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CAPTCHA in Graphical Protection System Using Hardoi Authentication

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ABSTRACT:

Text-based Protection Systems have inherent security and usability problems, leading to the development of graphical Protection Systems. However, most of these alternate Systems are vulnerable to hardoi attacks. We propose a new System, using CAPTCHA (Completely Automated Public Turing tests to tell Computers and Humans Apart) that retaining the advantages of graphical Protection Systems, while simultaneously raising the cost of adversaries by orders of magnitude. Furthermore, some primary experiments are conducted and the results indicate that the usability should be improved in the future work.

Keywords:

graphical Protection; CAPTCHA; hardoi; authentication

1.INTRODUCTION:

A key area in security research and practice is authentication, the determination of whether a user should be allowed to access to a given system or resource. Generally, the most common and convenient authentication method is the traditional alphanumeric Protection. However, their inherent security and usability problems [6-11] led to the development of graphical Protections as an alternative. To date, there have been several graphical Protection Systems, such as [7, 18, 20-26]. They have overcome some drawbacks of traditional Protection Systems, but most of the current graphical Protection Systems remain vulnerable to hardoi attacks. Commonly, a hardoi is a software that, from a user's perspective, covertly gathers information about a computer's use and relays that information back to a third party [1].

Hardoi has gradually become one of the most common security threats to computer systems. Protection collection by hardois has rapidly increased [4, 5, 12, 13, 15]. The research community has expended much effort [4, 16, 17, 18, 20, 26] on this topic. However, how to protect Protections effectively against hardoi attack continues to be a problem. Observing that a practical hardoi attack is done by an automated program, we propose a new approach where CAPTCHA is exploited.CAPTCHA (Completely Automated Public Turing tests to tell Computers and Humans Apart) is a program that generates and grades tests that are human solvable, but beyond the capabilities of current computer programs . The robustness of CAPTCHA is found in its strength in resisting automatic adversarial attacks, automatic adversarial attacks, and it has many applications for practical security, including online polls, free email services, search engine bots, worms and spam, and preventing dictionary attacks . Our proposal creates aninnovative use of CAPTCHA in the context of graphical Protections to provide better Protection protection against hardoi attacks.

In this paper, we have proposed a new authentication System combining graphical Protections with text-based CAPTCHA. The System is easy for humans but makes it almost impossible for automated programs to harvest Protections. The novel System is friendly for legitimate users, while simultaneously raising the time and computer capacity cost to adversaries by several orders of magnitude. Experiments showed its effectiveness, but also indicated further research would improve its usability.The rest of the paper is organized as follows. Section 2 briefly reviews related work. Sections 3 and 4 present our System and analyses its security. Section 6 provides the results of experiments described in section 5. Section 7 discusses additional observations and possible extension to our System. Conclusions and future work are addressed in section 8.

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2.RELATED WORKS:

Most current graphical Protection Systems, such as [7, 21, 23, 24, 25], require users to enter the Protection directly, typically by clicking or drawing. Hence, Protections are easily exposed to a third party who has the opportunity to record a successful authentication session. There have been a few graphical Protection Systems devoted to secure Protections against hardoi attacks. In the following, several representatives will be described.Man, et al [20] proposed that users remember a number of text strings as well as several images as pass-objects. To pass the authentication, users should enter the unique codes corresponding to the displayed pass-object variants and a code indicating the relative location of the pass-objects in reference to a pair of eyes. It is relatively hard to crack this kind of presented in [22] does not provide sufficient security, having only two objects in each group.In 2006, Weinshall proposed another challenge-response protocol that relied on a shared secret set of pictures [18].

To reduce the amount of information given out with each authentication session, the image set memberships are used to select a certain path on an image mosaic, with the user providing only a code that depends on the path's endpoint. This System was claimed to be so strong that an observer who fully records any feasible series of successful interactions could not compute the user's Protection. However, it was demonstrated by Golle and Wagner [19] that the attacker can learn a user'ssecret key with a SAT solver after observing as few as six successful user logins.In essence, the above methods adopt a challenge-response protocol to confuse the hardoi. They can prevent the Protections being cracked by the hardoi and falling into the hand of an adversary, along with resisting replay attacks. Taking the previous mechanisms for reference, our System also uses a challenge-response protocol to enhance security. But, unlike these methods, our System innovatively applies CAPTCHA to graphical Protections to create a highly secure authentication method.

