SHE based Non Interactive Privacy Preserving Biometric Authentication Protocols

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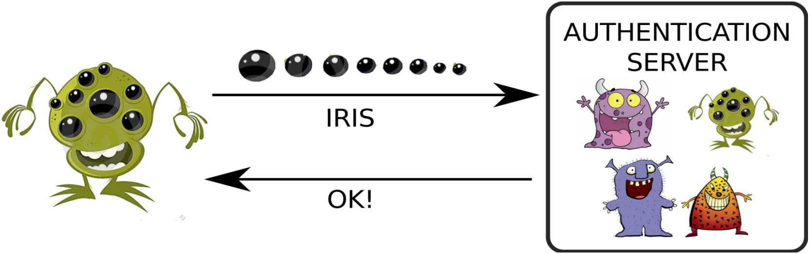
Motivation

Biometric signals often used in access control systems.



Privacy Preserving Protocols

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Examples: a database and a client, cloud computing.

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Interactive protocols.

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Our Solution: **Somewhat Homomorphic Encryption**. Non interactive protocol.

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* Classic homomorphic encryption (HE), are only additively or multiplicatively homomorphic.
* The schemes homomorphic for both addition and multiplication, are called:

Somewhat Homomorphic (SHE): it can perform a limited number of operations.

Fully Homomorphic (FHE): it can perform a virtually infinite number of operations.

The first FHE scheme was proposed by Gentry in 2009. From his intuition many others schemes followed.

Pisa et al. Cryptosystem

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* Given an integer base $b = 2^k$ ($k > 0$), a secret odd integer p, and two random integers r, q, a message m can be encrypted as:

$$c = [\![m]\!] = m + br + p \cdot q$$

* To decrypt:

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* We extend Pisa et al. scheme to encrypt negative integers.

Negative Numbers

Given the base $b = 2^k \Rightarrow$ we can encrypt number in the interval $(-b/2, b/2]$. The decryption function is performed as:

$$([c]_p \mod b)$$

The result is:

positive if $\left[[c]_p\right]_b < b/2$

negative if $\left[[c]_p\right]_b > b/2 \Rightarrow \left[[c]_p\right]_b - b$

In this case the base should be twice the maximum integer that needs to be computed.

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* After every operation the noise increases. Until $|m + br| < \frac{p}{2}$ the message can be recovered easily.
* Multiplication: The noise increases as $\mathcal{O}((br)^2)$, after few multiplications decryption becomes impossible.

Cryptosystem - Implementation

* The number of possible operations depends on the base and on a security parameter λ.
* Public key size grows with both λ and base b.
* For $\lambda = 20$, public key is too big (about 11GB for $b = 2^{50}$) to be used in practice.
* Multiplication is an expensive time-consuming operation.

Application of the Cryptosystem: Authentication Protocol

We assume client has already provided the public key and an encrypted feature vector $(s_1 \ldots s_n)$ in a registration phase.

Step 1: The client sends a probe $(q_1 \ldots q_n)$ to the server.

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Step 3: The client decrypts the received result by using the secret key and checks if it is positive or negative.

Server Computation: Distances

Hamming. Usual: $HD(\mathbf{q},\mathbf{s}) = \|(\mathbf{q} \otimes \mathbf{s})\|$.
With Integers: $HD(\mathbf{q},\mathbf{s}) = \sum_{i=0}^{n} s_i + q_i(1-2s_i)$.
Encrypted:
$[\![HD(q,s)]\!] = \sum_{i=0}^{n} \left([\![s_i]\!] + [\![q_i]\!] \cdot [\![1-2s_i]\!]\right)$.

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Euclidean. Usual: $ED(\mathbf{q}, \mathbf{s}) = \left\|(\mathbf{q} - \mathbf{s})^2\right\|$
Encrypted: $[\![ED(q, s)]\!] = \sum_{i=0}^{n} \left([\![q_i]\!] + [\![-s_i]\!]\right)^2$.

