Pathwords: a user-friendly schema for common passwords management

Michele Finelli*
7th February 2008

Abstract

Many computer-based authentication schemata are based on passwords. Logging on a computer, reading email, accessing content on a web server are all examples of applications where the identification of the user is usually accomplished matching the data provided by the user with data known by the application.

Such a widespread approach relies on some assumptions, whose satisfaction is of foremost importance to guarantee the robustness of the solution. Some of these assumptions, like having a “secure” channel to transmit data, or having sound algorithms to check the correctness of the data, are not addressed by this paper. We will focus on two simple issues: the problem of using adequate passwords and the problem of managing passwords.

The proposed solution, the pathword, is a method that guarantees:

• that the passwords generated with the help of a pathword are adequate (i.e. that they are not easy to guess),
• that managing pathwords is more user friendly than managing passwords and that pathwords are less amenable to problems typical of passwords.

Contents

1 Passwords: they are useful only if they are robust 2
2 A simple solution: write them down 4

*BIODEC — m@biodec.com
1 Passwords: they are useful only if they are robust

Assume to have a service $S$ which must be accessed only by trusted users. The authentication of a user $U$ is accomplished by having $U$ to provide for an identity (usually a user name $u$) and for a secret password $p$. The secret must be known only to $U$, to $S$ and to no other and it must match the secret that the service already know.

This schema allows $S$ to check that a user $U'$, faking for $U$, is not the intended user, since $U'$, by definition, is not able to provide to $S$ the $p$ that is linked to $u$. As usual, we assume that the identities are publicly known, or that an attacker can easily discover them, and that all that must be kept secret are indeed the passwords.

Since $p$ is known only to $U$, this system is robust only if the following assumptions hold:

1. $p$ is not “easy” to guess — we will make clear the exact formal meaning of “easy” in a moment,

2. $U$ has a simple and friendly way of managing its own many $p$, corresponding to its many identities in its many services, otherwise $U$ can be tempted to write them down somewhere, or to use “simple” $p$ that are amenable of being stolen or guessed.

Of course, the above list is not complete, since in a real-world case there can be many other issues to be considered, depending on the technology, on the relevance of the accessed services or on the particular characteristics of the interaction between $U$ and $S$.

From now on, when we talk about services, we assume them to be like those mentioned in the introduction (terminal login, access to email or to web-based applications, and so on), where an actor has to provide its own data to a computer program, through a keyboard or any other similar device: this range of services, far from being complete, is of great relevance to the daily practices of many Internet users.

1.1 Easy passwords are an hard problem

What is an “easy” password in the sense of item II above? It is a secret that is not so difficult to discover.
Assume, without loss of generality, that $p$ is simply a word in the full language $A^*$ of an alphabet $A$. If we know that $p$ is of length $n$, then there are $|A|^n$ possible guesses for $p$. This means, that, if $p$ is randomly chosen, and there are no biases, the probability of guessing it is only $|A|^{-n}$ and that there need approximately $|A|^n/2$ attempts to guess it. We associate to each service $S$ a time frame $T_S$ that measures how long it takes, on average, to guess one $p$ for $S$, and we say that that $p$ is adequate for $S$ when the estimated time to guess is greater that $T_S$. A $p$ which is not adequate, is easy.

Of course, in a perfect world, $T_S$ would be infinite, but this requirement is clearly impossible. For example, if we take $A$ as the binary alphabet $\{0, 1\}$, $T_S$ as one year, and we assume that an attacker can check by brute force $10^6$ passwords each second, we have that an adequate $p$ must be strictly more that 46 bits long since:

$$2^{45} > 10^6(\text{pwd/sec}) \times 3600(\text{sec/hour}) \times 24(\text{hour/day}) \times 365(\text{day/year})$$

If we assume that the attacker gets stronger or weaker computational power, the estimate changes consequently.

Forty-six bits of password are not too many: they are guaranteed by a 7 letter random string chosen from the ASCII alphabet (which has $2^7$ characters in it). In practice, we already face a problem, since a randomly chosen word in ASCII$^7$ can be very hard to remember and technically very hard to type on an ordinary keyboard, due to the presence of codes that are interpreted as control characters. If we stick to a more ordinary alphabet of 16 letters, like the hexadecimal code, we need a twelve letter password (which really is 48 bits long): it surely is simpler to write (since we have only ten digits and the letters A, B, C, D, E and F) but it can be even harder to remember. Please try to remember this string, you will be asked about it later:

`AC43 A172 E1CB 879D`

Remembering many different passwords is a heavy burden, recognised by many researchers. Many security practices (see [1] and [3], for example) warn against writing down complex or long passwords, since this helps potential attackers. On the other side, the same practices advise against using common words or strings that have a meaning since this makes the passwords amenable to dictionary attacks. In both cases it is entirely a user problem to manage their (many) passwords in order to fulfil security requirements and to be able to use the same passwords efficiently. In is reported in [2] (pages 104 - 105) that “... entropy (.) of standard English at less than 1.3 bits per characters; passwords have less than 4 bits of entropy per character”, as opposed to the theoretical 8 bits of entropy of an ASCII character.
2 A simple solution: write them down

Some solutions to the above conundrum have been proposed, like having external tokens or devices that provide the secret that uniquely identifies the user, or using helper programs that store securely the passwords.