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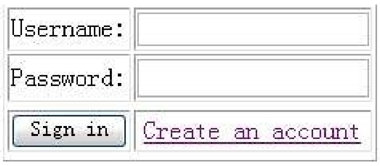


Figure 1. The interface of the basic System (The pass-images are circled).

3. OUR APPROACH:

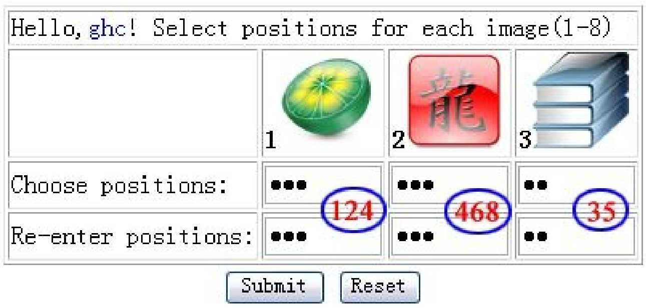
Our approach is motivated by the observation that effective hardoi attacks are launched from automated programs. We realized that to increase security Protections should be accompanied by a product of a "computation" that is difficult for machines. As an authentication method, the System should also be user friendly. Considering these requirements, we applied CAPTCHA to graphical Protection Systems.CAPTCHA is a program designed to test whether the user is a computer or a human, by creating a task easy for humansbut difficult for machines [27]. It is based on hard AI problems which cannot be solved with any greater accuracy than what is currently known to the AI community [31].

CAPTCHA is now almost a standard security mechanism for addressing undesirable or malicious Internet bot programs [28] and major web sites such as Google, Yahoo and Microsoft all have their own CAPTCHAs. The state-of-the-art CAPTCHAs mainly include three types: text-based Systems, sound-based Systems and image-based Systems. The most widely deployed Systems are text-based CAPTCHAs and we also use this in our Systems. After introducing a basic System with a hidden safety loophole, we will describe an improved System that is designed to fill the hole. The performances of the both Systems depend extremely on the property of CAPTCHA.

A. The Basic System:

The basic System embeds a text-based CAPTCHA into a simple graphical Protection System. Each image has a CAPTCHA instance called adjunctive string and the strings are generated at random by the system. In the register phase, users are required to select and remember images as their Protection images (pass-images). To be authenticated, users need to distinguish his/her pass-images as well as solve a test by recognizing and typing the adjunctive string below each pass-image. For example, in Figure 1, assume the three images with red circles are pass-images, users should input the adjunctive strings 'mewo', 'xnco' and 'nvso' correctly to pass the authentication.For simplicity, we assume that the CAPTCHA here is an ideal CAPTCHA that is hard enough for machines to recognize while easy for humans to solve.In the case that adversaries are automated programs without human intervention, the System has a strong resistance toreplay attack. Namely, even if it observes a successful login, a hardoi program cannot launch a replay attack. This can be illustrated from two aspects. Firstly, pass-images are entered by typing random adjunctive strings rather than clicking directly. In other words, the entered strings are the trap instead of the real Protection. Secondly, machines have no ability to recognize the characters embedded in each image. It follows that it is rather difficult for an automated program to find pass-images according to the recorded strings.

The loophole in this System occurs if the adversary is a person and the hardoi is an assistant. The Protection will be in danger because CAPTCHA is easy for a person. In this case, the person can see what the hardoi has gathered, a successful login scene along with the entered characters. Then, a person can crack the Protections without much effort. For 26 lower case letters in the System, the probability that different images have the same string is 1/456976, which can be ignored. One useful method for Protection cracking is to divide the gathered strings with four characters into groups and then compare each segment with that below each image. To close this loophole, we constructed an improved version.



(a) The interface of register.

