Automated Side Channel Analysis of Media Software with Manifold Learning

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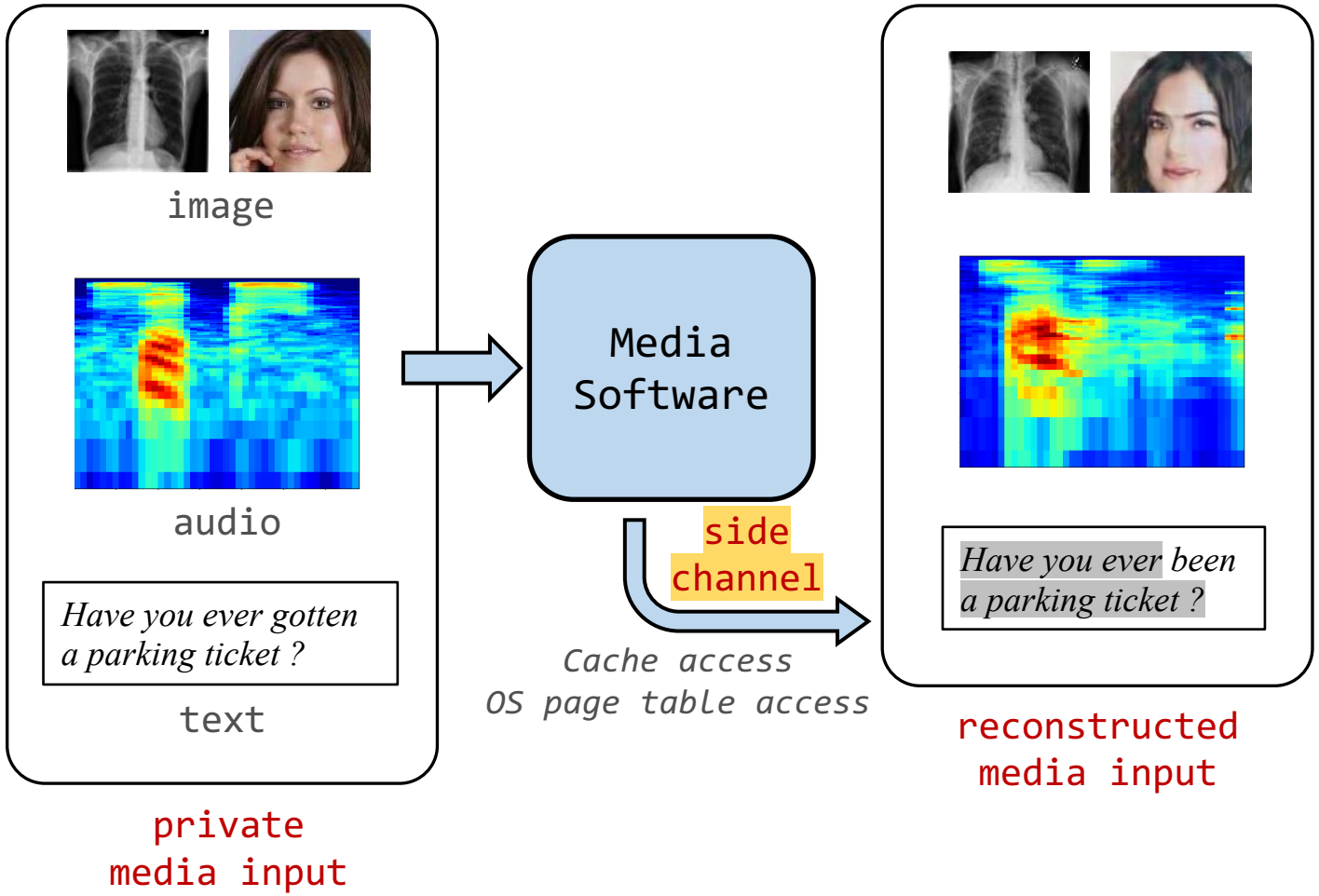
THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

Threat Model & Overview



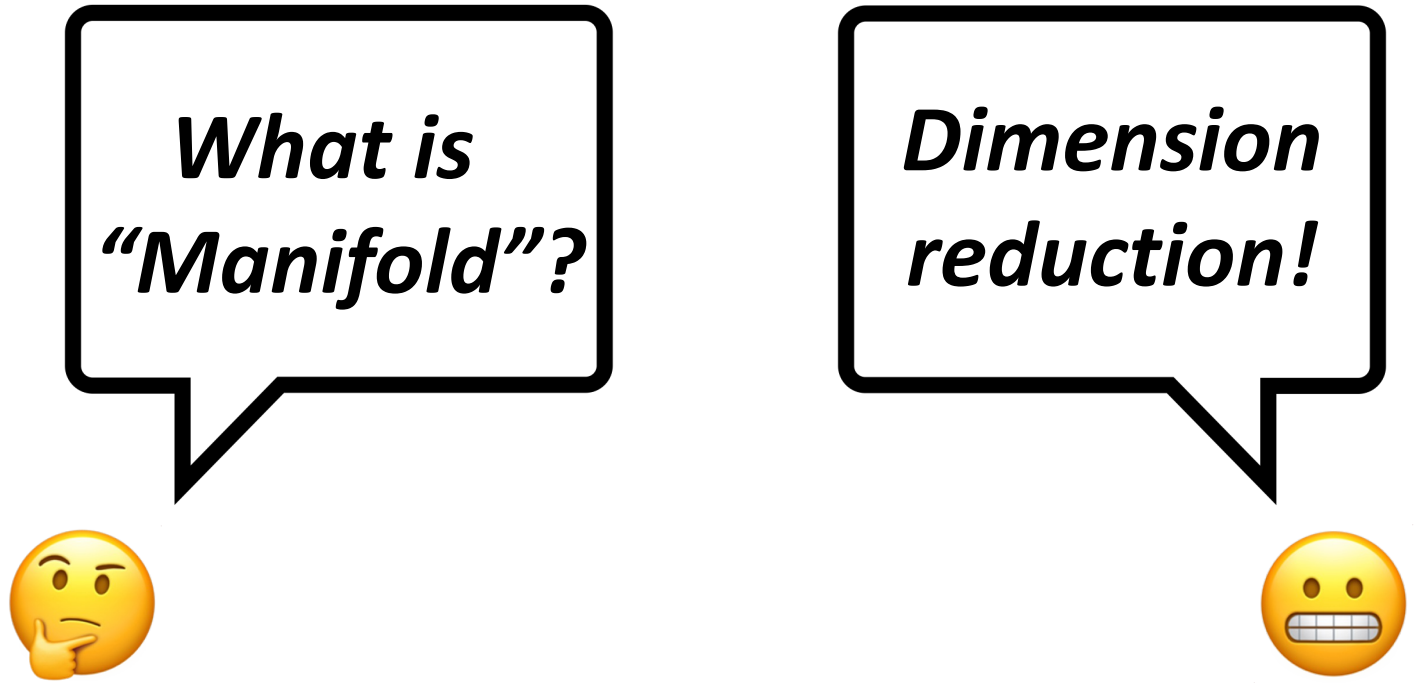
- Standard trace-based attack
- Executables
- Log side channels via
  1) Intel Pin (for "debugging")
  2) Prime & Probe

