The Apple PSI System [Bhowmick et al., 2021]

Alessandro Baccarini

University at Buffalo

anbaccar@buffalo.edu

December 15, 2021

Table of Contents

Motivations

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.
- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.
- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.
- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.

- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.

Why Apple's child safety updates are so controversial

Apple is trying to balance child safety and privacy, but some experts say the company is going too far.

- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.

- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.

- September 2021 – Apple postpones rollout indefinitely.

Why?

- August 2021 – Apple unveils plans for new Child Sexual Abuse Material (CSAM) detection system.
- Designed to automatically detect known CSAM images stored in iCloud, and report the users to authorities.
- Aimed to be packaged with iOS 15 and iPadOS 15.
- Very poorly received in media and tech communities.

- September 2021 – Apple postpones rollout indefinitely.

What security goals do "we" want?

- Server cannot recover the user's matched photos without exceeding some threshold.
- False positives are impossible.
- No information is learned about non-matched images.
- User cannot learn any information from the CSAM database.
- User cannot identify which images were flagged as CSAM by the system.

What security goals do "we" want?

- Server cannot recover the user's matched photos without exceeding some threshold.
- False positives are impossible.
- No information is learned about non-matched images.
- User cannot learn any information from the CSAM database.
- User cannot identify which images were flagged as CSAM by the system.

What security goals do "we" want?

- Server cannot recover the user's matched photos without exceeding some threshold.
- False positives are impossible.
- No information is learned about non-matched images.
- User cannot learn any information from the CSAM database.
- User cannot identify which images were flagged as CSAM by the system.

What security goals do "we" want?

- Server cannot recover the user's matched photos without exceeding some threshold.
- False positives are impossible.
- No information is learned about non-matched images.
- User cannot learn any information from the CSAM database.
- User cannot identify which images were flagged as CSAM by the system.

What security goals do "we" want?

- Server cannot recover the user's matched photos without exceeding some threshold.
- False positives are impossible.
- No information is learned about non-matched images.
- User cannot learn any information from the CSAM database.
- User cannot identify which images were flagged as CSAM by the system.

What security goals do "we" want?

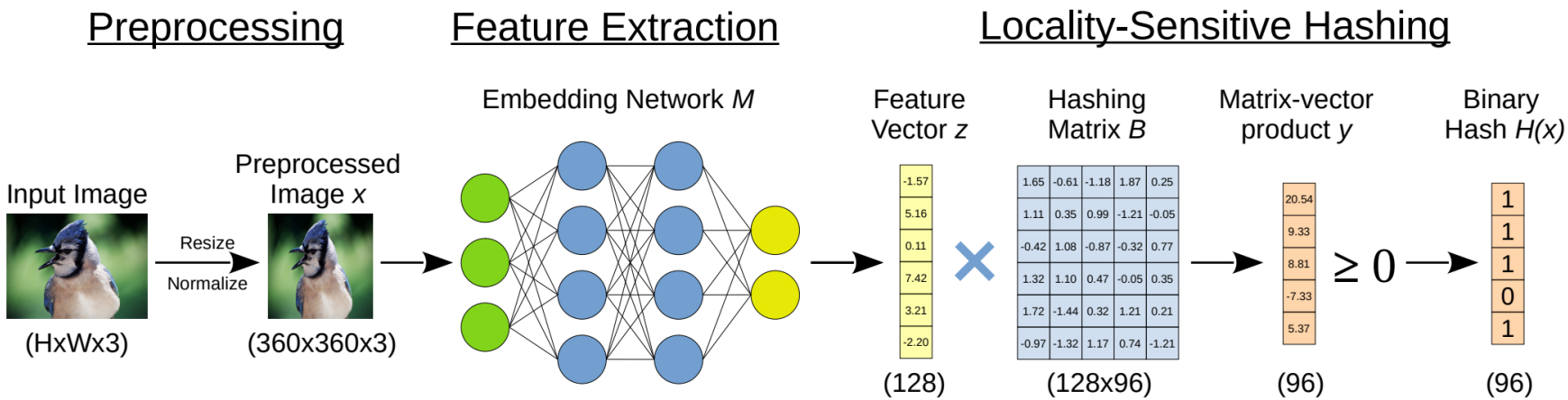
- Server cannot recover the user's matched photos without exceeding some threshold.
- False positives are impossible.
- No information is learned about non-matched images.
- User cannot learn any information from the CSAM database.
- User cannot identify which images were flagged as CSAM by the system.

