CS 419: Computer Security

Week 8: Authentication: CAPTCHA

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Combined Authentication & Key Exchange

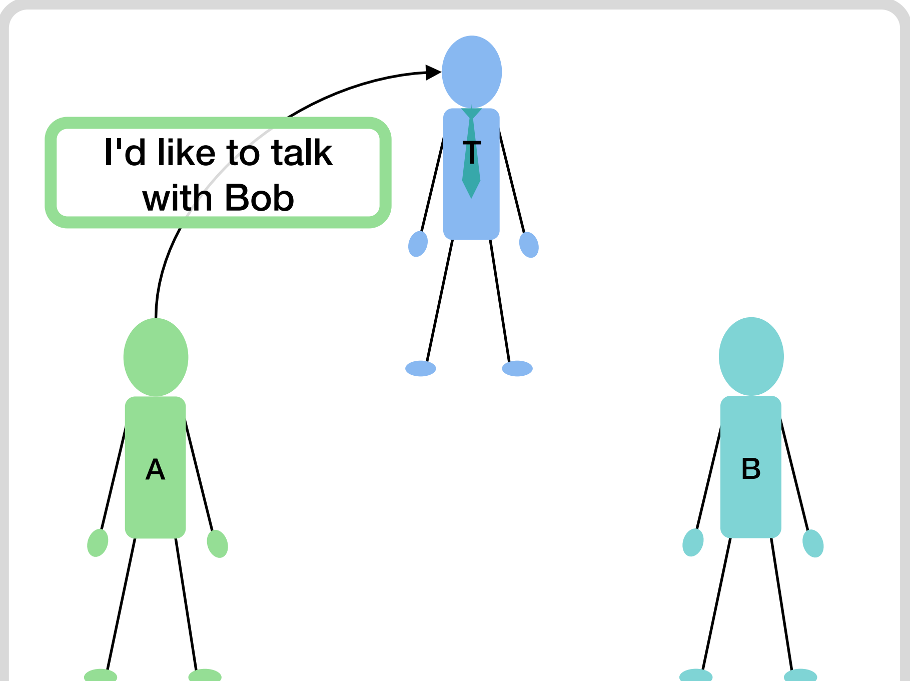
Goals

- Authenticate principals
- Distribute a session key to both securely
- Principals can communicate only if they are properly authenticated

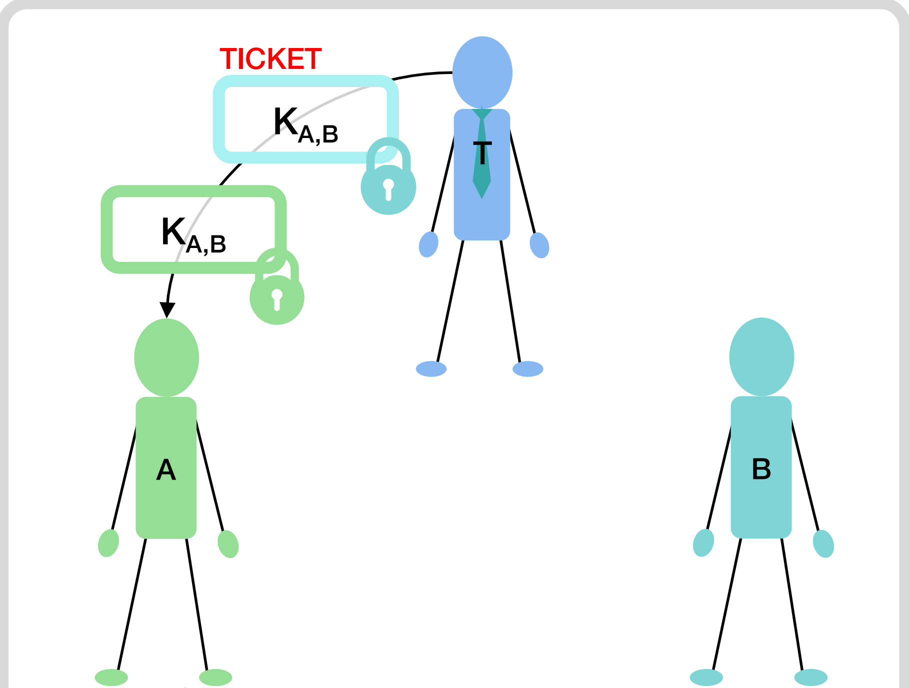
Authentication relies on proving you know your secret key

