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Captcha as Graphical Passwords—a New Security Primitive Based On Hard Ai Problems

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ABSTRACT: Many security primitives are based on hard mathematical problems. Using hard AI problems for security is emerging as an exciting new paradigm, but has been underexplored. In this paper, we present a new security primitive based on hard AI problems, namely, a novel family of graphical password systems built on top of Captcha technology, which we call Captcha as graphical passwords (CaRP). CaRP is both a Captcha and a graphical password scheme. CaRP addresses a number of security problems altogether, such as online guessing attacks, relay attacks, and, if combined with dual-view technologies, shoulder-surfing attacks. Notably, a CaRP password can be found only probabilistically by automatic online guessing attacks even if the password is in the search set. CaRP also offers a novel approach to address the well-known image hotspot problem in popular graphical password systems, such as PassPoints, that often leads to weak password choices. CaRP is not a panacea, but it offers reasonable security and usability and appears to fit well with some practical applications for improving online security.

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I. INTRODUCTION

A fundamental task in security is to create cryptographicprimitives based on hard mathematical problems that are computationally intractable. For example, the problem of integer factorization is fundamental to the RSA public-key cryptosystem and the Rabin encryption. The discrete logarithm problem is fundamental to the ElGamal encryption, the Diffie-

Hellman key exchange, the Digital Signature Algorithm, the elliptic curve cryptography and so on. Using hard AI (Artificial Intelligence) problems for security, initially proposed in [17], is an exciting new paradigm. Under this paradigm, the most notable primitive invented is Captcha, which distinguishes human users from computers by presenting a challenge, now a standard Internet security technique to protect online email and other services from being abused by bots. However, this new paradigm has achieved just a limited success as compared with the cryptographic primitives based on hard math problems and their wide applications. Is it possible to create any new security primitive based on hard AI problems? This is a challenging and interesting open problem. In this paper, we introduce a new security primitive based on hard AI problems, namely, a novel family of graphical password systems integrating Captcha technology, which we call CaRP (Captcha as gRaphical Passwords). CaRP is click-based graphical passwords, where a sequence of clicks on an image is used to derive a password. Unlike other click-based graphical passwords, images used in CaRP are Captcha challenges, and a new CaRP image is generated for every login attempt. The notion of CaRP is simple but generic. CaRP can have multiple instantiations. In theory, any Captcha scheme relying on multiple-object classification can be converted to a CaRP scheme. We present exemplary CaRPs built on both text Captcha and image-recognition Captcha. One of them is a text CaRP wherein a password is a sequence of characters like a text password, but entered by clicking the right character sequence on CaRP images. CaRP offers protection against online dictionary attacks on passwords, which have been for long time a major security threat for various online services. This threat is widespread and considered as a top cyber security risk [13]. Defense against online dictionary attacks is a more subtle problem than it might appear. Intuitive countermeasures such as throttling logon attempts do not work well for two reasons:

1) It causes denial-of-service attacks (which were exploited to lock highest bidders out in final minutes of eBay auctions [12]) and incurs expensive helpdesk costs for account reactivation.

2) It is vulnerable to global password attacks [14] whereby adversaries intend to break into any account rather than a specific one, and thus try each password candidate on multiple accounts and ensure that the number of trials on each account is below

the threshold to avoid triggering account lockout.

III CAPTCHA AS GRAPHICAL PASSWORDS

A. A New Way to Thwart Guessing Attacks

In a guessing attack, a password guess tested in an unsuccessful trial is determined wrong and excluded from subsequent trials. The number of undetermined password guesses decreases with more trials, leading to a better chance of finding the password. Mathematically, let S be the set of password guesses before any trial, ρ be the password to find, T denote a trial whereas Tn denote the n-th trial, and p(T = ρ) be the probability that ρ is tested in trial T. Let En be the set of password guesses tested in trials up to (including) Tn. The password guess to be tested in n-th trial Tn is from set S\En−1, i.e., the relative complement of En−1 in S. If ρ ∈ S, then we