- ❑ **Reconstruct**
  private media inputs
- ❑ **Localize**
  vulnerable program points
- ❑ **Mitigate**
  with *perception blinding*

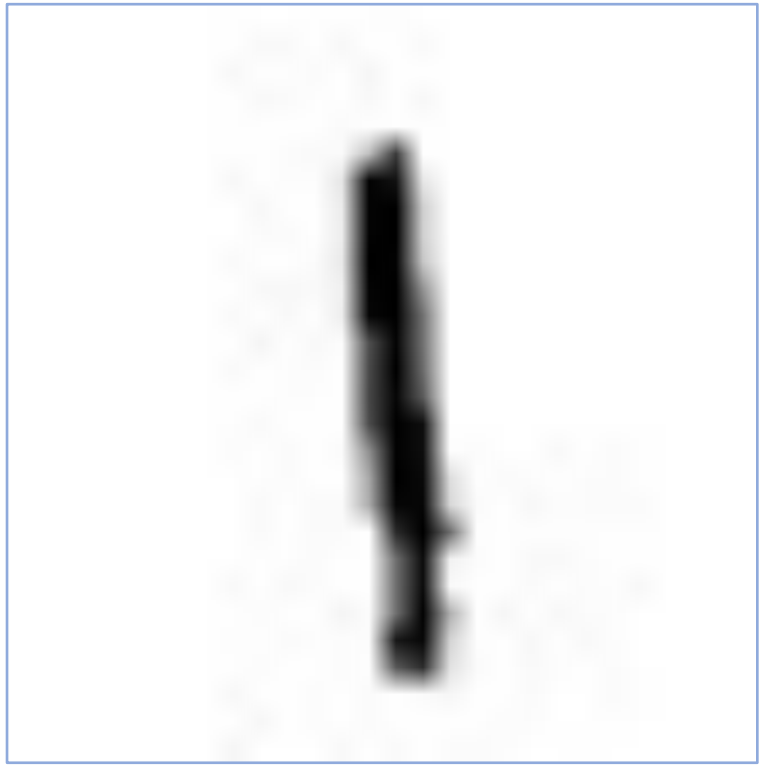
Contents

- Manifold of media data
- Reconstruction
- Localization
- Mitigation

Manifold



Manifold



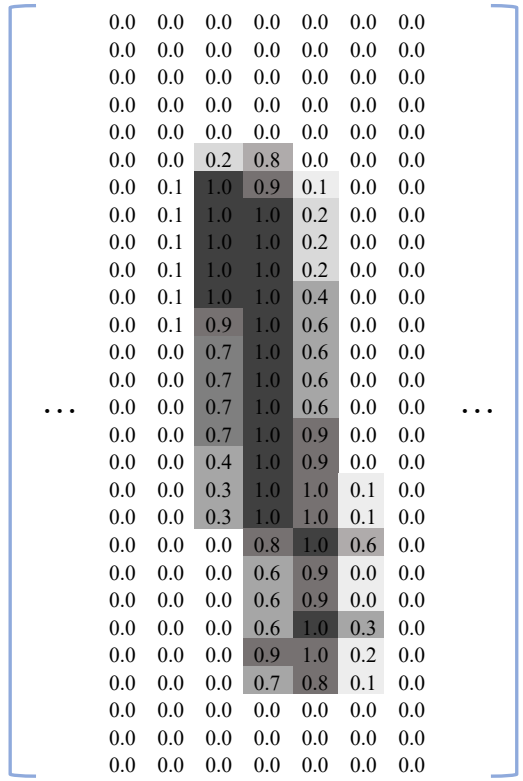
size: 1 x 30 x 30

An image in the pixel space

- A 900-dimension vector x
- Each $x[i] \in [0, 255]$

Too many dimensions!

Manifold



pixel value / 255

Not all $x \in [0, 255]^{900}$ are meaningful images; "images" of random pixel values are mostly meaningless.

- Meaningless image → ~~privacy~~
- "Perceptual" constraints over pixel values → primarily scope the privacy

