E-Meet (or Emit?) My Keystrokes

How Benign Screen-sharing Meetings Could Leak Typing Behaviors

Chrisando Ryan P. Siahaan

Security Researcher & Lecturer Specialist in Cybersecurity

About

- Call me **Chrisando Ryan**, **@chrisandoryan** or **Siahaan**
- Lecturer Specialist in Cyber Security, BINUS University, Indonesia
- CEO of Questlabs ID, a security-centered software development agency in Indonesia.
- Driven to a T-shaped culture by extensively studying AI, Computer Vision, and Big Data domains as well, and intertwine them with Cyber Security.

- Black Hat Asia Arsenal speaker, back in 2020 (covid-era ☹).
- CTF problem setter & judge at various competitions in Indonesia.
- Enjoy bounty hunting, building ventures, and conducting multi-disciplinary projects

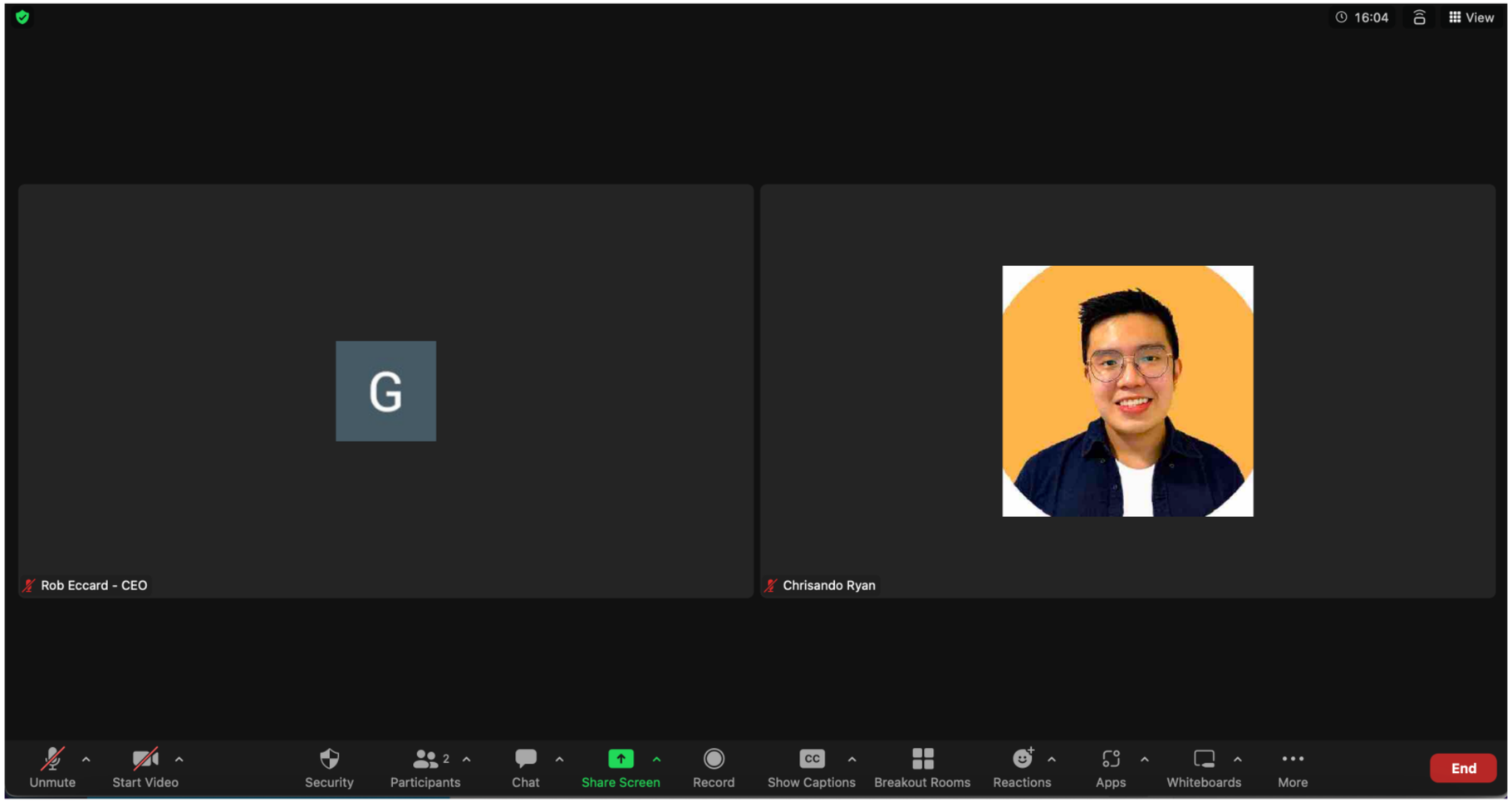
BINUS UNIVERSITY

Agenda

- Backstage story.
- Others who have tried…
- Our approach.
- The danger behind all these.
- Is there any cure?
- Takeaways.

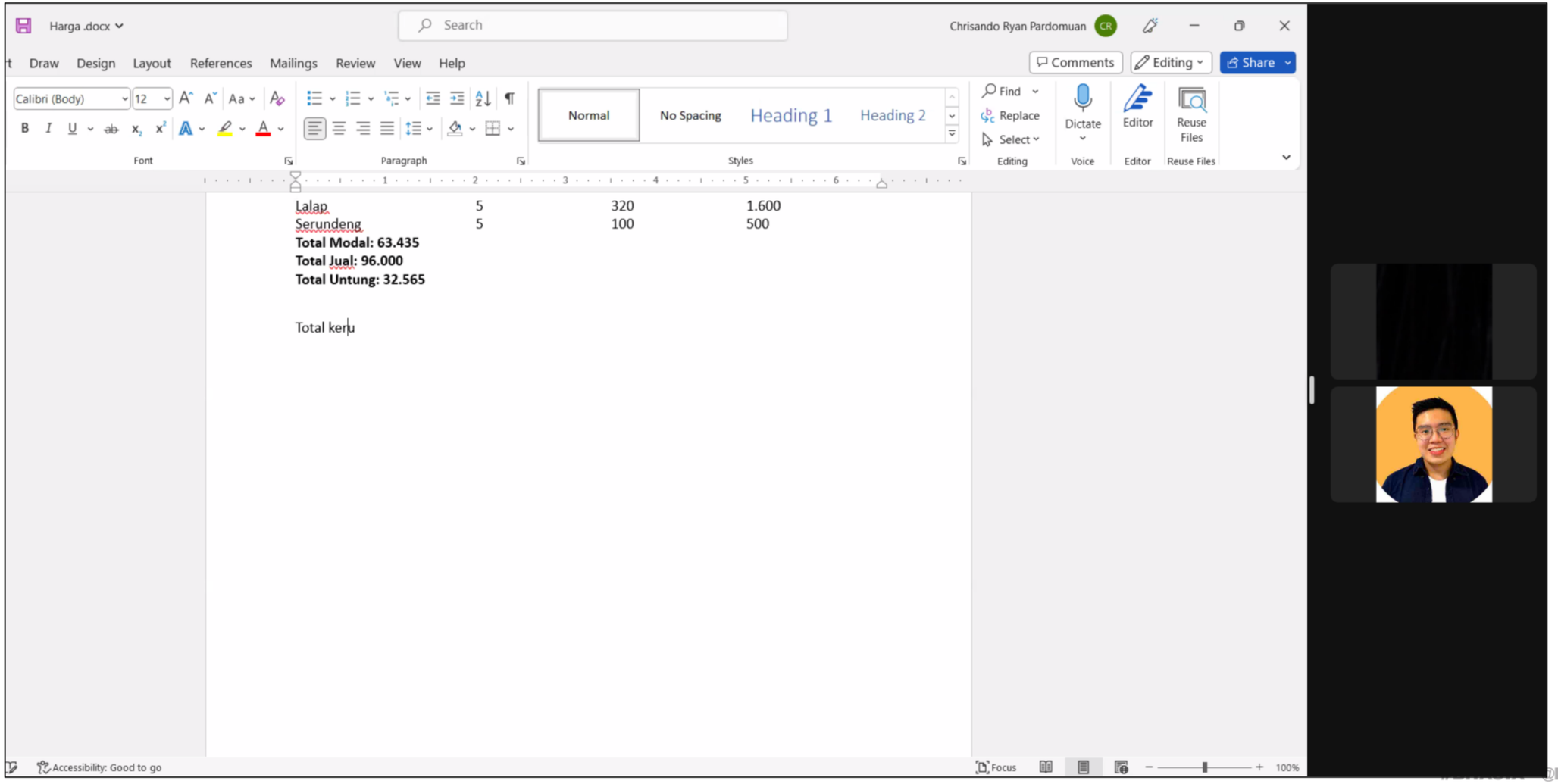
Backstage Story

One ordinary day, you're in a Zoom meeting with colleagues.