NeuralHash

- Different from our standard notion of hash functions.
- Insensitive to small perturbations (cropping, rotation, mirroring, watermarking).

NeuralHash

- Different from our standard notion of hash functions.
- Insensitive to small perturbations (cropping, rotation, mirroring, watermarking).



[Struppek et al., 2021]

NeuralHash

- Contains some collision-related issues [Athalye, 2021]...

NeuralHash

– Contains some collision-related issues [Athalye, 2021]...

$\stackrel{?}{=}$

NeuralHash

– Contains some collision-related issues [Athalye, 2021]...

$\overset{?}{=}$

```
$ python nnhash.py cat.png
59a34eabe31910abfb06f308
$ python nnhash.py dog.png
59a34eabe31910abfb06f308
```

A Crash Course in Private Set Intersection (PSI)

- Let $\mathcal{U}$ be the universe of all possible image hashes.
- $X \subseteq \mathcal{U}$ is set of image hashes we want to match against, stored on the server.
- A client has a list of m triples

$$\bar{Y} = \left((y_1, id_1, ad_1), \ldots (y_m, id_m, ad_m) \right) \in (\mathcal{U} \times \mathcal{ID} \times \mathcal{D})^m,$$

  where $y \in \mathcal{U}$ is the hash of an image, a unique identifier $id \in \mathcal{ID}$, and some associated data $ad \in \mathcal{D}$.
- When the protocol terminates, the server learns the identifiers and associated data of the intersection of $\bar{Y}$ and X, namely $id\left(\bar{Y} \cap X\right)$

A Crash Course in Private Set Intersection (PSI)

- Let $\mathcal{U}$ be the universe of all possible image hashes.
- $X \subseteq \mathcal{U}$ is set of image hashes we want to match against, stored on the server.
- A client has a list of m triples

$$\bar{Y} = \left((y_1, id_1, ad_1), \ldots (y_m, id_m, ad_m) \right) \in (\mathcal{U} \times \mathcal{ID} \times \mathcal{D})^m,$$

  where $y \in \mathcal{U}$ is the hash of an image, a unique identifier $id \in \mathcal{ID}$, and some associated data $ad \in \mathcal{D}$.
- When the protocol terminates, the server learns the identifiers and associated data of the intersection of $\bar{Y}$ and X, namely $id\left(\bar{Y} \cap X\right)$

A Crash Course in Private Set Intersection (PSI)

- Let $\mathcal{U}$ be the universe of all possible image hashes.
- $X \subseteq \mathcal{U}$ is set of image hashes we want to match against, stored on the server.
- A client has a list of m triples

$$\bar{Y} = \left((y_1, id_1, ad_1), \ldots (y_m, id_m, ad_m) \right) \in (\mathcal{U} \times \mathcal{ID} \times \mathcal{D})^m,$$

  where $y \in \mathcal{U}$ is the hash of an image, a unique identifier $id \in \mathcal{ID}$, and some associated data $ad \in \mathcal{D}$.
- When the protocol terminates, the server learns the identifiers and associated data of the intersection of $\bar{Y}$ and X, namely $id\left(\bar{Y} \cap X\right)$

A Crash Course in Private Set Intersection (PSI)

- Let $\mathcal{U}$ be the universe of all possible image hashes.
- $X \subseteq \mathcal{U}$ is set of image hashes we want to match against, stored on the server.
- A client has a list of m triples

$$\bar{Y} = \left((y_1, id_1, ad_1), \ldots (y_m, id_m, ad_m) \right) \in (\mathcal{U} \times \mathcal{ID} \times \mathcal{D})^m,$$

  where $y \in \mathcal{U}$ is the hash of an image, a unique identifier $id \in \mathcal{ID}$, and some associated data $ad \in \mathcal{D}$.
- When the protocol terminates, the server learns the identifiers and associated data of the intersection of $\bar{Y}$ and X, namely $id\left(\bar{Y} \cap X\right)$

Two PSI Protocols

Threshold PSI-AD

Add a threshold parameter t, such that if $\left|id\left(\bar{Y} \cap X\right)\right| \leq t$, the server learns only the *id*'s. If $\left|id\left(\bar{Y} \cap X\right)\right| > t$, then the server learns the associated data for all identifiers in the intersection.