Symmetric Key Authentication & Key Exchange

- **We use a trusted third party (Trent) who knows all the keys**



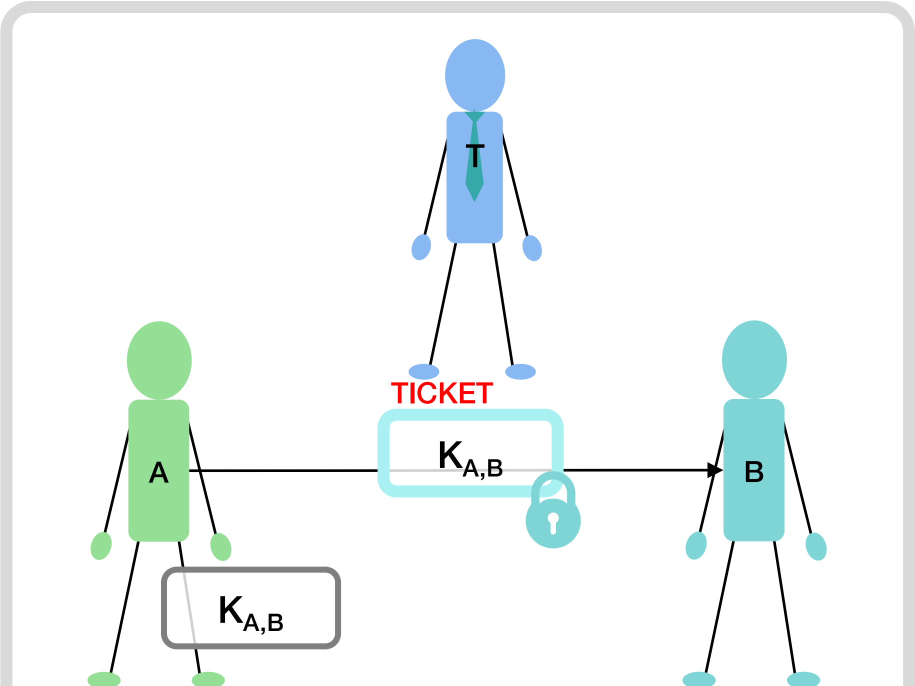
Request a session key



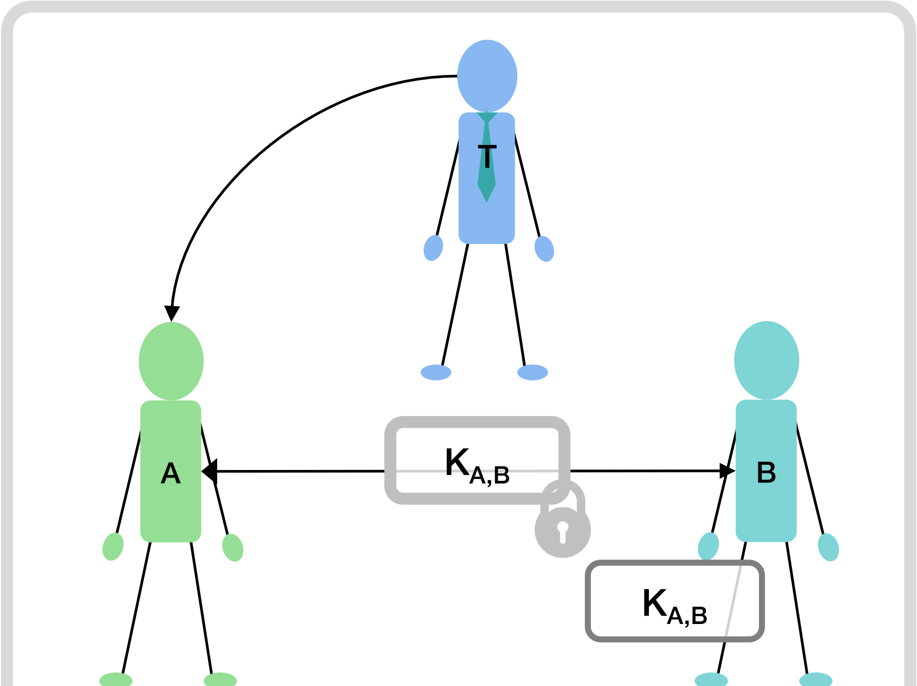
Get encrypted key + ticket

Symmetric Key Authentication & Key Exchange

We use a trusted third party (Trent) who knows all the keys



Send the ticket (key)



Let's talk

Guard against replay attacks

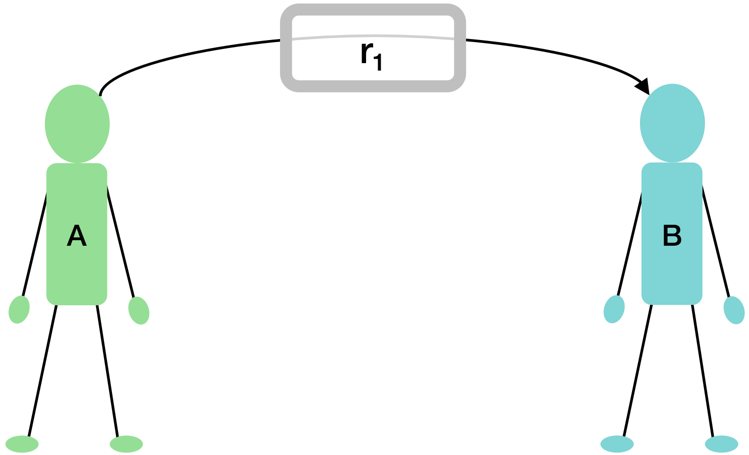
- **Needham-Schroeder: add nonces in encrypted messages**
  - Random numbers will be different with different sessions
  - Messages from old sessions will be rejected

Guard against attacker who knows an old session key

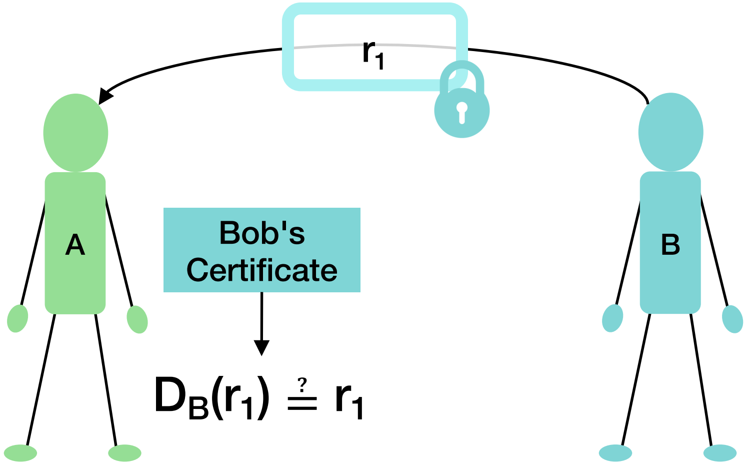
- **Add timestamps in encrypted messages**
  - Attacker's replayed messages will have an older timestamp – and be rejected
- **Add IDs (sequence numbers) in encrypted messages**
  - Attacker's replayed messages will have the wrong number – and be rejected

Public Key Authentication & Key Exchange

- No need for a third party – public keys can reside in X.509 certificates
- Prove you have your private key



Bob, can you encrypt this random number with your private key?

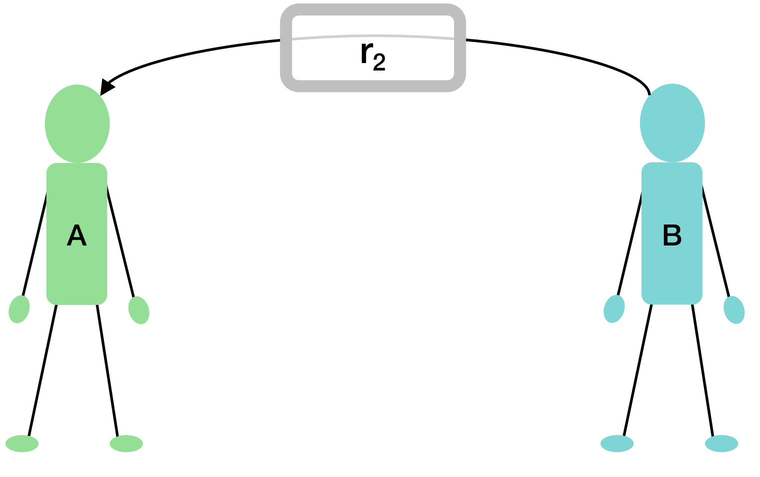


$D_B(r_1) \overset{?}{=} r_1$

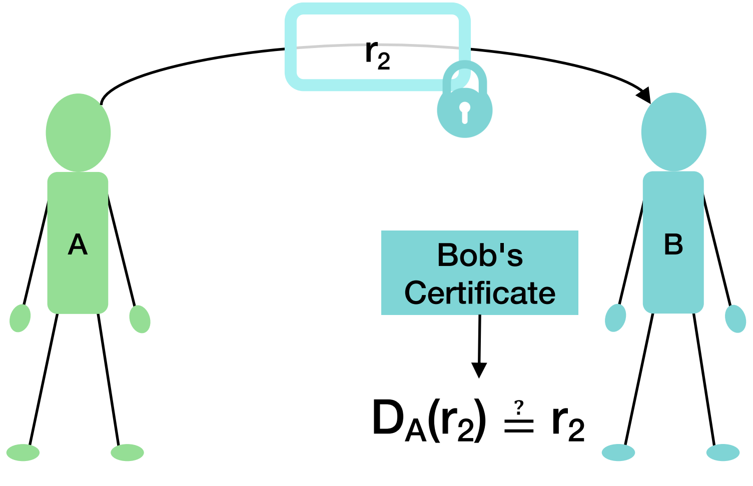
Alice is convinced Bob has Bob's private key

Public Key Authentication – mutual authentication

- No need for a third party – public keys can reside in X.509 certificates
- Prove you have your private key



Alice, can you encrypt this random number with your private key?

