then used to compute the next prompt r_j .

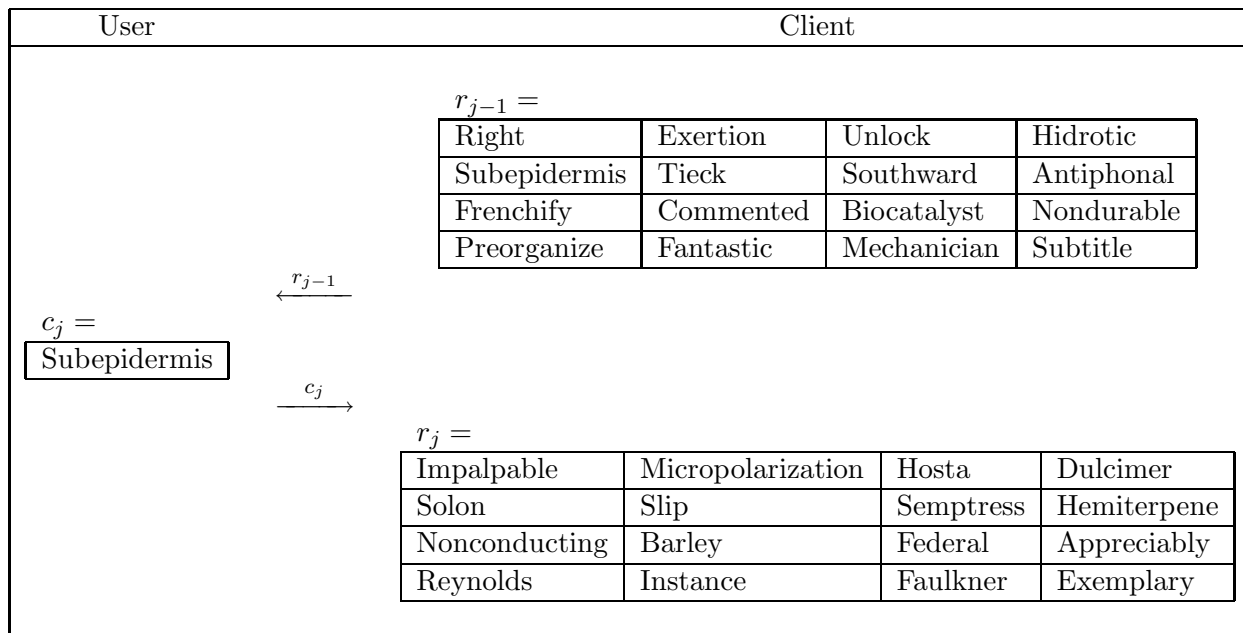


Figure 1: Prompt, Choice and Next Prompt in a User Interface

Other user interfaces are possible in the passmaze protocol:

- Other languages than English.
- Proper names, instead of dictionary words.
- Nonsense words, instead of dictionary words.
- Photographic images from a database, instead of words in the list.
- Client-generated abstract images, instead of words in the list.
- Larger (generated or from a database) images, instead of lists of images, where the user chooses a portion of the image.
- Larger (generated or from a database) images, instead of lists of images, where the user types some short string associated with the string.
- Animated images, such as a maze, that the user navigates in a game-like fashion.

Users can be given the option to customize the interface, without altering the underlying cryptographic protocol. Customized interfaces may enhance resistance to over-the-shoulder attacks,

where the adversary is a person who gets to see parts of the prompt, because the customized interface would be less familiar to the adversary and so less likely to be remembered. User interfaces may optionally provide a back feature that undoes the previous choice so that authorized users can correct occasional accidental mistakes.

For security, the user interface should have certain characteristics. User inputs must be convertible into precise cryptographic values that determine the user secret. Values of user’s secret should be assigned with enough entropy. (It is preferable to customize the interface rather than the secret values.) The user interface should not be accessible to adversaries. Each choice of the user contributes some entropy to the total secret. The entropy of the total secret is the sum of the entropy of each choice. The example user interface in Figure 1 has 4 bits of entropy per user input, so would provide 80 bits of entropy if 20 rounds of user input were used.

2.2 Cryptographic Operations

The underlying cryptographic operations of the passmaze protocol can be instantiated with a variety of different cryptographic algorithms. A single round of the protocol, using a client-server network model and an algorithm instantiation with hash functions and elliptic curve cryptography, is illustrated in Figure 2.

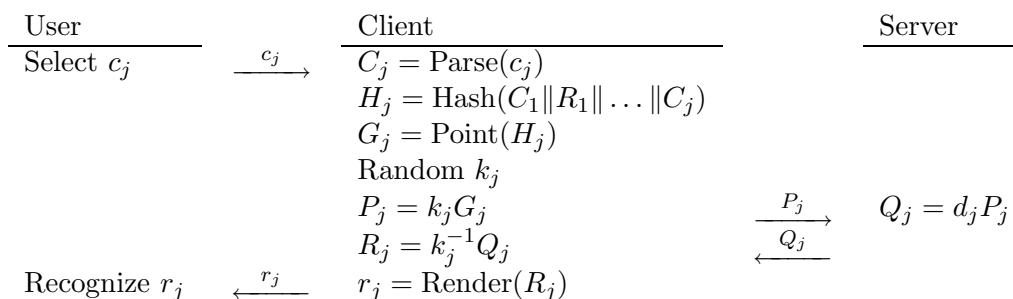


Figure 2: Round j of the protocol

After the final round, the client derives the retrieved key from all the intermediate round values. Neither the client nor the server stores any permanent records of any of the individual user choices c_j and client responses r_j . The only permanent record of the choices c_j must be derived in some way from the final retrieved key.

