

# Eye-Shield: Real-Time Protection of Mobile Device Screen Information from Shoulder Surfing

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Brian Tang, Kang G. Shin



**REAL-TIME COMPUTING LAB**

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE  
@ UNIVERSITY OF MICHIGAN



# What's Shoulder Surfing?



## ❖ Shoulder Surfing (Visual Hacking)

- Social engineering attack
- Pervasive, effective, low-budget

## ❖ Adversaries

- Are mostly curious or sometimes malicious
- Use eyes, camera, binoculars, etc.

# Shoulder Surfing in the News

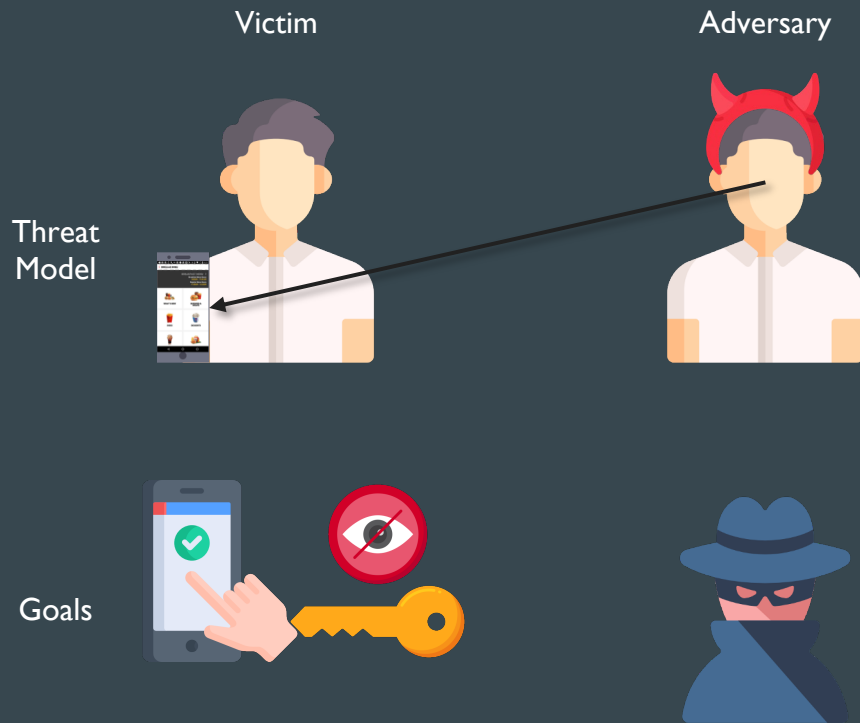
## ❖ PIN-Stealing

- Phone access, personal information
- Thief stole £22k



# Threat Model

- ❖ Users want: Security, privacy, usability
- ❖ Adversary: Obtain information from victim's device screen without getting noticed/caught
- ❖ Resources: Eyes, phone camera, quick glances, longer stares



# Statistics and Anecdotes

- ❖ Users are aware of only 7% of shoulder surfing [Eiband et al.]

- ❖ Steal authentication codes

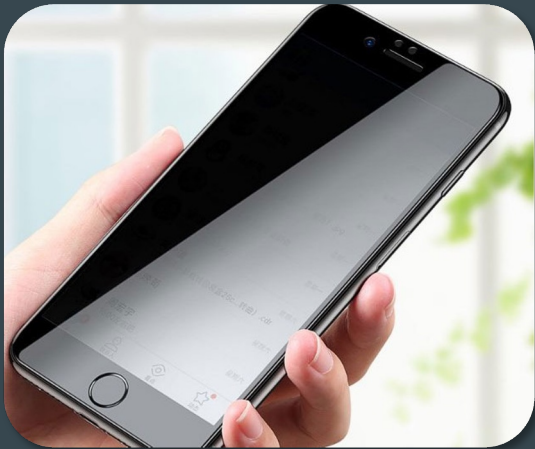
- Successfully obtain 6-digit PIN with one glance  
10.8% of the time [Aviv et al.]

- ❖ Unauthorized access to information

- 85% of shoulder surfers observed sensitive or private information [Honan et al.]

# A Key Research Question

- ❖ How do we protect users from shoulder surfing?



# Privacy Films

## ❖ Advantages

- Pervasive
- Darkens the screen
- Little to no usability cost



## ❖ Drawbacks

- Protects only at angles  $>30-45^\circ$
- Added cost (\$7-30)
- Requires (re)installation when switching device
- Not easily “deactivated”
- Incompatible with other screen protectors or matte/antiglare addons
- Does not protect landscape view

# A Key Research Question

❖ How can we build shoulder surfing protection into mobile devices?



❖ In a manner that is:

- Lightweight
- Continually active
- Protects information on the entire screen
- Little impediment on the user's tasks





# Our Solution: Eye-Shield

Protects on-screen information by making it appear blurry at a distance/angle.

Advantages:

- ❖ Easy to use
- ❖ Real-time operation
- ❖ Acceptable CPU, energy and memory usage
- ❖ Free!