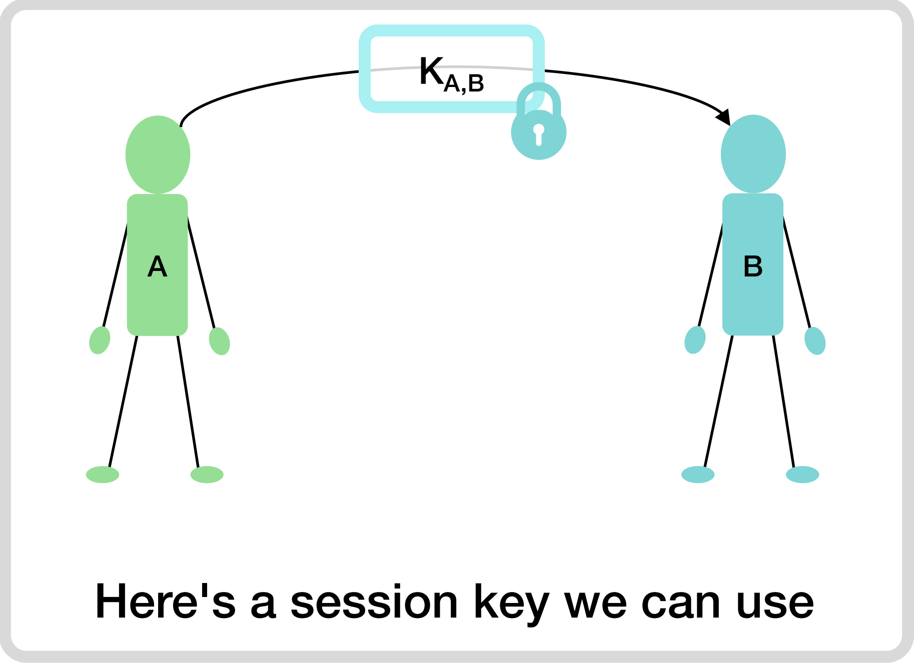


$D_A(r_2) \stackrel{?}{=} r_2$

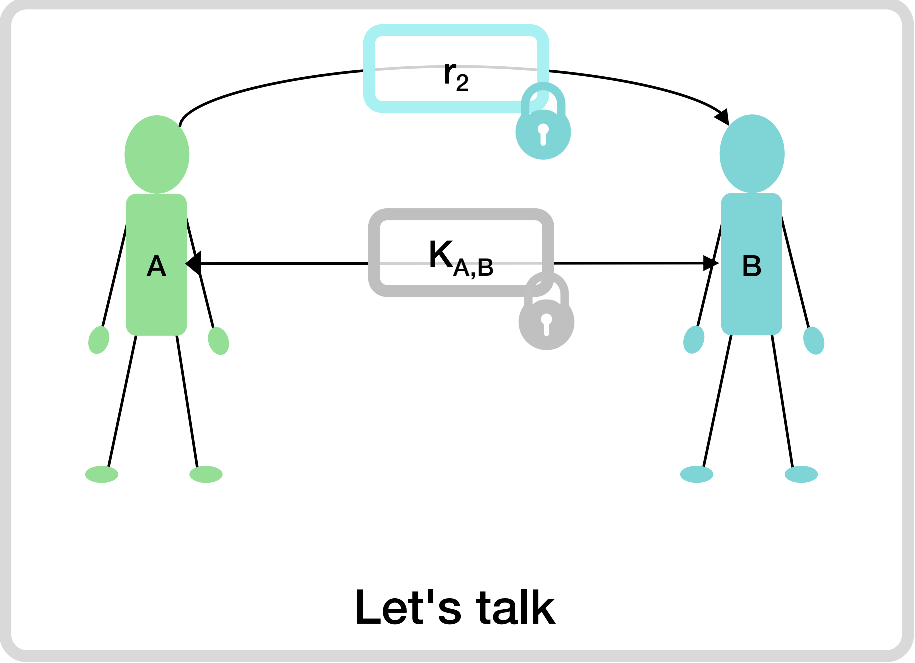
Bob is convinced
Alice has Alice's private key

Public Key Authentication – key exchange

- **Encrypt a session key with the other party's public key.**



Here's a session key we can use



Let's talk

User Authentication

Three Factors of Authentication

1. Ownership **Something you have**	*Key, card*	*Can be stolen*
2. Knowledge **Something you know**	*Passwords, PINs*	*Can be guessed, shared, stolen*
3. Inherence **Something you are**	*Biometrics (face, fingerprints)*	*Requires hardware* *May be copied* *Not replaceable if lost or stolen*

User authentication protols

- **Password Authentication Protocol (PAP)**
  - User: { name, password }
  - Server: *lookup*(name) $\overset{?}{=}$ password
- **Hashed password storage**
  - User: { name, password }
  - Server: *lookup*(name) $\overset{?}{=}$ *hash*(password)
- **Hashed passwords with salt**
  - User: { name, password }
  - Server: *lookup*(name) ⇒ salt, stored_password
    hash(stored_password) $\overset{?}{=}$ *hash*(salt || password)

One-time passwords

- **Sequence-based**
  - S/key:
    - $P_1 = \mathit{hash}(R)$, $P_2 = \mathit{hash}(P_1)$, $P_3 = \mathit{hash}(P_2)$, $P_4 = \mathit{hash}(P_3)$,…
  - User: { name, P_n }
  - Server:
    - $\mathit{lookup}(\text{name}) \stackrel{?}{=} \mathit{hash}(P_n)$
    - update database: name.password = P_n
- **Challenge-Handshake Authentication Protocol (CHAP)**
  - Server: challenge
  - Client: hash(challenge, secret)
  - Server hash(challenge, stored_secret) $\stackrel{?}{=}$ client_response

One-time passwords

- **Time-based One-Time Password**
  - User: { name, client_password=*hash*(secret, time) }
  - Server:
    - *hash*(*lookup*(name).secret), time) $\overset{?}{=}$ client_password
- **Hash-based One-Time Password**
  - User: { name, client_password = *hash*(secret, token_id, counter) }
  - Server:
    - Server: *lookup*(name) ⇒ stored_secret, stored_token_id, stored_counter
    - *hash*(stored_secret, stored_token_id, stored_counter), ti*me*) $\overset{?}{=}$ client_password
    - update database: name.counter = name.counter + 1