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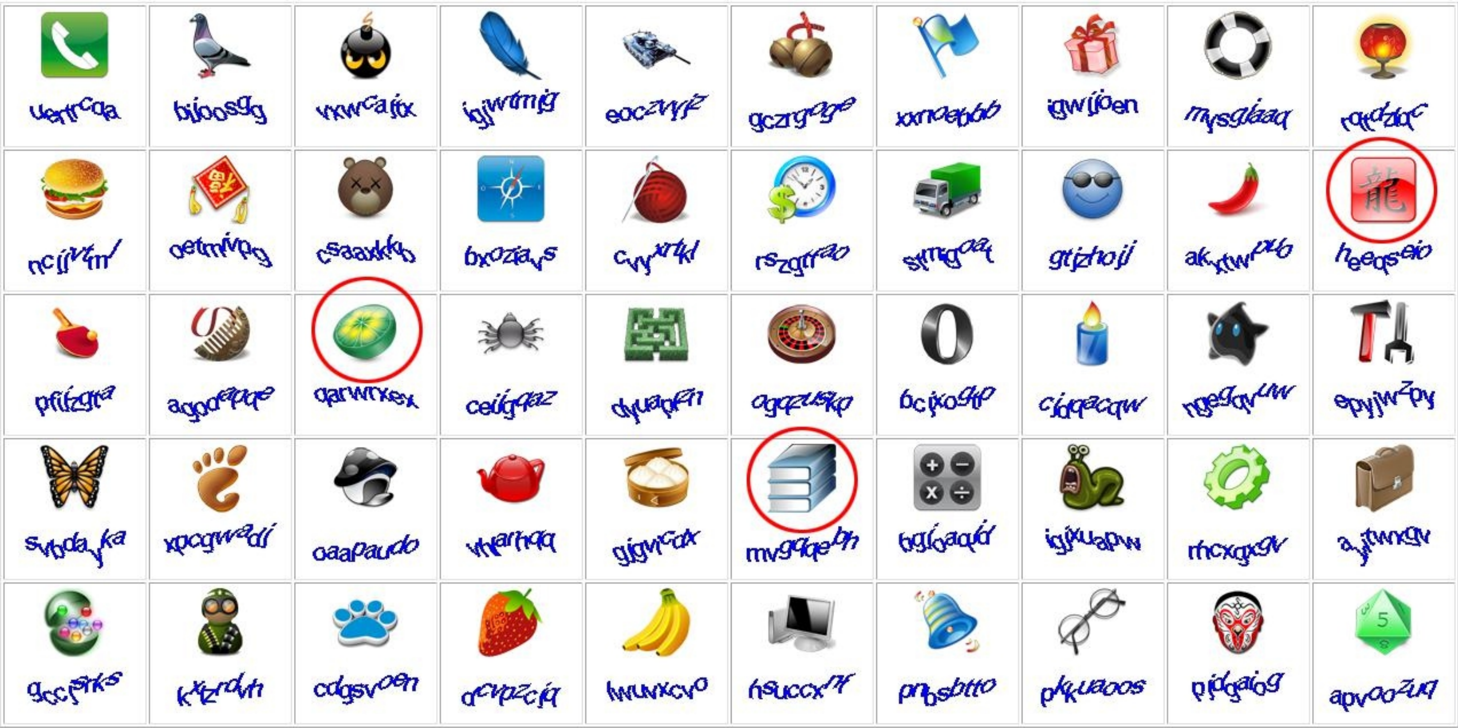

(b) A login screen of the same user 'ghc' in (a).
Figure 2. The interface of the basic System (The pass-images are circled).

B. The Imporved System:

The vulnerability of the basic System lies in two factors. One is the requirement that CAPTCHAs should be human user friendly. The other is the reversible relationship between Protections and what is entered. That is, pass-images determine what is entered and vice versa.

What's more, we noted that the reversible relationship depends greatly on the fact that the probability of different images with the same adjunctive string is close to zero and that the trap of each pass-image has a uniform length. While the former is necessary for a popular authentication System, we are encouraged to disturb the latter.

One possible method is increasing the probability by decreasing the types of letters or the length of adjunctive string. This method might work, but it will increase the probability of illegal login by random guessing. Thereby, it is ineffective as a security method. Our alternative is to replace the uniform length with a random one predefined by users. In other words, the number of characters entered is determined by users.