Server Computation: Thresholding

The distance $D(\mathbf{q}, \mathbf{s})$ is compared with the threshold ϵ, by computing the difference between the distance and the threshold under encryption, i.e.

$$D(\mathbf{q}, \mathbf{s}) < \epsilon$$

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$$[\![d]\!] = [\![D(\mathbf{q}, \mathbf{s}) - \epsilon]\!] = [\![D(\mathbf{q}, \mathbf{s})]\!] + [\![-\epsilon]\!]$$

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* Additive blinding cannot be used because it could change the sign of $[\![d]\!]$.
* Multiplicative blinding is much less secure.
* We adopt a hybrid multiplicative/additive blinding:

$$[\![k_1(D(\mathbf{q},\mathbf{s})-\epsilon)+k_2]\!] = [\![k_1]\!][\![D(\mathbf{q},\mathbf{s})-\epsilon]\!]+[\![k_2]\!]$$

where k_1, k_2 are randomly chosen in a way to preserve the sign.

First Example: Iriscode Protocol

* Find pupil center and iris boundaries.
* Each iris local region is demodulated to extract its phase information using 2-D Gabor filters.
* The resulting complex coefficients are used to set two bits for the iriscode vector.
* The process is repeated along all the iris with many filters configurations: sizes, orientations and frequencies.

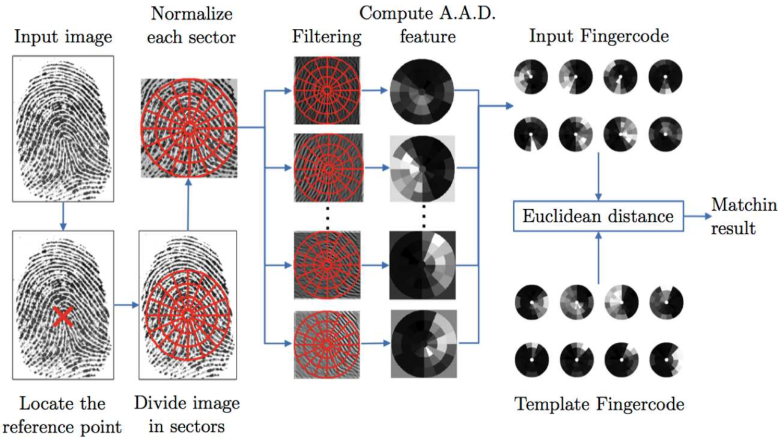
First Example: Iriscode Protocol

* An iris image can be encoded as a 2048 bit vector called iriscode.
* Maximum Hamming distance can be represented by 11 bits.

λ	Base	Step 1 Client Enc.	Step 2 Server Comp.	Step 3 Client Dec.
10	2^{50}	1.2 s	2.0 s	0.2 ms
	2^{100}	1.2 s	5.3 s	4.3 ms
	2^{150}	1.8 s	9.7 s	5.6 ms
15	2^{50}	29s	14 min 33 s	0.2 s

Table: Iriscode protocol's average execution time

Second Example: Fingercode Protocol



Second Example: Fingercode Protocol

* A fingerprint can be represented by a vector of 96 features of 2 bits each, called fingercode.
* The maximum distance value can be represented with 10 bits.

λ	Base	Step 1 Client Enc.	Step 2 Server Comp.	Step 3 Client Dec.
10	2^{50}	0.03 s	0.10 s	1 ms
	2^{100}	0.06 s	0.30 s	3 ms
	2^{150}	0.09 s	0.53 s	5 ms
15	2^{50}	1.37 s	37 s	0.18 s
	2^{100}	2.80 s	1min 48 s	0.45 s
	2^{150}	4.25 s	3 min 17 s	0.79 s

Table: Fingerprint protocol's average execution time

Communication Complexity

	λ	Base		
		2^{50}	2^{100}	2^{150}
Iris	10	13 MB	25 MB	38 MB
	15	750 MB	1.4GB	2 GB
Finger	10	606 KB	1.2 MB	1.7 MB
	15	34 MB	68 MB	102 MB

Table: Iriscode and fingercode communication complexity.

* Iriscode protocol has higher computational complexity than fingercode protocol.
* During computation, three vectors should be memorize at the same time. That needs about 6 GB in base 2^{150}.

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* We presented a new solution for privacy preserving biometric authentication protocols: SHE.
* Novelties: SHE for negatives numbers; blinding.
* The runtimes needed by the SHE implementation are by far larger than the execution time of protocols based on Paillier HE or GC (about 1s - interactive protocols).
* In our protocol all the computation is completely moved onto the server side and no interaction is needed.
* Runtimes can be lowered by using powerful servers allowing for parallelization across more threads.

Thank you for your attention.