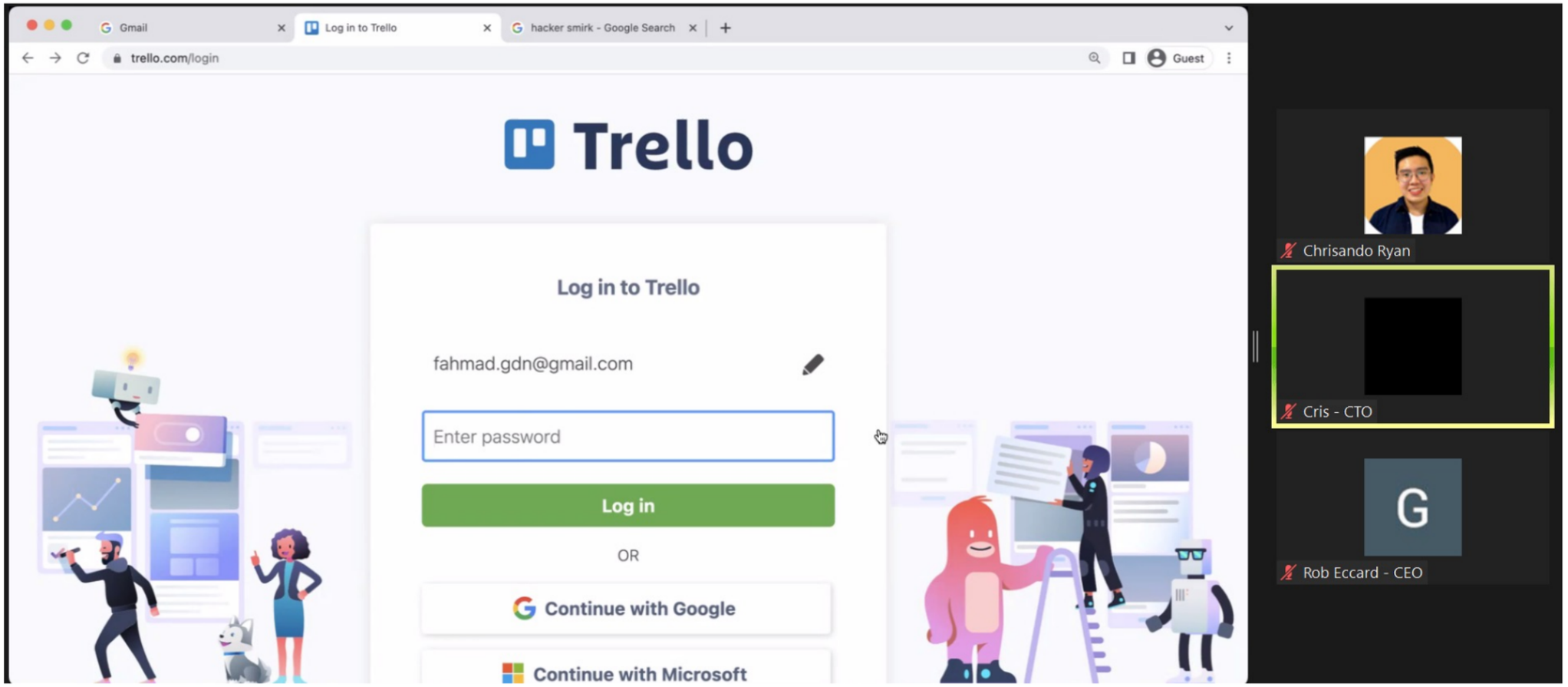
Backstage Story

You guys are doing your stuffs, discussing back and forth.



Backstage Story

Suddenly, while a colleague's sharing their screen, they stumbled upon a page which forces them **to do a sign-in using password**.



Backstage Story

Too lazy to stop the screen-sharing temporarily, they choose to continue typing their password;

Thinking that these **black bullet-mask symbol** **will protect them…**

Backstage Story

All those led to our attempt to test a hypothesis:

If we are to live in a world where most meetings will be conducted through online video meetings…

*Then it might be possible to **leak** and **mimic** a user's typing behaviour through a **screen-sharing video** alone.*

Backstage Story: The Basics

So, about **typing behavior**.

- A term coined as **keystroke biometrics,** that is: the process of measuring and analysing an individual's unique typing patterns or rhythms on a computer keyboard.
- Used for?

User authentication

Fraud detection

Forensic analysis

- But, how?

Time between keystrokes (called *Inter-key Latency*)

Duration of each keystroke (called *Hold Latency*)

Pressure or force applied to the keys

Backstage Story: The Basics

The Recipe (Simplified):

How short (or long) **the delay between** each **keypress**

+

How short (or long) **you hold-press** each **character**

+

(**) How hard/strong you press the character keys

+

(**) How many typos/mistakes you made

=

Authentication/Classification. [i.e., Welcome, Bob!]

(**): **less-common metrics**

Backstage Story: The Basics

- Although not as widely-accepted as fingerprint, but **keystroke biometrics** are gaining attention.

coursera

Verification: Signature Track is the first program of its kind on a MOOC platform that links your online coursework to your real identity. By matching your photo and creating a biometric profile of your unique typing patterns, Coursera lets you easily participate wherever you may be in the world.

The New York State DMV and European Banking Authority approve typing biometrics as a compliant method of identity authentication.

- Some major players in the **keystroke dynamics** industry.

The Idea, Originally

~~Create a better **keystroke dynamics** approach as a way to robustly **authenticate legitimate users**~~

Create a technique to extract **typing key-delay** out of a screen-recorded video,

…and maybe use them for despicable reasons >:)

(we'll come back for this)

The Idea, Originally

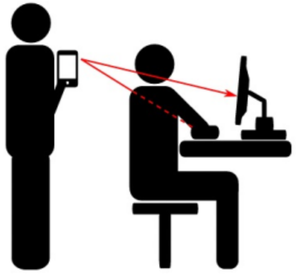
We call this technique, **Camstroke**.

Camstroke Private

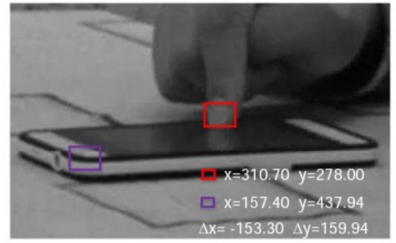
Annotate keystroke from recorded typing video, a utility for video-based Keystroke Inference Attack

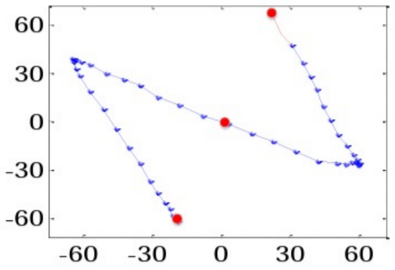
Others Who Have Tried...

- Silk-tv: Secret information leakage from keystroke timing videos (Balagani, et al., 2020)
  - Studied the **leakage of user secrets** (*password* and PIN) from typing activities.
  - Use video footage of a computer/ATM machine screen where password masking characters are displayed when users type their password/PIN.
  - Extract **inter-keystroke** timing information from the video and feed them to Random Forest (RF) classifier to predict the typed password/PIN.

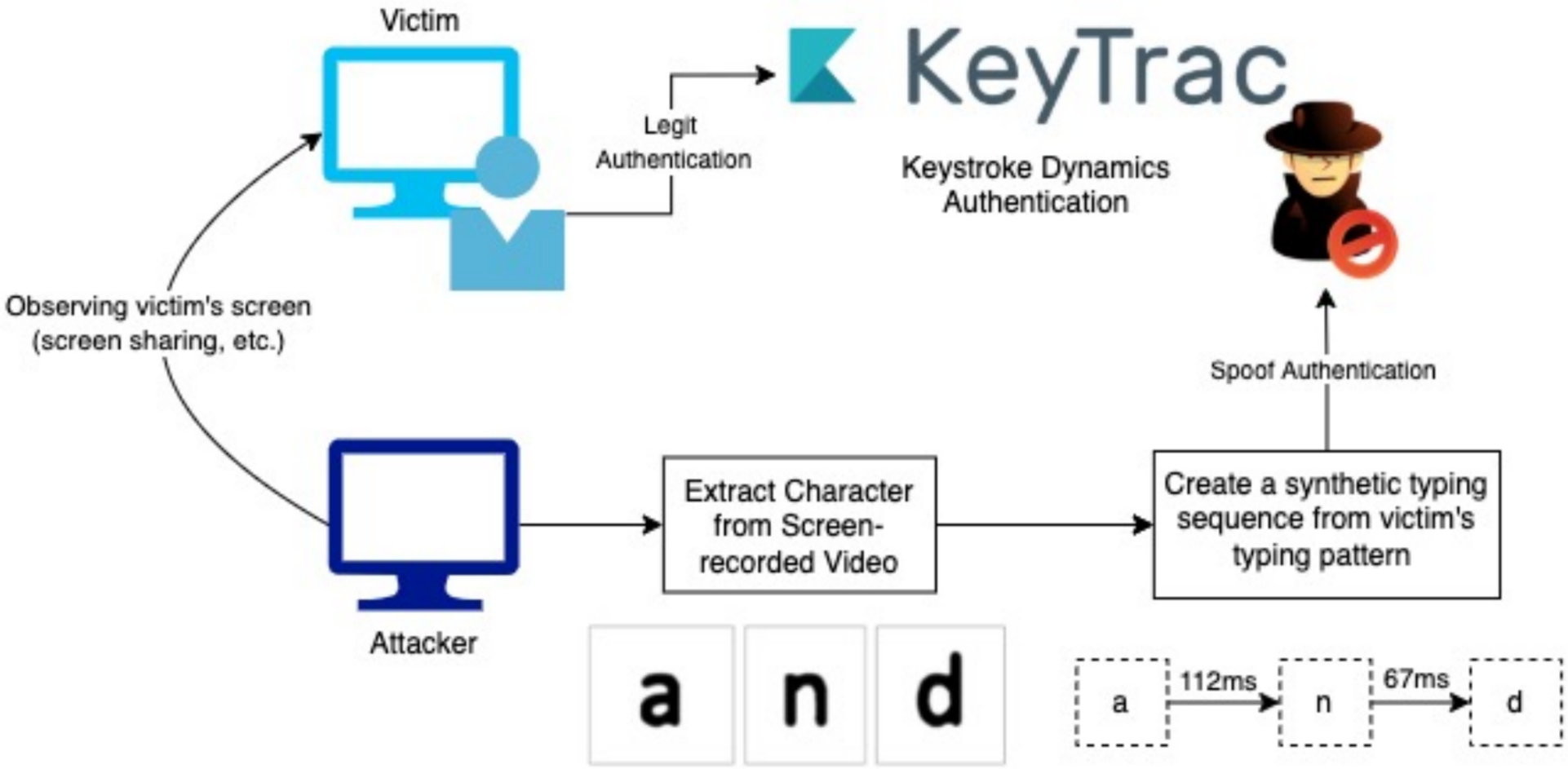


- Cracking Android pattern lock in five attempts (Ye, et al., 2017)
  - Proposed a novel video-based attack to **reconstruct Android lock patterns**.
  - **Does not require** the video to capture **any content displayed on the screen**, only **fingertip movements.**
  - Use TLD (*tracking—learning—detection)* algorithm to generate movement trajectory.