Original, unprotected screen

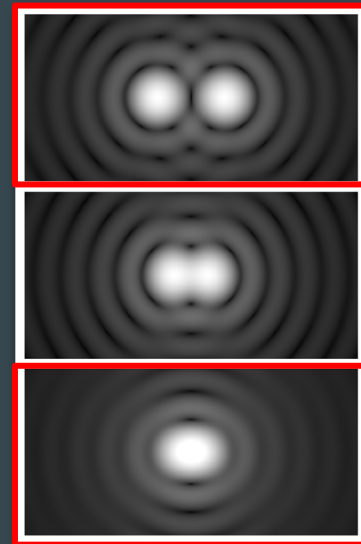
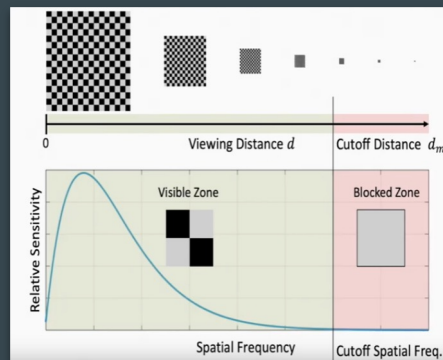
Protected screen with Eye-Shield



# Design - Grids

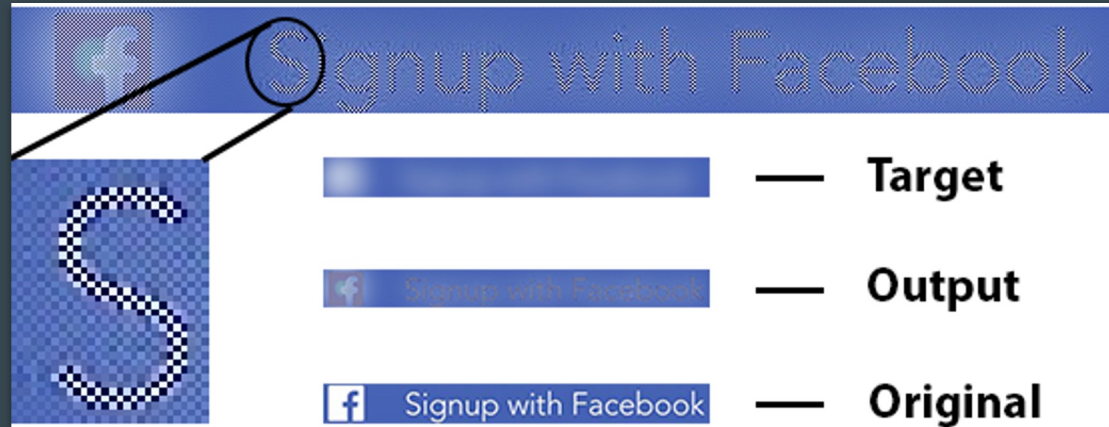
## ❖ Resolving Power

- $\theta = 1.22\lambda / D$
- Observation from HideScreen (Chen et al.)



# Design - Blurred Target

- ❖ Use blurred version of original image
  - Design checkered grid such that colors average out to be a blurred version.



# Design - Overview

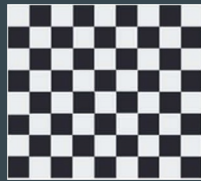
1. Blur/pixelate image
2. Generate grid of image size
3. Run Eye-Shield algorithm

**Algorithm 1** Where  $img$  is the original  $w \times h \times 3$  image where  $grid$  is a  $w \times h$  checkered grid of 1s and 0s where  $targ$  is the  $w \times h \times 3$  image, blurred or pixelated

```
1: procedure EYE-SHIELD ALGORITHM( $img$ ,  $grid$ ,  $targ$ )  
2:    $complement = (targ^2 * 2) - img^2$   
3:    $delta = (complement - img^2) * grid$   
4:    $newimg = \sqrt{img^2 + delta}$   
5:    $clip(newimg, 0, 255)$ 
```



(1)



(2)

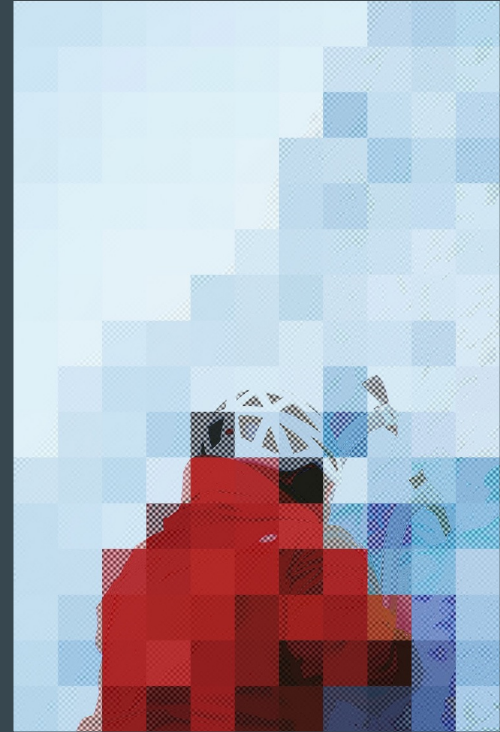
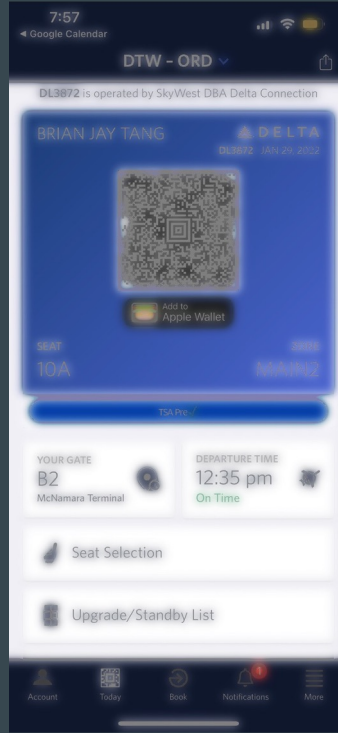


(3)