Biometric Authentication

- **Pattern matching**
  - Set thresholds to determine if the match is close enough
- **False Accept Rate (FAR)**
  - Non-matching pair of biometric data is *accepted* as a match
- **False Reject Rate (FRR)**
  - Matching pair of biometric data is *rejected* as a match
- **Balance security (low FAR) vs. convenience (low FRR)**

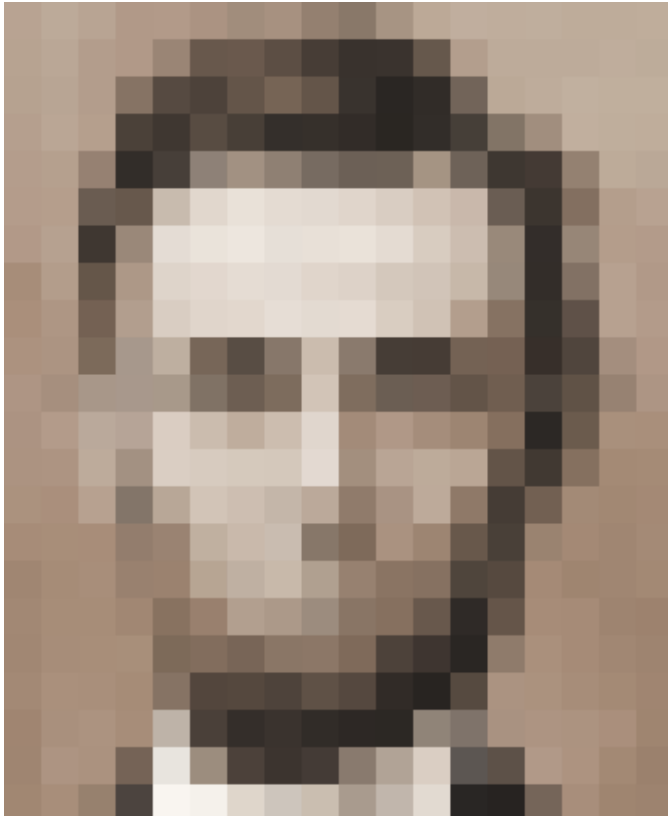
CAPTCHA: Detecting Humans

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

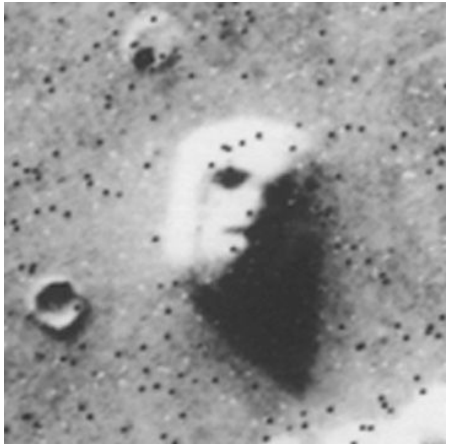
Gestalt Psychology



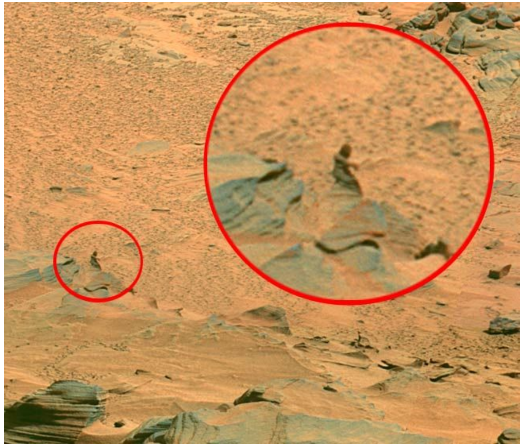
18 x 22 pixels

Objects on Mars?