Two PSI Protocols

Threshold PSI-AD

Add a threshold parameter t, such that if $\left|id\left(\bar{Y} \cap X\right)\right| \leq t$, the server learns only the id's. If $\left|id\left(\bar{Y} \cap X\right)\right| > t$, then the server learns the associated data for all identifiers in the intersection.

Fuzzy Threshold PSI-AD

Extension of prior scheme, but adds "synthetic matches" so the server does not know the number of matches in the intersection before the threshold t is exceeded.

Two PSI Protocols

Threshold PSI-AD

Add a threshold parameter t, such that if $\left|id\left(\bar{Y} \cap X\right)\right| \leq t$, the server learns only the *id*'s. If $\left|id\left(\bar{Y} \cap X\right)\right| > t$, then the server learns the associated data for all identifiers in the intersection.

Fuzzy Threshold PSI-AD

Extension of prior scheme, but adds "synthetic matches" so the server does not know the number of matches in the intersection before the threshold t is exceeded.

Protocol Description

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Server Setup

1. Remove any duplicates from X, and let $n = |X|$.
2. Construct a hash table T:
   - Let $n' \geq n$ be the size of the table (minimize collisions).
   - Choose hash function $h : \mathcal{U} \to \{1, \ldots, n'\}$ (SHA256 modulo n').
   - Insert elements of X into T, each cell should have at most one element.
3. Choose a random nonzero $\alpha \in \mathbb{F}_q$, compute $L = G^\alpha \in \mathbb{G}$, where $\mathbb{G}$ is a DH group modulo prime p (2048-bit) with a fixed generator $G = 2$.
4. For $i = 1$ to n' do:
   - If $T[i]$ is non-empty, set $P_i = H(T[i])^\alpha \in \mathbb{G}$, where $T[i] \in X \subseteq \mathcal{U}$, and $H : \mathcal{U} \to \mathbb{G}$ (SHA256 modulo p).
   - If $T[i]$ is empty, choose a random $P_i \in \mathbb{G}$.
5. set $pdata = (L, P_1, \ldots, P_{n'})$.

Client Setup

1. Obtain *pdata* from the server.
2. Generate keys:
   - $adkey \leftarrow \mathcal{K}'$ for encryption scheme (Enc, Dec).
     - We use AES128-GCM for its "random key robustness" property.
     - $Dec(Enc(k, m), k')$ should fail, where $k \neq k'$ are independent random keys.
   - $fkey \leftarrow \mathcal{K}''$ for the PRF $F : \mathcal{K}'' \times \mathcal{ID} \rightarrow \mathbb{F}_{\text{Sh}}$.
   - Initialize threshold *Shamir secret sharing* for $adkey$:

$$f(x) = a_0 + a_1 x + a_2 x + \cdots + a_t x^t,$$

where $a_0 = adkey$ is the secret. Reconstruction involves Lagrange interpolation.

Client Setup

1. Obtain *pdata* from the server.
2. Generate keys:
   - $adkey \leftarrow \mathcal{K}'$ for encryption scheme (Enc, Dec).
     - We use AES128-GCM for its "random key robustness" property.
     - $Dec(Enc(k, m), k')$ should fail, where $k \neq k'$ are independent random keys.
   - $fkey \leftarrow \mathcal{K}''$ for the PRF $F : \mathcal{K}'' \times \mathcal{ID} \rightarrow \mathbb{F}_{\text{Sh}}$.
   - Initialize threshold *Shamir secret sharing* for $adkey$:

$$f(x) = a_0 + a_1 x + a_2 x + \cdots + a_t x^t,$$

     where $a_0 = adkey$ is the secret. Reconstruction involves Lagrange interpolation.