Have p (T = ρ|T1 _= ρ, . . . , Tn−1 _= ρ) > p(T = ρ), (1)

and En → S p(T = ρ|T1 _= ρ, . . . , Tn−1 _= ρ) →1 _ with n → |S|, (2)

where |S| denotes the cardinality of S. From Eq. (2), the password is always found within |S| trials if it is in S; otherwise S is exhausted after |S| trials. Each trial determines if the tested password guess is the actual password or not, and the trial's result is deterministic. To counter guessing attacks, traditional approaches in designing graphical passwords aim at increasing the effective password space to make passwords harder to guess and thus require more trials. No matter how secure a graphical password scheme is, the password can always be found by a brute force attack. In this paper, we distinguish two types of guessing attacks: automatic guessing attacks apply an automatic trial and error process but S can be manually constructed whereas human guessing attacks apply a manual trial and error process. CaRP adopts a completely different approach to counter automatic guessing attacks. It aims at realizing the following equation:

p(T = ρ|T1, . . . , Tn−1) = p(T = ρ), ∀n (3)

in an automatic guessing attack. Eq. (3) means that each trial is computationally independent of other trials. Specifically, no matter how many trials executed previously, the chance of finding the password in the current trial always remains the same. That is, a password in S can be found only probabilistically by automatic guessing (including brute-force) attacks, in contrast to existing graphical password schemes where a password can be found within a fixed number of trials. How to achieve the goal? If

a new image is used for each trial, and images of different trials are independent of each other, then Eq. (3) holds. Independent images among different login attempts must contain invariant information so that the authentication server can verify claimants. By examining the ecosystem of user authentication, we noticed that human users enter passwords during authentication, whereas the trial and error process in guessing attacks is executed automatically. The capability gap between humans and machines can be exploited to generate images so that they are computationally independent yet retain invariants that only humans can identify, and thus use as passwords. The invariants among images must be intractable to machines to thwart automatic guessing attacks. This requirement is the same as that of an ideal Captcha leading to creation of CaRP, a new family of graphical passwords robust to online guessing attacks.

B. CaRP: An Overview

In CaRP, a new image is generated for every login attempt, even for the same user. CaRP uses an alphabet of visual objects (e.g., alphanumerical characters, similar animals) to generate a CaRP image, which is also a Captcha challenge. A major difference between CaRP images and Captcha images is that all the visual objects in the alphabet should appear in a CaRP image to allow a user to input any password but not necessarily in a Captcha image. Many Captcha schemes can be converted to CaRP schemes, as described in the next subsection. CaRP schemes are clicked-based graphical passwords. According to the memory tasks in memorizing and entering a password, CaRP schemes can be classified into two categories: recognition and a new category, recognition-recall, which requires recognizing an image and using the recognized objects as cues to enter a password. Recognition-recall combines the tasks of both recognition and cued-recall, and retains both the recognition-based advantage of being easy for human memory and the cued-recall advantage of a large password space. Exemplary CaRP schemes of each type will be presented later. We present two recognition-based CaRP schemes and a variation next.

IV EMPIRICAL EVALUATIONS

A. Implementations

ClickText and AnimalGrid were executed using ASP.NET. ClickText was implemented by calling a configurable text Captcha engine commercially used by Microsoft. This Captcha device accepts only capital letters.

B. Usability Study1) Experimental Settings We shown an in lab usability study to compare Click Text, AnimalGrid, PassPoints, text password

2) Experimental Results Usability. Among all the verified login attempts, 24.4% failed. Tests after a larger interval managed to have more failed attempts. Some participants contributed notably more failed attempts than others. At the end of tests, 40 (100%) participants retained

their PassPoints passwords, 39 (97.5%) remembered their passwords of both ClickText and AnimalGrid, and 34 (85%) remembered their Text passwords.

V CONCLUSION

We have proposed CaRP, a new security primitive relying on unsolved hard AI problems. CaRP is both a Captcha and a graphical password scheme. The notion of CaRP introduces a new family of graphical passwords, which adopts a new approach to counter online guessing attacks: a new CaRP image, which is also a Captcha challenge, is used for every login attempt to make trials of an online guessing attack computationally independent of each other. A password of CaRP can be found only probabilistically by automatic online guessing attacks including brute-force attacks, a desired security property that other graphical password schemes lack. Hotspots in CaRP images can no longer be exploited to mount automatic online guessing attacks, an inherent vulnerability in many graphical password systems. CaRP forces adversaries to resort to significantly less efficient and much more costly human-based attacks. In addition to offering protection from online guessing attacks, CaRP is also resistant to Captcha relay attacks, and, if combined with dual-view technologies, shoulder-surfing attacks. CaRP can also help reduce spam emails sent from a Web email service. Our usability study of two CaRP schemes we have implemented is encouraging. For example, more participants considered AnimalGrid and ClickText easier to use than PassPoints and a combination of text password and Captcha. Both AnimalGrid and ClickText had better password memorability than the conventional text passwords. On the other hand, the usability of CaRP can be further improved by using images of different levels of difficulty based on the login history of the user and the machine used to log in. The optimal tradeoff between security and usability remains an open question for CaRP, and further studies are needed to refine CaRP for actual deployments.

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