Manifold

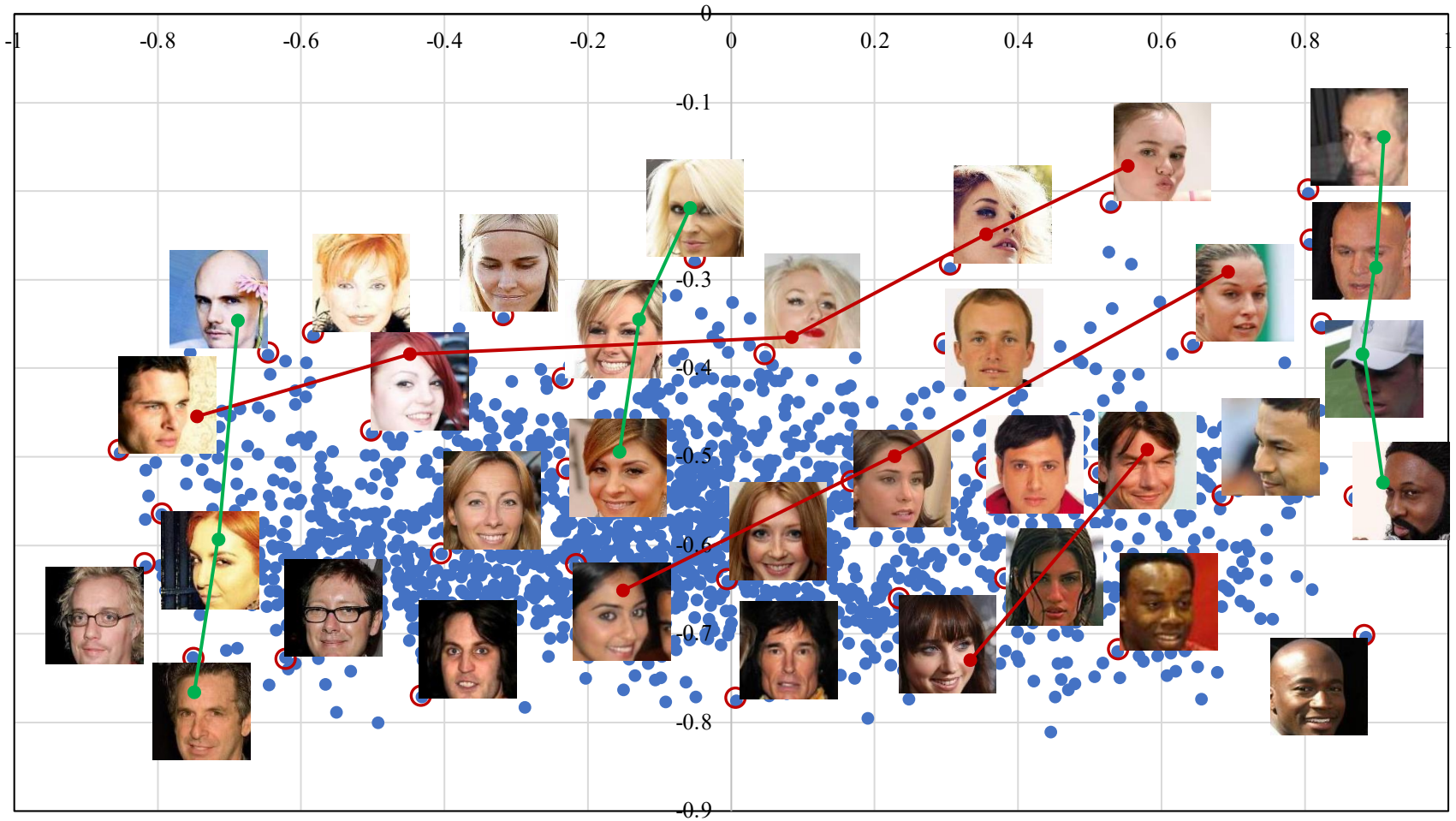
An intuitive example

Imagine that we simplify the digit “1” as a segment. Then project it onto the polar coordinate.

Only two dimensions!

Manifold

Project face photos onto a 2-dimensional manifold using our framework



Two dimensions are correlated to face colors and orientations

100 dimensions for face photos in practice

🤔

Reconstruction

side channel domain

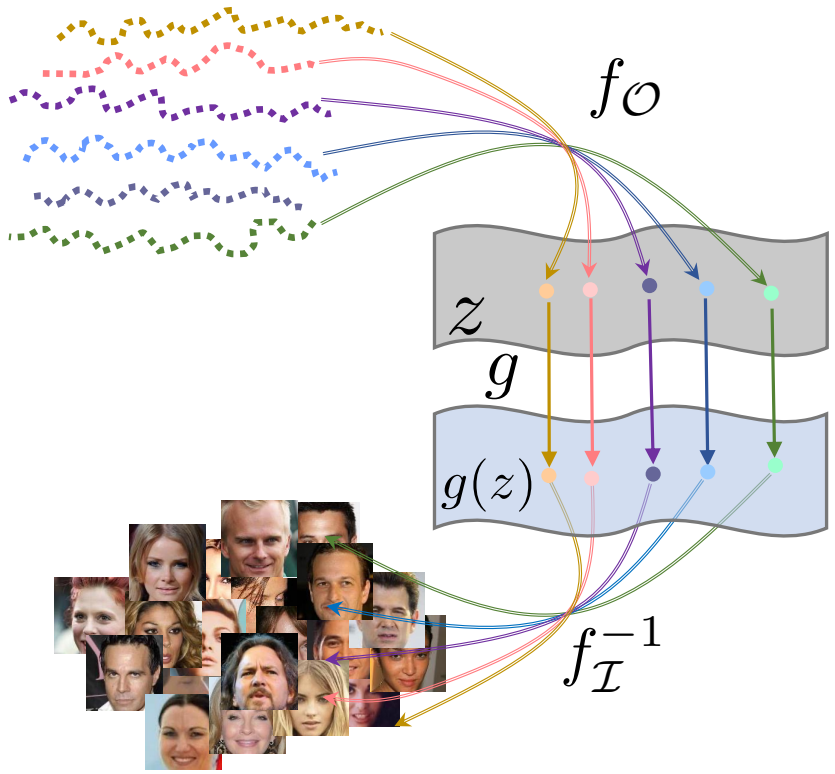


image domain

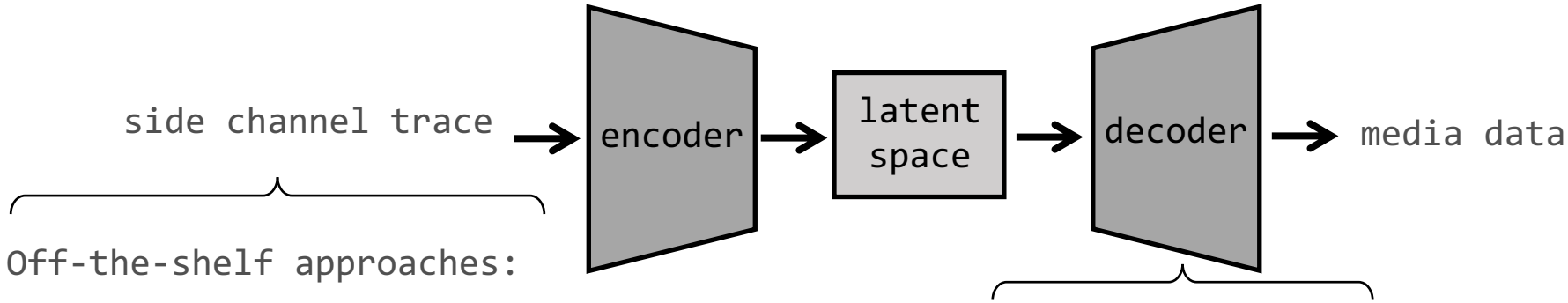
A manifold view on side channel analysis of media software

~~Data bytes (e.g., pixel values)~~ ✗

Perceptual contents (e.g., facial attributes) of much lower dimensions ✓

Reconstruction

The high-level framework



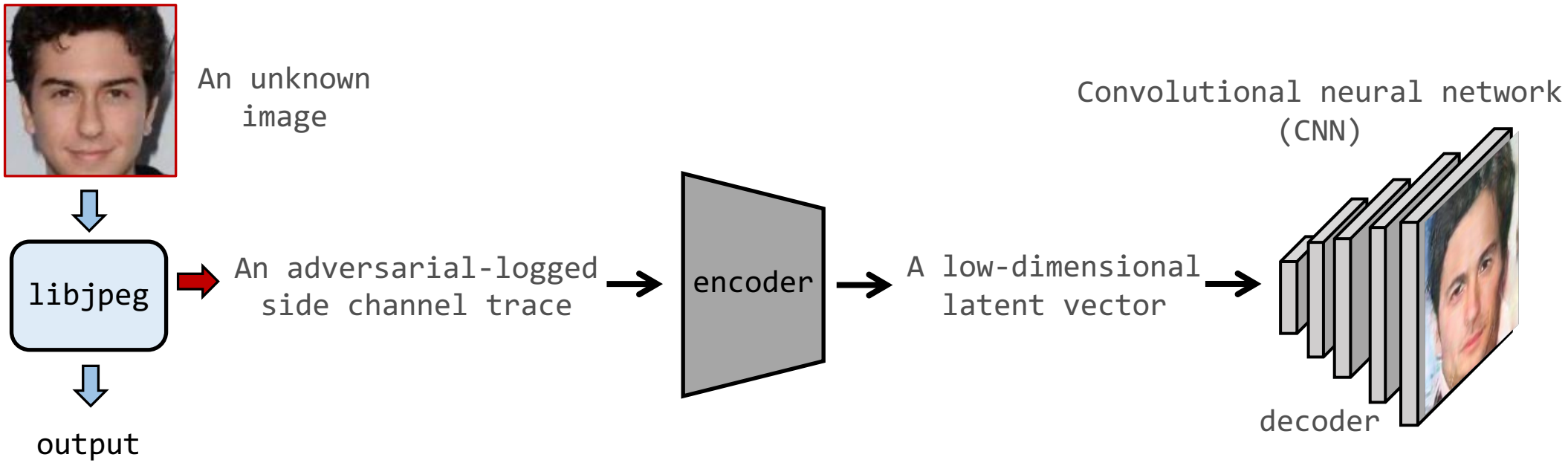
Off-the-shelf approaches:

- Prime & Probe (real attack)
- Intel Pin (“debug”)

Different decoders:

- Image
- Audio
- text

Reconstruction

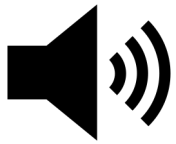


Images are continuous

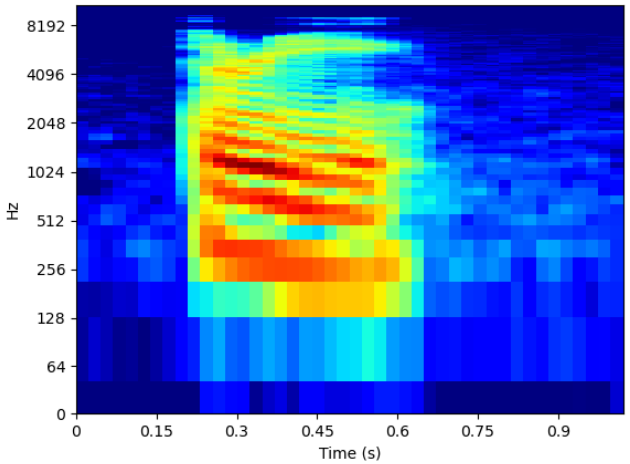
Reconstruction

raw audios

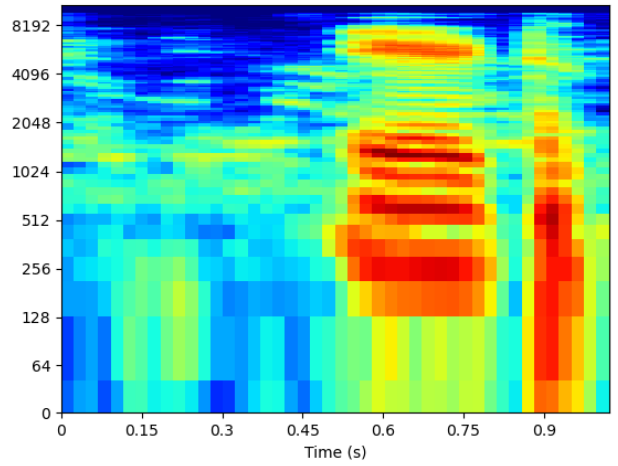
(e.g., *.wav*)



lossless

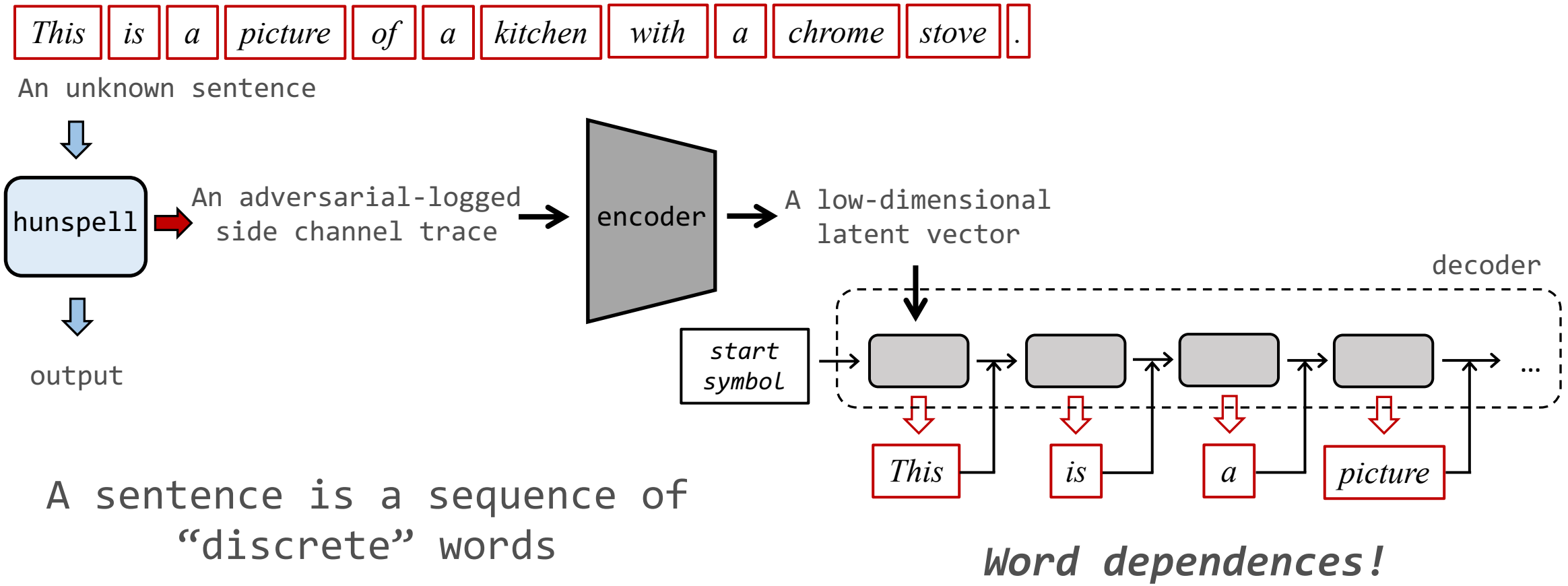


An “image”-representation of audios



log-amplitude of Mel spectrum

Reconstruction



A sentence is a sequence of "discrete" words

Word dependences!

