CS 419: Computer Security

Week 6 Recitation: CAPTCHA

CAPTCHA: Detecting Humans

Gestalt Psychology (1922-1923)

- **Max Wertheimer, Wolfgang Köler, Kurt Koffka**
- **Laws of organization**
  - Proximity
    - We tend to group things together that are close together in space
  - Similarity
    - We tend to group things together that are similar
  - Good Continuation
    - We tend to perceive things in good form
  - Closure
    - We tend to make our experience as complete as possible
  - Figure and Ground
    - We tend to organize our perceptions by distinguishing between a figure and a background

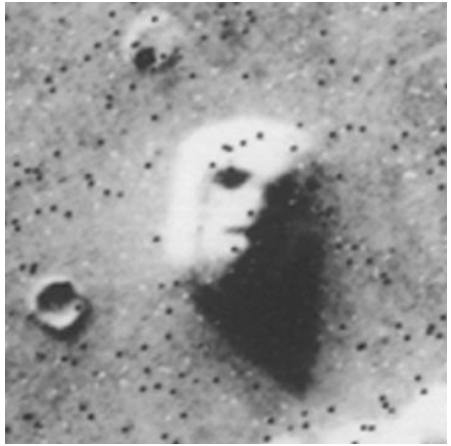
Source: http://www.webrenovators.com/psych/GestaltPsychology.htm

Gestalt Psychology

18 x 22 pixels

Objects on Mars?

Elvis



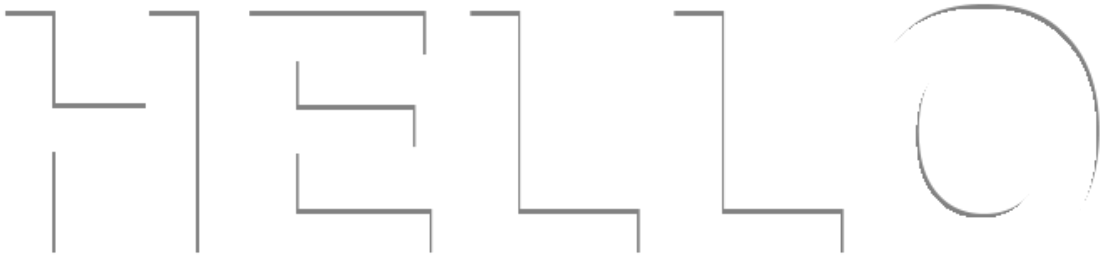
Face

Female statue

Our brains try to map objects into things we know

Gestalt Psychology: text continuity

This isn’t text but it we can read it like text:



Gestalt Psychology

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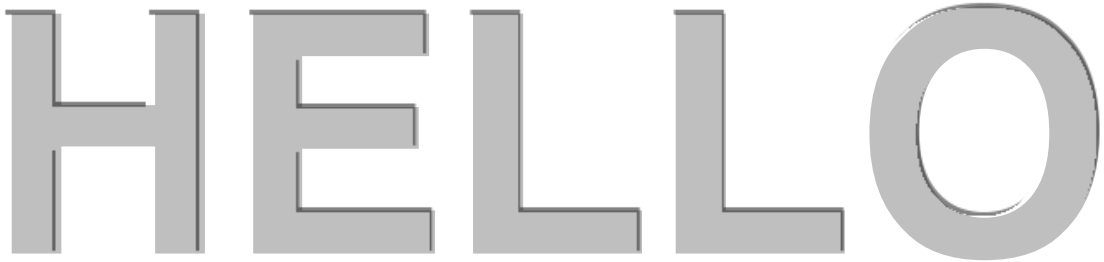


(This is trivial for today's AI models to parse)

Authenticating humanness

Battle the Bots:

- Create a test that is easy for humans but extremely difficult for computers

CAPTCHA: Completely Automated Public Turing test to tell Computers and Humans Apart