# Design - Protection Parameters

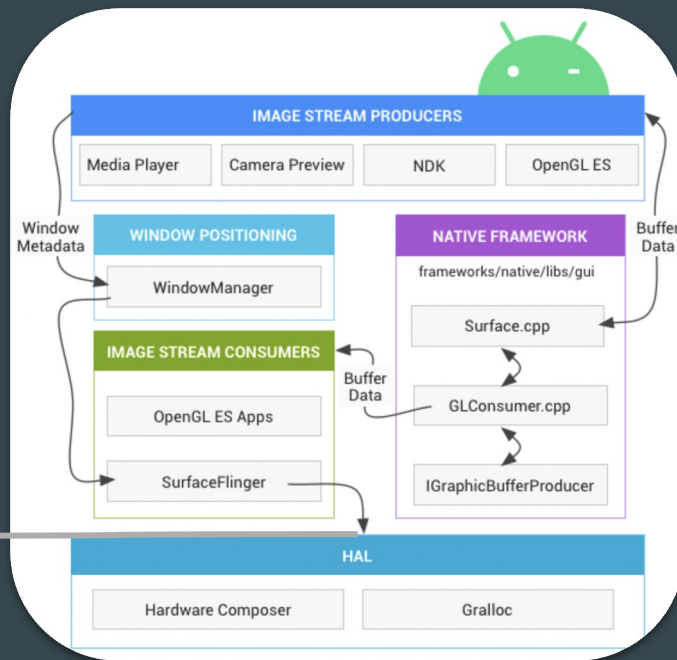
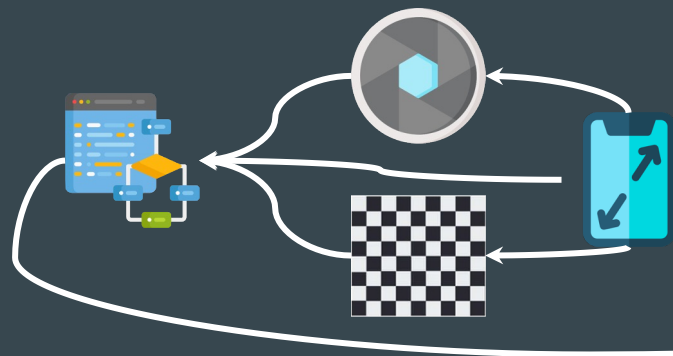
- ❖ Checkered grid
  - Grid pixel size (1×1, 2×2, etc)
- ❖ Blurring
  - Window size ( $\sigma$ )
- ❖ Pixelation
  - Number of blocks
- ❖ Contrast
  - Image contrast



# Design - Stack

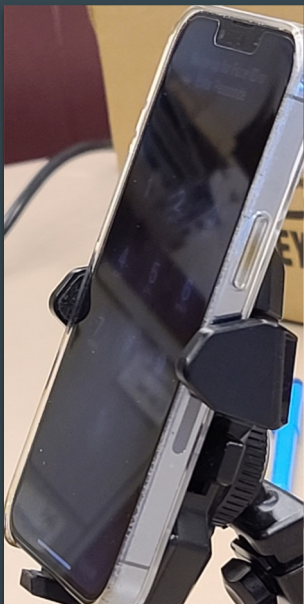
## ❖ GPGPU Frameworks

- CUDA 11.6 CuPy (Windows/Ubuntu)
- Vulkan Kompute (Android)
- Metal (MacOS)