Elvis

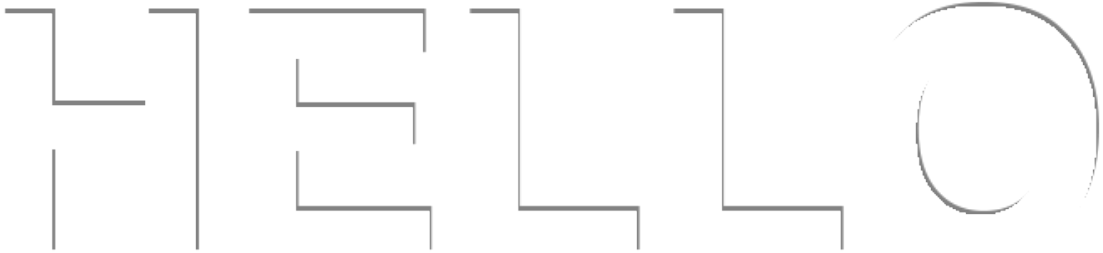


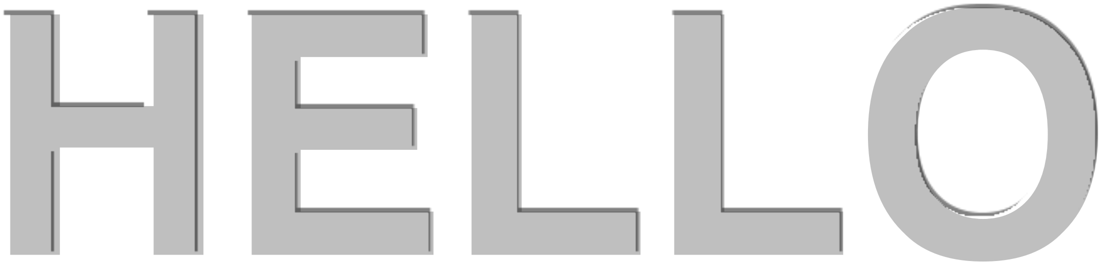
Face



Female statue

Gestalt Psychology: text continuity




HELLO

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

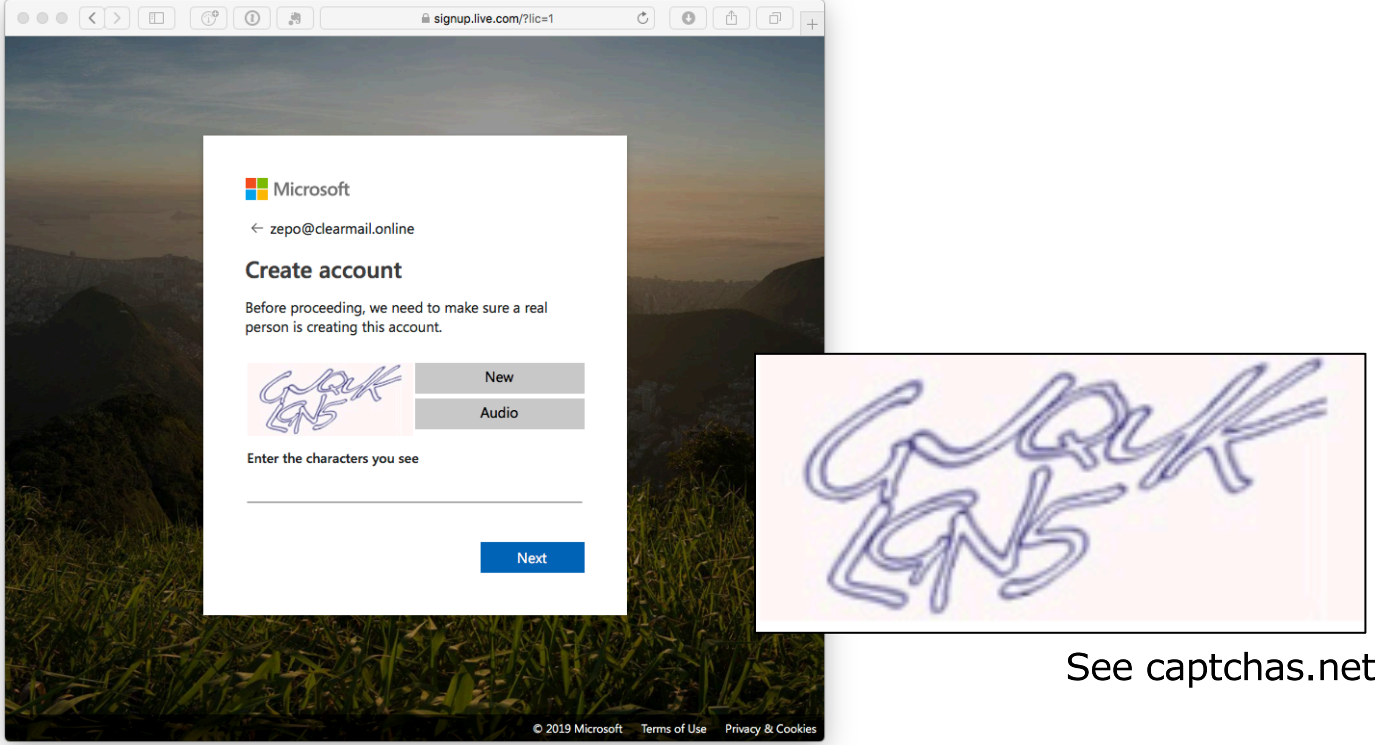
- Image Degradation
  - Exploit our limits in OCR technology
  - Leverages human Gestalt psychology: reconstruction

Origins

- 1997: AltaVista – prevent bots from registering URLs with the search engine
- 2000: Yahoo! and Manuel Blum & team at CMU
  - EZ-Gimpy: one of 850 words
- Henry Baird @ CMU & Monica Chew at UCB
  - BaffleText: generates a few words + random non-English words

CAPTCHA Example (2019)

Microsoft



signup.live.com/?lic=1

Microsoft

← zepo@clearmail.online

Create account

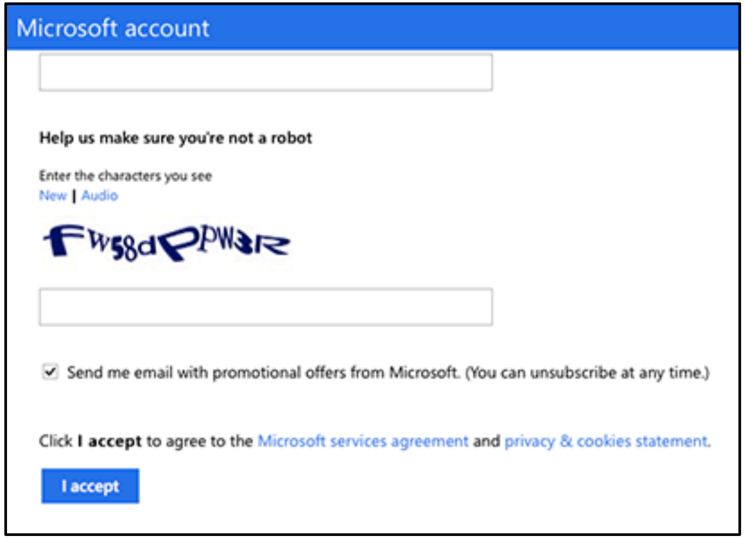
Before proceeding, we need to make sure a real person is creating this account.

Enter the characters you see

© 2019 Microsoft Terms of Use Privacy & Cookies

See captchas.net

They’re getting harder



Microsoft account

Help us make sure you're not a robot

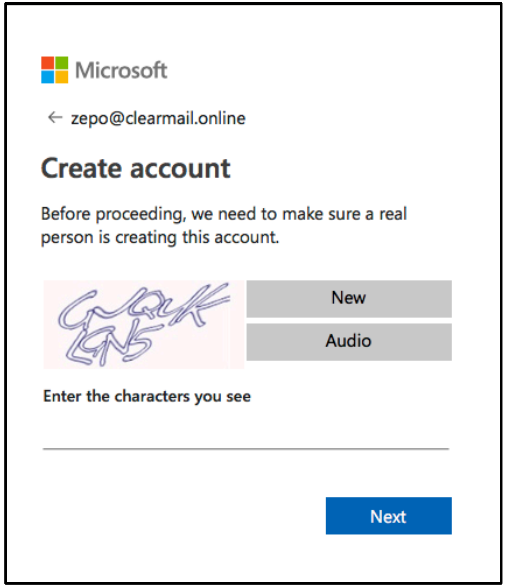
Enter the characters you see

New | Audio

☑ Send me email with promotional offers from Microsoft. (You can unsubscribe at any time.)

Click **I accept** to agree to the Microsoft services agreement and privacy & cookies statement.

I accept



Microsoft

← zepo@clearmail.online

Create account

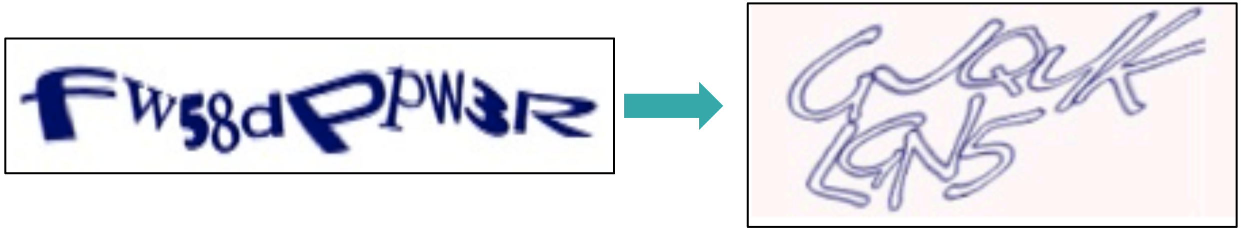
Before proceeding, we need to make sure a real person is creating this account.