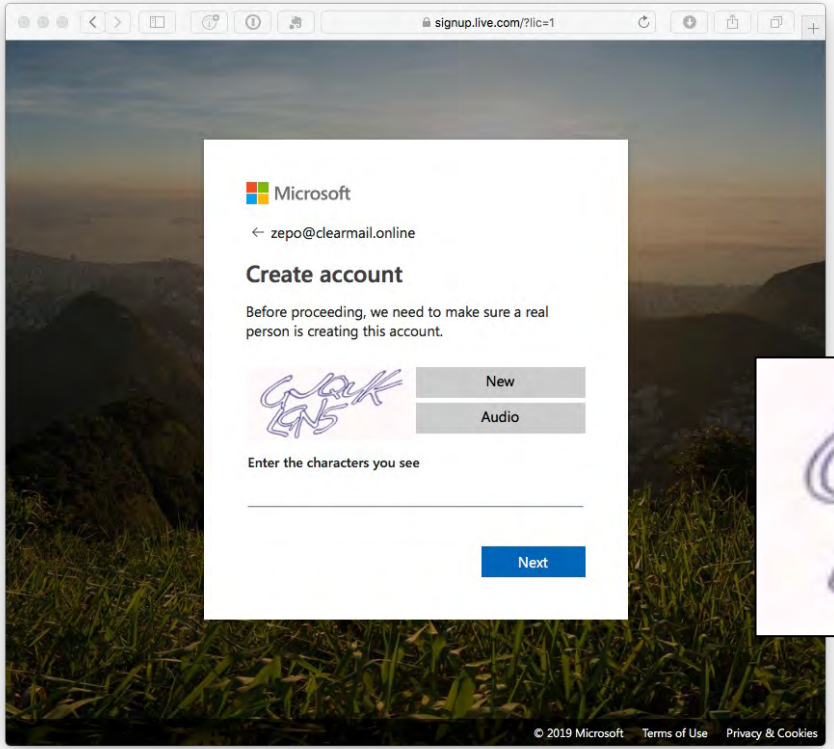
- Image Degradation
  - Exploit our limits in OCR technology
  - Leverages human Gestalt psychology: reconstruction

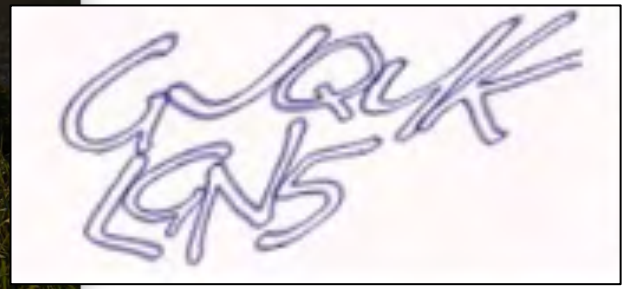
Origins

- **1997**: AltaVista (an early search engine) – prevent bots from registering URLs with the search engine
- **2000**: Yahoo! and Manuel Blum & his team at CMU created **EZ-Gimpy**
  - Distort one of 850 words
- **2003**: Henry Baird @ CMU & Monica Chew at UCB created **BaffleText**
  - Generates a few words and random non-English words

CAPTCHA Example (2019)