# Implementation (Weakest Protection)

19.7", 45°, Protected



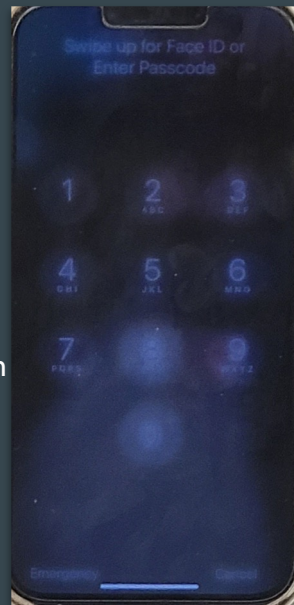
108MP  
f/1.8  
26mm  
3× zoom

19.7", 45°, Unprotected



48MP  
f/1.8  
103mm  
5× zoom

41", Protected



41", Unprotected

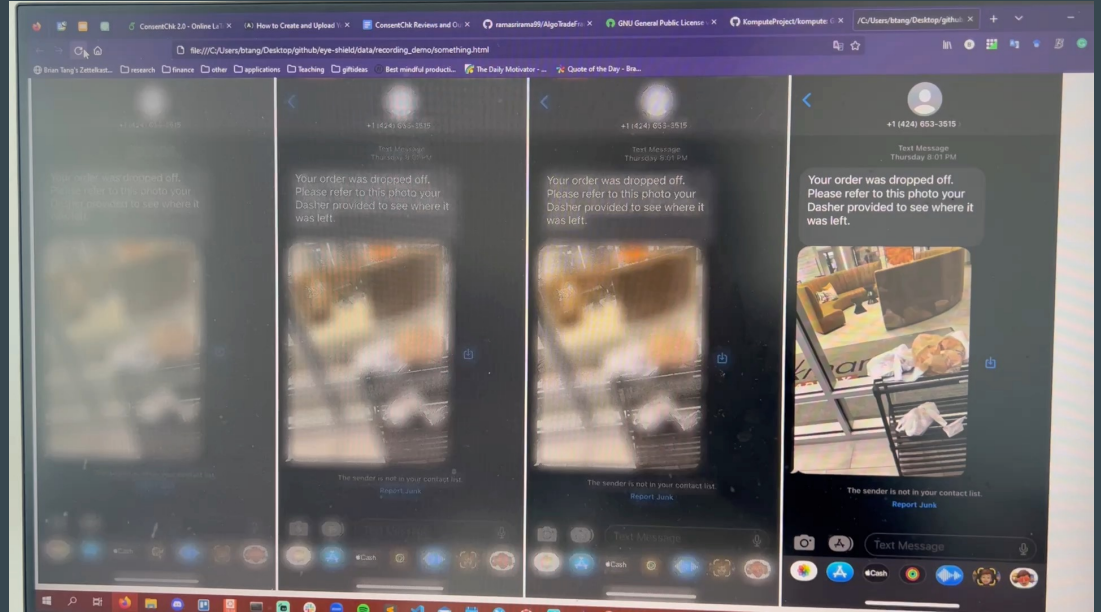




# Recorded Demos



Shoulder  
Surfer  
Perspective



Intended User Perspective

Left – Most Protection  
Right – No Protection





# Methodology - Efficacy

- ❖ DIV2K, RICO, DAVIS
- ❖ Parameters
  - Grid size (1 to 4 pixels)
  - Blurring/pixelation intensity
  - Downscaling 4× for average seat pitch
- ❖ SSIM index
- ❖ 124,224 total images generated, protected, and evaluated

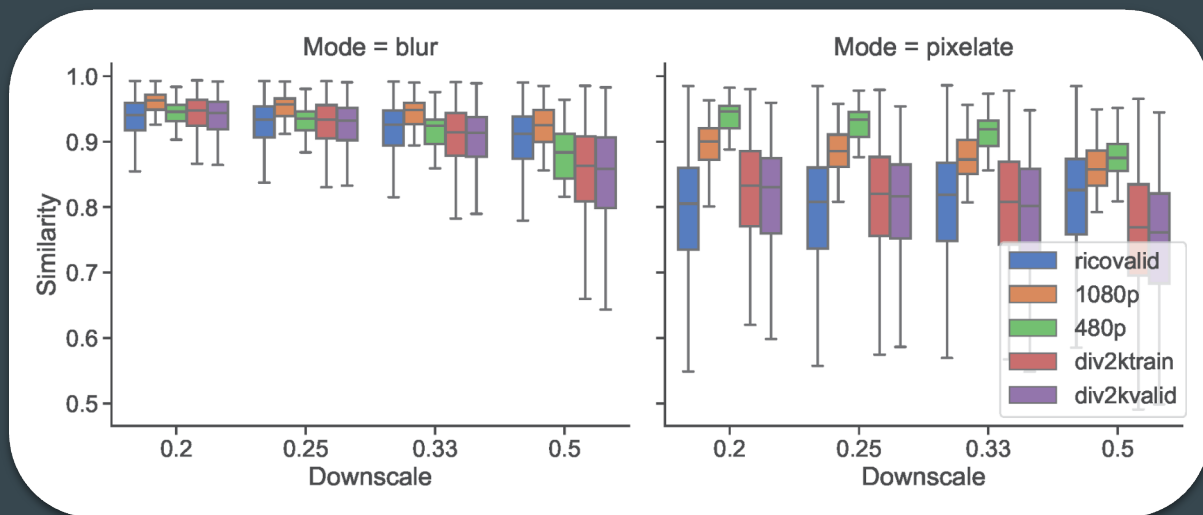
High Resolution Images	Mobile App UIs	Video Datasets (# Frames)
900	1460	1522



# Evaluation - Efficacy (SSIM)

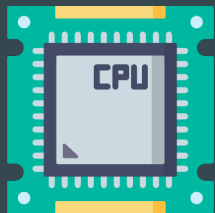
## ❖ SSIM (0 - low similarity, 1 - high similarity)

- SSIM > 0.9, Eye-Shield mimics blurred images
- SSIM > 0.7 for pixelated images



# Methodology - Performance

- ❖ CPU utilization, memory consumption, energy usage, and latency
- ❖ Android Studio and Xcode debuggers/profilers



# Methodology - Performance



Device	CPU Cores	GPU	Resolution	GPGPU
PC Workstation	12 Cores	RTX 2080 Super (432 Cores)	1920×1080	CUDA 11.6 (CuPy)
2021 Macbook Air	8 Cores	Apple M1 (8 Cores)	2560×1600	Metal
Samsung Galaxy S20 Ultra	8 Cores	Mali G77 (11 Cores)	1440×3200	Vulkan (Kompute)
iPhone 13 Pro	6 Cores	A15 (5 Cores)	1170×2532	Metal

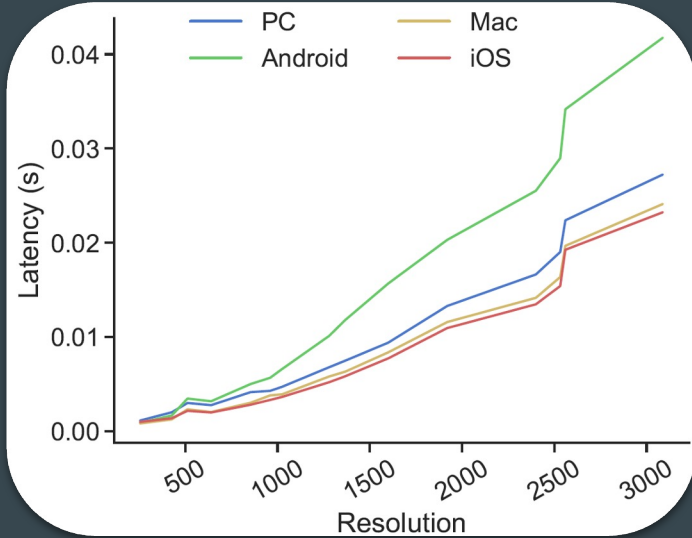
Platform and Device Details

Resolution	Aspect Ratio
256×144	16:9
...	16:9
2560×1440	16:9
512×512	1:1
1080×2400	9:20
1170×2532	90:195
1440×3088	90:193