Our Approach, Originally



Our Approach, Originally

During this study, we encountered (at least) **four** of the most pain-staking, mind-bending, and brain-melting obstacles:

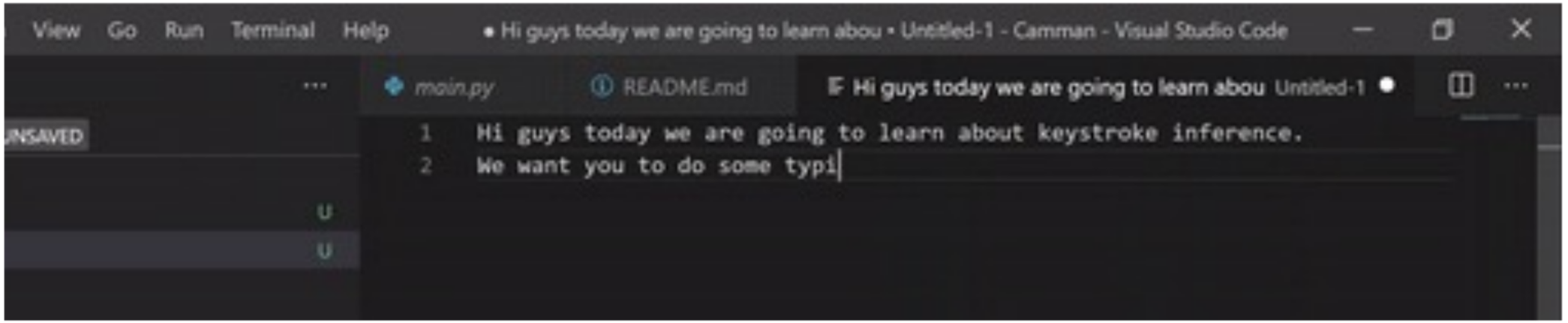
- **Challenge #1:** How to **detect when a user is typing** from a mere screen-recording video data?
- **Challenge #2:** How to **detect what character** is **typed** by the user **on each millisecond** of the video?
- **Challenge #3:** How to **reconstruct the victim's typing pattern** (extract each keystroke's timing/delay information)?
- **Challenge #4:** How to **predict/expose a victim's password** from **the leaked typing pattern**?

Cursor Tracking and Text Detection Alg.

- First things first. From a mere **screen-recording video**, we need to:
    1. **Isolate the segment** of the video **where a typing activity occurs**.
    2. **Extract what character** is being **typed** by the user **on each millisecond** of the video.

The AHA!💡 Assumption:

the **most recent typing activity** must be **occurred to the left of a text cursor object** that appears on the screen.



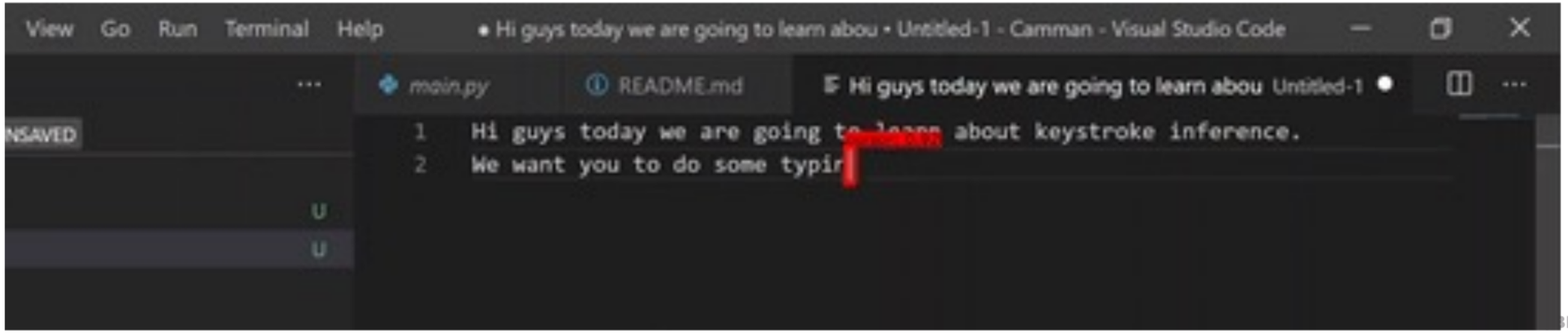
Cursor Tracking and Text Detection Alg.

Challenge #1. Isolate the segment of the video where a typing activity occurs.

- Use **OpenCV** to identify **a moving rectangle-shaped object** (i.e., the **Text Cursor**)
  - Grayscale Conversion & Otsu's Thresholding
  - Canny Edge Detection & Bitwise XOR
- Identifies location of the **Text Cursor**, called **Cursor Bounding Box (CBB)** **(the red box)**

Takeaway

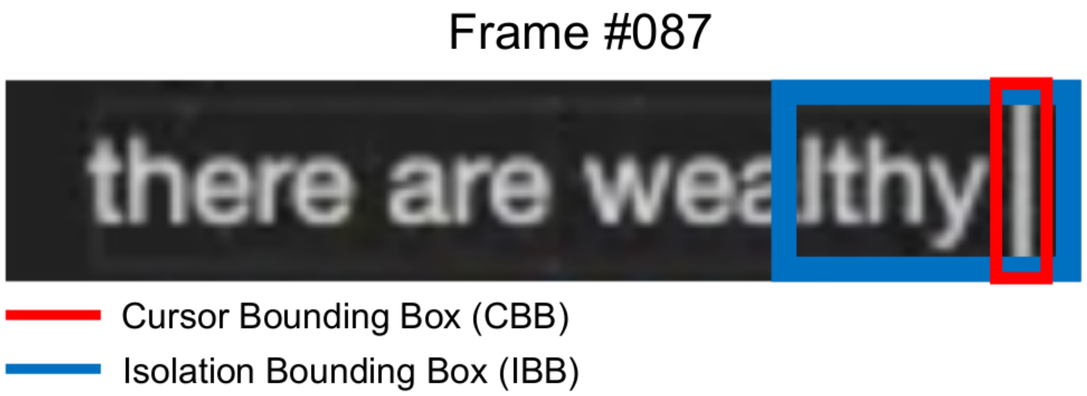
The occurrence of CBB **marks the start of the video segment** with typing activities.



Cursor Tracking and Text Detection Alg.

Challenge #2. Extract what character typed by the user on each millisecond of the video.

- We generate another bounding-box, called **Isolation Bounding Box (IBB)** relatively **to the left** of the **Cursor Bounding Box (CBB)** coordinates.
- However, in a single IBB region, there might be more than one character captured ☹.
- Hence, we need to **know, which one is the most recently-typed character?**



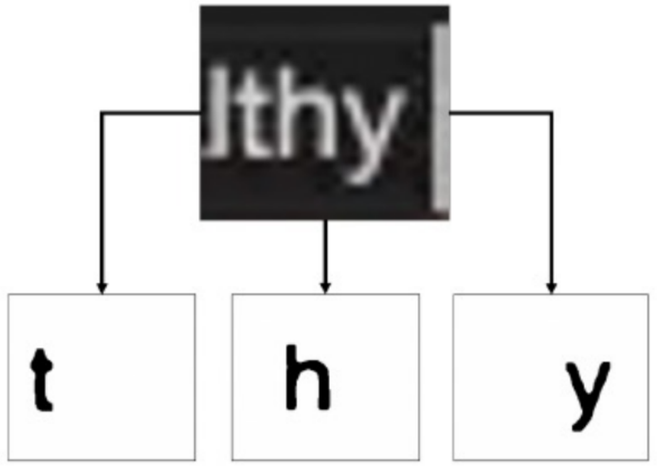


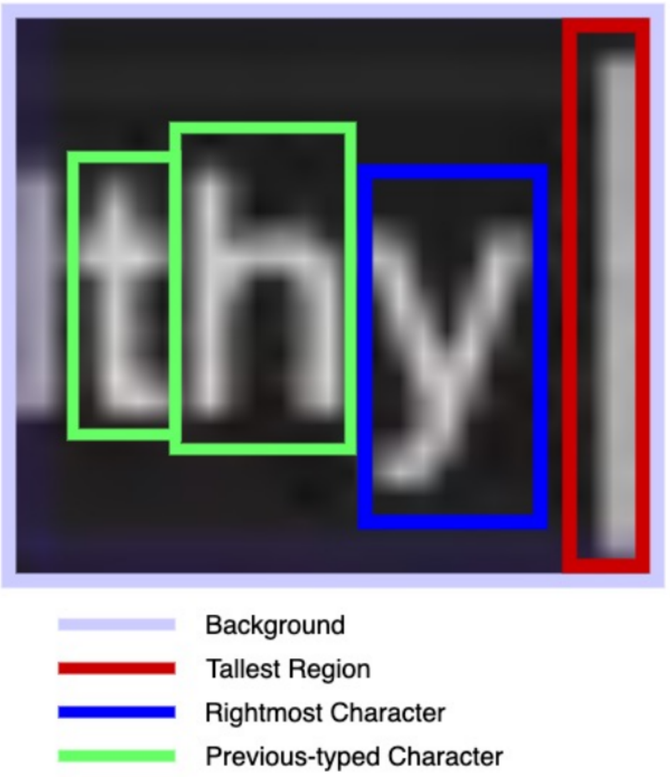
Fig: IBB with multiple characters captured

Cursor Tracking and Text Detection Alg.

Challenge #2. Extract what character typed by the user on each millisecond of the video.