New

Audio

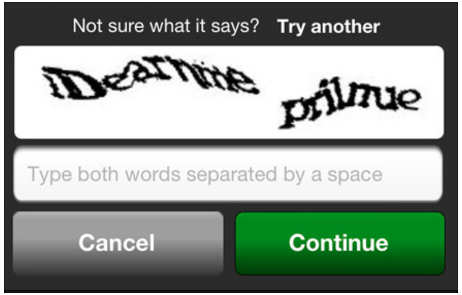
Enter the characters you see

Next



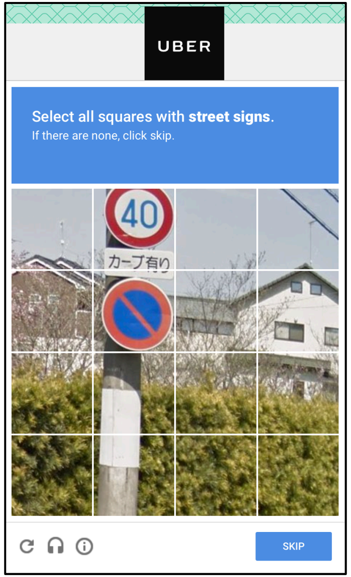
Problems

- **Accessibility**
  - Visual impairment → audio CAPTCHAs
  - Deaf-blind users are left out
- **Frustration**
  - OCR & computer vision has improved a lot!
  - Challenges that are difficult for computers may be difficult for humans
- **Attacks**
  - Man in the middle attacks
    - Use human labor – CAPTCHA farms
  - Automated CAPTCHA solvers
    - Initially, educated guesses over a small vocabulary

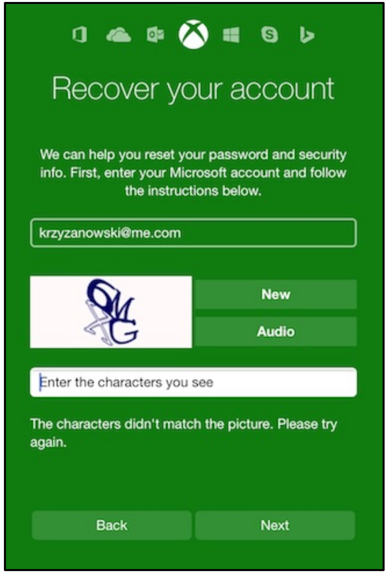

Not sure what it says? Try another
Type both words separated by a space
Cancel
Continue

Alternate approaches

- **MAPTCHAs = math CAPTCHAs**
  – Solve a simple math problem
- **Puzzles, scene recognition**



Select all squares with **street signs**.
If there are none, click skip.



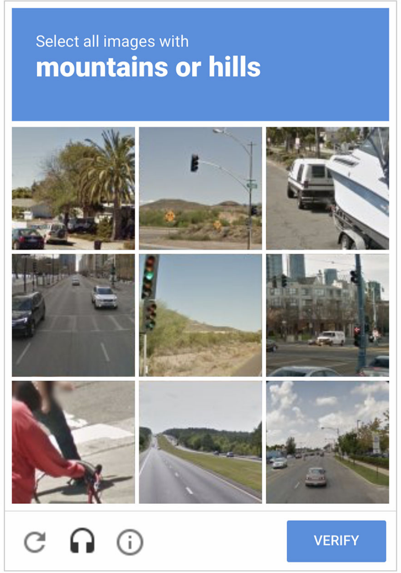
Recover your account

We can help you reset your password and security info. First, enter your Microsoft account and follow the instructions below.

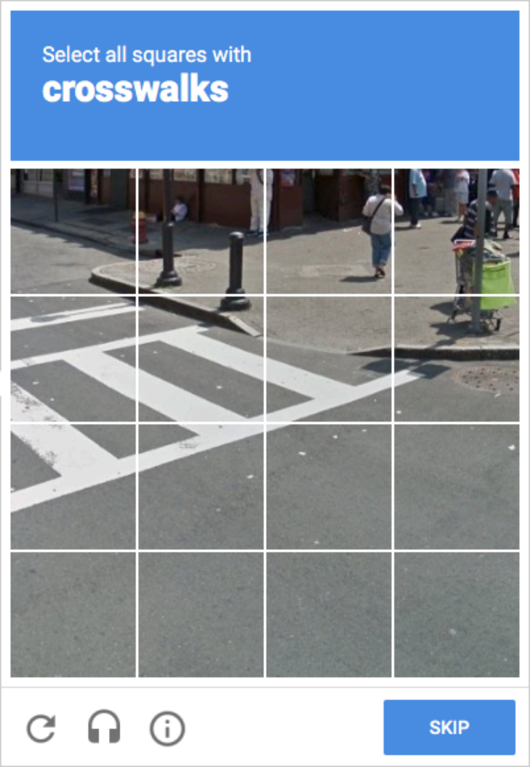
krzyzanowski@me.com

Enter the characters you see

The characters didn't match the picture. Please try again.