Evaluated Resolutions



# Evaluation - Performance



Latency

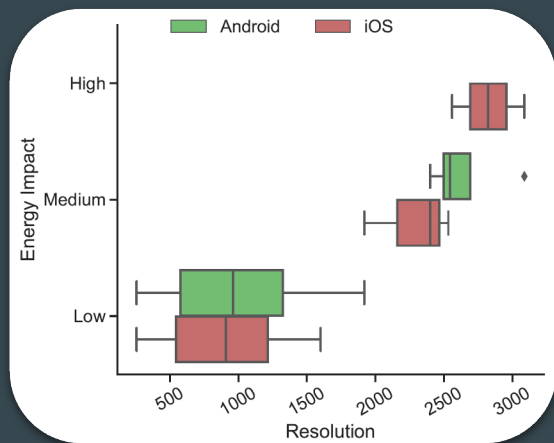
Resolution	Android (FPS)	iOS (FPS)
1920×1080	49.25	91.39
1080×2400	39.20	74.29
1170×2532	34.52	64.95
2560×1440	29.27	51.95
1440×3088	23.95	43.05

Mobile Performance  
Benchmarks

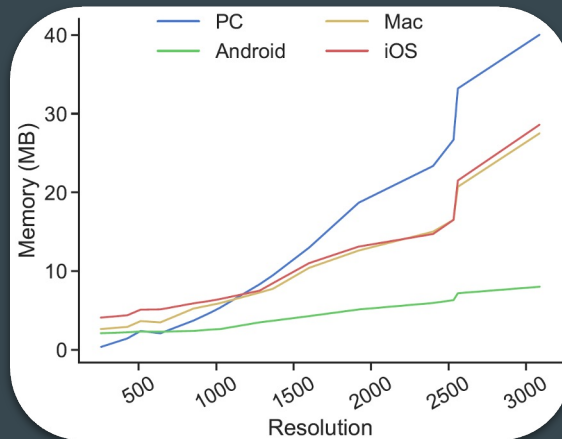
**High performance at high resolutions**



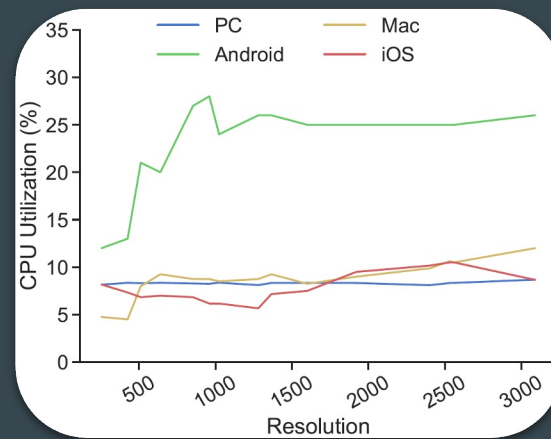
# Evaluation - Performance



Mobile Battery Consumption



Memory



CPU Util

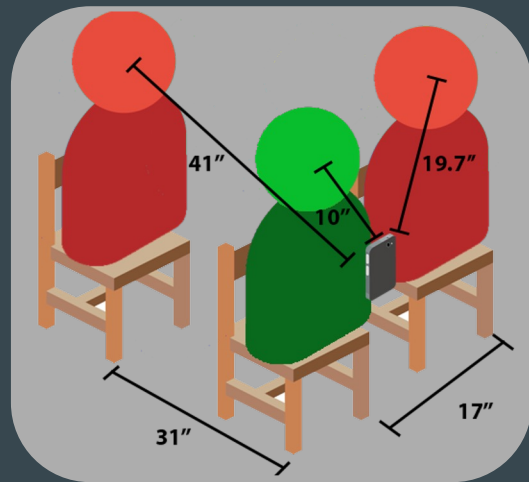
**Acceptable energy and resource consumption**



# Methodology - User Study

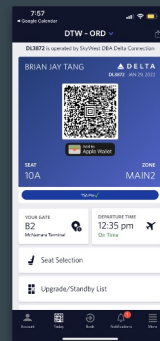
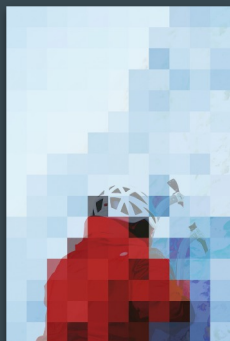
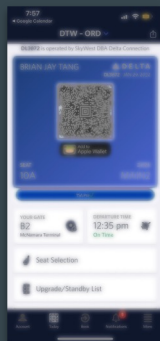
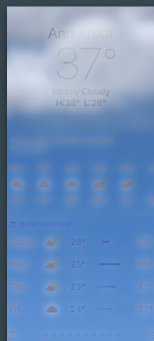
## ❖ In-Person Study

- 22 U.S. participants
- Diversity in age, occupation, ethnicity, and gender
- Brightly lit lab with device brightness at 66%
- 6 images, 2 videos, 7 mobile app UIs, 2 screen recordings
- Evaluation in 6 settings (in order)
  - Shoulder surfer (41", 20" and 45°, with film + Eye-Shield)
  - Intended user 10" away (with protection)
  - Shoulder surfer without protection (41", 20" and 45°)