- Use **Connected-Component Labeling (CCL)** to separate multiple characters from the IBB frame.
- Yields the following components:
  - Background Region
  - Tallest Region (aka Text Cursor)
  - Rightmost Character
  - Previous-typed Character

Frame #087



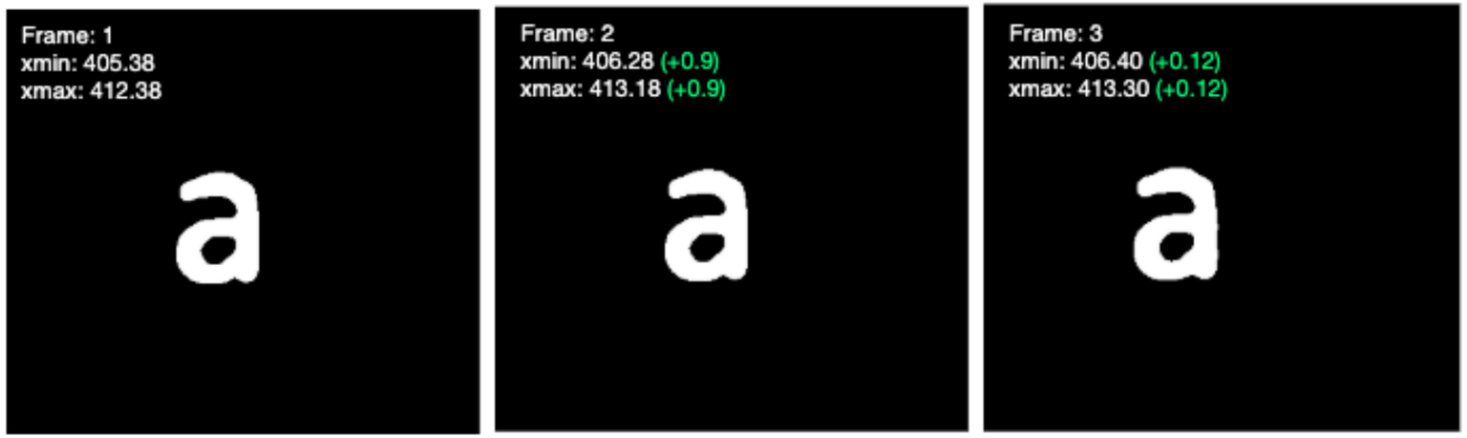
Takeaway

The **Rightmost Character**, always located to the left of Tallest Region, indicates the most-recently typed character on the frame.

Typing Pattern Reconstruction

Challenge #3. Reconstruct the victim's typing pattern (extract each keystroke's timing/delay information)

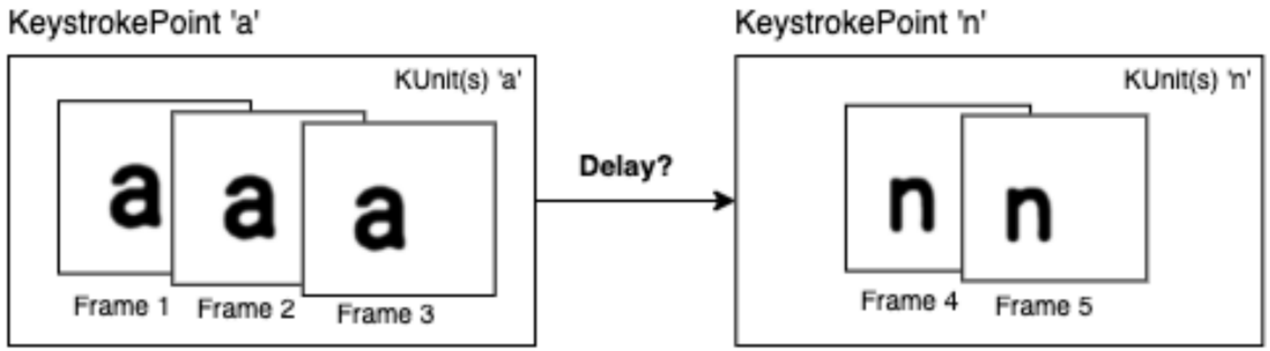
- From every frame in the video, we extract a character (aka the **Rightmost Character** component) and convert them to digital data with **OCR (Optical Character Recognition).**
- A single character in a single video frame is called a **KUnit**.
- But we observe that the same character might **appear** in **more than one frame** consecutively.
- **Why?**



Typing Pattern Reconstruction

Challenge #3. Reconstruct the victim's typing pattern (extract each keystroke's timing/delay information)

- If the same character appears in more video frames adjacently, we can **assume the longer the key-delay** of that character.
- Hence, we group characters from different frames based on similarity of the character's coordinates relative to each other. We named it **KeystrokePoint.**



KeystrokePoint Attributes

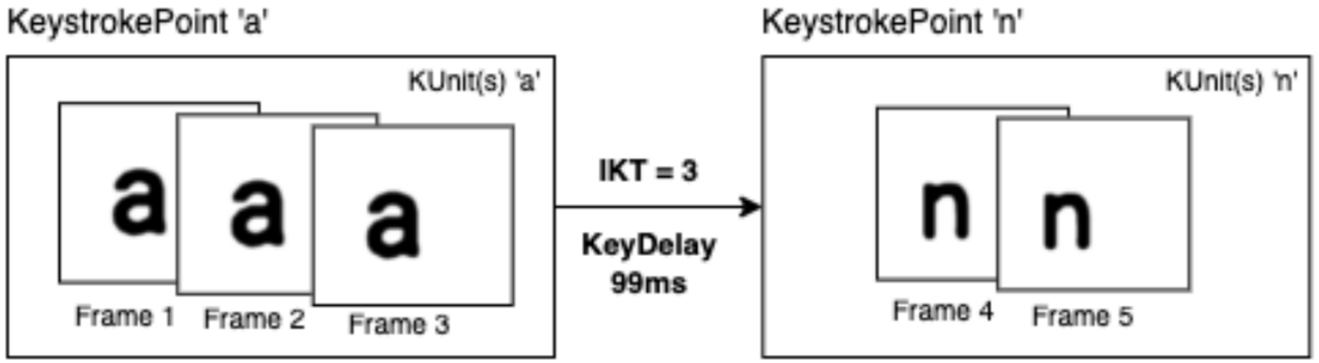
FirstSeen	1
LastSeen	3
KeyText	a

KeystrokePoint Attributes

FirstSeen	4
LastSeen	5
KeyText	n

Typing Pattern Reconstruction

Challenge #3. Reconstruct the victim's typing pattern (extract each keystroke's timing/delay information)

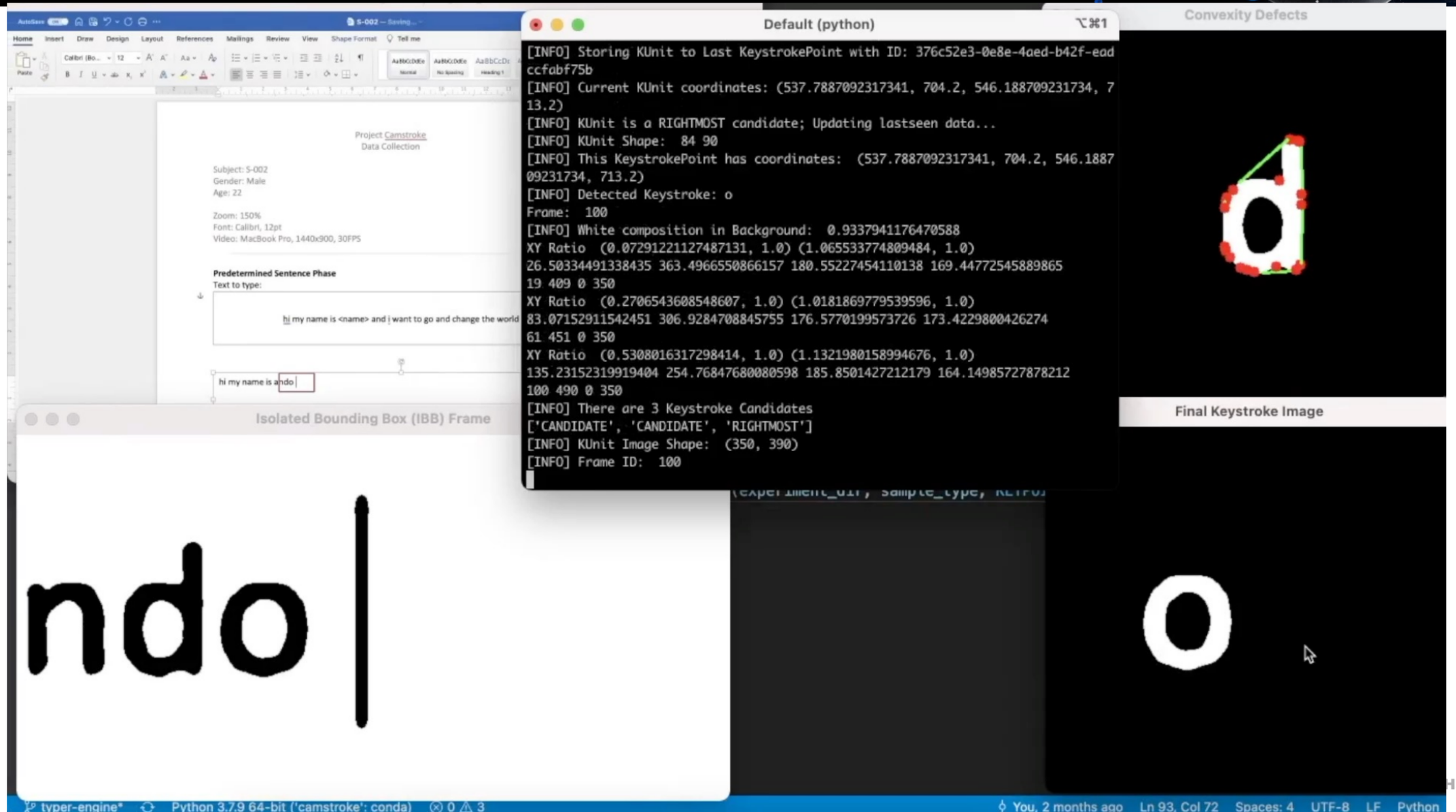


- On the image, character '**a**' is displayed in 3 video frames. Hence, the **key-delay** is **99ms**.
- **Why?**
- Because every video frame lasts for 33ms (30FPS). Thus, 3 video frames last for **99ms**.

Takeaway

The higher the number of KUnits (frame) are inside a KeystrokePoint (group), we assume the longer the key-delay of that character.

Attack in Action



Wait. Why the Fuss?

- At this point, **key-delay** between characters can be extracted through a video alone.
- It is **permission-less.** No need to insert/install **keylogger** into the victim's machine.
- This attack can occur when:
  - A victim makes their screen visible to the attacker (i.e., in a Zoom meeting).
  - The attacker records the victim's screen, where the victim's typing activities is visible.
  - The delays between characters is extracted from the obtained video frames.
- Thus, this attack can be conducted remotely, without the victim even realizing.
- If the victim's account is protected with **keystroke dynamics** authentication, we can **mimic** their typing pattern and **replay them** to bypass the authentication.

Okay. But is it Working?