Client Setup

1. Obtain *pdata* from the server.
2. Generate keys:
   - $adkey \leftarrow \mathcal{K}'$ for encryption scheme (Enc, Dec).
     - We use AES128-GCM for its "random key robustness" property.
     - $Dec(Enc(k, m), k')$ should fail, where $k \neq k'$ are independent random keys.
   - $fkey \leftarrow \mathcal{K}''$ for the PRF $F : \mathcal{K}'' \times \mathcal{ID} \rightarrow \mathbb{F}_{\mathsf{Sh}}$.
   - Initialize threshold *Shamir secret sharing* for *adkey*:

$$f(x) = a_0 + a_1 x + a_2 x + \cdots + a_t x^t,$$

where $a_0 = adkey$ is the secret. Reconstruction involves Lagrange interpolation.

Client Setup

1. Obtain *pdata* from the server.
2. Generate keys:
   - $adkey \leftarrow \mathcal{K}'$ for encryption scheme (Enc, Dec).
     - We use AES128-GCM for its "random key robustness" property.
     - $Dec(Enc(k, m), k')$ should fail, where $k \neq k'$ are independent random keys.
   - $fkey \leftarrow \mathcal{K}''$ for the PRF $F : \mathcal{K}'' \times \mathcal{ID} \rightarrow \mathbb{F}_{\mathsf{Sh}}$.
   - Initialize threshold *Shamir secret sharing* for *adkey*:

$$f(x) = a_0 + a_1 x + a_2 x + \cdots + a_t x^t,$$

where $a_0 = adkey$ is the secret. Reconstruction involves Lagrange interpolation.

Client Setup

1. Obtain *pdata* from the server.
2. Generate keys:
   - $adkey \leftarrow \mathcal{K}'$ for encryption scheme (Enc, Dec).
     - We use AES128-GCM for its "random key robustness" property.
     - $Dec(Enc(k, m), k')$ should fail, where $k \neq k'$ are independent random keys.
   - $fkey \leftarrow \mathcal{K}''$ for the PRF $F : \mathcal{K}'' \times \mathcal{ID} \rightarrow \mathbb{F}_{\text{Sh}}$.
   - Initialize threshold *Shamir secret sharing* for *adkey*:

$$f(x) = a_0 + a_1 x + a_2 x + \cdots + a_t x^t,$$

where $a_0 = adkey$ is the secret. Reconstruction involves Lagrange interpolation.

Client Voucher Generation on Input Triple (y, id, ad)

1. Encrypt ad as $adct \leftarrow \mathrm{Enc}(adkey, ad)$, and all $adct$ must be the same length.
2. Compute $x = F(fkey, id) \in \mathbb{F}_{\mathrm{Sh}}$.
3. Generate a share $sh = (x, f(x)) \in \mathbb{F}_{\mathrm{Sh}}$ of $adkey$ (guarantees duplicate triples with the same id will produce the same sh).
4. Choose a random key $rkey \leftarrow \mathcal{K}'$ and compute $rct \leftarrow \mathrm{Enc}(rkey, (adct, sh))$.

Client Voucher Generation on Input Triple (y, id, ad)

1. Encrypt ad as $adct \leftarrow \mathrm{Enc}(adkey, ad)$, and all $adct$ must be the same length.
2. Compute $x = F(fkey, id) \in \mathbb{F}_{\mathsf{Sh}}$.
3. Generate a share $sh = (x, f(x)) \in \mathbb{F}_{\mathsf{Sh}}$ of $adkey$ (guarantees duplicate triples with the same id will produce the same sh).
4. Choose a random key $rkey \leftarrow \mathcal{K}'$ and compute $rct \leftarrow \mathrm{Enc}(rkey, (adct, sh))$.

