# Image Understanding for Automatic Human and Machine Separation

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# Abstract

The research presented in this thesis aims to extend the capabilities of human interaction proofs in order to improve security in web applications and services. The research focuses on developing a more robust and efficient Completely Automated Public Turing test to tell Computers and Human Apart (CAPTCHA) to increase the gap between human recognition and machine recognition. Two main novel approaches are presented, each one of them targeting a different area of human and machine recognition: a character recognition test, and an image recognition test. Along with the novel approaches, a categorisation for the available CAPTCHA methods is also introduced.

The character recognition CAPTCHA is based on the creation of depth perception by using shadows to represent characters. The characters are created by the imaginary shadows produced by a light source, using as a basis the gestalt principle that human beings can perceive whole forms instead of just a collection of simple lines and curves. This approach was developed in two stages: firstly, two dimensional characters, and secondly three-dimensional character models.

The image recognition CAPTCHA is based on the creation of cartoons out of faces. The faces used belong to people in the entertainment business, politicians, and sportsmen. The principal basis of this approach is that face perception is a cognitive process that humans perform easily and with a high rate of success. The process involves the use of face morphing techniques to distort the faces into cartoons, allowing the resulting image to be more robust against machine recognition.

Exhaustive tests on both approaches using OCR software, SIFT image recognition, and face recognition software show an improvement in human recognition rate, whilst preventing robots break through the tests.

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# Contents

# Chapter 1

# Introduction

In the last two decades, since the commercialisation in the nineties of the Internet, the number of users has grown exponentially until reaching more than 2.2 billion people [77]. This is the result of its popularisation and incorporation into virtually every aspect of modern human life from daily affairs such as education, web search or goods shopping to more professional oriented tasks. Advances in the protocols and the services have brought a wide variety of services. The most important one is the World Wide Web (WWW) that communicates via the Internet a series of resources such as interconnected documents, linked by hyperlinks and URLs.

Since its creation, the Internet has no centralised governance in either policies for access and usage, technological implementation, or management, and it is maintained by each constituent network with its own standards. Due to this fact, security has become an important issue for the users, companies and services. One of the primary sources of abuse on the Internet is spam, that targets electronic messaging services by sending unsolicited bulk messages indiscriminately, especially advertising, among other actions such as instant messaging spam, web search engine spam, spam in blogs, in wikis, in ads, in forums and in social networks, mobile phone messaging spam, and file sharing network spam. It became a serious problem

when the internet was opened up to the general public in the mid-90s. The fact that people have quick and easy access to the internet network made this problem grow exponentially in the following years, reaching proportions of 85% and 90% of all the emails in the world [122].

Besides the huge expansion it has experienced, spam is also a serious problem because of the property rights and the consumed resources. First of all, spam is difficult to get rid off because property rights in several countries are difficult to enforce. Nowadays in Europe, there is a new legislation that tries to reduce the quantity of spam coming from the continent [59]. Secondly, if we talk about resources, spam consumes shared resources such as bandwidth or the load of the servers, or private resources such as money and time. Finally, another serious issue that derives from the existence of spam is that it has become a tool for malware authors and phishers to abuse the Internet.

Malware or malicious software is the term used for a diverse kind of hostile, intrusive, or annoying software that can be used to gather personal or private information, or to harm computer operations. The most common forms of malware are viruses, worms, trojan horses, spyware, adware, and other malicious programs [149]. On the other hand, phishing is a software used to acquire information such as usernames, passwords, and credit card details by disguising itself as a trustworthy entity in an electronic communication or transaction [159] with the aim of stealing money. Spam can be used by malware authors and phishing software through unsolicited commercial e-mails to spread harmful software with the objective of identity theft or even worse; fee fraud. These software programs take advantage of the victim's inexperience with technology or attempt to call on human greed for money (see Figure 1.1).

One of the most effective methods for reducing the amount of spam circulating on Internet and ensuring safety for users is the use of CAPTCHAs. A CAPTCHA is a program that protects internet companies and human users against spam or bots through the generation of grading tests that most humans can pass but current computers cannot [20].The term CAPTCHA stands for Completely Automated Turing Test to Tell Computers and Humans Apart and was