Microsoft

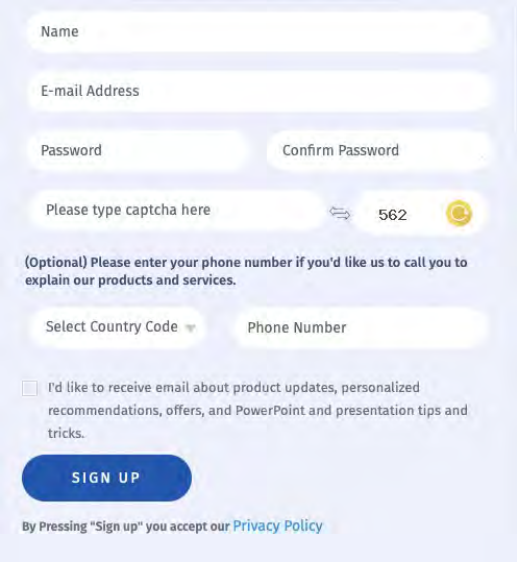


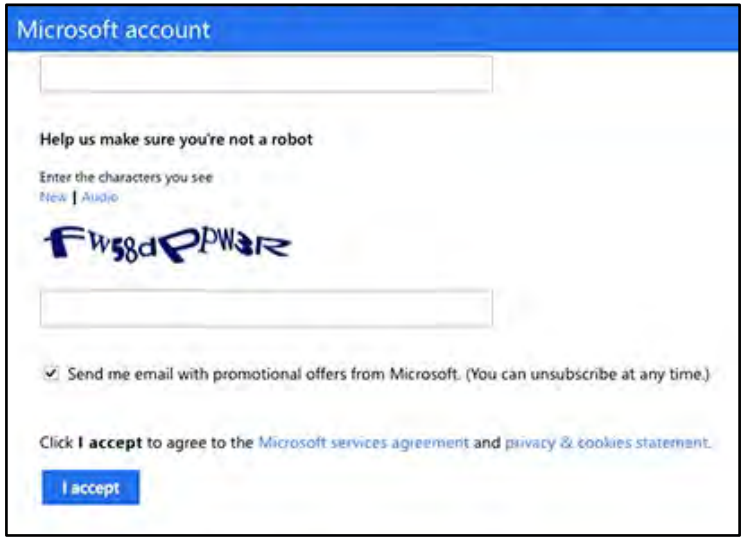


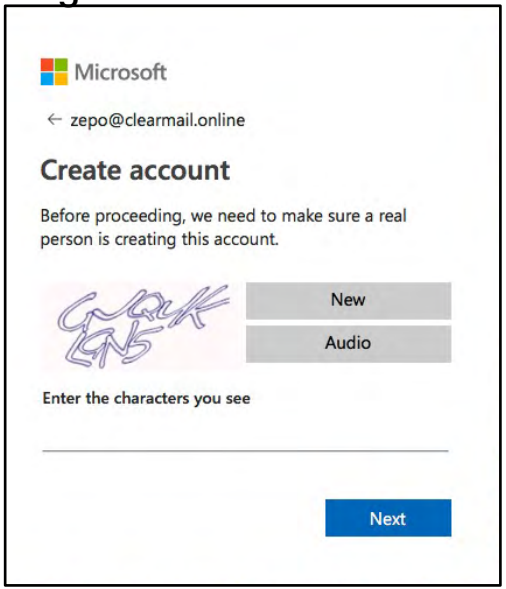
See captchas.net

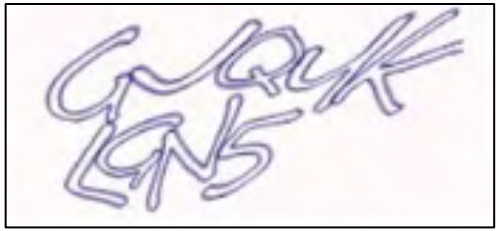
They had to get more difficult

Advances in machine learning & character recognition led to automated solving









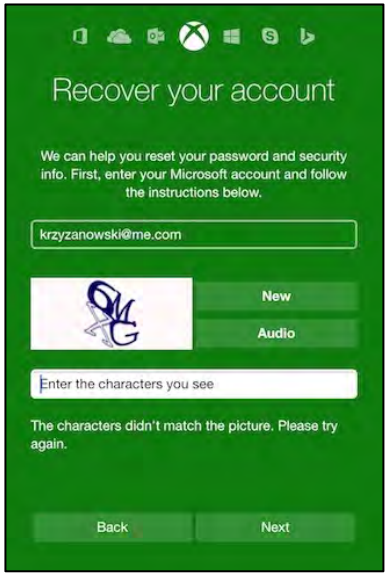
Problems

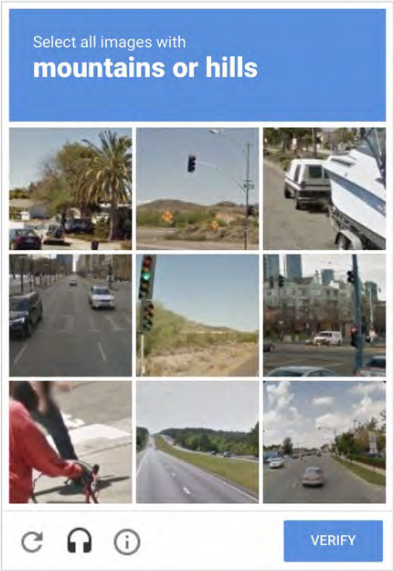
- **Accessibility**
  - Visual impairment → audio CAPTCHAs
  - Deaf-blind users are left out