The client does not know whether any user selection c_j is correct or not, so does not provide any explicit feedback on the correctness of each c_j to the user. The client responds to every choice as if correct, so computes the next prompt r_j as a function of c_j , for whatever value of c_j the user entered, whether correct or not.

The authorized user may be able to detect if her choice c_j was correct by observing r_j . The prompt r_j , if correct, should contain her next choice c_{j+1} . If she does not see her next choice c_{j+1} if r_j , then she will conclude that either she accidentally misentered the wrong choice for c_j or that something is amiss in that the client and server are failing to operate correctly. If the user notices the problem frequently, then she should temporarily cease using the protocol and seek help from a system administrator because of the possibility of an attack.

The adversary as an unauthorized user, however, will not be able to tell whether response r_j is valid, because he does not know c_{j+1} . He has no way to confirm his guess at c_j . This explains why it is crucial for the client not to reveal the correctness of individual values c_j to the user, because if it did, then the adversary could guess values of c_j until the correct one is confirmed.

The client should force the user to make all choices c_1, c_2, \dots, c_n before getting any feedback about correctness. A result is correct only if all the c_j are correct.

Because the client blinds its communication with the server, the user can remain anonymous during the key retrieval process. Anonymity has certain advantages and disadvantages. If anonymity is not desired, then the client can reveal the identity of the user to the server. Furthermore, the server may be able to customize its responses to individual users, which may enhance the security somewhat. Another blinding mechanism and server secret function pair is based on the RSA and its variants. See [19] for details.

The server acts as a raw ECDH oracle, which has some potential security risks [9]. This risk can be avoided by using specially chosen groups, or by the client being implemented as a trusted module that the server can authenticate.

Although the retrieved key can be used for any purpose, probably the most versatile use of the retrieved key is to protect other user keys. The retrieved key can then protect an arbitrary amount of user keying material.

The server and the client can be embedded on the same device. In this approach, the server could be specific to the user, so that the server private key is unique to the user. Then, other devices cannot impersonate the user's device in order to steal the user's secret. This mechanism has considerable security benefit.

The client can include decoys in the prompt. The decoys are random options that are not deterministic functions of the user's previous selections. The decoys serve mainly to prevent over-the-shoulder attacks in which an adversary sees just one option per round. Even if these options are not the user selections, the adversary can test all the choices for c_j to see if r_j has an observed option. The number of log-on attempts adversary would need in this case is about the number of rounds times half the number of options per round. Each observation that is a decoy, however, costs such an adversary somewhat. If the j^{th} seen option is a decoy, then the adversary has to guess both c_j and c_{j+1} to see if the $(j+1)^{\text{st}}$ option appears in r_{j+1} .

3 Analysis

This section presents some preliminary usability and security analysis of the protocol.

3.1 Usability

Preliminary experiments have shown that sixteen randomly assigned challenges rounds of sixteen choices of random words can be successfully recognized, even with delays of a few months between attempts. Longer periods tend to result in an inability to recognize to identify the correct challenges from the previous responses.

In a Java prototype of the system, the client and server were merged and the responses calculated by inclusion of a secret in the SHA-256 evaluation. The user's first challenge consisted of a conventional user identity `dbrown` and password (not displayed) `certicom`, which was not randomly assigned. The dictionary of words used was 2^{16} words extracted from a commonly available freeware spell-checker.

The prototype included, for testing purposes, back and forward buttons to give the test-user a chance to try to challenges until they got a response they recognized. Responses were generally recognized mainly by the presence or absence of the next challenge word, but also somewhat by the presence of other words. Familiarity with the other words in the response could gradually erode the user's ability to select the next challenge, as all words sparked recognition to similar degrees. A mechanism for emphasizing recognition of the user's challenge values was not incorporated in

the prototype but might be helpful in an actual system, provided it does not compromise security. The prototype did not incorporate decoys or randomized presentations, so the usability of these features is not yet established.

3.2 Security

If strong entropy is enforced, (that is, the user challenges are assigned not user-selected), the server key is not useful for launching an off-line dictionary attack against the user.

Denial-of-service attacks on the server are a serious concern, because the server applies its secret function to any message it receives. An attacker could bombard the server with numerous messages, forcing the server to calculate its secret function repeatedly. One method to partly mitigate these attacks is to require the client to perform a slow calculation that the server can verify quickly, such as solving the discrete logarithm problem in a small group, or factoring a small integer.

Another risk of the protocol is that user makes the challenge selection by rote, without examining the responses. In this case, the user will not authenticate the responses, which could be risky. The user will not be sure the correct key will be retrieved. In addition, if an over-the-shoulder attack or keyboard-bug attack is being launched the pattern of the user's selections may be learnt. To mitigate these two risks, the client can randomized the presentation of the responses and challenges. Thus, although the user's challenges are identical, they must be entered in a different way each time.

The main advantages of this interactive protocol over typical password-only protocols are that users are:

1. Able to remember cryptographically strong secrets.
2. Immune to off-line dictionary searches, even from trusted authorities.
3. Able to retrieve a stable signature or decryption key.
4. Not prone to accidentally revealing secrets into existing insecure password systems.
5. Able to directly authenticate server, not just through a certificate installed in the client.
6. Able to be anonymous.
7. Able to customize representation of challenges and responses.
8. Less likely to forget secrets after long periods without use.

This set of security advantages may fit some security application niche in which passwords do not provide adequate security.

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