CAPTCHA Celebrating its Quattuordecennial – A Complete Reference

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Abstract

Recently web services have become an important business tool in e-commerce. The emergence of intelligent, sophisticated attacks like DoS makes web services more vulnerable than ever. One of the most common attacks against web services is a denial of service attack. To mitigate the Dos attack, CAPTCHA is used as one of the standard security technology. CAPTCHAs generate and grade tests that most humans can pass but current computer programs can't. Such tests often called CAPTCHA challenges are based on hard, open artificial intelligence problems. During past years, many researchers worked on HIP and CAPTCHA systems. This paper is a collection of 179 published works on HIP and CAPTCHA. CAPTCHA scheme, attacks and analysis, applications, usability issues and recaptcha are the heads under which the papers have been categorised. We hope that this paper would help new researchers in CAPTCHA domain to quickly find the works that are done previously.

Keywords: ***CAPTCHA, Security, DoS***

1. Introduction

Completely Automated Public Turing Tests to Tell Computers and Humans Apart (CAPTCHAs) are one of the important branches of HIP systems. It is used for defending against undesirable and malicious bot programs on the Internet.

Internet spans the globe crossing national boundaries. Internet security is of critical importance to our society, as the government and economy increasingly rely on the Internet to conduct their business, and people use the Internet as a convenient vehicle for simplifying a wide range of tasks, from banking to shopping. Unfortunately, the current Internet infrastructure is vulnerable to Denial of Service (DoS) attack. Because DoS attacks typically depends on compromising a large number of hosts to generate traffic to a single destination, the severity of DoS attacks will likely increase as greater numbers of poorly secured hosts are connected to high bandwidth Internet connections. This occupies a large volume of the resources of the site in favor of the profit-seeking programmers and reduces the performance of the system. Various methods have been presented in order to prevent such attacks, aiming at distinguishing human users from computer programs. A turing test was proposed [156] for proving the intelligence of a computer. A similar test administered by computer was generated by Carnegie Mellon University [159] known as CAPTCHA. These are the automatic filters that are widely used these days to disallow any automated script that can perform the work of a human.

In this paper, we bring out the work carried out by people around the globe on CAPTCHA. In Section II we briefly discuss various CAPTCHA schemes like text based CAPTCHAS; Image based CAPTCHAS and sound Based CAPTCHAS. In Section III we attempt to collect the entire novel CAPTCHAS developed recently. Section IV deals with applications of CAPTCHAS. CAPTCHAS are not free from attacks. They are also tested by attacks and analysis. This is brought out in Section V. Enthusiastic Artificial Intelligent Experts create more and more novel CAPTCHAS in a way to provide security actually creates havoc amidst humans. As a result, the humans are unable to prove that they are humans. In Section VI, we have discussed the usability issues with respect to human usage. Section VII emphasizes on reengineering CAPTCHAS.

2. CAPTCHA Schemes

Moni Naor in 1996 was the first to design the turing test [90], followed by him a method was designed by AltaVista in 1997 which is one of the first CAPTCHA

methods. A formal definition of CAPTCHA was given by von Ahn in [161]. The authors in [160] explained how this turing test can be conducted automatically. In [5] H.S. Baird has generated some CAPTCHA methods and in [6, 7] he has discussed how human interactive proof can be used to identify bots. CAPTCHA can be broadly classified into four schemes. The various schemes of CAPTCHA are discussed in detailed in the following sections

2.1 Text – Based CAPTCHAs

Text-Based CAPTCHAs have been the most widely deployed schemes. Major web sites such as Google, Yahoo and Microsoft all have their own text-based CAPTCHAs deployed for years. Pessimal Print [9] is one of the first text based scheme. Another early work on text -based CAPTCHA scheme is [169]. BaffleText [27], ScatterType [8] are text based schemes that generate meaning less pronounceable words. In [11], [165], [43] the authors have discussed how to generate random words.