Before we go into the more despicable part. **Let's see how good the algorithm performs.**

Benchmarking the Attack

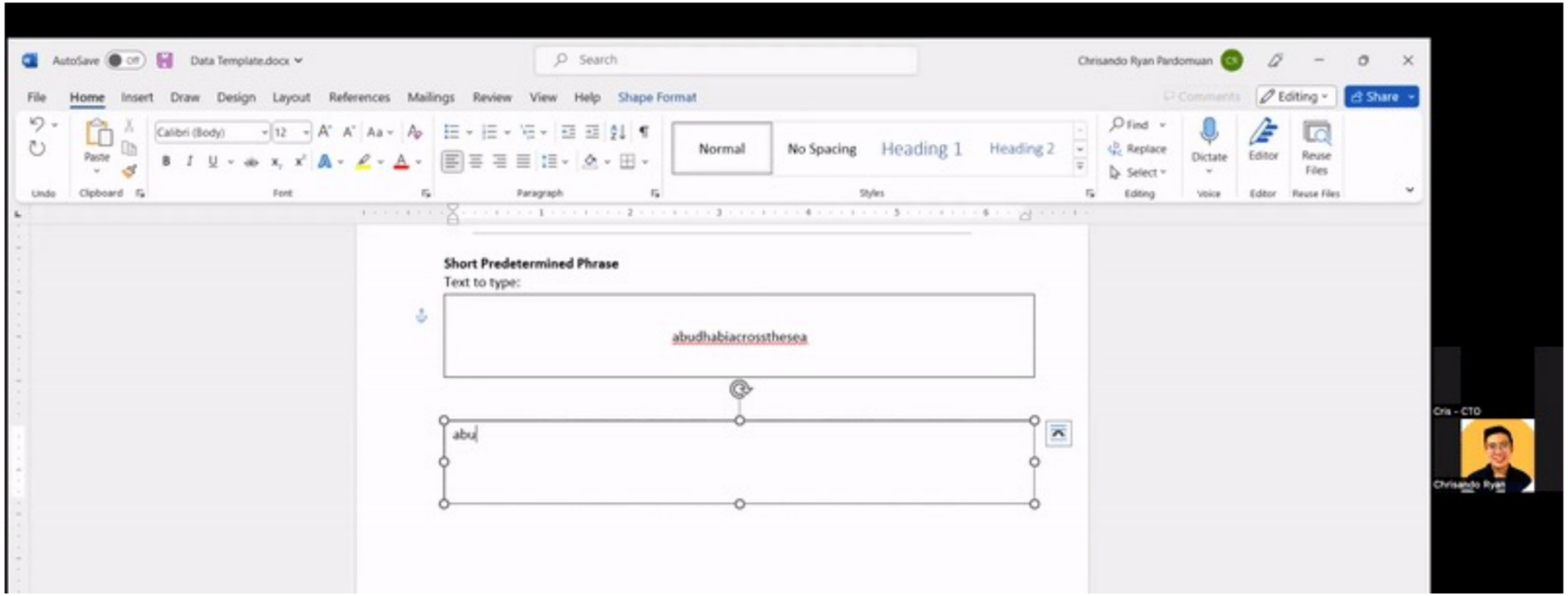
- Aspects evaluated:
  - **How similar** the **reconstructed typing pattern** of the victim? (Statistic Similarity)
  - **How effective** the attack against **KeyTrac** authentication (Evasion Rate & EER)

- We tested the attack on 14 victims (with consent), each on different Zoom meetings.
- The victims were asked to perform these **typing activities**:

No	Evaluation Group	Typed Text	Total Samples
1	Password Phrase	abudhabiacrossthesea	210
2	Greeting Sentence	hi my name is [NAME]	
3	Long Sentence	i want to go and change the world	

Benchmarking the Attack

We asked each victim to perform a typing activity, and record them:

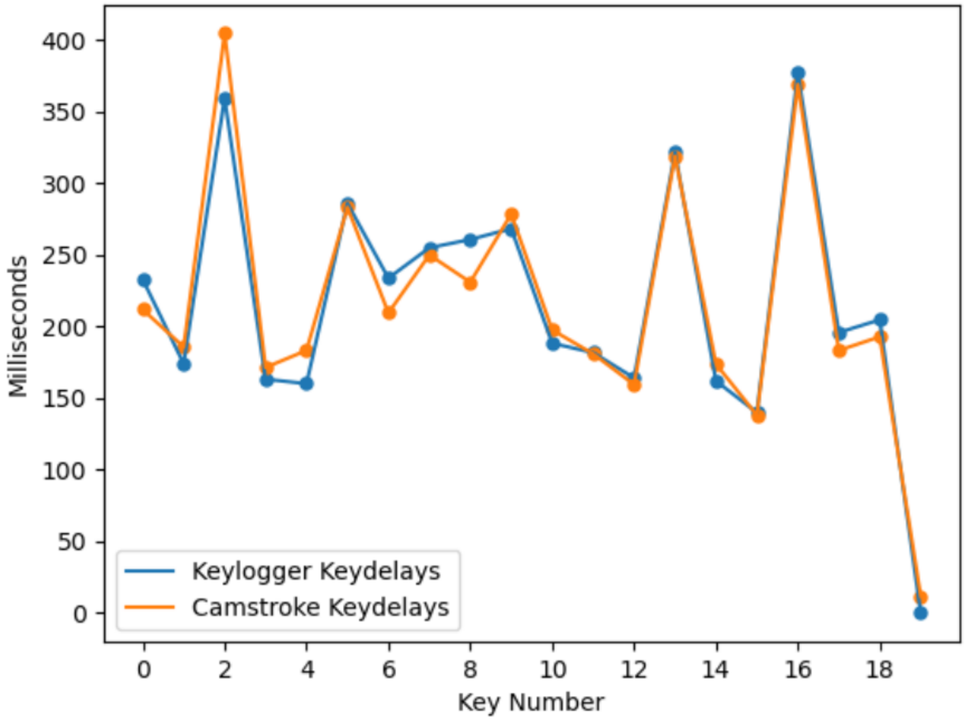


And, to collect actual key-delay data, we use **keylogger** installed on the victim's device.

Similarity Test: Password Group

Text typed: abudhabiacrossthesea

- Tested using Shapiro-wilk Test (Normality Test), Levene's Test (Variance Test), and Wilcoxon Signed-rank Test (Mean Similarity Test).
- Both key-delays are **distributed normally** and have **equal variance**.
- There is **no significant mean differences** between the **reconstructed key-delays** and the **actual key-delays;** the data can be considered similar.
- Process time is **5.61FPS**, or **5.35x longer** than the actual video duration (30FPS).

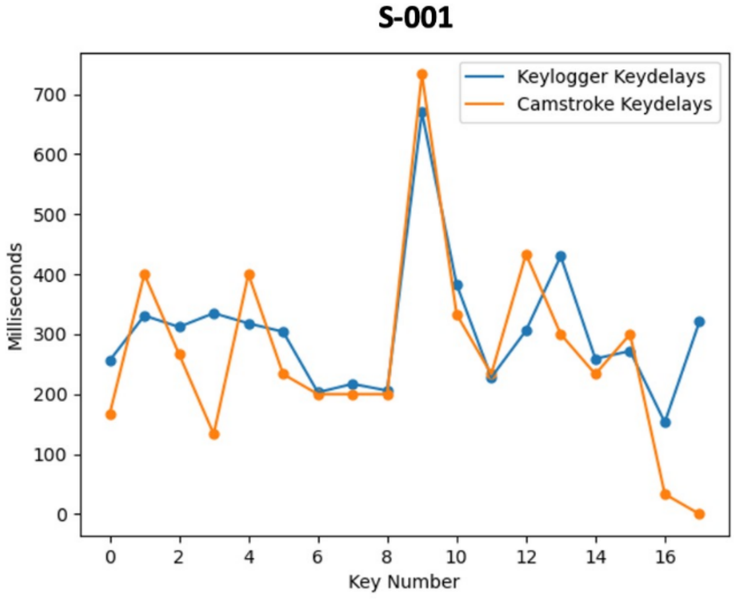


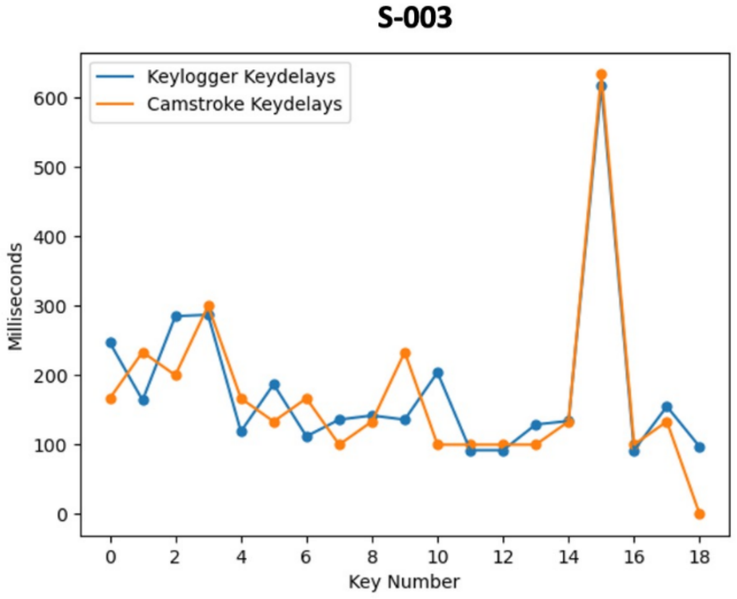
Comparison of the Reconstructed Key-delay and the Actual Key-delay (averaged).