In the following we will propose an alternate schema, called path-words, which we believe is:

- secure (i.e. it allows the management of adequate passwords),
- user friendly (i.e. it is easy to devise helper applications, to remember and use passwords, and so on).

The following example explains the idea behind the pathword approach.

![Figure 1: First example](image1)

How easier is an attacker job if we state that our own secret password is stored in the diagram of picture [1]? By “stored” we mean that we are able to read it out from the picture, with no other help.

Quick, now: which was the secret hexadecimal word of the previous section? Have you been able to remember it correctly? If the answer is yes, congratulations for your memory, otherwise the following hint may be useful.

![Figure 2: Annotated example](image2)
The numbers appearing at the exponent of some letters indicate the order to follow to read out the secret word: first the letter \(a\), then \(c\), and so on, ending with \(9\) and \(d\). Another picture shows even more clearly the pattern followed to read out the password.

It is our position that remembering patterns (or paths) like those depicted in picture 3 is easier than remembering passwords, that this practice leads people to use stronger passwords and that no security is lost in the process. By “security”, here, we mean that the practice of remembering passwords with the help of patterns like those sketched above does not help an attacker significantly.

3 Analysing pathwords

Informally, a pathword \(\pi\) is any walk on the cells of a table like that previously depicted. Formally, a pathword \(\pi\) is a function between elements of some space \(S\) (in the previous example, \(S\) is the space of 6x6 matrices over the hexadecimal code alphabet) to the strings over another alphabet. For the sake of simplicity, and with no loss of generality, we assume that the two alphabets are always the same. It is easier to represent pathwords with diagrams like those of figure 3 but any other representation is obviously equivalent. For example, the transformation given by figure 3 is

\[
\pi(\{a_{i,j} | 1 \leq i, j \leq 6\}) = a_{1,1}a_{1,2}a_{1,5}a_{2,1} \ldots a_{5,5}a_{6,1}a_{6,2}a_{6,6}a_{6,5}
\]

Some key points to be considered are the following:

- users should have more than one pathword, perhaps a least three or four, perhaps clustered around different security concerns (for example, an “easy” pathword like the one above to read out password to access less important services, another one for more important services and a more complex one to read out password of really sensitive services),
• the diagrams themselves can even be public, since they convey no useful information to potential attackers (see about this in section 3.1),

• users should not try to make their passwords easier to remember or to build them following rules: in fact doing this will lower the effective complexity of the password, making it easier to guess.

The key question to be answered is: “Assuming the adoption of a pathword, does this undermine the security of the identification process? If not, under which further assumptions?” The remaining of the paper is devoted to examining this question.

3.1 Robustness of pathwords vs passwords

Let’s define as \( d \) any diagram (for example a table) on an alphabet \( A \). Then a pathword is a function \( \pi : d \rightarrow p \) which maps \( d \) to a \( p \) in \( A^* \). Given a length \( n \), the probability of guessing a random string in \( A^n \) is \(|A|^{-n}\). If \( d \) contains only a subset \( A' \) of letters, and \( \pi \) does not have repetitions (i.e. it never passes twice on any cell), then the number of possible sequences is lower-bounded by

\[
\prod_{j=1}^{n} (|A'|- (j-1))
\]

Since we have no constrains on \( d \), other than the usability of the proposed solution, we can declare that the process of generating \( d \) is not completely random, and that \( A' = A \). The ratio \( r \) between the number of sequences obtained by \( \pi \) and the number of sequences of a perfectly random process is

\[
r = \frac{\prod_{j=1}^{n}(|A| - (j-1))}{|A|^n} = \prod_{j=1}^{n} (1 - \frac{j-1}{|A|}) \geq (1 - \frac{n-1}{|A|})^n
\]

if we set \( k = |A|/(n-1) \) then we have

\[
r \geq (1 - \frac{1}{k})^{1+|A|/k}
\]

if \( |A| >> n \), \( |A| \) is big and \( n \) is small, also \( k \) is big (since it is approximatively a \( n^{th} \) fraction of \( A \)) and \( (1 - 1/k)^k \) is approximable by \( e^{-1} \), so

\[
r \geq \frac{1}{e|A|/k^2}
\]
but $|A|/k^2 = (n - 1)/k << 1$. This means that $r$ is not far from 1
(in the worst case, if $A$ is comparable with $k^2$, $r$ is still bigger that $e^{-1}$
or approximately 37%).