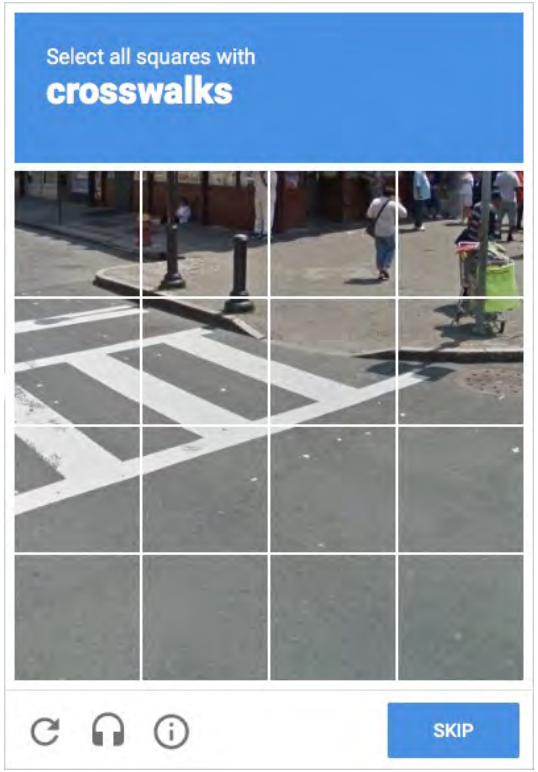
- **Frustration**
  - Typing text was more of a pain on mobile devices
  - OCR & computer vision algorithms improved a lot!
  - Challenges that are now difficult for computers may be difficult for humans
- **Attacks**
  - Man in the middle attacks – software can redirect the challenge to humans
    - Use human labor – CAPTCHA farms
  - Automated CAPTCHA solvers
    - Initially, educated guesses over a small vocabulary – later, use improved image recognition

Alternate approaches

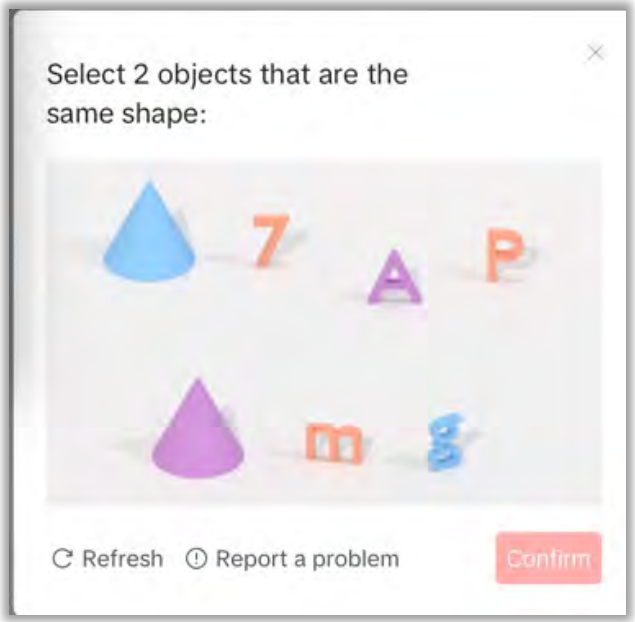
- **Puzzles, scene recognition**
- **Touching is easier than typing on phones**