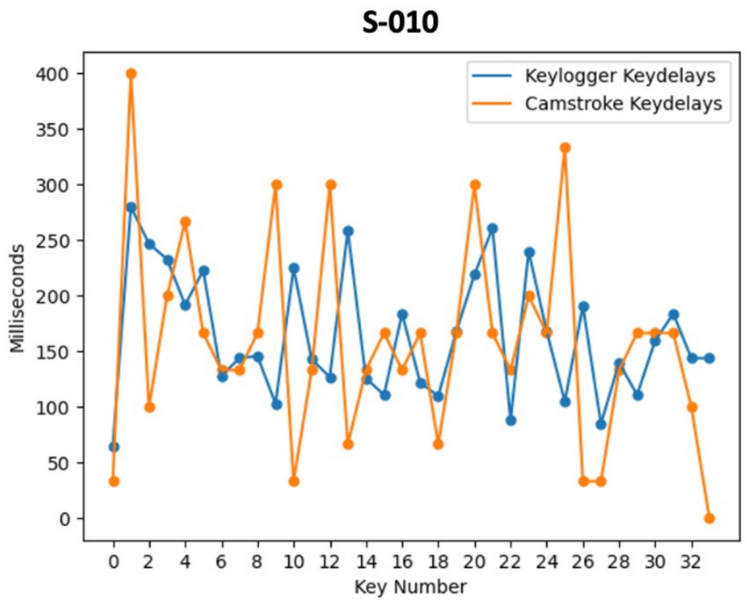
Similarity Test: Greeting Group

Text typed: hi my name is [NAME]

- Suffers **lower performance** compared to the **password text group**.
- There is **still no significant mean differences** between the **reconstructed key-delays** and the **actual key-delays;** the data can be considered similar.
- Process time is **6.78FPS**, or **4.43x longer** than the actual video duration (30FPS).





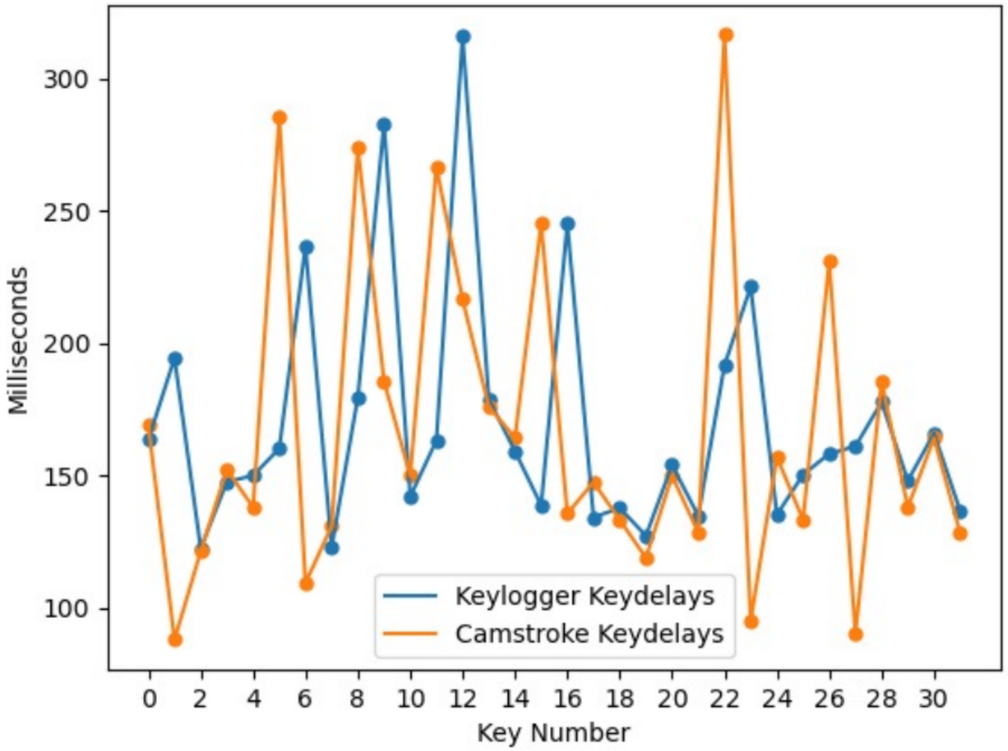


Comparison of the Reconstructed Key-delay and the Actual Key-delay (NOT averaged).

Similarity Test: Longtext Group

Text typed: i want to go and change the world

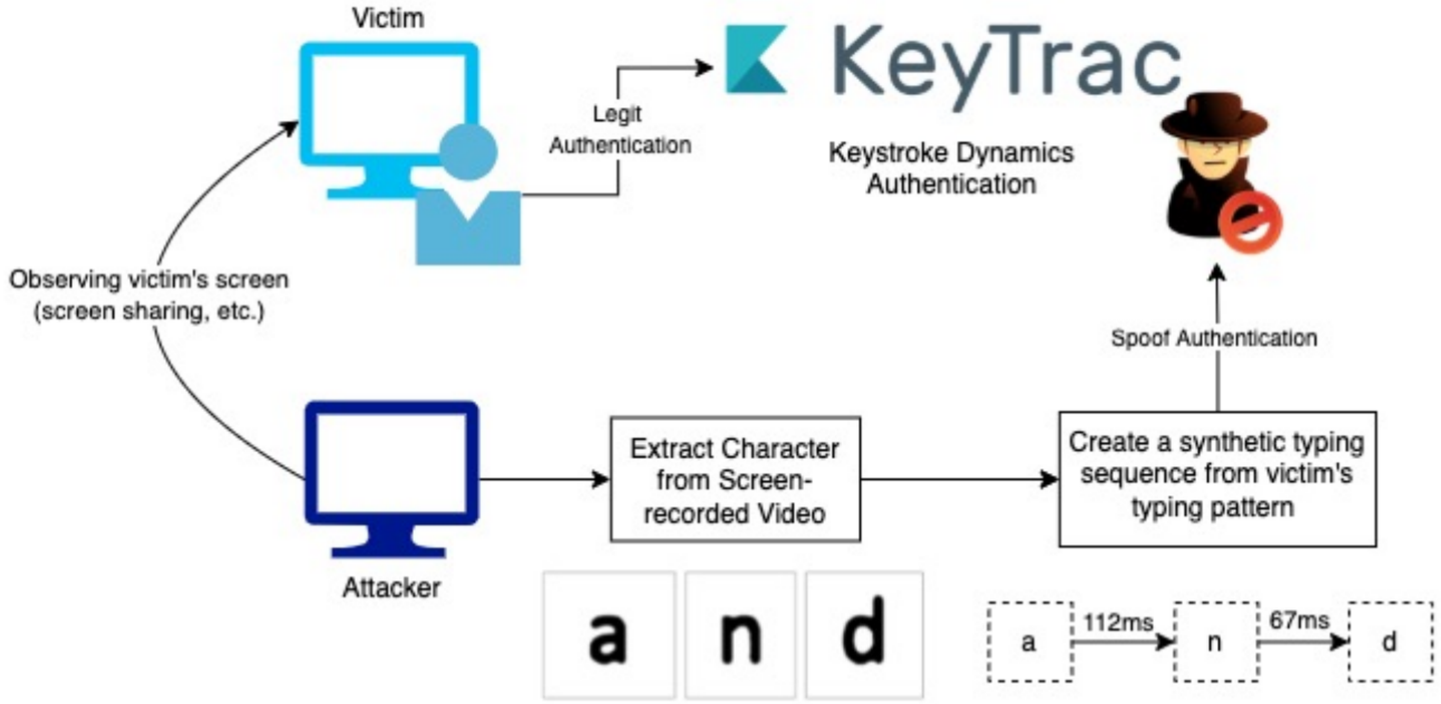
- Also suffers **lower performance** compared to the **password text group**.
- There is **still no significant mean differences** between the **reconstructed key-delays** and the **actual key-delays;** the data can be considered similar.
- Process time is **5.91FPS**, or **5.08x longer** than the actual video duration (30FPS).



Comparison of the Reconstructed Key-delay and the Actual Key-delay (averaged).

Attack Effectiveness

- KeyTrac is a AaaS (Authentication-as-a-service) platform that's widely used by global companies around the world.
- KeyTrac supports two modes: **Password-hardening** mode and **Freetext** mode.
- **How do we perform the attack against KeyTrac?**



Performance Metrics

- Evasion Rate (**ER**): measures **the rate of the attack being undetected**.
- Equal Error Rate (**EER**): measures the increase/decrease of performance of **KeyTrac** authentication service.