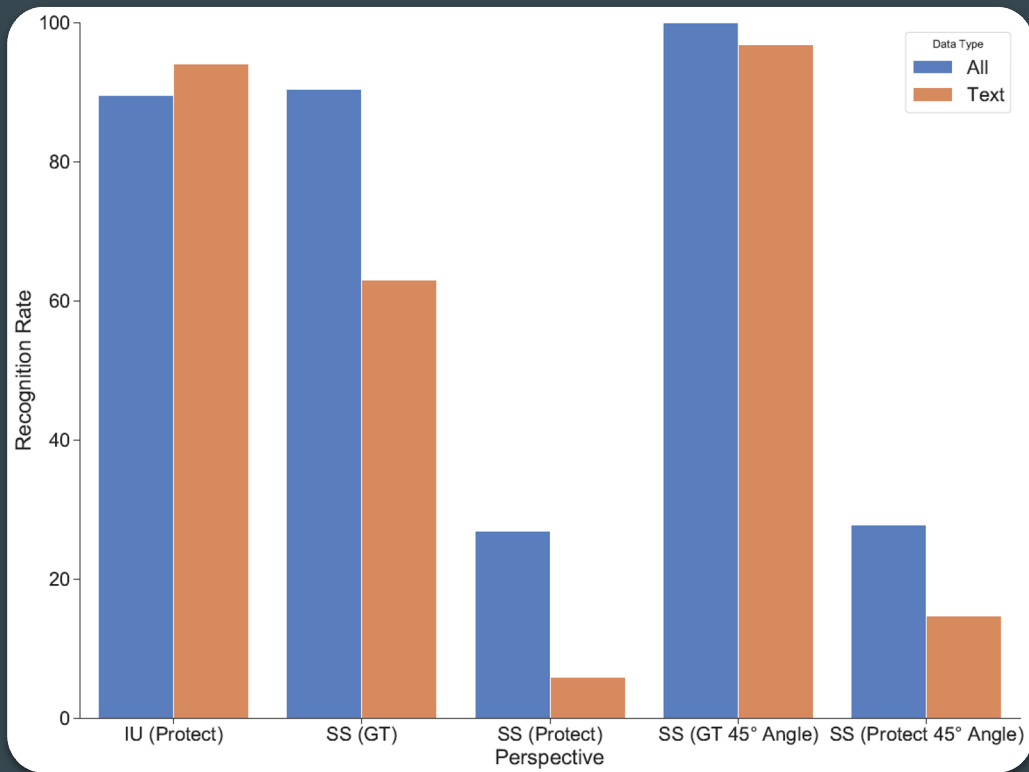
# User Study - Examples

- ❖ What is the current high and low temperature?
- ❖ Can you read the first word in each sentence?
- ❖ Can you describe the displayed image?





# User Study - Efficacy (In Person)



**Protects information  
without harming  
intended user's  
reading/viewing**

Acronym	Meaning
IU	Intended User (10")
SS	Shoulder Surfer (41" or 20"+45°)
GT	Ground Truth (Unprotected)