Client Voucher Generation on Input Triple (y, id, ad)

1. Encrypt ad as $adct \leftarrow \mathrm{Enc}(adkey, ad)$, and all $adct$ must be the same length.
2. Compute $x = F(fkey, id) \in \mathbb{F}_{\mathsf{Sh}}$.
3. Generate a share $sh = (x, f(x)) \in \mathbb{F}_{\mathsf{Sh}}$ of $adkey$ (guarantees duplicate triples with the same id will produce the same sh).
4. Choose a random key $rkey \leftarrow \mathcal{K}'$ and compute $rct \leftarrow \mathrm{Enc}(rkey, (adct, sh))$.

Client Voucher Generation on Input Triple (y, id, ad)

1. Encrypt ad as $adct \leftarrow \mathrm{Enc}(adkey, ad)$, and all $adct$ must be the same length.
2. Compute $x = F(fkey, id) \in \mathbb{F}_{\mathsf{Sh}}$.
3. Generate a share $sh = (x, f(x)) \in \mathbb{F}_{\mathsf{Sh}}$ of $adkey$ (guarantees duplicate triples with the same id will produce the same sh).
4. Choose a random key $rkey \leftarrow \mathcal{K}'$ and compute $rct \leftarrow \mathrm{Enc}(rkey, (adct, sh))$.

Client Voucher Generation on Input Triple (y, id, ad)

5. Compute $w = h(y) \in \{1, \ldots, n'\}$.
6. Sample random $\beta, \gamma \in \mathbb{F}_q$, and use P_w, L from *pdata* to compute:

$$Q = H(y)^{\beta} \cdot G^{\gamma} \text{ and } S = P_w^{\beta} \cdot L^{\gamma},$$

   where if $y = T[w]$, then $P_w = H(y)^{\alpha}$ and $S = Q^{\alpha}$ (DH random self reduction).
7. Compute $ct \leftarrow \mathrm{Enc}\left(H'(S), rkey\right)$, where $H' : \mathbb{G} \to \mathcal{K}'$ (HKDF with SHA256).
8. Send $voucher = (id, Q, ct, rct)$ to the server.

Client Voucher Generation on Input Triple (y, id, ad)

5. Compute $w = h(y) \in \{1, \ldots, n'\}$.
6. Sample random $\beta, \gamma \in \mathbb{F}_q$, and use P_w, L from *pdata* to compute:

$$Q = H(y)^{\beta} \cdot G^{\gamma} \text{ and } S = P_w^{\beta} \cdot L^{\gamma},$$

   where if $y = T[w]$, then $P_w = H(y)^{\alpha}$ and $S = Q^{\alpha}$ (DH random self reduction).
7. Compute $ct \leftarrow \mathrm{Enc}\left(H'(S), rkey\right)$, where $H' : \mathbb{G} \to \mathcal{K}'$ (HKDF with SHA256).
8. Send $voucher = (id, Q, ct, rct)$ to the server.

Client Voucher Generation on Input Triple (y, id, ad)

5. Compute $w = h(y) \in \{1, \ldots, n'\}$.
6. Sample random $\beta, \gamma \in \mathbb{F}_q$, and use P_w, L from *pdata* to compute:

$$Q = H(y)^{\beta} \cdot G^{\gamma} \text{ and } S = P_w^{\beta} \cdot L^{\gamma},$$

   where if $y = T[w]$, then $P_w = H(y)^{\alpha}$ and $S = Q^{\alpha}$ (DH random self reduction).
7. Compute $ct \leftarrow \text{Enc}\left(H'(S), rkey\right)$, where $H' : \mathbb{G} \rightarrow \mathcal{K}'$ (HKDF with SHA256).
8. Send $voucher = (id, Q, ct, rct)$ to the server.

Client Voucher Generation on Input Triple (y, id, ad)

5. Compute $w = h(y) \in \{1, \ldots, n'\}$.
6. Sample random $\beta, \gamma \in \mathbb{F}_q$, and use P_w, L from *pdata* to compute:

$$Q = H(y)^{\beta} \cdot G^{\gamma} \text{ and } S = P_w^{\beta} \cdot L^{\gamma},$$

   where if $y = T[w]$, then $P_w = H(y)^{\alpha}$ and $S = Q^{\alpha}$ (DH random self reduction).
7. Compute $ct \leftarrow \mathrm{Enc}\left(H'(S), rkey\right)$, where $H' : \mathbb{G} \rightarrow \mathcal{K}'$ (HKDF with SHA256).
8. Send $voucher = (id, Q, ct, rct)$ to the server.