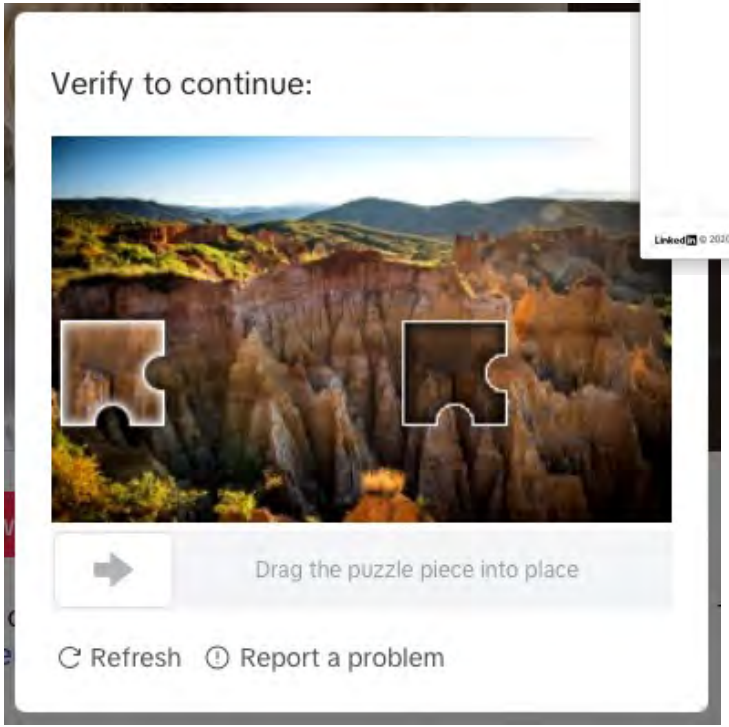


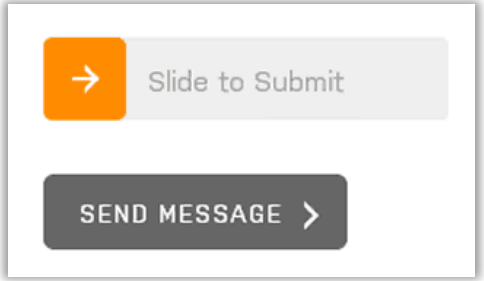




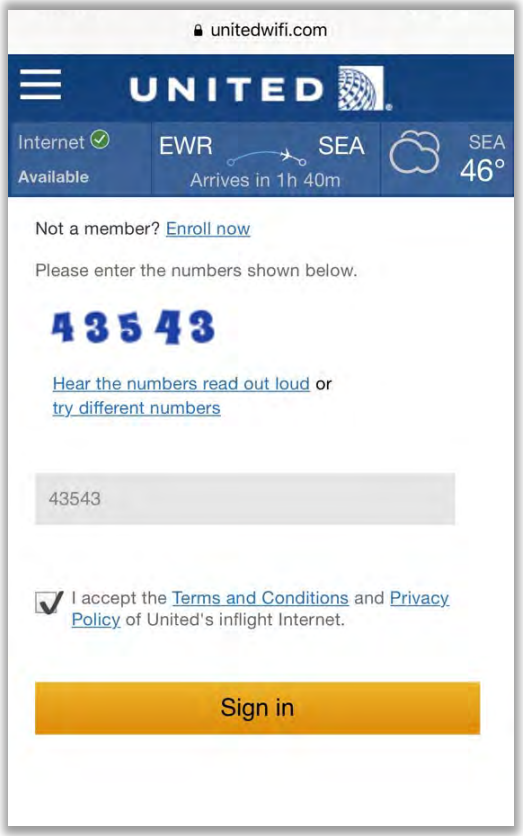
Alternate Approaches

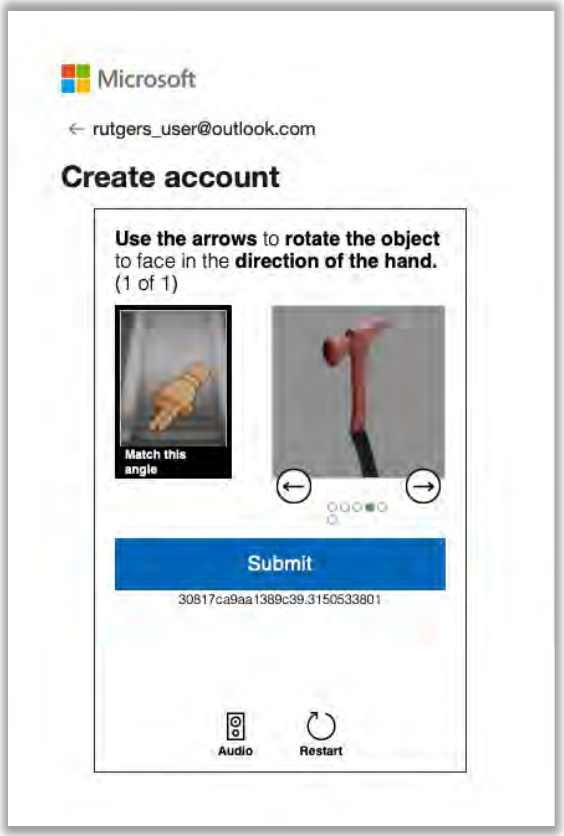






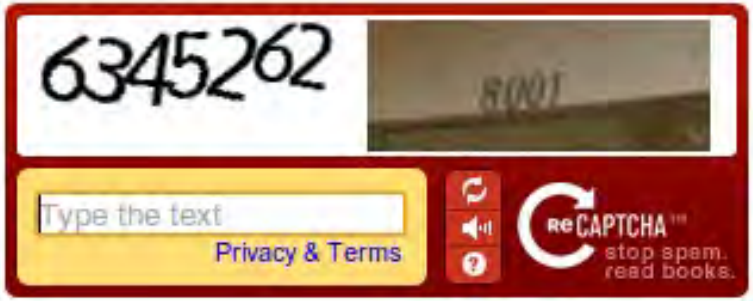
More CAPTCHA Examples





reCAPTCHA

Ask users to translate images of real words & numbers from archival texts



Two sections

(1) known text

(2) image text

- Assume that if you get one right , then you get the next one correct
  - Try it again on a few other people to ensure identical answers before marking it correct