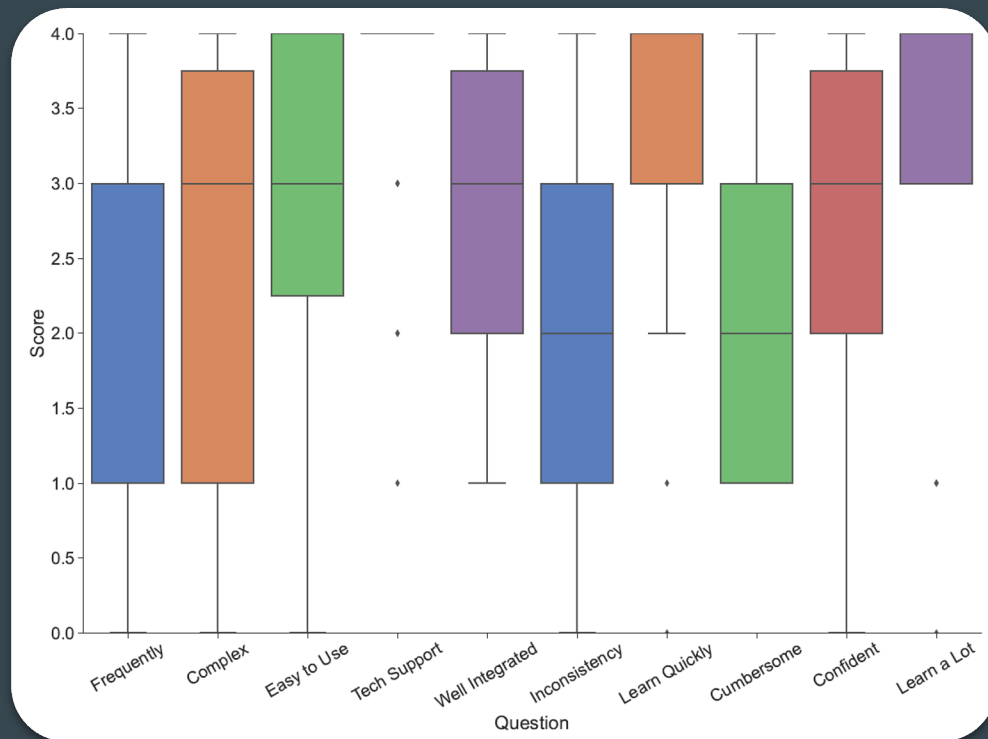
# User Study - Usability

## ❖ SUS score 68.86

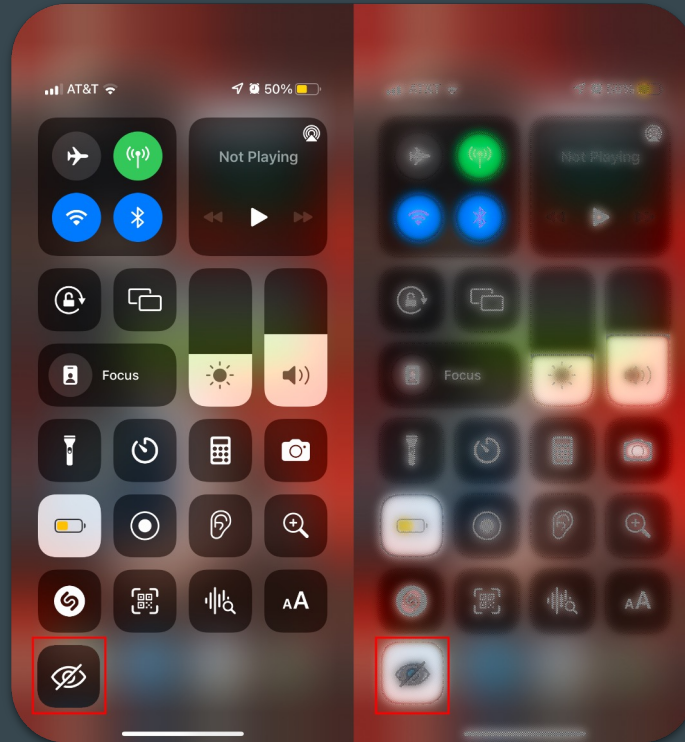
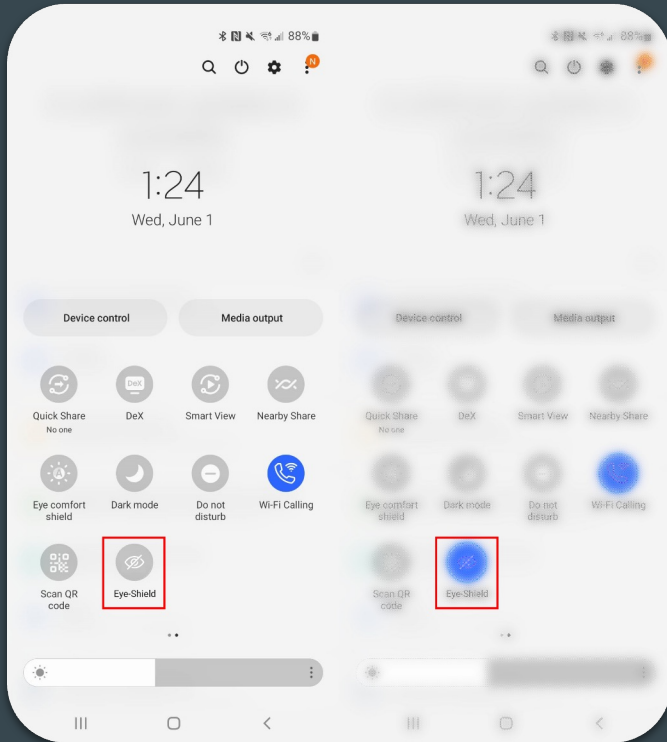
- About average usability
- Cutoff range = 68

## ❖ Observations

- Sometimes referable to privacy film
- Indicated that a toggle widget or brightness meter would be best
- Minor eye strain after shoulder surfing for 1 hour