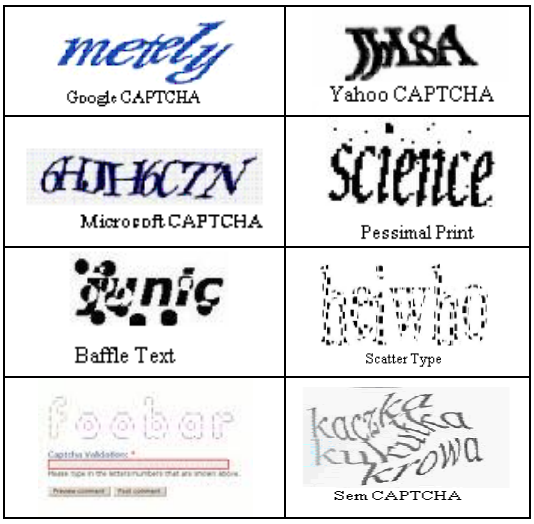

Fig 1: Some Text Based CAPTCHA

Human Interactive Proofs (HIPs) which is currently used by Microsoft web services is described in [23,24,25, and 26]. Embedding information within dynamic visual patterns is discussed in [83]. Here various visual patterns are used as foreground and background for displaying the text. The majority of works done on CAPTCHA are for English CAPTCHA methods. There are a few CAPTCHA methods for other languages like Arabic, Chinese etc., [117, 170, 118, 119, 120, 121 and 39]. A unified model for character recognition is presented in [30]. A SemCAPTCHA has been proposed in [86]; here the system is based not only on text recognition but also on text understanding. The Text-Graphics Character (TGC) CAPTCHA is proposed in [36] demonstrates its utility in a prototype based on the SSH (Secure Shell) protocol suite. A novel Visual word-based CAPTCHA using 3D characters is projected in [111] which use 3D characters with 3D boundaries delimited by shadows.

2.2 Image Based CAPTCHAs

Image-based CAPTCHAs such as [4, 10, 12, 106 and 28] have been proposed as alternatives to the text media. PIX and EPS methods [162] are one of the first Image Based methods. Bongo, which is created in the CMU CAPTCHA project, is described in [15]. **ASIRRA (**Animal Species Image Recognition for Restricting Access) is a HIP that works by asking users to identify photographs of cats and dogs [41]. More robust and user-friendly systems have been developed. Images are randomly distorted before presenting them. State-of-the art content-based image retrieval (CBIR) and annotation techniques are taken as the main perception and are discussed in [108, 109]. The idea discussed in method [82] is to exchange a number of blocks in an image and ask the user to click on that blocks. CAPTCHAs using facial expressions, facial features and face recognition are brought out in [112, 152, 87 and 88]. A new type of CAPTCHA called as Collage CAPTCHA is introduced in [122, 123] where distorted shapes are used instead of images. While most of the image CAPTCHA is 2D, there is yet another discovery of 3D CAPTCHAs discussed in [57, 60, 35 and 94]. [59],[84] talks about how 3D images can be used interactively for CAPTCHA.

Most of visual image based methods require a database of labeled images. Creating a database of labeled images is costly and time consuming. An approach for solving this problem is creating games such as EPS-Game [162]. Another idea is using image search engines for this purpose [124, 125].

Moving images can also be used instead of stable images. CAPTCHAs using moving images are discussed in [4, 126]. A combination of both text and image CAPTCHA is brought out as a hybrid CAPTCHA in [85]. In another novel proposal where a real time image is used which will portray some action and the user have to type the answer [149]. An algorithm for designing CAPTCHA is proposed in [61] where the images are splitted and rotated against OCRs. In another method, activity recognition is taken as the criteria and is discussed in [159]. Based on the principle of cognitive psychology [113] a new type of image based CAPTCHA was proposed.
Automatic image tagging appears to be a harder problem, an effort to tag images based on nonpixel data is discussed and proposed in [95]. . Visual CAPTCHAs can

be used for securing the path without the need for additional hardware; the way is paved in [44].

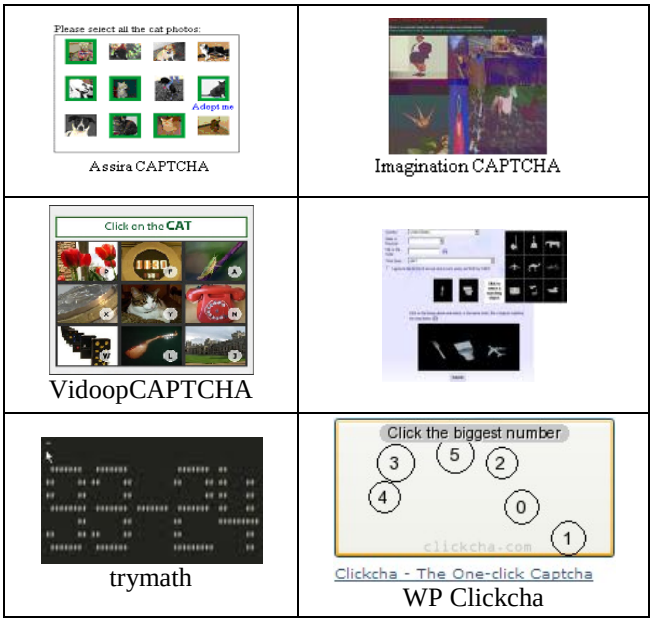

Fig 2: Some Image Based CAPTCHA

Yamamoto.T.et al proposed a humorous CAPTCHA with cartoons in [175]. An image based CAPTCHA using Jigsaw Puzzle is discussed in [50]. In [63] Sequenced Picture Captcha (SPC) which comprises of object pictures accompanied by a Tag, is given, the user is required to determine the logical sequence of the displayed object pictures based on the Tags. Hence, the user is required to identify both the object pictures and the Tags. In [72] an effective image-based CAPTCHA based on the orientation of N-gonal cropped sub-images as a solution of CAPTCHAs is given by Jong-Woo Kim et al.