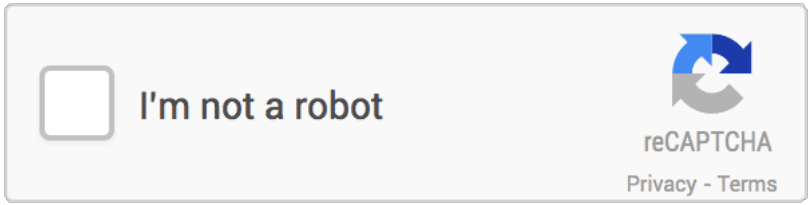
Google bought reCAPTCHA 2009

- Used free human labor to improve transcription of old books & street data
- This enabled the use of human labor to fix up the archives of the New York Times

By 2014:
Google found that AI could crack CAPTCHA & reCAPTCHA images with 99.8% accuracy

NoCAPTCHA reCAPTCHA: reCAPTCHAv2

Just ask users if they are a robot!



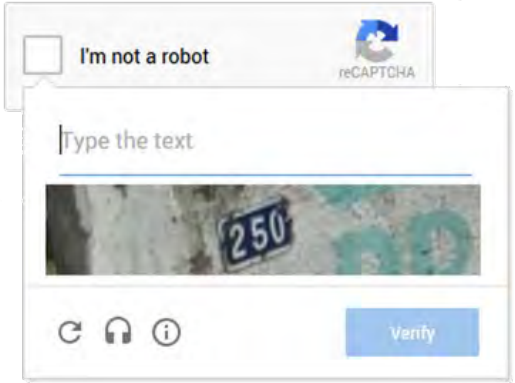
- **Reputation management**
  - "Advanced Risk Analysis backend"
  - Check IP addresses of known bots
  - Check Google cookies from your browser
  - Considers user's engagement with the CAPTCHA: before, during, and after
    - Mouse movements & acceleration, the precise location of clicks
  - Generate a confidence score and allow the service to decide if it's good enough

reCAPTCHAv2 fallback

If risk analysis fails, present a CAPTCHA

Three challenge types:

1. **Classification**: identify which images in a 3x3 grid belong to a given description (e.g., find all images with bridges)
2. **Classification**: like (1) but images are replaced after clicking ("click until there are none left")
3. **Segmentation**: break an image into a 4x4 grid and identify parts that are relevant to the request (e.g., identify all parts of a motorcycle)



reCAPTCHAv3 (invisible reCAPTCHA) makes a decision only based on past interactions, potentially locking users out of a service

The AI Threat

- **In 2024, a team at ETH Zurich demonstrated that reCAPTCHAv2 challenges can be solved 100% of the time using publicly-available AI software**
  - Apply a fine-tuned version of the open-source YOLO (You Only Look Once) object-recognition model
  - Use a VPN to connect with a different IP address for lots of repeated attempts – makes each connection appear to be unique
  - Incorporate artificial Bezier curve-based mouse movements to simulate human behavior

See https://arxiv.org/abs/2409.08831

IllusionCAPTCHA: An attempt at defeating AI

AI-created optical illusions are not recognized by other AI systems

- Gen AI combines an input image and a prompt
- AIs can create images but not detect the illusions: **LLMs failed 100% of the time**
- **Humans passed the test 83% of the time**

https://arxiv.org/abs/2502.05461

https://archive.is/mAHQC

https://www.newscientist.com/article/2468020-ai-generated-optical-illusions-can-sort-humans-from-bots/

Fake CAPTCHA Prompts Used Maliciously

In 2024, the Ukrainian Computer Emergency Response Team warned that the APT28 threat group (Fancy Bear, thought to be affiliated with Russian Intelligence) has been using CAPTCHA impersonation

- Present a fake "I am not a robot" message to get users to click on the checkbox
- This initiates a malicious PowerShell command to the user's clipboard
- The attack targets government workers in Ukraine but can inspire other attackers to use the same technique

https://www.forbes.com/sites/daveywinder/2024/10/26/new-google-cyber-attack-warning-as-russian-apt28-hackers-strike/

Other approaches: Text/email verification

- **Text/email verification**
  - Ask users for a phone # or email address
  - Similar to two-factor authentication, but we're *not authenticating* the user
    - Just having them do something
  - Service sends a message containing a verification code
    - Still susceptible to spamming & automation
    - Makes the process more cumbersome
    - Requires users to disclose information
- **Measure form completion times**
  - Users take longer than bots to fill out and submit forms
  - Measure completion times and randomness in delays
    - But bots can program delays if they realize this is being done

The End