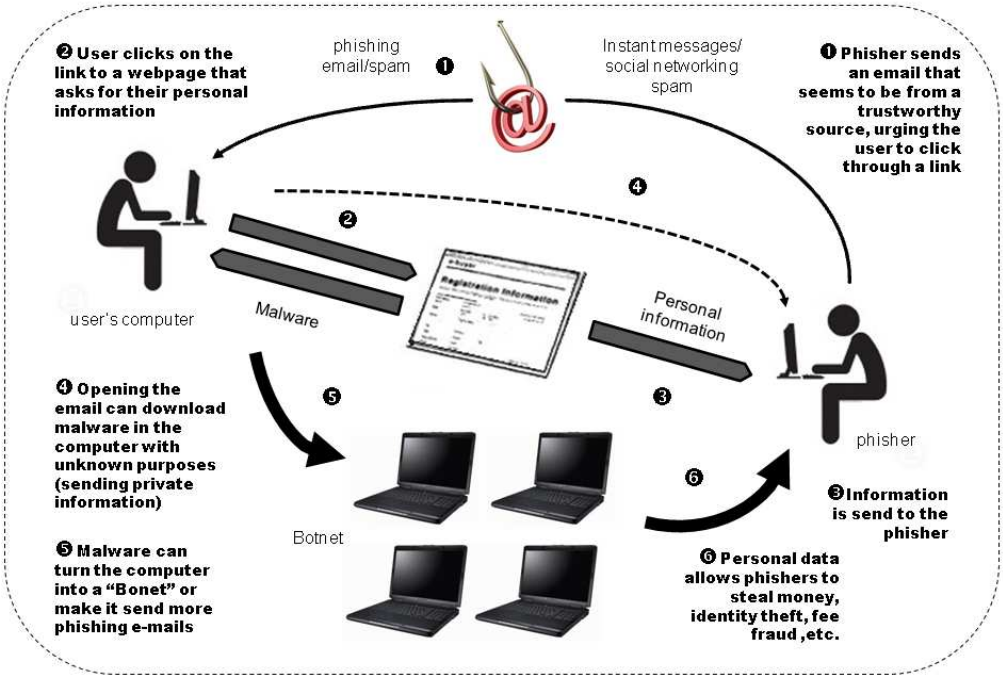


**Figure 1.1:** Flow diagram of a phishing and malware attack through spam.

firstly coined in 2000 by Luis von Ahn, Manuel Blum, Nicholas Hopper and John Langford of Carnegie Mellon University [188].

The primary application of CAPTCHA is to prevent malicious attacks to the systems by spammers. However, they also serve to protect vulnerable systems, such as Yahoo or Hotmail, against e-mail spam, automated posting to forums, blogs and wikis as a result of commercial interests or harassment. Another important function is bit rate limiting when excessive use of a service is observed.

Nowadays, most of the methods to discriminate humans from computers are based on optical character or image recognition, or sound recognition. In a word-based CAPTCHA, the characters are distorted to make its recognition more difficult for the bots. Among the basic distortions, it can use translation, rotation (clockwise or counterclockwise) and scaling, among others such as sight angle, lighting effects, context, and camouflage [38]. A word-based CAPTCHA test consists on an image that contains distorted and noisy characters or words. To

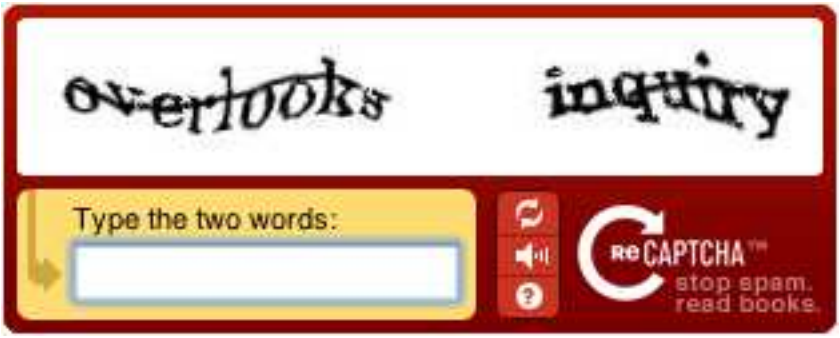


**Figure 1.2:** Word-based CAPTCHA extracted from http://www.captcha.net.

solve this test, the user has to type the characters presented in the image. Usually, the distortions applied to the image are complicated enough to prevent a robot to recognise the word while allowing humans to do so. An example of common CAPTCHA used in current web applications can be appreciated in Figure 1.2.

An image-based CAPTCHA contains primarily an image that the user has to recognise. Amongst these tests, the user can be asked to implement different kinds of actions; solve a quiz, match symbols, recognise faces, etc. Usually, the images do not appear straightforwardly, instead they can contain warping, occlusion or lighting effects to avoid being recognised by machines. The last type is a sound-based CAPTCHA, which was implemented in the first place for those users that cannot solve visual CAPTCHAs due to an impairment. The test presents an audio file that contains words, letters, or numbers, mixed with background noise, that the user has to type correctly.