CAPTCHA methods are usually designed for using with computers and are not suitable for other devices such as mobile phones and PDAs. A number of methods are designed especially for devices such as mobile phones [127, 128, 129, and 58].

2.3 Sound Based CAPTCHAs

Audio CAPTCHAs were introduced as an accessible alternative for those unable to use the more common visual CAPTCHAs. In [77, 20, and 130] it typically requires users to solve a speech recognition task. The different types of audio CAPTCHAs are discussed in [131, 132, 133, 134 and 16]. Audio CAPTCHAs are clearly more difficult and time-consuming. In order to address this concern, a new interface is developed for solving CAPTCHAs optimized for non-visual use that can be added in-place to existing audio CAPTCHAs[68]. Haichang Gao et al has proposed a new sound based CAPTCHA in [51].

3. Novel CAPTCHAs

Apart form the commonly deployed CAPTCHAs like text, image and sound CAPTCHAs, there are other novel CAPTCHAs designed for security purpose. Collaborative filtering, a new type of CAPTCHA methods is proposed in [29] in which there is no specific answer to the question asked to the user.

POSH [166] –a puzzle only solvable by human is a prompt with three import properties: it can be generated by a computer, it can be answered consistently by a human, and a human answer cannot be efficiently predicted by a computer. Here, the user is checked for consistency, not for correction.

To convert the regular keyboard-entry CAPTCHAs into clickable CAPTCHAs is discussed in [106]. Linguistic problem of word-sense ambiguity CAPTCHA in text domain was desired from the beginning, but there are few works done in this field including [13, 168]. As the authors of these paper said, it seems that designing a Text Domain CAPTCHA is very difficult. Another group of methods uses questions which need reasoning to be answered such as [135]. This idea can be extended to create HIP systems which can distinguish between different groups of people, such as method explained in [79, 80]. In another proposal a system [150] is designed with two components, one to detect unknown chat bots, and the other to detect known bots.

Sequenced Tagged CAPTCHA [49],[105], a novel scheme where numbers are embedded in text CAPTCHA. Rusu proposed Handwritten CAPTCHA, which uses scanned handwritten words for generating CAPTCHA images [115]. A new scheme of Synthetic handwritten CAPTCHAs is presented in [1]. AssoCAPTCHA [31] is another type of CAPTCHA that requires no greater user-interaction than conventional solutions. [45] G.Geetha has discussed how RBFN (Radial Basis Function Network) can be used to mitigate DoS Attack.

Zhang's CAPTCHA [167] is based on intelligent interaction via RIA. It includes two lines of defenses against various types of attacks. SS-CAPTCHA [174] is based on even more advanced human-cognitive-processing abilities. The CAPTCHA uses the human ability of recognizing “strangeness”. CAPTCHA using Strangeness in Sentences (SS-CAPTCHA), which detects malware by checking if users can natural

sentences created by humans from machine-translated sentences. CAPTCHA design based on moving object identification and tracking problems is discussed in [34, 69]. A Multiple Challenge-Response system call M-CR CAPTCHA mechanism is proposed in [84]. Here a user is expected to respond to multiple questions before access is granted.

Another approach 'drag and drop CAPTCHA' or 'DnD' is a HIP challenge that uses conventional mouse events to recognize human intervention proof [39]. A 3-layer Dynamic CAPTCHA uses 3-layer structure to makes the design of CAPTCHA is given by JingSong Cui et al in [70]. A novel CAPTCHA that is based on the current hard AI problem of mixed-text (handwriting and printed-text) segmentation is given in [156].

