Peekaboom: A Game for Locating Objects in Images

By Luis von Ahn, Ruoran Liu, and Manuel Blum

ESP Game

- Only attaches labels to random images from the internet
- Does not specify location of image
  - Thus, insufficient for training computer vision algorithms

- Given label, can we identify where label actually is?

What is Peekaboom?

- 2 players:
  - Boom
    - Start with an image & related word
    - Gradually reveal 20 pixel radius circles of the image at a time
  - Peek
    - Start with blank screen
    - Try to guess the image label
- Every round, 4 images processed

Sample Boom Image

Sample Peek Image

Extra Features of Peekaboom

- Pass
- Hint
- Ping
- Bonus Round

Each one of these features can help provide examples for machine learning

Data that is collected for training

- Which pixels are necessary to guess the word?
- From hints: what is the relation between word and image?
- Data from pings: which pixels are inside the object?
- What are the most relevant aspects of the object?
- Elimination of poor image-word pairs

Dealing with single player games

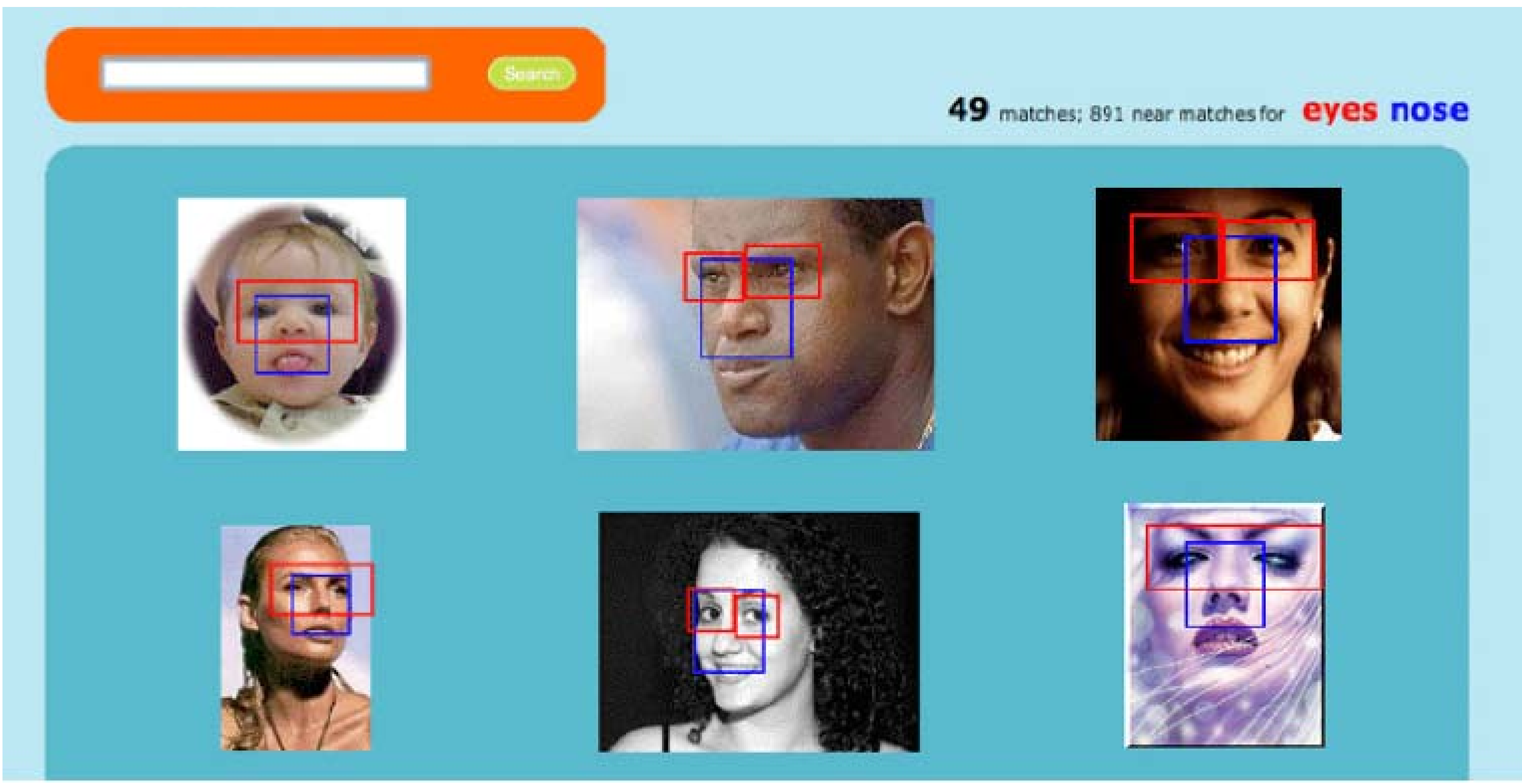
- Bot can easily simulate a Boom from previously saved human clicks
- Simulating Peek is much harder