In our improved System, users are required to select and remember letter positions, ie choose several specific letter positions within a string of letters; for example, letters in 1st, 4th and 5th position in the string will become the code. These letter positions are the called pass-positions for each pass-image. During the authentication, users should enter the characters shown in the pass-positions of each pass-image. An example is shown in Figure 2.

In Figure 2(b), the three circled images are pass-images, the strings with them are 'qarwrxex', 'heeqseio', and 'mvgqqebh' respectively, and the corresponding pass-positions are (1, 2, 4), (4, 6, 8), and (3, 5) shown in Figure 2 (a). A user can input any combination of the three sequences, 'qaw', 'qeo', and 'gq' to be authenticated successfully.

This System is strongly resistant to attacks launched by humans with hardoi, while simultaneously preserving the advantages of graphical Protection Systems. The related security analysis will be given in the following section and usability problems will be discussed in Section 5, 6 and 7 through experiments.

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4.SECURITY ANALYSIS OF THE IMPROVED SYSTEM:

A. Capability to Withstand Hardoi:

There are many different kinds of hardoi [1, 2], such as browser hijackers, keyloggers and spybots. We have focused on the hardoi cluster that runs in the background collecting Protections. The security of our System relies on the robustness of CAPTCHA in resisting automatic adversarial attacks. However, it is not clear whether there is a true CAPTCHA at all and some reports show that some text-based CAPTCHAs can be partly or almost broken by automatic programs [3, 29, 30].

With the assumption that hardoi is capable of detecting and recording screen snapshots, entered strings and the system feedback, we will analyze the security of the improved System from two extreme aspects. Firstly, it is impossible for machines to solve the CAPTCHAs in our System, the ideal case. Secondly, CAPTCHAs can be completely solved by machines, the worst case.

Under ideal conditions, hardois have no chance of gaining the Protections without human invention, similar to t assistance can help users to break the System. What the hardoi needs to do is to catch the Protection string entered by the legal user. To crack Protections, adversaries should solve the CAPTCHA himself or by employing human workers. It is costly to obtain a Protection because the pass-positions of each pass-image are unknown and thereby it is hard to manually find the correspondence between pass-images and what is entered. Even for the lowest level security, adversaries must recognize 400 CAPTCHAs. In this case, there are three pass-images, each with a pass-position and then the attacker can easily divide the entered string into three segments each with a specific character. The probability of a letter displayed below one

image is $1-\left(\frac{25}{26}\right)^8 \approx 0.27$. For each authentication, there are

100 images on screen in our System with about 27 images which have a common specific character. That is, there are 27 candidates including a pass-image and 26 decoys. This illustrates that the attacker can gain a pass-image with a

probability of $\frac{1}{100\cdot\left(1-\left(\frac{25}{26}\right)^8\right)} \approx 0.037$ and can penetrate the

Protections with a probability of 3

observation and analysis. Through interaction, the attacker can gradually get rid of all the decoys. For the second observation,

the number of decoys will be $26\cdot\left(1-\left(\frac{25}{26}\right)^8\right) \approx 7$. After the

third observation, there will only be about three CAPTCHAs which contain the specific character. The attacker can find the users Protections correctly in four sessions. So the attacker must solve approximately 400 CAPTCHAs and conduct many observations and comparisons, which is time consuming and costly. More complex work is required if the correspondence between pass-images and entered strings are unknown. Therefore, our System has a strong resistance against hardois under the ideal environment.Projecting the worst condition, that CAPTCHAs can be completely solved by machines, it is possible that hardois could crack Protections because each successful login reveals some information about the Protection. One method is to divide the entered strings into different segments and find the Protections from images which contain the same segments from analyzing different login sessions. Another method is to find the common images by excluding images without any character of the entered string. For instance, when the Protections lie in the lowest security level, it is possible to crack the Protections in four sessions, as discussed above.

This worst case scenario is not probable, unless hardois can gather sufficient information in the background and can break CAPTCHAs quickly. Currently, no programs can break a CAPTCHA automatically in a short time. Furthermore, even ifDuring the testing phase, fifty images of 60×60 pixels and corresponding CAPTCHAs were displayed on the screen in the prototype of the improved System. All the images were downloaded from http://www.chinaz.com freeware website and processed for study only. The length of CAPTCHA strings was 8, and the characters contained 26 lowercase letters. The CAPTCHA algorithm was designed to generate crowded, distorted and rugged strings similar to the CAPTCHA being used in Google email service for its acknowledged robustness.