4. CAPTCHA Applications

CAPTCHA methods was initially designed to prevent spammers from registering free accounts in the free email services [7]. Nowadays CAPTCHAs are not only used for the above but many more. They are been employed to prevent spam emails [53, 74, 137, 138]. Another application of CAPTCHA is online games [47, 173, 110,179,56] where it is used to prevent bots from playing games. CAPTCHA methods are used in different applications to identify bots. These methods identify bots and block them in automated attacks such as Denial of Service (DoS) attacks [73, 75]. Spammers are also using CAPTCHA techniques for sending undetectable spams [81]. A new method for filtering images is discussed in [14]. CAPTCHA is used in preventing dictionary attacks in many applications [18, 139, 140, 100, 151, 171]. An extended idea of CAPTCHA is applied for addressing online threats [19, 37, 116, 32, 152]. CAPTCHA is not only used for defending online threats but also for offline attack [42]. The various other special applications are [45, 141, 142, 143, and 95]. CAPTCHA is applied in filtering group sending SMS spam [98] and prevent Phishing [154]. CAPTCHA is also employed in defending ecommerce [101]. An innovative solution for security of Internet polls is described in [3, 89]. CAPTCHA is widely used in smart cards to prevent illegitimate users [172]. To prevent the spam in VoIP (Voice over Internet Protocol) CAPTCHA is used [2]. [52] suggests a novel solution to eradicate the Sybil threat using a unique combination of neural networks and CAPTCHA. [163] discusses how to eliminate botnets in Internet Relay Chat (IRC), Peer-to-Peer (P2P) and web-based protocols using an encryption algorithm with session keys and a CAPTCHA verification.

5. Attacks and Analysis

CAPTCHAs that are carefully designed are vulnerable to novel but simple attacks; one of the first and well known attacks to CAPTCHA methods (Gimpy method) is [91]. Other attacks on Gimpy method are [93, 155, 92]. In [102] two attacks are discussed on how text-based CAPTCHAs have been broken. A more recent attack on character-based CAPTCHA methods are reported in [64]. Similar text-based attacks are discussed in [24, 27]. A low-cost attack on Microsoft CAPTCHA with a success rate of more than 60% is analysed in [65]. In [99] an investigation of attacking the image based CAPTCHA was successful with a success rate of 82.7%. Similar attack on image based CAPTCHA is discussed in [40]. Attacking in the form of a game is given in [66]. An algorithm to break visual CAPTCHA is proposed in [21]. The limitation of CAPTCHA is used to bypass its vulnerability are analysed in [33]. An analysis of different CAPTCHA breaking algorithms is brought in [62], a method by which child users can be identified is given in [144]. Algorithms were developed [13, 78, 164, 48, 176, 177 and 92] to break CAPTCHAs. In [46] G.Geetha et al, have discussed how curvelets can be used to break image CAPTCHA. Algorithm for Secured Online Authentication Using CAPTCHA [22] discusses how CAPTCHA can be verified by a three step process. In [71] Jisong Zhang; Xingfen Wang, have discussed how to use instance learning for breaking Internet Banking CAPTCHA. Hernandez-Castro et al in [54] have explained how by using image recognition and machine learning can break HumanaAuth CAPTCHA.

6. Usability Issues

Usability and robustness are two fundamental issues with CAPTCHA, and they often interconnect with each other. In [67, 78] the authors discuss the usability issues that should be considered and addressed in the design of CAPTCHA. In [103, 97] it explores the usability issues of image based CAPTCHA. In [79] we can see how usability meets access control. In [145] the authors taking into account the issues of the existing CAPTCHA propose a new system where the user is given options regarding to the user's needs such as user language and disabilities. A new method for disabled people with more than one disability is proposed in [146]. The various issues of both text-based and image-based CAPTCHA are brought to light in [153]. Kurt Alfred et al in [80] have discussed how to balance the usability and security of video CAPTCHA. In [76] Karunathilake et al has discussed in detail about the various usability issues humans are facing and proposed a novel technique for reverse Turing test. In [17] the author has spoken about

the usability issues of audio CAPTCHA in particular. Issues in image based captcha is elaborated in [104].

7. ReCAPTCHA

CAPTCHAs are generated by software and the structure of a **CAPTCHA** gives hints to its implementation. Thus due to these properties of image processing and image composition, the process that creates CAPTCHAs can often be reverse engineered. Once the implementation strategy of a family of CAPTCHAs has been reverse engineered the **CAPTCHA** instances may be solved automatically by leveraging weaknesses in the creation process or by comparing a **CAPTCHA**'s output against itself, this concept is discussed in [55].

8. Conclusion

CAPTCHA systems are used to distinguish between human users and computer programs. Today they are widely deployed in web applications to offer better services to human users. In this paper we have surveyed the works done on CAPTCHA during past years. We find that lots of work needs to be done on the usability issues of CAPTCHA and reCAPTCHA. As spammers advance, the puzzles get progressively harder and more of a burden is placed on humans. We hope that this paper can assist many researchers who work in the area.

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