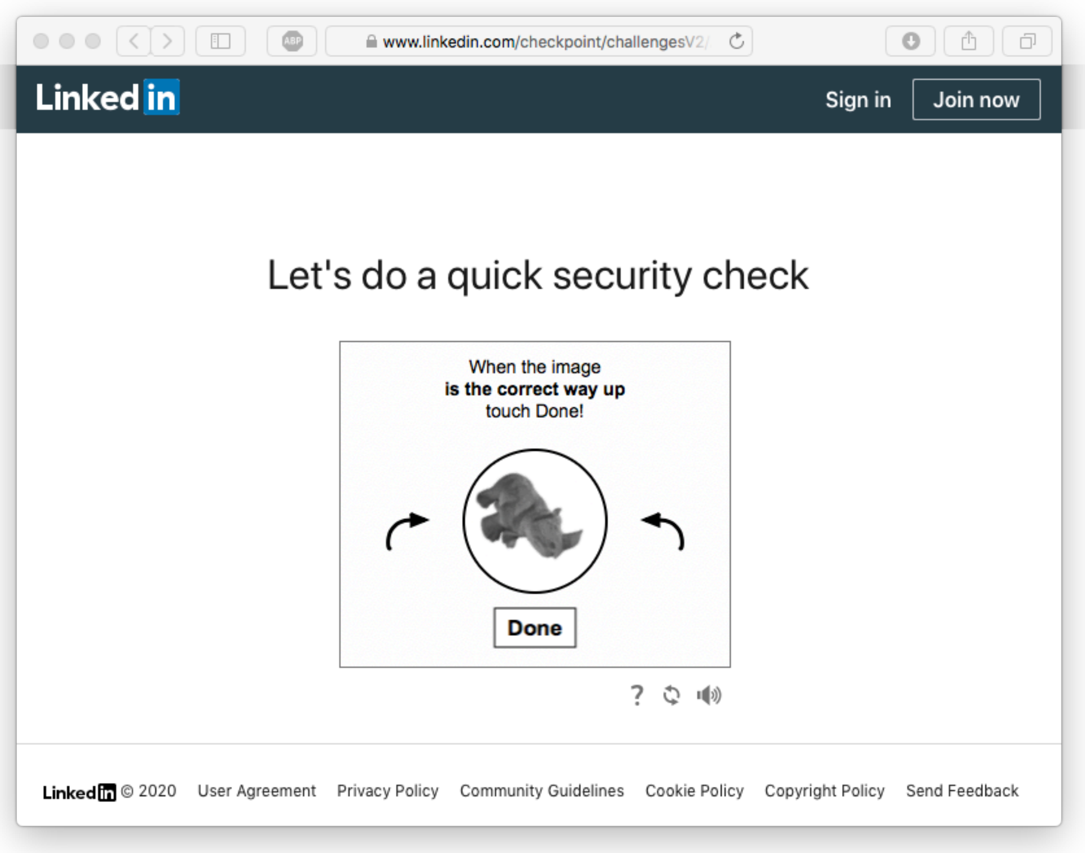


Select all images with
mountains or hills



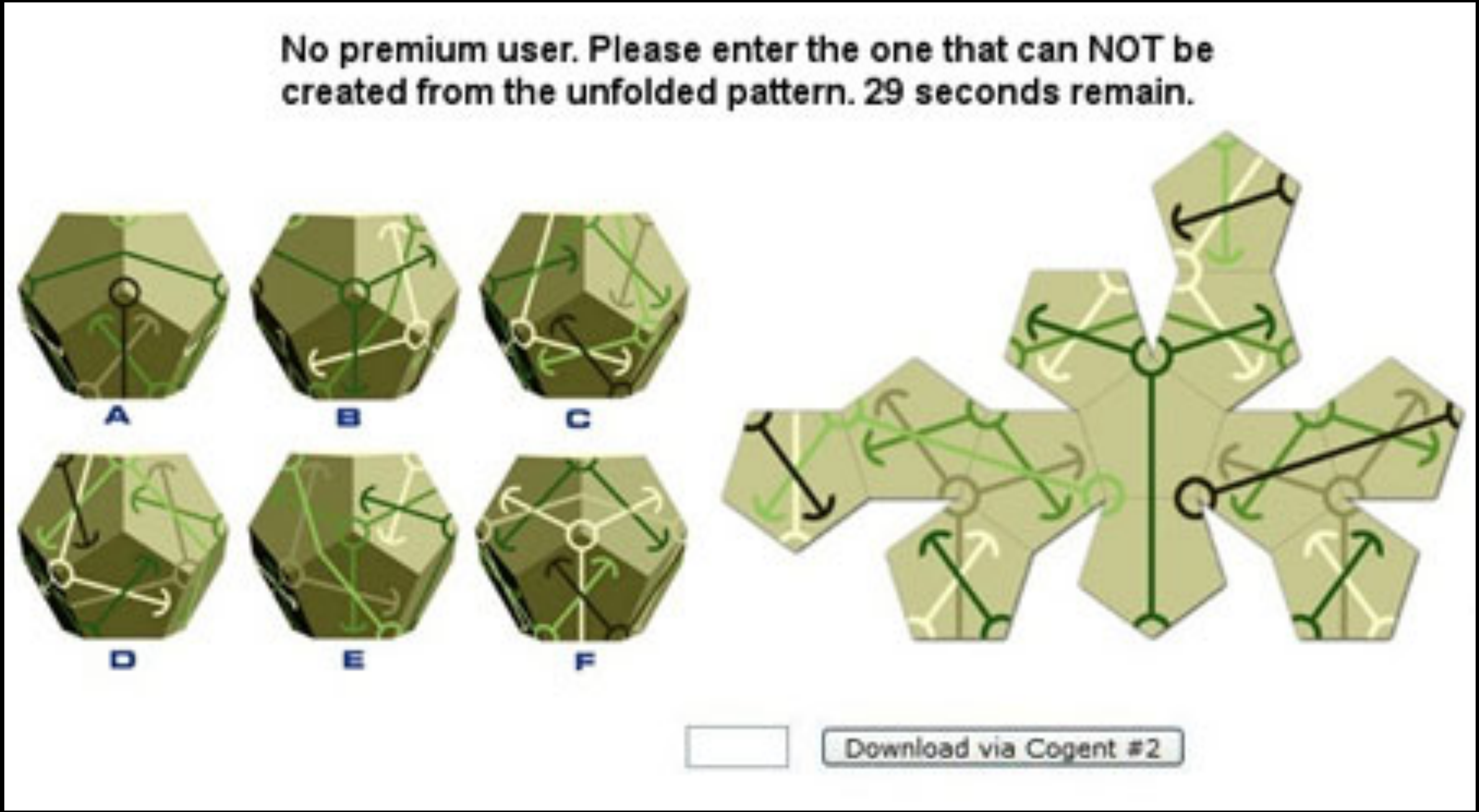
Select all squares with
crosswalks

Alternate approaches

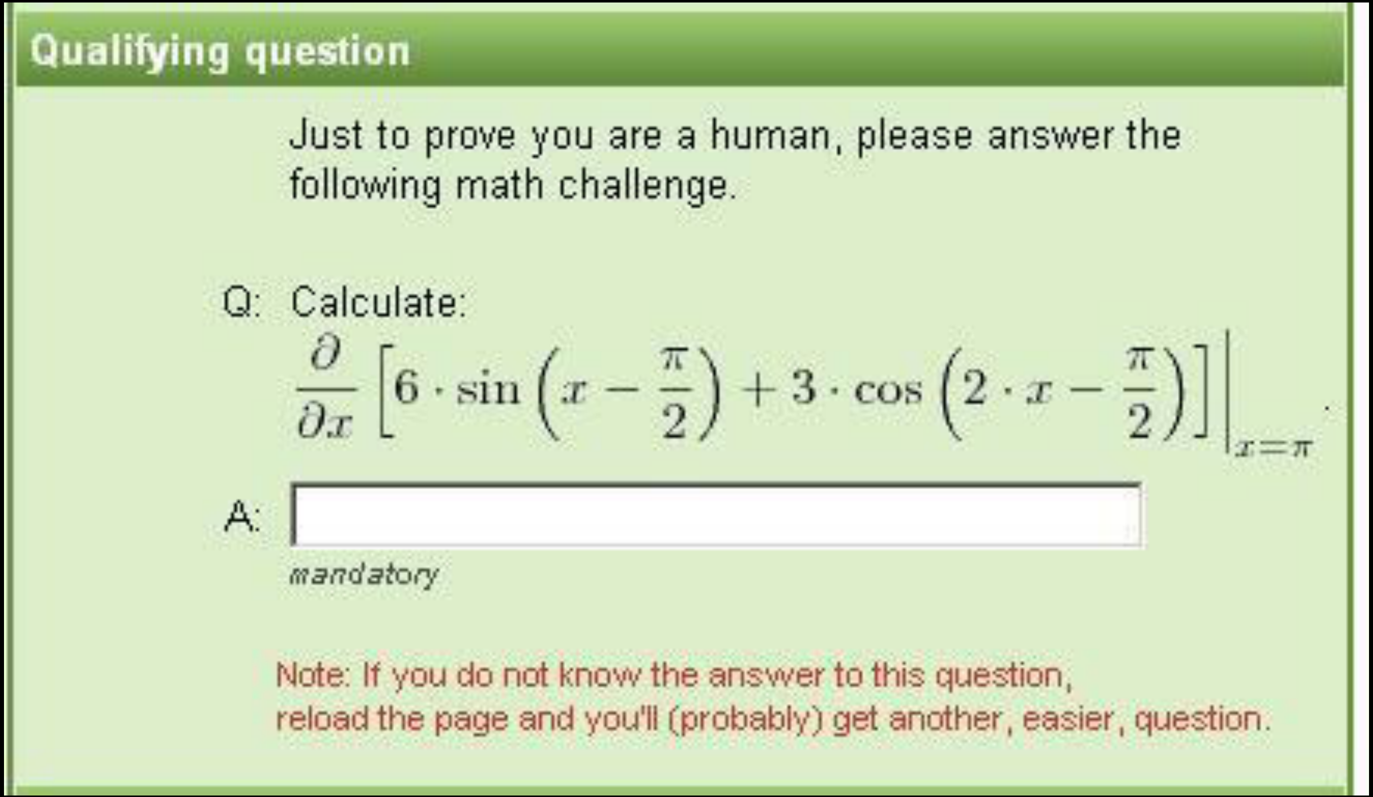


Let's do a quick security check

When the image
is the correct way up
touch Done!



No premium user. Please enter the one that can NOT be created from the unfolded pattern. 29 seconds remain.



Qualifying question

Just to prove you are a human, please answer the following math challenge.

Q: Calculate:

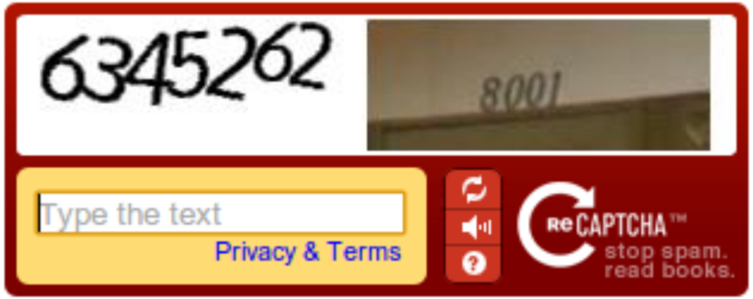
$$\frac{\partial}{\partial x}\left[6\cdot\sin\left(x-\frac{\pi}{2}\right)+3\cdot\cos\left(2\cdot x-\frac{\pi}{2}\right)\right]\Bigg|_{x=\pi}.$$

A:

mandatory

Note: If you do not know the answer to this question, reload the page and you'll (probably) get another, easier, question.

reCAPTCHA

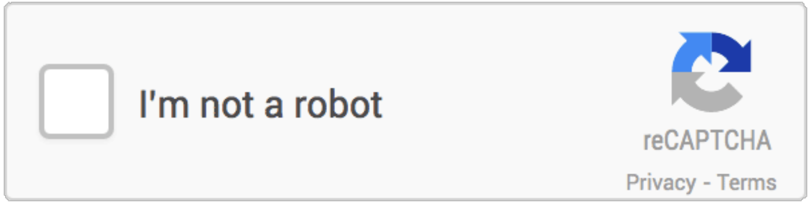


- **Ask users to translate images of real words & numbers from archival texts**
  - Human labor fixed up the archives of the New York Times
- **Two sections**
  - (1) known text
  - (2) image text
  - Assume that if you get one right then you get the next one correct
    - Try it again on a few other 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