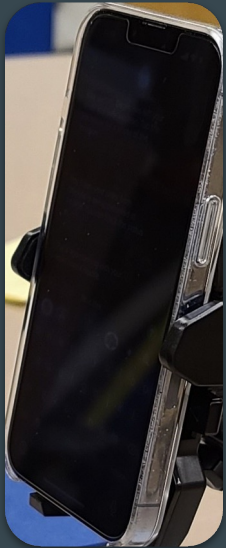
# User Study - UI Prototypes



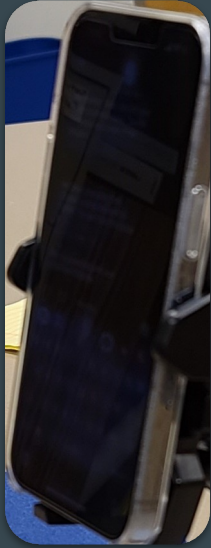
# Device Screen Brightness

## Shoulder Surfer

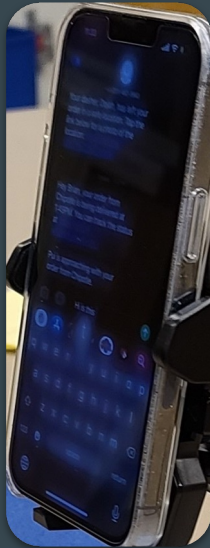
33%



66%

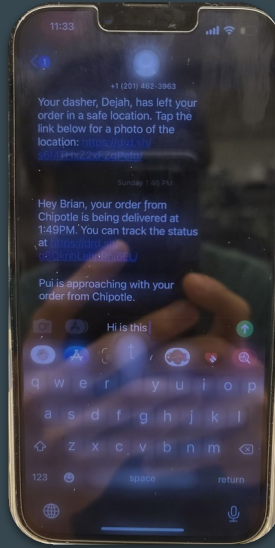


100%

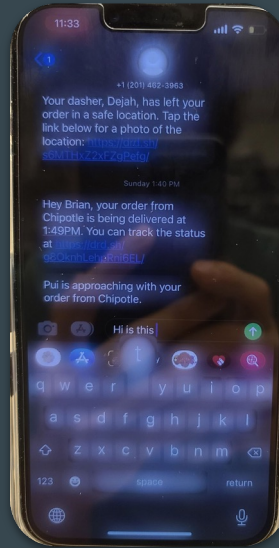


## Intended User

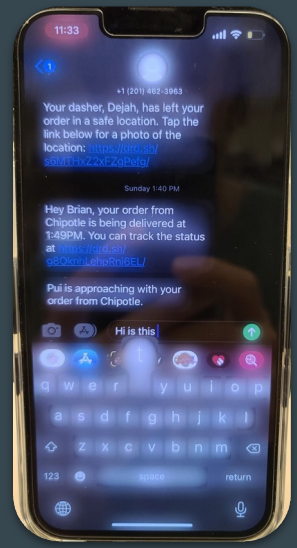
33%



66%

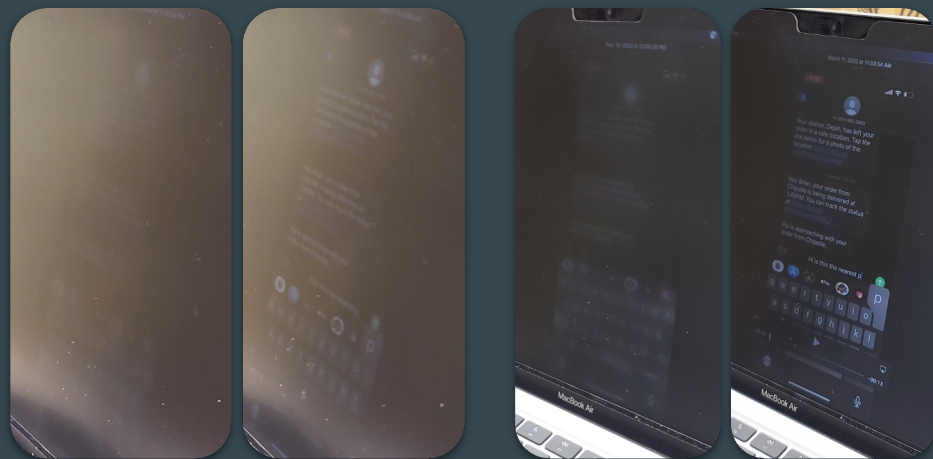


100%



# User Study - Privacy Films

- Privacy film only
  - At high brightness, doesn't protect screen
  - No protection from behind
  - No protection from landscape orientation
- Both privacy film and Eye-Shield
  - Reduces visible angle (added privacy)



Both

Privacy Film

Both

Privacy Film

Wide Angle

Narrow Angle

# Citations and Acknowledgements

## Privacy Article Screenshots:

- ❖ <https://www.makeuseof.com/what-is-shoulder-surfing/>
- ❖ <https://www.nbcnews.com/video/kanye-west-appears-to-unlock-his-phone-with-passcode-of-all-zeroes-1342136387883>
- ❖ <https://www.rappler.com/nation/181806-hontiveros-aguirre-text-expedite-cases/>

## Photos:

- ❖ <https://www.secure-od.com/prevent-shoulder-surfing-and-theft-of-corporate-credentials/>
- ❖ <https://lifelock.norton.com/learn/identity-theft-resources/what-is-shoulder-surfing>
- ❖ <https://www.nbcnews.com/video/kanye-west-appears-to-unlock-his-phone-with-passcode-of-all-zeroes-1342136387883>
- ❖ <https://www.thisiswhyimbroke.com/privacy-protecting-smartphone-screen-film/>
- ❖ <https://source.android.com/docs/core/graphics/hwc>
- ❖ <https://www.adweek.com/agencyspy/monday-stir-109/176952/>

## Statistics:

- ❖ <https://multimedia.3m.com/mws/media/1254232O/global-visual-hacking-experiment-study-summary.pdf>
- ❖ <https://multimedia.3m.com/mws/media/950026O/secure-white-paper.pdf>

## Icons:

- ❖ Freepik and Flat Icons

Thank you to the ARO for supporting this project



# Papers

## Shoulder surfing behavioral statistics:

- ❖ Eiband, Malin, et al. "Understanding shoulder surfing in the wild: Stories from users and observers." *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 2017.
- ❖ Aviv, Adam J., et al. "Towards baselines for shoulder surfing on mobile authentication." *Proceedings of the 33rd Annual Computer Security Applications Conference*. 2017.
- ❖ B. Honan, "Visual data security white paper," Secure, 2012. [Online]. Available: <https://multimedia.3m.com/mws/media/9500260/secure-white-paper.pdf>

## Shoulder surfing past defenses:

- ❖ Eiband, Malin, et al. "My scrawl hides it all: protecting text messages against shoulder surfing with handwritten fonts." *Proceedings of the 2016 CHI conference extended abstracts on human factors in computing systems*. 2016.
- ❖ Papadopoulos, Athanasios, et al. "Illusionpin: Shoulder-surfing resistant authentication using hybrid images." *IEEE Transactions on Information Forensics and Security* 12.12 (2017): 2875-2889.
- ❖ von Zezschwitz, Emanuel, et al. "You Can't Watch This! Privacy-Respectful Photo Browsing on Smartphones." *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 2016.

## HideScreen:

- ❖ Chen, Chun-Yu, et al. "Keep others from peeking at your mobile device screen!." *The 25th Annual International Conference on Mobile Computing and Networking*. 2019.

# Conclusion

## Takeaways:

- ❖ Shoulder surfing poses a significant threat to mobile security and privacy
- ❖ **Eye-Shield** can prevent many details of on-screen information from being leaked to shoulder surfers
- ❖ Thorough evaluations of Eye-Shield's efficacy, performance, and usability demonstrate its usefulness

## Resources:

- ❖ Websites
  - <https://www.bjaytang.com/>
  - <https://rtcl.eecs.umich.edu/rtclweb/>
- ❖ Contact
  - [bjaytang@umich.edu](mailto:bjaytang@umich.edu) | [kgshin@umich.edu](mailto:kgshin@umich.edu)



**Paper & Demo**