Reconstruction

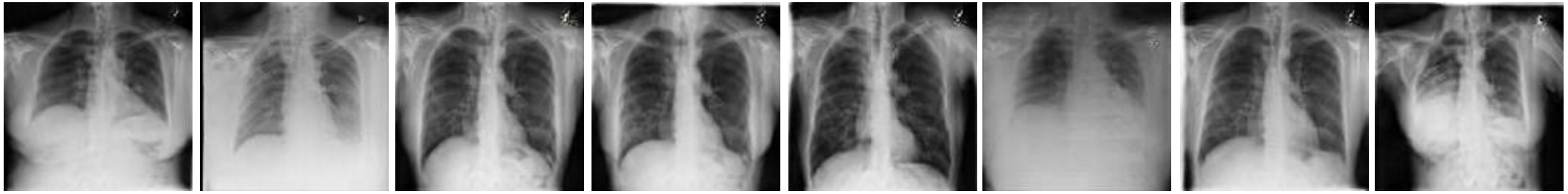
Reconstructed images

Private inputs

Reconstructed images

Private inputs

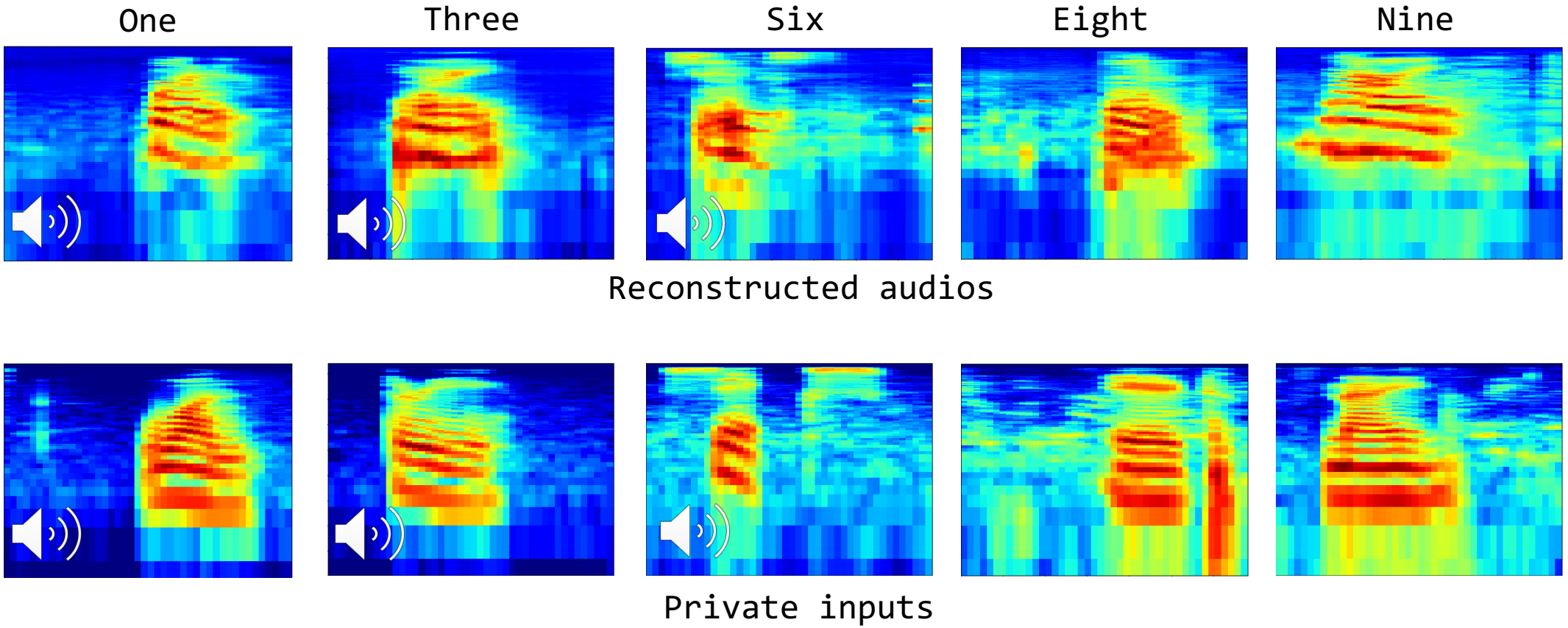
Reconstruction



Reconstructed images

Private inputs

Reconstruction

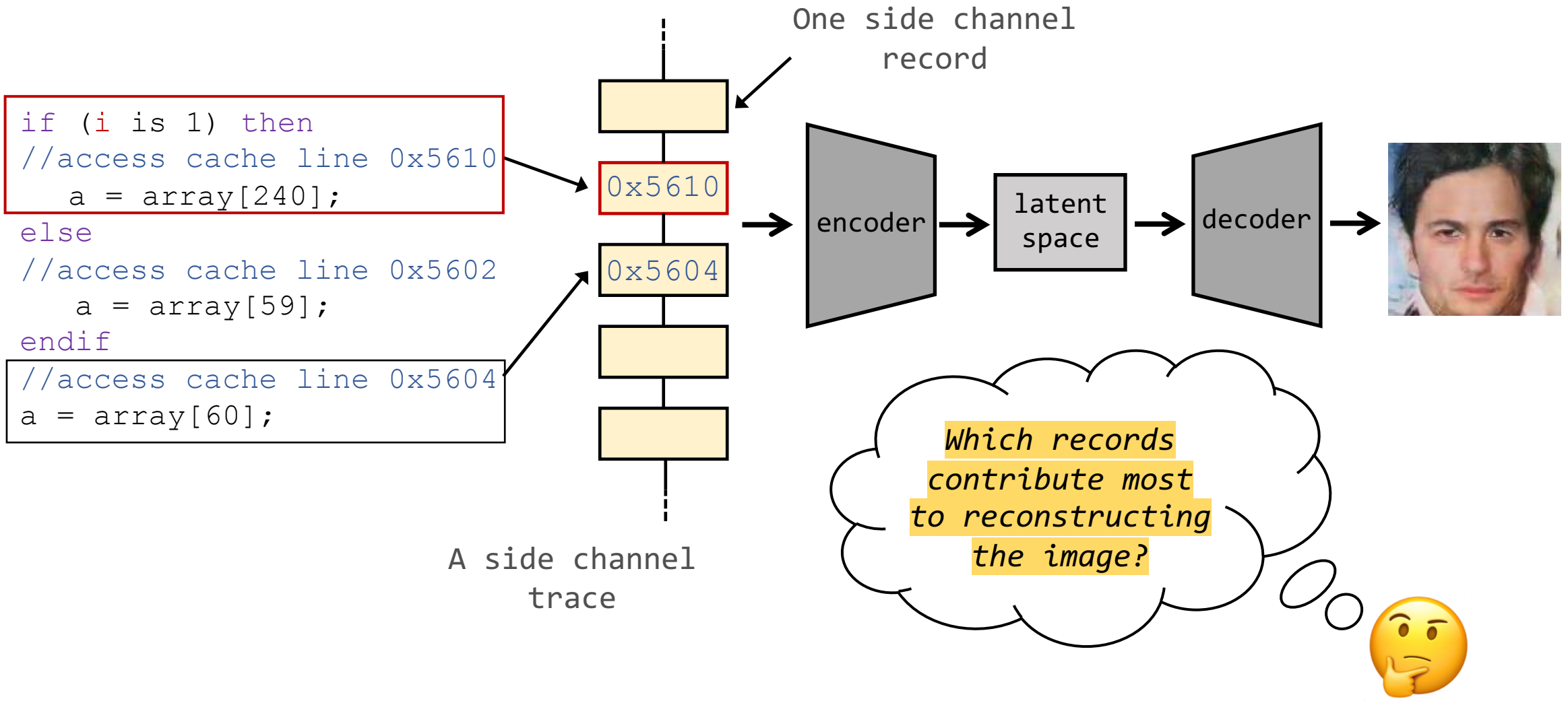


Reconstruction

Reconstructed Text	Private Input
*<UNK> I supposed to do **now** ?*	*What am I supposed to do then ?*
***I have** , the sunshine and **beautiful up** me **to the** honeymoon . The island , the sound of the <UNK> , the salty **style** air and the sunshine . . .*	*You know , the sunshine and wind remind me of our honeymoon . The island , the sound of the waves , the salty sea air and the sunshine . . .*
Mam , another minute , could I ?	*Mam , another minute , could I ?*
***It ' s** like a good idea .*	*That sounds like a good idea .*
*I <UNK>' t want to insult Jill or her **brother** . I think Jill **,** could be it . But I ' **ll** rather have some **to** little older .*	*I don ' t want to insult Jill or her mother . I think Jill maybe could do it . But I ' d rather have someone a little older .*
*I think it **'** be better **for find** a good babysitter here . It **' be cost , an** or three days .*	*I think it would be better to have a good babysitter here . It might even be for two or three days .*
*She **is** a **single** cold , and **it** don ' t want to take **care to** us . But we don ' t know **how** can stay with her .*	*She has a bad cold , and we don ' t want to take her with us . But we don ' t know who can stay with her .*
*This is **very** <UNK>, I **have** . But Hank and I are leaving tonight .*	*This is short notice , I know . But Hank and I are leaving tonight .*
*I ' m sorry **, say that** . What ' s wrong with her ?*	*I ' m sorry to hear it . What ' s wrong with her ?*