Even thought there are many CAPTCHA methods available to prevent spam circulating, there are many researchers that have developed techniques to break through them [70, 130, 131, 161] since it means a technological advance in machine learning. Additionally, companies have exploited the fact that users find the tests annoying to create commercial DeCAPTCHAs to break the CAPTCHA tests automatically, without the direct intervention of the users. Due to these facts and the greed of spammers, most of the current tests are becoming obsolete.

In this thesis, the major motivation was the creation of advanced software tools that enables separation of humans and machines in an automated environment and increases the gap of what humans can recognise and machines cannot. The targeted strategies have exploited extremely difficult tasks related to image understanding and human perception. These objectives were established in order to prevent all the security breaches produced by spam and other forms of attack, which are also caused by the inexperience of using computer technology by the majority of users. The primary contributions of this thesis are the development of two efficient and robust CAPTCHA approaches and a categorisation for the current CAPTCHA tests.

## 1.1 Contributions

For the Visual-word based CAPTCHA:

- identification of the issues on the current word-based CAPTCHAs;
- development of a new type of characters based on 3D objects with 3D boundaries delimited by shadows [150];
- design of an efficient algorithm to optimise the distortions applied to the characters and ensure safety against possible external attacks to break the code [150];
- exhaustive experiments to test the efficiency of the approach and improve the human friendliness regarding the current approaches available [150].

For the Image-based CAPTCHA:

- identification of the issues on the current image-based CAPTCHAs;
- development of a database of faces of well known people and a second database with cartoons and animals to create a final image that is the result of the morphing between a selected image from each database [151];

- design of an efficient algorithm to optimise the morphing between images and ensure safety against possible external attacks to break the code [151];
- exhaustive experiments to test the robustness of the approach and improve the human friendliness regarding the current approaches available [151].

Finally, the categorisation gives a classification for every kind of test available and for future techniques since it goes from three general branches to a subclassification that can be enlarge if necessary.

## 1.2 Overview of the thesis

This thesis has been organised in a self-contained manner. The initial chapter presents the fundamental aspects of the addressed technology and the corresponding state of the art, the following three chapters present the techniques used to develop the approaches presented in the thesis. The subsequent two chapters present the proposed approaches, fully explaining the algorithms and the results obtained. The last chapter concludes the work, presenting the conclusions and considerations for future research. This thesis is organised as follows:

Following the introductory chapter, Chapter 2 presents an overview of CAPTCHA methods, as well as a survey of the available CAPTCHA tests. Important evaluation concepts, such as efficiency and robustness, and human friendliness, are explained, as they will be important in the later chapters. Also, several well-known commercial and published CAPTCHAs are presented along with one of the contributions of the thesis; a categorisation of the CAPTCHAs.

Chapter 3 summarises the basic concepts in digital image manipulation used to create visual CAPTCHA tests. Firstly, the digital image warping and morphing tools are presented, which are used to create the pertinent distortions for both approaches. Additionally, a 3D computer graphics study is introduced, since it will play a major role in the development of the new con-

cepts that differentiate the new CAPTCHA tests presented in this thesis with the ones currently available.

In Chapter 4 the digital image recognition tools are presented. These tools are used to evaluate the efficiency and robustness of the approaches created. For the OCR-based CAPTCHA, the SIFT tool is explained, since it will be used to evaluate the grade of machine recognition for characters. It also presents the state-of-the-art study in face recognition techniques, because different techniques will be used to measure the capacity of machines to recognise the distorted faces created by the image-based CAPTCHA.

Human perception and recognition theories are the focus of Chapter 5. The main aim of this chapter is the evaluation of the human friendliness of the approaches presented in this thesis. Human perception theories are explained in the two sections that the chapter is divided. The first section focuses on Gestalt psychology, which defines a branch of psychology than explains how human beings perceive objects when they are incomplete, which is used to create the OCR-based CAPTCHA. The second section focuses on face perception and recognition with the aim of creating a good interactive image-based CAPTCHA.

Chapter 6 introduces the first approach: the visual word-based CAPTCHA. The developed scheme introduces a new concept in the creation of a word-based CAPTCHA: the use of shadows to represent characters. Additionally, it presents both the experiments made to evaluate the efficiency and robustness, and the human friendliness and the results for these experiments, along with a complexity analysis of the test and a brief discussion of these results.

Chapter 7 focuses on the second approach, the image-based CAPTCHA. This scheme is developed with the aim of creating a more interactive and secure test. It uses distorted faces of well known people from diverse cultural sectors, such as politics, sports, cinematographic industry, etc. Following the lead of the first approach, it also presents both the experiments made to evaluate the efficiency and robustness, and the human friendliness and the results for

these experiments, along with a complexity analysis of the test and a brief discussion of these results.