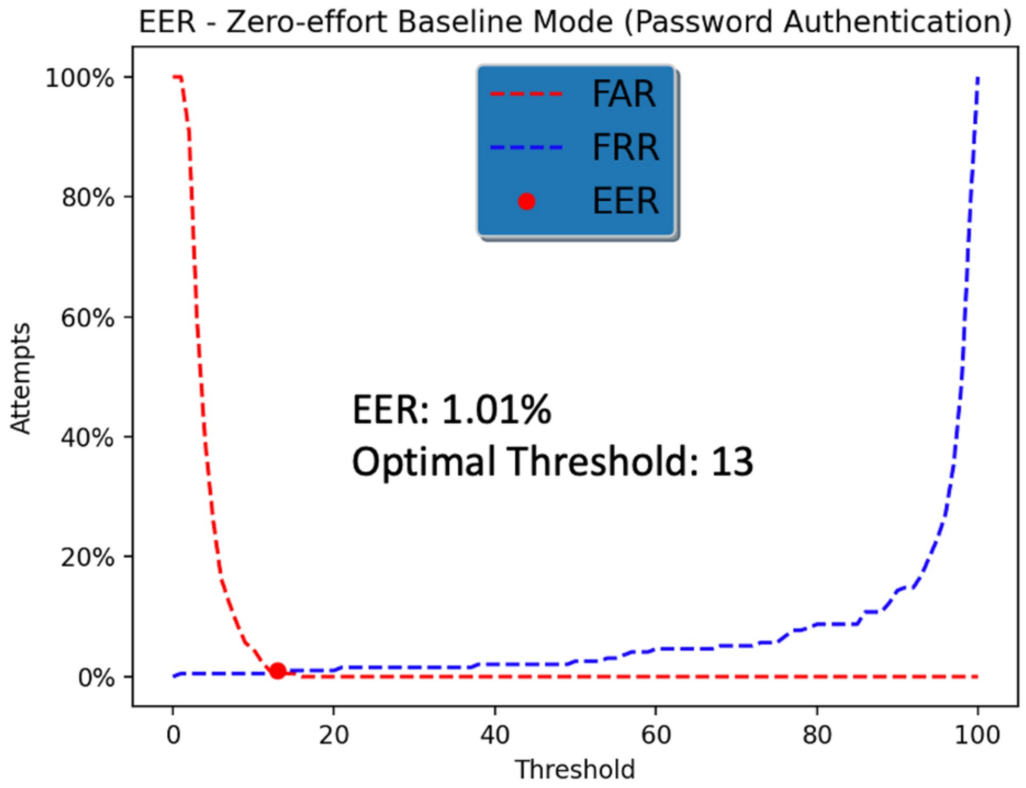
Attack Effectiveness: FAR-FRR-ERR

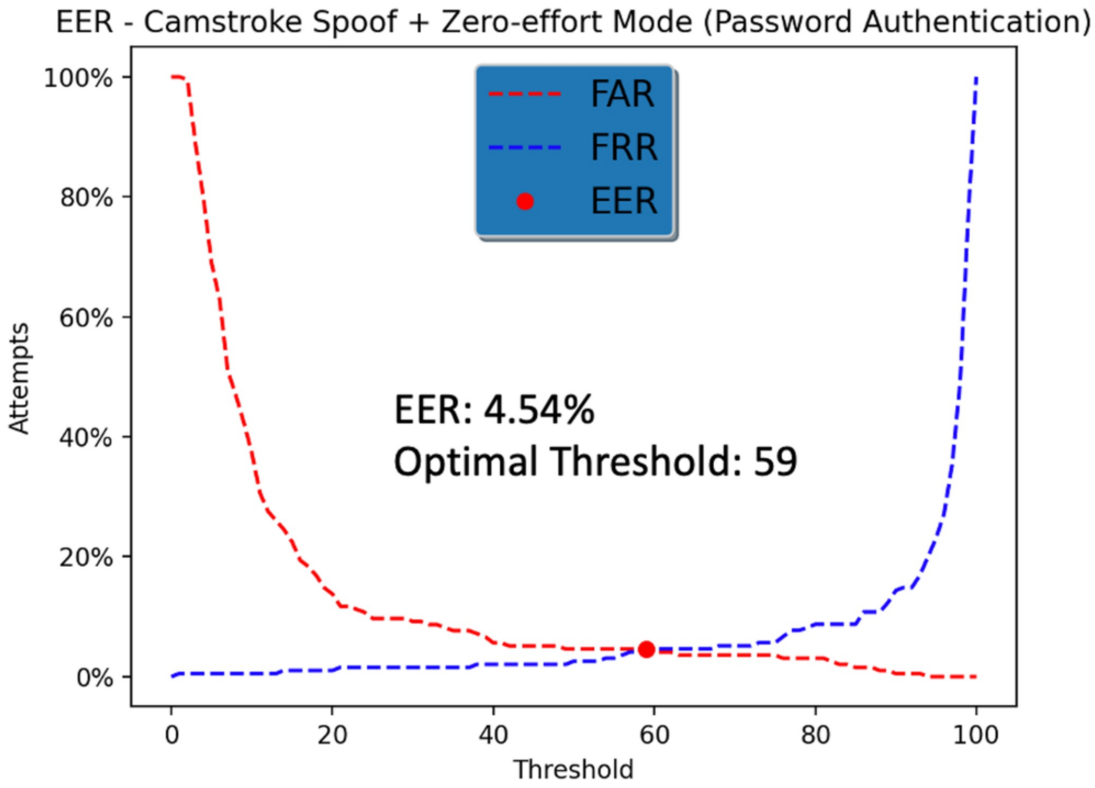
KeyTrac performance in **Password** mode, before (**left**) and after (**right**) the attack.

EER increased 349.5% post-exploitation,

Optimal authentication threshold increased from 13 to 59

High ERR indicates the decreasing accuracy of the biometric system (due to FAR is increasing).





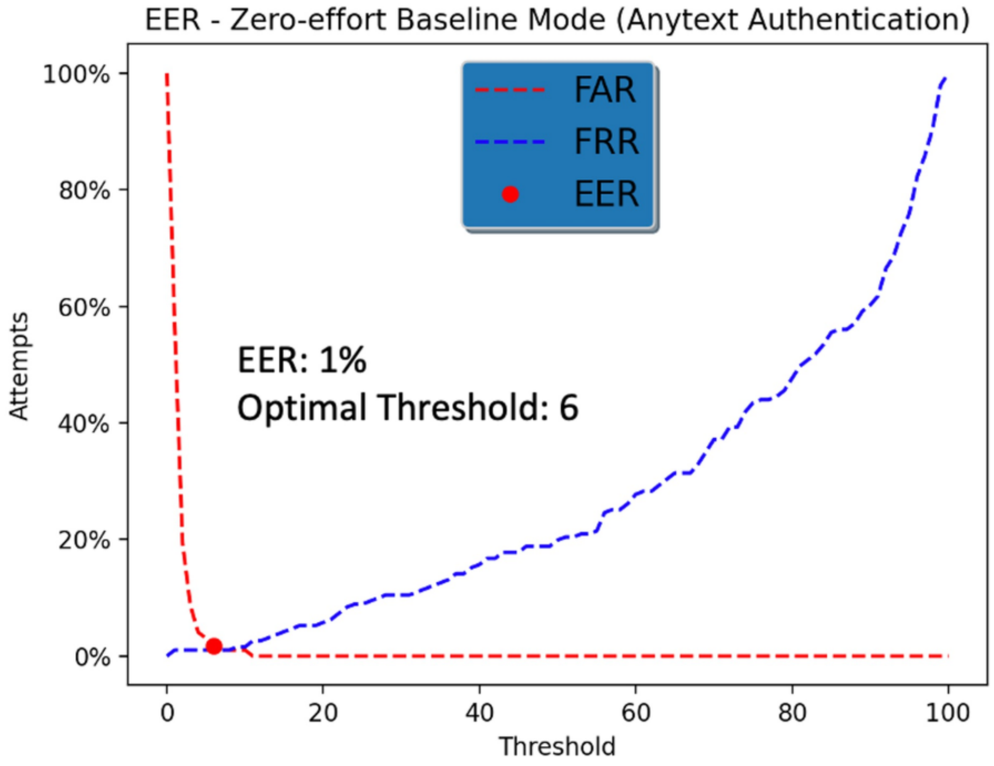
Attack Effectiveness: FAR-FRR-ERR

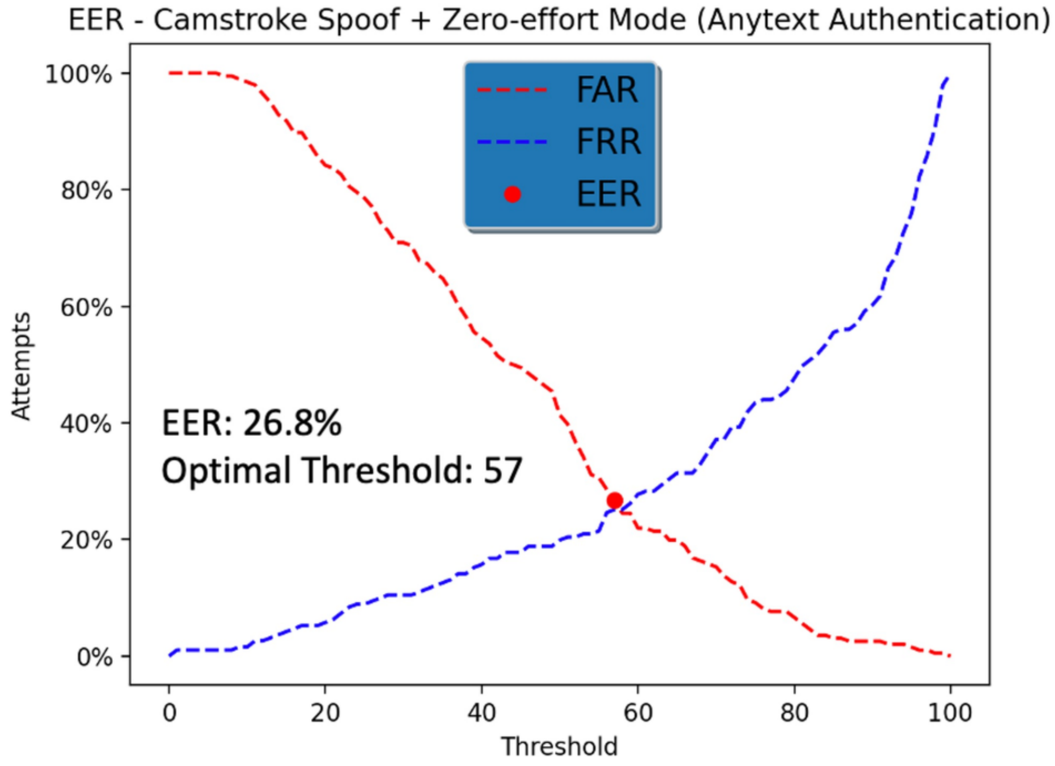
KeyTrac performance in **Freetext** (**Greeting** + **Longtext** group) mode, before (**left**) and after (**right**) the attack.

EER increased 2553.5% post-exploitation,

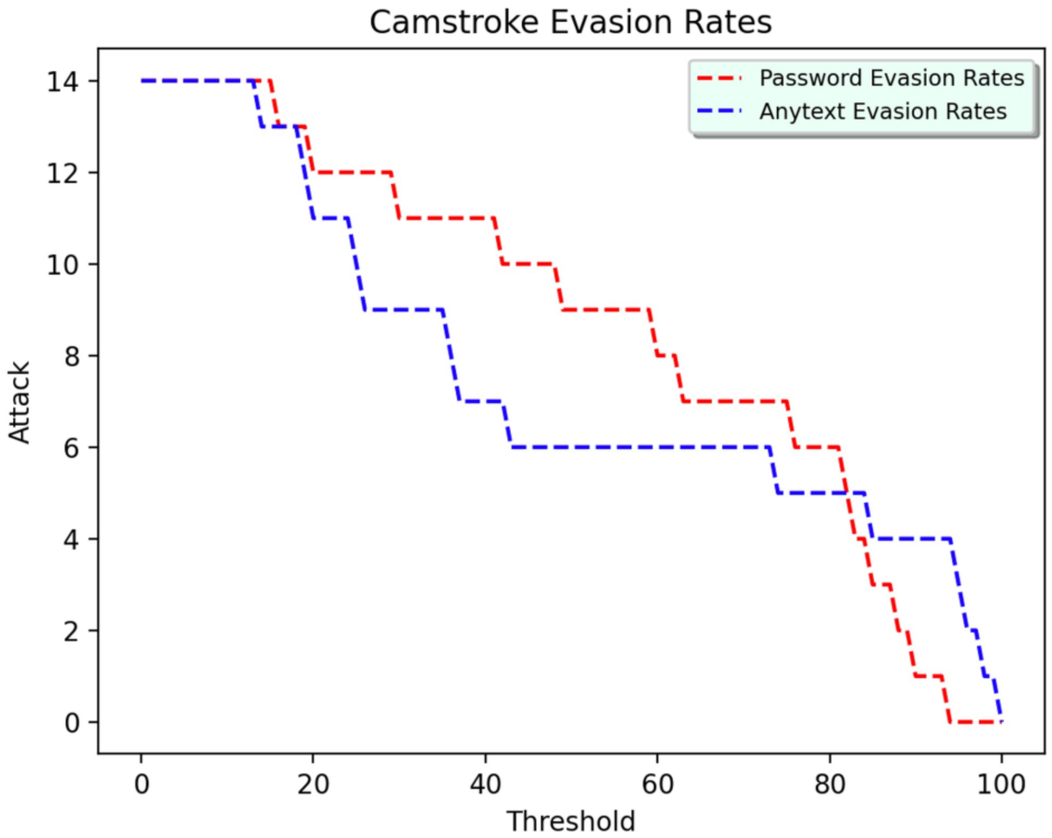
Optimal authentication threshold increased from 6 to 57