Cheating and Collusion

- Anti-cheating mechanisms include:
  - Random matches with a matching interval when all players are matched at once
  - IP address checks
  - Blacklisting after consistent failure on "seed" images
    - By definition, bots cannot successfully play Peekaboom
  - Limited freedom to enter guesses

Object Bounding Boxes

- We can use Peekaboom results to establish tags for keywords in images
- Example below: eyes and nose



Results

- Is this an effective way to collect data?

  Yes!

- Game is enjoyable
  - Each person played average of 158.7 images
  - That's 72.96 minutes per person in one month!
    - User review: "This game is like crack. I've been Peekaboom-free for 32 hours…"

How Good is the Data?

- Bounding Boxes:
  - .754 overlap between Peekaboom-generated bounding box and bounding box generated by human volunteer
    - Note: Only looked at images with noun keywords
- Pings:
  - All the sample pings were in the object, as determined by human volunteers

Discussion

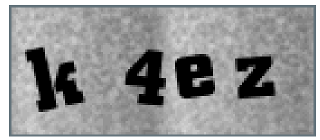
- What are some weaknesses of Peekaboom?
- Can you think of any other applications of Peekaboom?

CAPTCHA: Using Hard AI Problems for Security

By Luis von Ahn, Manuel Blum, Nicholas J. Hopper, John Langford

Examples of CAPTCHAs

Configuration file



Configuration file

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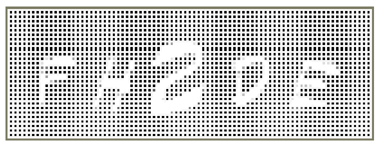
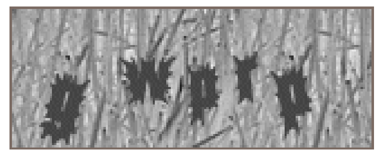
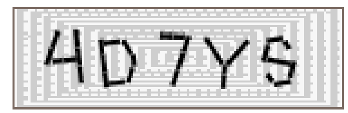
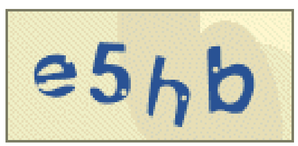

Configuration file


Configuration file



Configuration file



Configuration file

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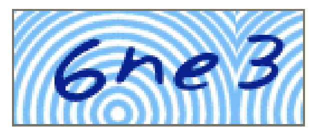
Configuration file


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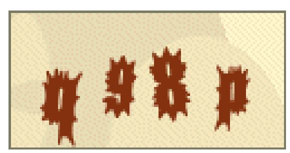
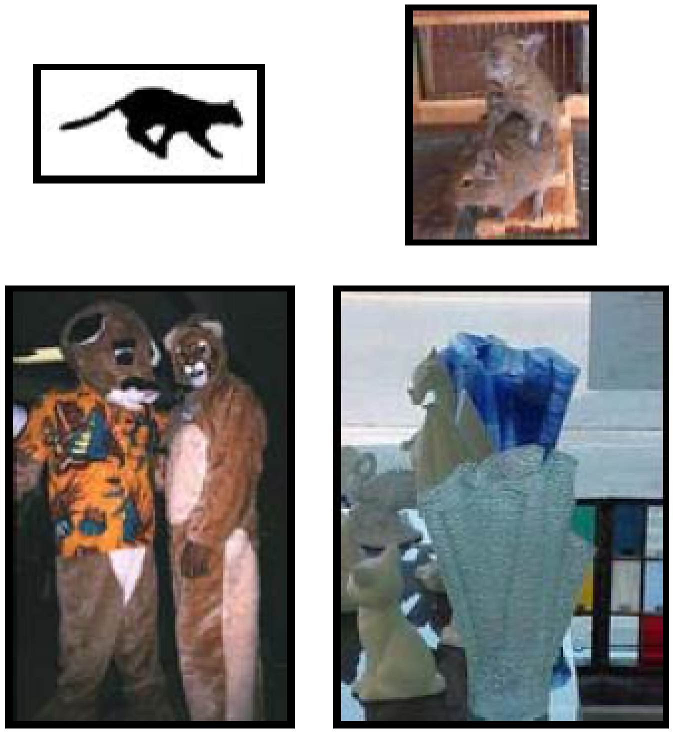