Server Voucher Processing

1. Initialize empty set *SHARES* and an empty list *IDLIST*.
2. For each voucher (id, Q, ct, rct) received, do:
   - Append *id* to IDLIST.
   - Compute $\hat{S} = Q^{\alpha} \in \mathbb{G}$,
   - Set $rkey = \mathrm{Dec}(H'(\hat{S}), ct)$.
   - Set $(adct, sh) = \mathrm{Dec}(rkey, rct)$.
   - If either decryptions "fails", y is a non-match, and ignore the voucher.
   - Otherwise, we found a match and add $(id, adct, sh)$ to *SHARES*.

Server Voucher Processing

1. Initialize empty set *SHARES* and an empty list *IDLIST*.
2. For each voucher (id, Q, ct, rct) received, do:
   - Append *id* to IDLIST.
   - Compute $\hat{S} = Q^{\alpha} \in \mathbb{G}$,
   - Set $rkey = \mathrm{Dec}(H'(\hat{S}), ct)$.
   - Set $(adct, sh) = \mathrm{Dec}(rkey, rct)$.
   - If either decryptions "fails", y is a non-match, and ignore the voucher.
   - Otherwise, we found a match and add $(id, adct, sh)$ to *SHARES*.

Server Voucher Processing

1. Initialize empty set *SHARES* and an empty list *IDLIST*.
2. For each voucher (id, Q, ct, rct) received, do:
   - Append *id* to IDLIST.
   - Compute $\hat{S} = Q^{\alpha} \in \mathbb{G}$,
   - Set $rkey = \mathrm{Dec}(H'(\hat{S}), ct)$.
   - Set $(adct, sh) = \mathrm{Dec}(rkey, rct)$.
   - If either decryptions "fails", y is a non-match, and ignore the voucher.
   - Otherwise, we found a match and add $(id, adct, sh)$ to *SHARES*.

Server Voucher Processing

1. Initialize empty set *SHARES* and an empty list *IDLIST*.
2. For each voucher (id, Q, ct, rct) received, do:
   - Append *id* to IDLIST.
   - Compute $\hat{S} = Q^{\alpha} \in \mathbb{G}$,
   - Set $rkey = \mathrm{Dec}(H'(\hat{S}), ct)$.
   - Set $(adct, sh) = \mathrm{Dec}(rkey, rct)$.
   - If either decryptions "fails", y is a non-match, and ignore the voucher.
   - Otherwise, we found a match and add $(id, adct, sh)$ to *SHARES*.

Server Voucher Processing

3. Let t' denote the number of *unique* shares in $SHARES$, and t' should equal the size of $id(\bar{Y} \cap X)$.
   - If $t' \leq t$, let $OUTSET$ be the set of identifiers in $SHARES$.
   - If $t' > t$, do:
     - Use $(t+1)$ shares to reconstruct $adkey \in \mathcal{K}'$.
     - Initialize $OUTSET = \{\emptyset\}$.
     - For each triple $(id, adct, sh) \in SHARES$, compute $ad = \text{Dec}(adkey, adct)$. If it fails, discard the voucher. Otherwise, add (id, ad) to $OUTLIST$.
   - Output $IDLIST$ and $OUTSET$.

Server Voucher Processing

3. Let t' denote the number of *unique* shares in *SHARES*, and t' should equal the size of $id(\bar{Y} \cap X)$.
   - If $t' \leq t$, let *OUTSET* be the set of identifiers in *SHARES*.
   - If $t' > t$, do:
     - Use $(t+1)$ shares to reconstruct $adkey \in \mathcal{K}'$.
     - Initialize $OUTSET = \{\emptyset\}$.
     - For each triple $(id, adct, sh) \in SHARES$, compute $ad = \text{Dec}(adkey, adct)$. If it fails, discard the voucher. Otherwise, add (id, ad) to *OUTLIST*.
   - Output *IDLIST* and *OUTSET*.