*Have you ever **been** a parking ticket ?*	*Have you ever gotten a parking ticket ?*

Localization

```
if (i is 1) then
//access cache line 0x5610
   a = array[240];
else
//access cache line 0x5602
   a = array[59];
endif
//access cache line 0x5604
a = array[60];
```



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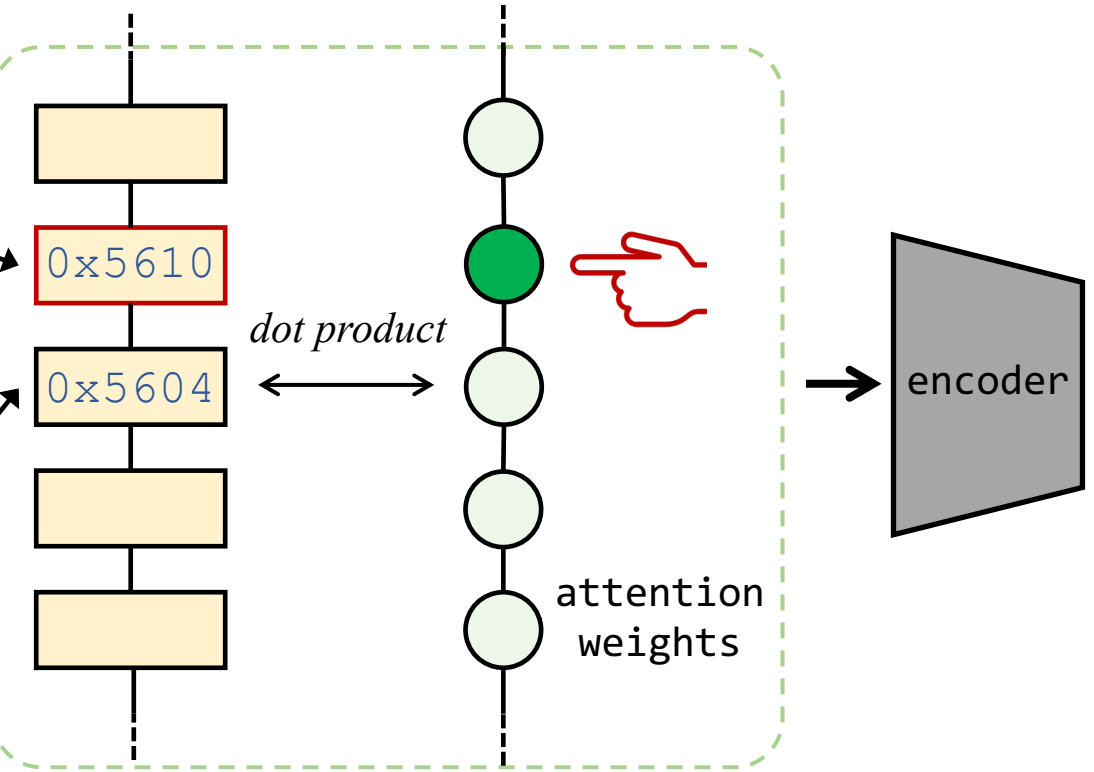


Neural attention! 😎

Localization

```
1  int HUFF_EXTEND(int x, int s) {
2    // ‘‘ex_test’’ and ‘‘ex_offset’’ are
3    // pre-calculated arrays
4    if (x < ex_test[s])
5      return x + ex_offset[s];
6    else
7      return x;
8    }
9
10 boolean decode_mcu_fast(j_decompress_ptr cinfo,
11   JBLOCKROW *MCU_data) {
12   huff_entropy_ptr entropy =
13    (huff_entropy_ptr)cinfo->entropy;
14   /* preprocessing */
15   for (int i = 0; i < cinfo->blocks_in_MCU; i++)
16     d_derived_tbl *dctbl = entropy->dc_cur_tbls[i];
17     int s, k, r, l;
18     /* get index ‘‘idx’’ based on ‘‘s’’ */
19     /* update ‘‘r’’ */
20     s = dctbl->lookup[idx];
21     // ‘‘lookup’’ is pre-calculated array
22     if (s)
23       s = HUFF_EXTEND(r, s);
24     }
25     /* do something */
26   }
27   /* do something and return */
28 }
```

Localized vulnerabilities in libjpeg

- Minimum coded unit (MCU)-related modules
- Inverse discrete cosine transformation (IDCT)-related modules [1] [2]
- Other image transformation routines and output dumping routines

[1] *Controlled-channel attacks: Deterministic side channels for untrusted operating systems.* In S&P 2015.
[2] *High-resolution side channels for untrusted operating systems.* In USENIX ATC 2017.

Mitigation

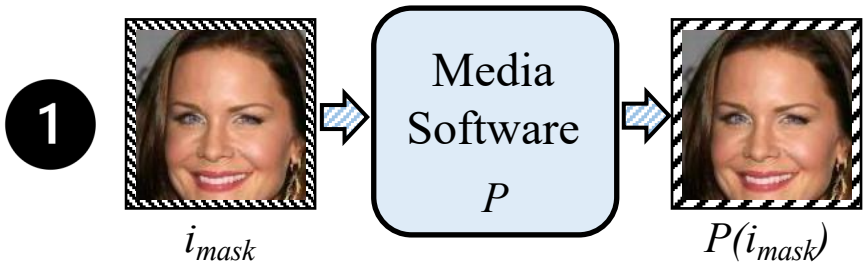
Media software: process **data bytes**
(e.g., a pixel value)