Configuration file


Configuration file

More Examples

More Examples

The CAPTCHA Project



Choose a word that relates to all the images.

TIP: You can type the first letter of a word and then use the down arrow to find it.

Submit

What is a CAPTCHA?

- A cryptographic protocol whose underlying hardness assumption is based on an AI problem
  - Certain problems, such as image / audio / voice recognition, are hard AI problems but easy problems for humans to solve
- So CAPTCHA is meant to prevent adversaries (aka bots) from performing a malicious task

What is a CAPTCHA?

- What kind of AI problems do we want to use?

1. Hard problems
   - Hard w.r.t. complexity
   - AI community agrees it's hard
2. Useful problems

What is a CAPTCHA?

- The fact that CAPTCHA is based on a hard AI problem gives us a win-win situation
  - Either someone figures out a bot to solve CAPTCHAs (solving a hard, useful AI problem)
  - Or there is a way to tell humans from computers, which is useful for security

What is CAPTCHA?

- To be useful, CAPTCHA must be generated automatically
- The adversary (in our case, the bot) knows exactly how the CAPTCHA works
  - The code for reCAPTCHA is online!
    - www.captcha.net
- The only thing that the bot doesn't know is the random number the algorithm generates
- So CAPTCHA cannot base its security on a piece of code or a database

For More Security

- Establish a time limit for the user to respond to the CAPTCHA
- Repeated CAPTCHAs – so if a bot has a .1 probability of guessing the answer, it only has a .01 probability of guessing the answer twice

Some Notation

- An AI problem is represented by

$$P = (S, D, F)$$

- S = Set of problems
- D = Probability distribution over S
- f = function from S to $\{0,1\}$

- We require that a fraction α of humans can solve the problem with probability > δ
- P is $(\delta, \tau) - hard$ if there is no program to solve the problem with probability δ in at most time τ and the AI community agrees that it's hard

Definitions

- So an (α, β, η) CAPTCHA is a test that at least α of humans can solve with probability β
- $\exists$a $(\delta, \tau) - hard$ problem *P* where if some program *B* solves the CAPTCHA with at least η probability, reduction of program B to a program A is a (δ, τ) solution to *P*
- A win-win situation – either there is no program to solve the CAPTCHA or we solve the $(\delta, \tau) - hard$ problem *P*

Two AI Problem Families

- 2 families of AI problems that can be used for CAPTCHAs: both relate to images and image transformations

- Some notation before we begin:

$$I = \text{distribution on set of images} [I]$$

$$T = \text{distribution on set of image transformation} [T]$$

$$S_{I,T} = \{t(i) : t \in [T], i \in [I]\}$$

$$D_{I,T} = \text{distribution on } S_{I,T}$$

$$f_{I,T} = fn : S_{I,T} \to [I] \text{ s.t. } f_{I,T}(t(i)) = i$$

Two AI Problem Families

- Family ***P1***:

$$(S_{I,T}, D_{I,T}, f_{I,T})$$

  - Write a program that takes in t(i) as input and outputs image I

- Family ***P2***:

$$(S_{I,T}, D_{I,T}, g_{I,T,\lambda})$$

  - Write a program that takes in t(i) as input and outputs a label λ for image i

Hard Problems in P1 and P2

- We generally have a fairly small set of images to choose from, so the hardness from hard problems in families ***P1*** and ***P2*** come from the large number of transformations t
- Listing all possible transformations should be computationally infeasible