Server Voucher Processing

3. Let t' denote the number of *unique* shares in *SHARES*, and t' should equal the size of $id(\bar{Y} \cap X)$.
   - If $t' \leq t$, let *OUTSET* be the set of identifiers in *SHARES*.
   - If $t' > t$, do:
     - Use $(t+1)$ shares to reconstruct $adkey \in \mathcal{K}'$.
     - Initialize $OUTSET = \{\emptyset\}$.
     - For each triple $(id, adct, sh) \in SHARES$, compute $ad = \text{Dec}(adkey, adct)$. If it fails, discard the voucher. Otherwise, add (id, ad) to *OUTLIST*.
   - Output *IDLIST* and *OUTSET*.

Server Voucher Processing

3. Let t' denote the number of *unique* shares in *SHARES*, and t' should equal the size of $id(\bar{Y} \cap X)$.
   - If $t' \leq t$, let *OUTSET* be the set of identifiers in *SHARES*.
   - If $t' > t$, do:
     - Use $(t+1)$ shares to reconstruct $adkey \in \mathcal{K}'$.
     - Initialize $OUTSET = \{\emptyset\}$.
     - For each triple $(id, adct, sh) \in SHARES$, compute $ad = \text{Dec}(adkey, adct)$. If it fails, discard the voucher. Otherwise, add (id, ad) to *OUTLIST*.
   - Output *IDLIST* and *OUTSET*.

(Brief) Discussion

- Protocol is correct if the client and server adhere to the protocol (proof omitted for obvious reasons).
- Using "simpler" constructions guarantees the same level of security as the original protocol (potentially for the price of degraded performance).
- Construction naturally extends to ftPSI-AD, requires novel primitives.
  - Detectable hash functions, hashing to elliptic curves, etc.

(Brief) Discussion

- Protocol is correct if the client and server adhere to the protocol (proof omitted for obvious reasons).
- Using "simpler" constructions guarantees the same level of security as the original protocol (potentially for the price of degraded performance).
- Construction naturally extends to ftPSI-AD, requires novel primitives.
  - Detectable hash functions, hashing to elliptic curves, etc.

(Brief) Discussion

- Protocol is correct if the client and server adhere to the protocol (proof omitted for obvious reasons).
- Using "simpler" constructions guarantees the same level of security as the original protocol (potentially for the price of degraded performance).
- Construction naturally extends to ftPSI-AD, requires novel primitives.
  - Detectable hash functions, hashing to elliptic curves, etc.

(Brief) Discussion

- Protocol is correct if the client and server adhere to the protocol (proof omitted for obvious reasons).
- Using "simpler" constructions guarantees the same level of security as the original protocol (potentially for the price of degraded performance).
- Construction naturally extends to ftPSI-AD, requires novel primitives.
  - Detectable hash functions, hashing to elliptic curves, etc.

Conclusions

Conclusions

- Presented Apple's PSI system for CSAM detection.
- The protocol is cryptographically sound, and meets the security goals specified earlier.

Conclusions

- Presented Apple's PSI system for CSAM detection.
- The protocol is cryptographically sound, and meets the security goals specified earlier.

Conclusions

- So why is something like this still bad?
- What are the implications of this system?

Conclusions

- So why is something like this still bad?
- What are the implications of this system?

References

Athalye, A. (2021).

NeuralHash Collider.

https://github.com/anishathalye/neural-hash-collider.

original-date: 2021-08-19T00:06:20Z.

Bhowmick, A., Boneh, D., Myers, S., and Tarbe, K. T. K. (2021).

The Apple PSI System.

https://www.apple.com/child-safety/pdf/Apple_PSI_System_Security_Protocol_and_Analysis.pdf.

Struppek, L., Hintersdorf, D., Neider, D., and Kersting, K. (2021).

Learning to break deep perceptual hashing: The use case neuralhash.

arXiv preprint arXiv:2111.06628.

Thank you!

Questions?