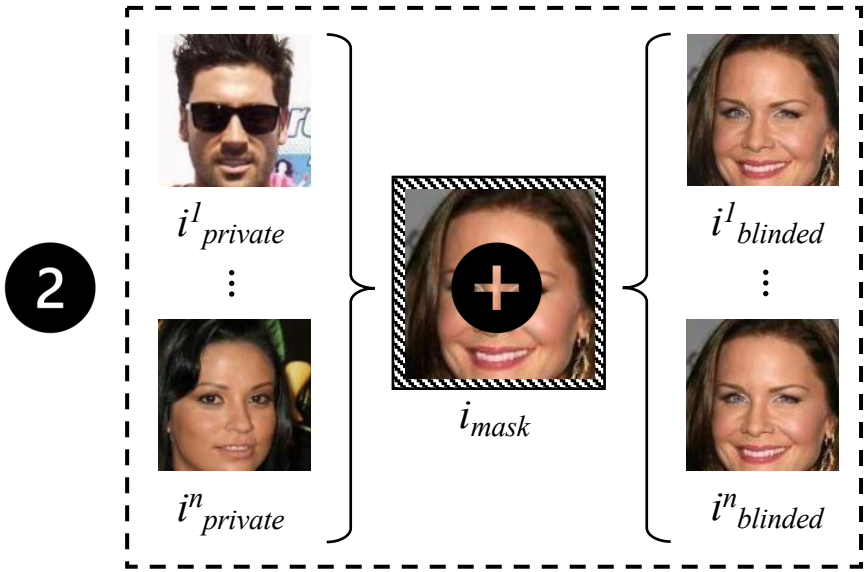
V.S.

Our attack: focus on **perceptions**
(e.g., facial attributes)

"Blind" the perceptions!

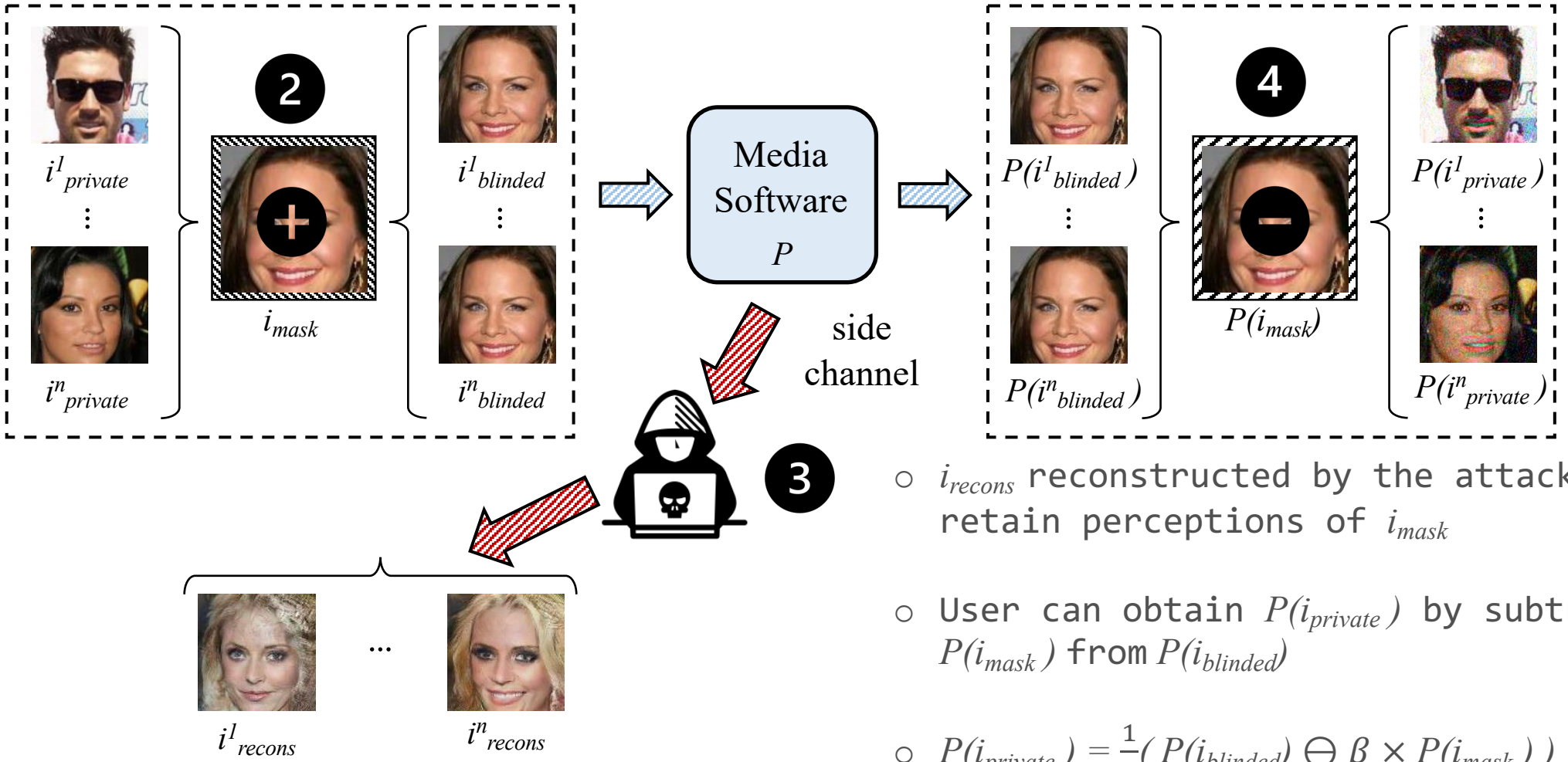
Mitigation





- Randomly pick one universal mask i_{mask}
- Pre-compute $P(i_{mask})$
- i_{mask} must be perceptually correlated to private input $i_{private}$ (e.g., both are face photos)
- Set $i_{blinded} = \alpha \times i_{private} \oplus \beta \times i_{mask}$, rather than $i_{private}$, as the input of P
- $\beta \gg \alpha$ and $\alpha + \beta = 1$