A total of 36 participants were invited to complete the experiments and answer some questions. The participants, of (4)of logging on successfully with a brute force attack.the currently applied CAPTCHAs are effectively broken, there will always be versions with higher security in production. In addition, as long as the hard AI problems underlying CAPTCHA are unsolved, successful attacks will advance the development of more robust CAPTCHAs.Therefore, it is demonstrated that our System is secure against hardoi as long as CAPTCHAs can not be broken by automa ted programs. Any defeated CAPTCHAs will be substituted by more robust ones. If humans are involved, the cost of cracking a Protection is significantly increased.

B. The Size of the Protection Space:

Now, we consider the raw size of the Protection space, assuming users are equally likely to pick any element as their Protection. According to the definition in [23], the raw size is an upper bound on the information content of the distribution that users choose in practice. We compute the size S(L, N, M) of Protection space oftotal entered length equal to L when there are N images displayed and the length of CAPTCHAs is equal to M. In our System, for security reasons, the number of pass-images is required to be not less than 3. Thus, S is defined in terms of P(K , L, N , M) , the number of Protections with number ofpass-images equal to K by:

$$S(L,N,M)=\sum_{K=3}^{L} P(K,L,N,M) \quad (1)$$

In turn, $P(K,L,N,M)$ can be defined in terms of $O(K,L,N,M)$, the number of Protections when the K pass-images have been confirmed, by:

$$P(K,L,N,M)=C_N^K\cdot O(K,L,N,M) \quad (2)$$

The reason is that the K pass-images have no relative order. Assume the number of pass-positions for one pass-image is n, we can get,

$$n_1+n_2+\ \ +n_K=L \quad (3)$$

Here, the problem can be seen as an issue of the ordered partitions of positive integer. L is partitioned into K ($1\le K\le L$) sections. According to the theorem of the partition of positive integer, the generating function of sequence of partitionnumbers is $(\sum_{j=1}^{M} x^j)^K$. We assume that there are $G(M,K,L)$ different partition situations in all, and any one partition can be denoted by:

$$F_i: n_{1i}+n_{2i}+\ +n_{Ki}=L\ (i=1,2\ldots G) \quad (4)$$

Then, $O(K,L,N)$ can be defined in terms of n by:

$$O(K,L,N,M)=\sum_{i=1}^{G}\prod_{q=1}^{K} C_M^{n_{qi}} \quad (5)$$

Combining the formulae, we can compute the size of the Protection space. The results for the Protection space are given in Table 1, when N=50, M=8, and 3 ≤ L ≤ 10 .Table 1 results are encouraging. however, that is the raw size of our Protection space. In practice, actual Protection space will be reduced due to users' individual preferences. Additionally, the size of the Protection space of our System is actually smaller than that of text-based Protections (94 printable characters available) when the length is equal to or greater than 10(9410 ≈ 5.4 1019). As we know, the exhaustive-search attack is always produced automatically by software rather than by people. In our System, CAPTCHA is introduced to resist this kind of attack. Subsequent CAPTCHA development maintains the security of our method, as each round of development becomes more difficult for automated cracking programs and more expensive for manual, human-based cracking programs.

TABLE I.NUMBER OF PROTECTIONS OF ENTERED LENGTH EQUAL TO L (N=50 AND M=8).

L	Protection space size	$\log_2$(#space size)
3	$1.0\cdot10^{7}$	23.3
4	$1.0\cdot10^{9}$	30.0
5	$8.3\cdot10^{10}$	36.3
6	$5.5\cdot10^{12}$	42.3
7	$3.1\cdot10^{14}$	48.1
8	$1.5\cdot10^{16}$	53.8
9	$6.6\cdot10^{17}$	59.2
10	$2.6\cdot10^{19}$	64.5

C. Brute Force Attacks:

Brute force attack, trying to randomly guess the correct Protections, is the simplest form of attack for an authentication System. For our System, with a candidate set of A characters,the probability that a single random guess succeeds is K! AL .