High ERR indicates the decreasing accuracy of the biometric system (due to FAR is increasing)





Attack Effectiveness: Evasion Rate



Evasion Rates (ER) on different authentication thresholds

- On **Password mode** with authentication threshold of 60%, 9 out of 14 attempts successfully spoof KeyTrac into allowing the authentication to pass through.
- That means, **Evasion Rates (ER) is 67%,** or almost **2 of 3 attacks is successful.**
- Unfortunately, on **Freetext mode** with authentication threshold of 60%, only 6 out of 14 attempts successfully spoof KeyTrac into allowing the authentication to pass through.
- That means, **Evasion Rates (ER) is 43%.**

What Have We Learned?

The evasion rates (ER) were not able to reach beyond 70%, why?

- This is mainly affected by the typing speed of the respondent (WPM or word-per-minute).
- The higher the WPM, the lower the number of captured frames.
- Hence, the delay similarity of the reconstructed typing pattern is also decreased.
- High WPM should be compensated with high video frame rates (FPS).

So, are we done here? Well, not apparently.

Another Layer of Curiosity

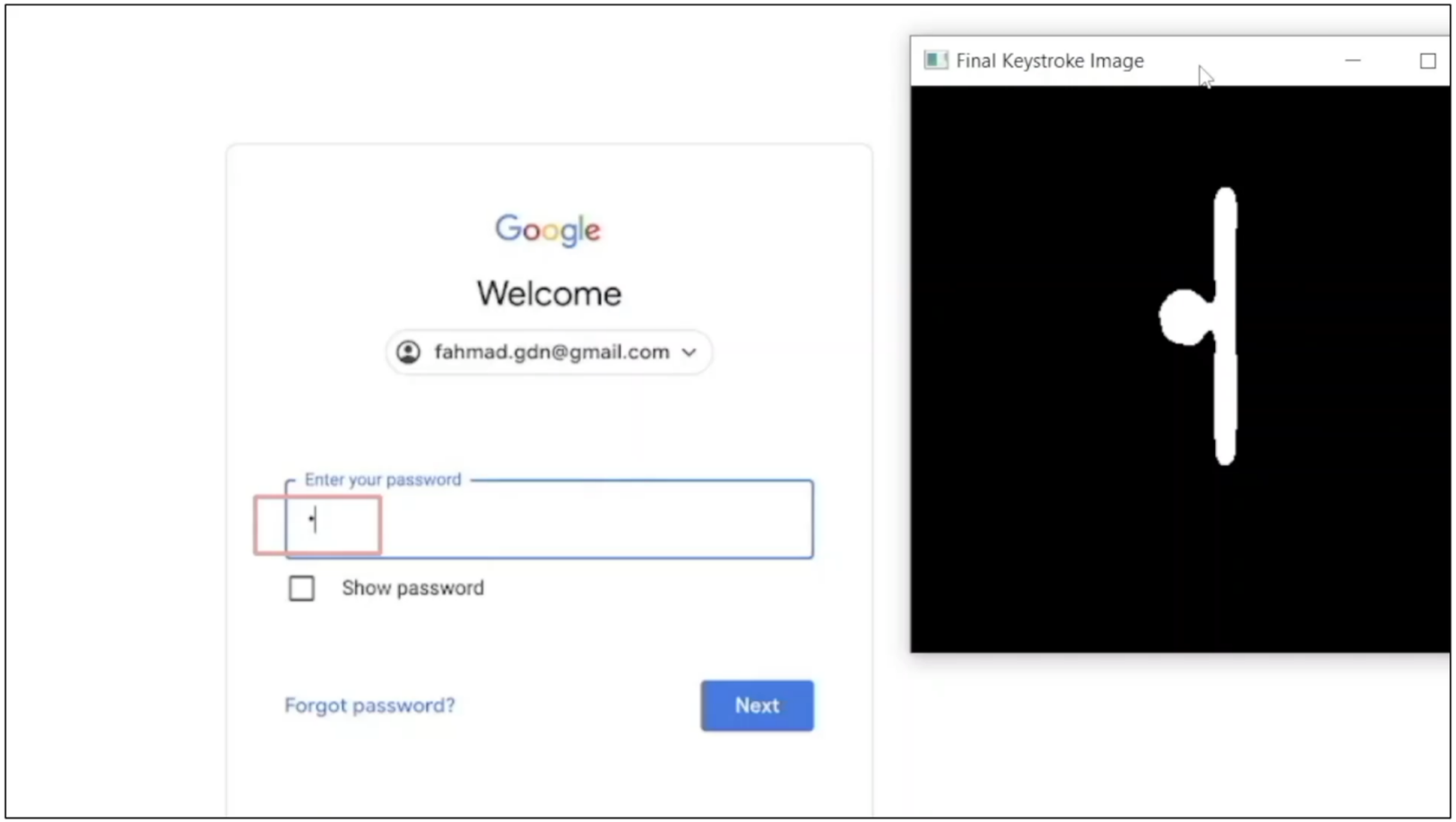
We believe the method is working, but perfection is still far away…

Amidst the study, we encountered **another WHAT-IF question scratching our curiosity.**

*If we're able to **track text cursor** and **extract typing pattern** out of screen-recording video, then what happens if **inside the video** occur **a user typing their password**?*

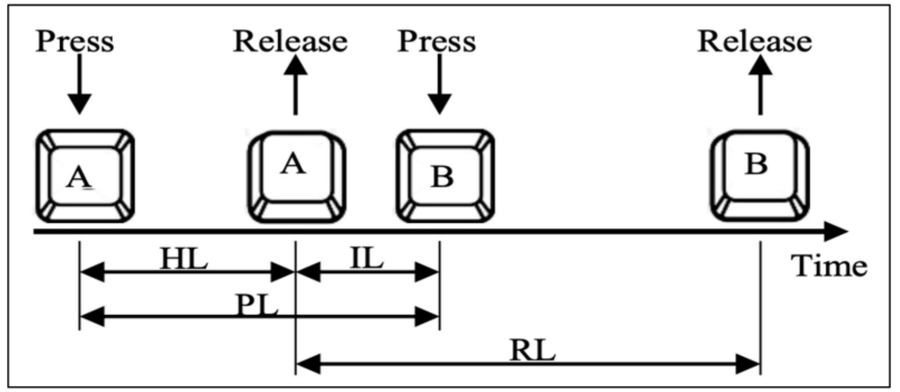
Another Layer of Curiosity

We’re able to track them as well.



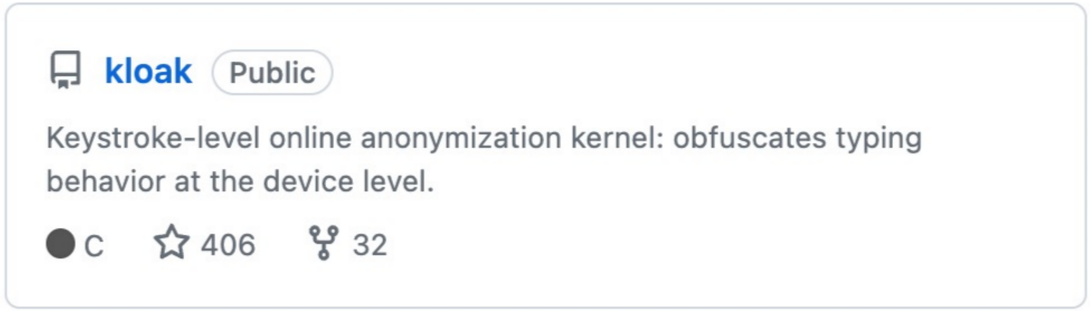
Limitations

- Typing pattern extraction sensitivity drops when there is a lot of movements, e.g., video playing, heavy screen-scrolling, etc.
- The higher the WPM requires more FPS to maintain high accuracy of the extraction. Most online-meeting platforms only support 30/60FPS video recording.
- Many **keystroke biometrics** authentication also uses **hold-delay** metric. As of now, we're only able to extract the **inter-key delay** metric.



Is There Any Cure?

- As in many other behavior-based attacks, there are no better solution than to applies a secure user behavior to prevent the leakage.
- That means, **being mindful** on who's your audience during screen-sharing meetings.
- And **being eager** enough to stop the screen-sharing whenever we're about to input something sensitive and confidentials.
- However, we also found some projects interesting to inhibit **typing pattern** extraction, such as:
  - **Kloak** by Vinnie Monaco: introduces random delay to keyboard typing at the device level.
  - Keystroke Dynamics Anonymization System (Migdal, D., & Rosenberger, C., 2019)



Takeaways

1. Should **keystroke biometrics** adoption growth consistently in the next few years, we expect that more advanced mimicry (side-channel) attack will be demonstrated from unexpected sources of data.
2. By using a screen-recorded video, someone can achieve a statistically staggering similarity in key-delay timings as if they used a keylogger.
3. Relying on videos allows for the elimination of the need for any external hardware or modifications on the victim's computer (i.e., **keylogger**).