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

NoCAPTCHA reCAPTCHA

Just ask users if they are a robot

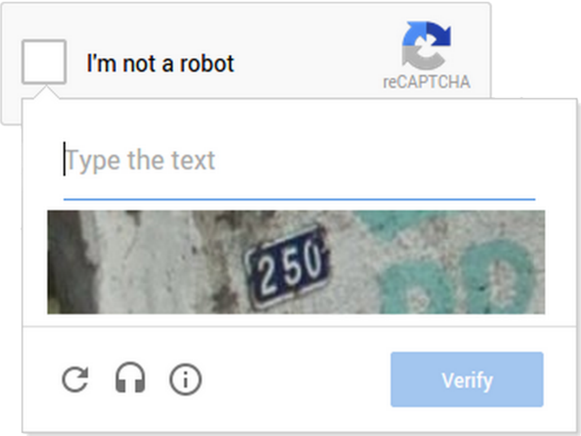


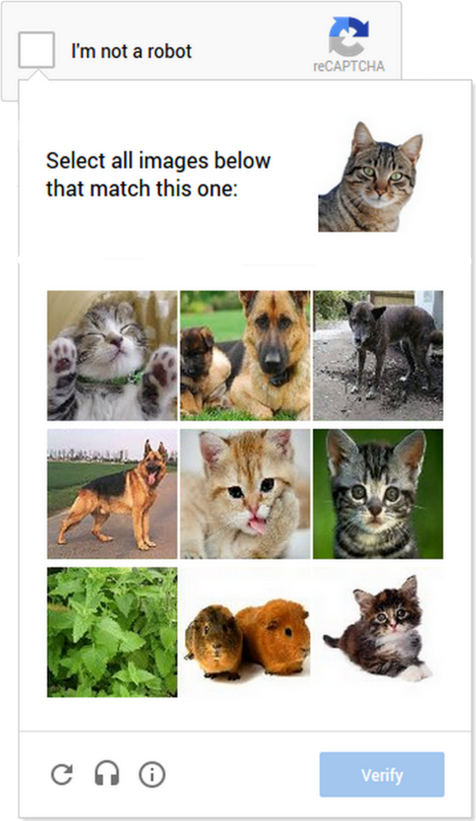
- **Reputation management**
  - "Advanced Risk Analysis backend"
  - Check IP addresses of known bots
  - Check Google cookies from your browser
  - Considers user's engagement with the CAPTCHA: before, during, and after
    - Mouse movements & acceleration, precise location of clicks
- **Newest version: invisible reCAPTCHA**
  - Don't even present a checkbox

NoCAPTCHA fallback

If risk analysis fails,

- Present a CAPTCHA
- For mobile users, present an image identification or labeling problem





Select all images below that match this one:

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
  - Service sends a message containing a verification code
    - Still susceptible to spamming & automation
    - Makes the process more cumbersome
    - Requires users to disclose some information

- **Measure form completion times**
  - Users take longer than bots to fill out and submit forms
  - Measure completion times
    - Bots can program delays if they realize this is being done

The End.