Two Families of CAPTCHAs

- MATCHA
  - Programs that can solve MATCHA can solve anything in ***PI***
  - How it works:
    - Choose a transformation t
    - Flip an unbiased fair coin
    - Heads => pick image k and set i=k, j=k
    - Tails => pick images i,j s.t. i != j
    - Send (i, t(j)) and ask the user (the prover) to state whether i = j
    - If incorrect, then reject. If correct and i != j, play another round. If correct and i = j, accept

Two Families of CAPTCHAs

- Matcha is not very useful, since if you always return true, you have a 50% probability of being correct
- Nevertheless, if a program is success enough at MATCHA we can solve AI problems in ***P1***

Lemma 1. *Any program that has success greater than η over $M = (\mathcal{I}, \mathcal{T}, \tau)$ can be used to $(\delta, \tau|[\mathcal{I}]|)$-solve $\mathcal{P}1_{\mathcal{I},\mathcal{T}}$, where*

$$\delta \geq \frac{\eta}{1 + 2|[\mathcal{I}]|(1-\eta)}.$$

- Proof idea: From program B that is successful enough over MATCHA, construct a program that can solve the corresponding problem in ***P1***

Two Families of CAPTCHAs

- PIX
  - Being successful against PIX means that we can solve AI problems in ***P2***
  - How it works:
    - PIX program picks a random image i and transformation t
    - Sends the user (or bot) (t(i), L) where L is a set of possible labels
    - User sends back a label. If label = λ(i) where λ is the correct label, accept

Two Families of CAPTCHAs

- PIX is actually used in Gmail, Hotmail, Yahoo! etc to identify bots
- To summarize, we have 2 theorems to define how problems in ***P1*** and ***P2*** are translated to CAPTCHAs

(M is MATCHA and X is PIX)

Theorem 1. *If $\mathcal{P}1_{\mathcal{I},\mathcal{T}}$ is $(\delta, \tau|[\mathcal{I}]|)$-hard and $M = (\mathcal{I}, \mathcal{T}, \tau)$ is (α, β)-human executable, then M is a* $(\alpha, \beta, \frac{(2-|[\mathcal{I}]|)\delta}{2\delta-|[\mathcal{I}]|})$-CAPTCHA.

Theorem 2. *If $\mathcal{P}2_{\mathcal{I},\mathcal{T},\lambda}$ is (δ, τ)-hard and $X = (\mathcal{I}, \mathcal{T}, L, \lambda, \tau)$ is (α, β)-human executable, then X is a* (α, β, δ)-CAPTCHA.

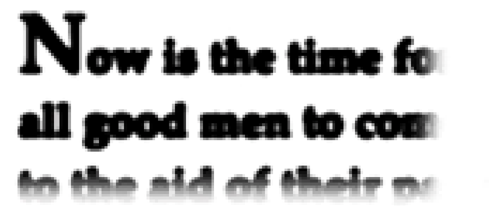
Application: Robot Steganography

- Alice wants to send an image to Bob and hide some secret information in the image
- Eve wants to transform the image to remove this information. However, Eve's transformation cannot significantly impact human interpretation of the images
- The authors create a construction of a stegosystem where Alice can transform the message (key) into an image, which is indistinguishable from regular images and is robust against transformations by Eve
  - Formally, the stegosystem is steganographically secret and robust

reCAPTCHA

- reCAPTCHA is a project to use CAPTCHAs to help digitize old books
  - Currently, Optical Character Recognition is not perfect
  - The words that the OCR is not sure about are presented in a CAPTCHA for users to solve
- The CAPTCHA will present 2 words – one known one generated and one from a digitized book
- If the user correctly identifies the word that is known, the program assumes the word from the digitized book was entered correctly as well

1 We start with a scanned book containing thousands of words.



2 Next we extract a word that cannot be read by OCR. These words come in a variety of fonts, and are inherently distorted by the age of the book or the quality of the scan.

3 To add extra security, the word is then distorted even more, using random lines and warps.

4 A CAPTCHA is generated with two distorted word images from books.

Discussion

- What are some other applications of CAPTCHA?
- Besides image/audio recognition, are there other hard AI problems that can become CAPTCHAs?
- What are some vulnerabilities of CAPTCHAs as they are implemented now?