For one legitimate user, every time to authenticate, there are K! choices of entered string, since pass-images have no relative order. Just as the instance shown in Session 3.2, the user can enter any combination of three sequences to authenticate. Thus, there are six possible strings to enter, 'qawqeogq', 'qawgqqeo', 'qeoqawgq', 'qeogqqaw', 'gqqawqeo', 'gqqeoqaw'. For (A, L, K) (26,8,4) , we of logging on successfully with a brute force attack.

5. EXPERIMENTAL MENTHODOLOGY:

During the testing phase, fifty images of 60×60 pixels and corresponding CAPTCHAs were displayed on the screen in the prototype of the improved System. All the images were downloaded from http://www.chinaz.com freeware website and processed for study only. The length of CAPTCHA strings was 8, and the characters contained 26 lowercase letters. The CAPTCHA algorithm was designed to generate crowded, distorted and rugged strings similar to the CAPTCHA being used in Google email service for its acknowledged robustness. total of 36 participants were invited to complete the experiments and answer some questions. The participants, of whom there were 15 women and 21 men, were staff and students from a university community and unfamiliar with our System.

The average age of the participants was 27 years (StdDev=4.5), and ranged from 21 to 39 years. All the participants were required to complete the following operations individually.Firstly, they need answer a demographic questionnaire, which collected information including age, sex, highest degree earned and computer experience. At this session the System and procedures for the experiments were explained to them in detail.Secondly, the user was required to select three or more pass-images. After selecting the pass-images, the user set the pass-positions for each image. During the testing phase, if the participants forgot the pass-images or the pass-positions, the Protection which they have just set was shown to them.In the testing phase, the data were collected longitudinally: first, at end of the training session (P1), then one week later (P2), and finally one month later (P3). For P1, each participant was asked to set a Protection, and authenticate ten times. For P2 and P3, if a participant entered an incorrect Protection, he or she was allowed to re-enter the Protection. Three login attempts were permitted for each participant.

6.RESULTS:

A. The Mean Success Login Percentage:

In P1 testing session, 9 of 36 participants completed with no mistakes in ten times of login, while the others, to a greater or less extent, made some incorrect submissions. The mean success login percentage is 87.8% (StdDev=9.29) . The reasons offered by the participants for the incorrect submissions included difficulty in identifying the text-based CAPTCHAs generated by our algorithms and sometimes in locating the exact pass-positions.

B. The Mean Login Time:

In P1 testing session, the mean login time of all participants is 22.04 seconds (StdDev=10.9) which is acceptable for most participants. The results show that there is a significant difference in terms of time to respond to a challenge ($F(35,280) = 15.48$, $p<0.01$). The main reason may be that the CAPTCHAs are randomly generated so that sometimes they are easy to recognize but sometimes more difficult. As the images are randomly located, the time for recognition also differs. Results show that the majority of participants chose three to five pass-images, with only three participants choosing more than five pass-images. Mean times and standard deviations of logins with different pass-images are shown in Table 2.

C. Protection Memorability:

In P2 testing session, 80.6 percent of participants successfully logged into his/her account in three attempts, and in P3 session, 72.2 percent participants were successful. Interviews with participants provided the following reasons for memory lapses: a) the difficulty of remembering the pass-positions and b) the difficulty of remembering the relationships between pass-positions and pass-images.

TABLE II.MEAN TIMES (SECONDS) AND STANDARD DEVIATIONS OF CHALLENGES WITH DIFFERENT PASS-IMAGESL

Numbers of pass-images	Numbers of persons	Mean	StdDev
3	18	17.57	7.7
4	12	24.76	6.7
5	3	44.00	16.8
6	1	25.87	4.5
7	1	16.87	3.6
9	1	15.37	5.4

7.COCLUSION:

In comparison to other graphical Protection Systems, such as [7,14,26], there are some advantages and disadvantages in our improved System. One disadvantage is that it is more complex and increases users' memory load. Users have to remember both the pass-images and pass-positions. To be authenticated, users need to recognize the pass-images and input the characters of the text-based CAPTCHAs on the pass-positions correctly. These factors have increased the complexity of the login process. However, although it is complex and cumbersome, the improved System is strongly resistant to hardois, which is our primary focus.

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