The conclusions are summarised in Chapter 8. The list of author's publications is given at the end of the thesis along with the references used.

# Chapter 8

# Conclusions and Future Work

## 8.1 Conclusions

The aim of the research presented in this thesis was to increase the gap of what humans can recognise and machines cannot. Additionally, the creation of more robust and efficient novel methods was targeted. The main focus was centred on creating CAPTCHA tests using human psychology and universal common knowledge. The first step towards the developed methods was to analyse the current approaches and distinguish their weaknesses and possible ways to improve them. This includes a research of computer vision software that allows machines to break through the tests.

The research on the current methods available uncovered the necessity of a classification to categorise the algorithms by the computer vision techniques used and by human aptitudes. For the classification, three main categories have been considered: OCR-based methods, Visual non OCR-Based methods and non Visual methods. These categories have been divided into subcategories for a more accurate classification. Along with the sub-categorisation, an extensive analysis of the available methods and their reliability was presented in the thesis, reaching the following conclusions:

OCR-Based methods were the first CAPTCHAs to emerge. They had a quick expansion to many different web applications as well as many prototypes. Along with the expansion, several different programs to break through them arose which provoked an increase in difficulty in the tests. Nowadays, most users find the annoying and time consuming.

- Visual non OCR-Based methods emerged to explore diverse sides of HIP methods. At the beginning they focused on solving quizzes or matching problems but rapidly expanded to many other areas. Also, their reliability increased with time, going for easy to break to more secure that OCR-Based methods. Their diversity make them more human friendly and less time consuming.

-Non visual methods arose as an alternative to visual methods due to some visual impairments users may have. They weren't as successful as the others due to their difficulty and language restrictions.

The second step in this research was the development of two novel methods to prevent spam and malicious software to break through web applications and increase security when login in. The first method uses shadows to represent characters. The shadow boundaries were chosen to develop the fact that humans can easily recognise objects and characters only by the shadows but machines cannot. The distortions applied to the images are based upon geometric transformations that include affine and perspective transformations. The approach based on 2D shadow characters shows an improvement in efficiency and robustness over the actual CAPTCHAs. The visual word-based CAPTCHA using 3D models is based upon lighting effects to create 3D shadows boundaries. The performance of this algorithm highlights that using 3D models yields better results in terms of efficiency and robustness. These tests are more difficult to solve for computer vision techniques but they still remain easy for humans. In this method, one of the challenges faced was that people visually impaired or with mental illness as dyslexia should be able to recognise the characters. However, it is also necessary to make the tests difficult enough for the machines not to break through them.

Humans can easily recognise cartoons or sketches from famous people, even if they are rotated or manipulated. A machine cannot recognise this type of image because it does the matching by pattern or feature extraction and the original one is very different. The second method uses distorted faces of world famous people to create a test to secure web applications. The main basis for the development of this method was the innate ability of human beings to recognise faces. The distortions applied to the face images are based upon a feature-based morphing process with multiple pairs of lines. The performance of this algorithm highlights two facts; firstly, using distorted faces as a test increments the efficiency and robustness of the previous approaches and secondly, it increments the difficulty for face recognition techniques to break through our system.

## 8.2 Future Work

In addition to the developed work, there are some challenges that have appeared while developing the second approach. The main focus addresses the level of distortions applied to the faces. The main reason is that a high distortion factor can make the faces indistinguishable and a low rate can make it to easy for the face recognition system to break through the test. To measure the appropriate levels of morphing, different variables and factors were taken into account; cross-dissolve factor range, human recognition capabilities and the cartoon or animal used in the destination image. Another important factor to take into account was that people with prosopagnosia have more difficulties when recognising and distinguishing human faces, and even though there is nothing much that can be changed in this approach, the only alternative to help the human users with this problem is which kind of faces can be used.

Practical realisations of methods presented in this thesis have enabled a high efficiency and robustness in the OCR-based CAPTCHA approach and the Image-based CAPTCHA approach. On the other hand, these realisations have also uncovered several interesting topics for future research, as well as some issues that have not been yet adequately resolved. These include:

-Since human and machine recognition depends on the diverse distortions applied, it is necessary an optimisation of the warping and morphing techniques by improving the algorithms and creating smoother transitions for the original image to the distorted one. New morphing techniques should also be taken into consideration.

-Evaluation study of face recognition by human users depending on geographical locations. Knowing the cultural background and social knowledge is an important factor to increase the success rate by users. Also, it will be necessary to update the database depending on the latest celebrities or personalities that are famous at that moment.

-Although the developed methods can prevent machines to successfully pass the current CAPTCHAs, as the computer vision techniques research advances similarly the CAPTCHAs should improve. Therefore, the techniques applied and the human psychology used should be further studied.

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