**Theorem 1** Assume that $A$ is large and $n$ is small, as in the above analysis. Given a password $p \in A^n$, and given a diagram $d$ where all the letters in $A$ appear, it is possible to have a $\pi(d)$ of the same strength of $p$ just taking $\pi(d) \in A^{n+1}$

**Proof:** Since in the worst case the ratio between the number of available sequences and the full set is only of $e^{-1}$, this means that the gain of a possible intruder is less than $e$ times. Choosing a longer word, of just two more bits, enlarges the password space by four times, negating the above speedup. Since $A$ is large, by definition, it is enough to add one single letter. □

By theorem 1, using pathwords does not imply to have longer passwords, in the worst case, just one character longer.

### 3.2 An interface to a pathword system

It is not clear yet which is the better trade-off between the size of the alphabet $A$, the size of passwords $p$ and the best way to deploy diagrams $d$.

Assume that $d$ is a square matrix of 100 elements and that the alphabet is composed of all the couples of digits (i.e. the alphabet of the 100 “letters” ranging from 00, 01, … to … 98, 99).

Notice that to have a 64 bits password $p$, $p$ must be at least ten characters long. A pathword of length ten is not too complex to remember and can be even something with very few structure in it, and yet short enough to be remembered. Just to make a comparison, the pathword of picture 3 is structured, the one 4 is less, the one 5 has been randomly generated.

|   | 1 | 4 | 10 |
|---|---|---|----|
|   | 7 |
| 9 | 3 |
| 6 | 2 |
|   | 5 | 8 |

*Figure 4: “Triangle-shaped” path*
In the above example we have by explicit calculation that $r \approx 63\%$. This means that it can be a realistic scenario. Notice that a 10 x 10 square table is not very big; it can be easily shown on a web page, even on a PDA or printed on a sheet of paper of the size of a credit card.

### 4 Discussion

The following are some question that naturally arise.

*What happens if a user loses a pathword? And if it stolen?*

If a user has just one single pathword, and if it is stolen or lost, this can be a big problem, since an attacker will be able to access all the users’ passwords, just by reading them from the diagrams. If a user had many pathwords, the loss is mitigated by the reduced number of accessible passwords.

Comparing the loss of a password to the loss of a pathword, losing the pathword is potentially worse, since it subsumes the simultaneous loss of many passwords.

*Why should be easier to remember a pathword instead of a password?*

It should be easier for two reasons:

1. a user should have few pathwords, instead of passwords by the dozen,
2. humans are better suited to remember visual patterns than random (i.e. structure-less) strings.

*Is it not enough to keep passwords in a secure device — like a PDA with some application — in some encrypted form?*

Maybe. But notice that if a secure solution is available to manage passwords, there should be no reason, in principle, for not using it also to manage pathwords.

Having pathwords, instead of passwords, exposes the user to no further risk, if the application is secure.
Are passwords really not secure, in practice?

We are not aware of definitive conclusions on this issue, but some previous works point out that:

- **real** passwords are not truly random and are exploitable with brute force attacks,
- people reuse the same passwords, sometimes even for services of different importance (for example, exposing the risk to have their electronic bank account accessed with the same credentials used to post on a public web forum devoted to their hobbies),
- if people are forced to use really strong passwords, or to change them frequently, they tend to write them down somewhere, devising their own tricks to camouflage them,
- changing passwords is an issue: people tend to reuse two passwords, switching between them (i.e. having a summer password and a winter password), or to generate a new password appending or changing some character to their previous password (i.e. passwordA, passwordB, and so on). Technical solutions avoid these behaviours, but empirical evidence shows that changing passwords frequently really annoys users.

Notice how pathwords address the above issues:

- passwords read from pathwords tend to be adequate,
- passwords are never reused: in fact, since a diagram can be generated by the service to be accessed, there is a practical guarantee that no two diagrams are equal,
- the number of pieces of information that has to kept secret is low, and so there is less pressure to devise ways of remembering them,
- changing passwords can be an issue no more: a service can even change the password each time it is accessed, just by providing the user with a different diagram each time.

References

[1] ed. Daniel F. Sterne. An introduction to computer security: The nist handbook. NIST Special Pubblications 12, 1995.

[2] B. Schneier. *Applied Cryptography*. Wiley, 1999.

[3] Marianne Swanson and Barbara Guttman. Generally accepted principles and practices for securing information technology systems. NIST Special Pubblications 14, 1996.