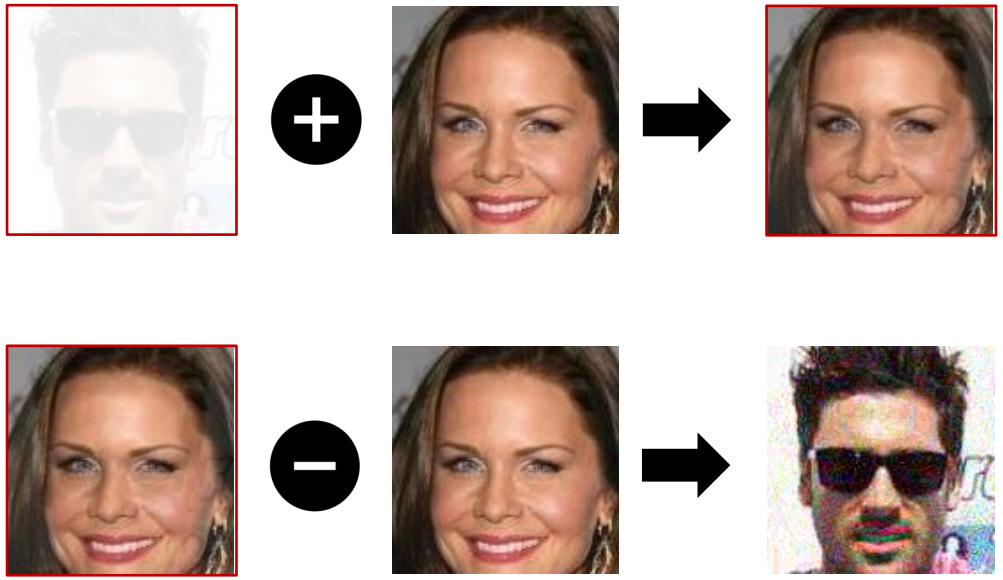
Mitigation



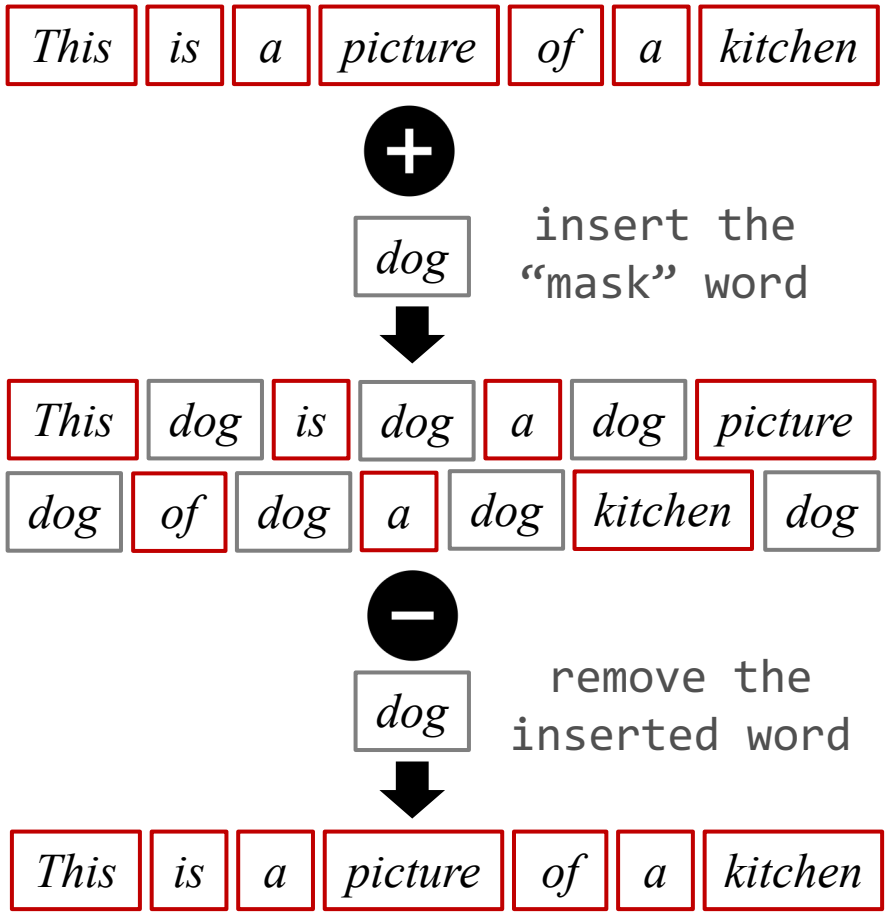
- i_{recons} reconstructed by the attacker mostly retain perceptions of i_{mask}
- User can obtain $P(i_{private})$ by subtracting $P(i_{mask})$ from $P(i_{blinded})$
- $P(i_{private}) = \frac{1}{\alpha}(P(i_{blinded}) \ominus \beta \times P(i_{mask}))$

Mitigation

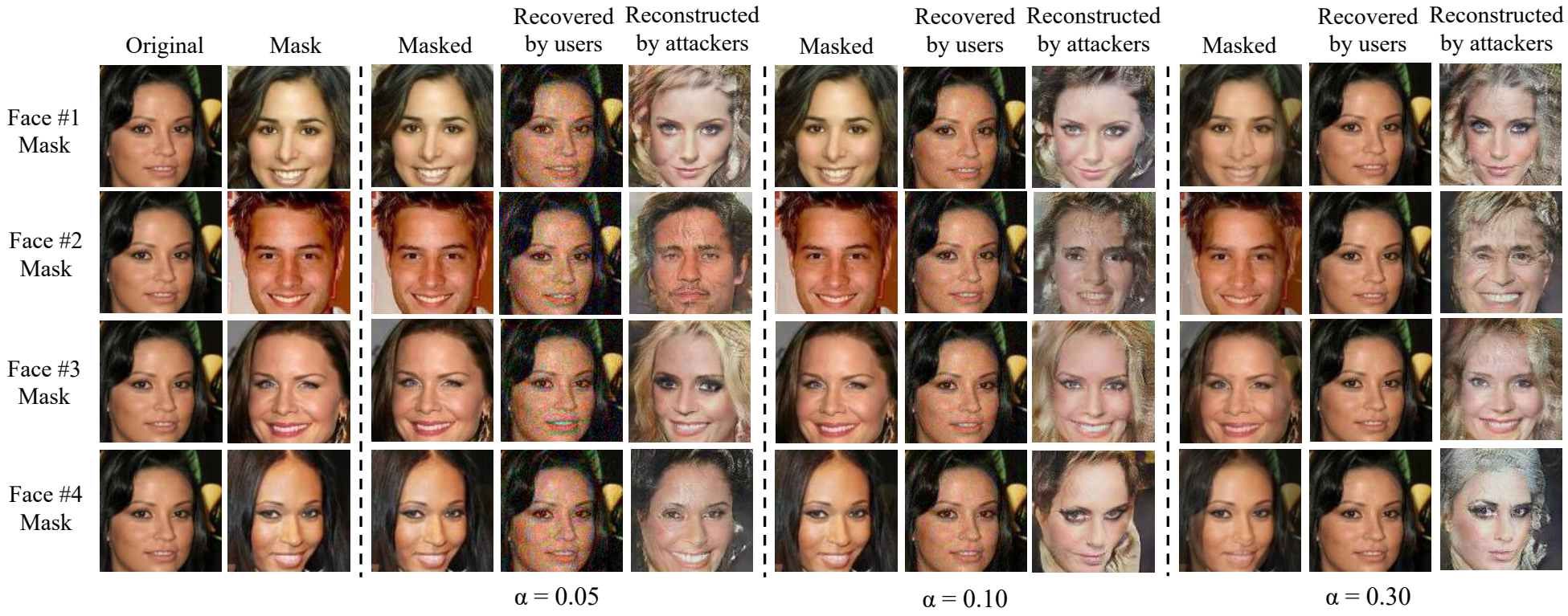
lower weight higher weight



data bytes addition & subtraction



Mitigation



- Attacker only reconstructs perceptions of the mask
- User can recover the perceptions of private inputs

Thank you for listening!

Contact Yuanyuan Yuan (https://yuanyuan-yuan.github.io/)
for more details

https://arxiv.org/pdf/2112.04947.pdf

Preprint

(an extended version of 35 pages)

https://github.com/Yuanyuan-Yuan/Manifold-SCA

Artifact

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