Face recognition technology

face identification
(surveillance)
arbitrary conditions

face identification
(login)
controlled conditions

SCiFI – A system for Secure Computation of Face Identification

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Face recognition in surveillance

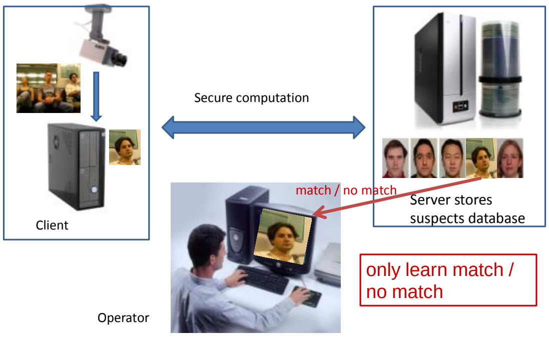
- Privacy problem: the ubiquity of surveillance is a major concern for the public
  - Can be misused to track people regardless of suspicion
  - Can be combined with a universal database linking faces to identities (e.g., drivers' license photos)

We focus on the surveillance problem

surveillance

Example scenario:
- a government has a list of suspects
- wants to identify them in a crowd

Our approach: protecting the privacy of the public and the confidentiality of the data



Secure computation

Client

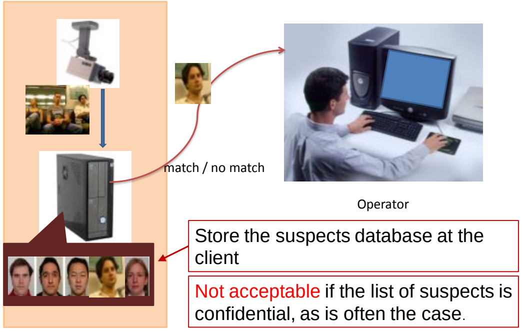
Server stores suspects database

match / no match

Operator

only learn match / no match

A solution to the privacy concern



match / no match

Operator

Store the suspects database at the client

Not acceptable if the list of suspects is confidential, as is often the case.

System architecture

Client		**Server**
		Input: set of images of suspects
Acquires an image		
Generates representation of image		
Runs secure protocol	⟷	Runs secure protocol
Output: match / no-match		Output: match / no-match

Protocol enforces an upper bound on the size of the database used by the server.

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Our Contributions

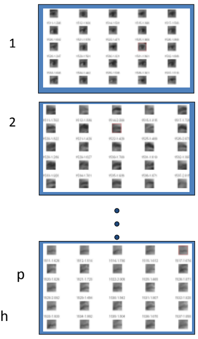
- A new and unique face identification algorithm
  - Specifically designed for secure computation
  - Has state-of-the-art recognition performance
  - Assumes only a *single* image is known per suspect
- A secure protocol for computing face identification
- SCiFI - A system implementing the protocol

- Previous work [EFGKLT09]: secure computation of the well known Eigenfaces face recognition algorithm.
  - Performance of eigenfaces is inferior to state-of-the-art.
  - The secure protocol is less efficient than ours.

The Problem

- Exact / fuzzy match
  - Secure computation of *exact* matches is well known.
  - Face identification is *fuzzy*. A match is between *close*, but *not identical*, images.
- Continuous / discrete math
  - Face recognition algorithms use *continuous* face representations, and complex measures of similarity.
  - Secure computation is always applied to *discrete* numbers. Best with linear operations.
  - Simple quantization of face recognition algorithms results in poor performance.

Gallery / Dictionary

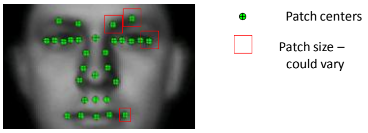


A public database (gallery) of *N* faces

⇒ A dictionary of *N* values for each patch

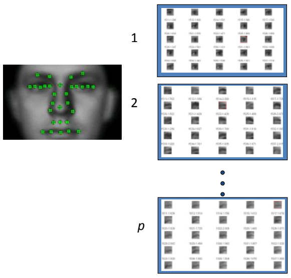
New Face Representation: Patch-Based Face Representation

- A face is represented by a collection of informative patches:



- Assume that the face is represented by *p* patches.

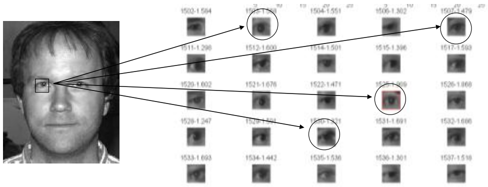
Representing a face



$$V=\begin{array}{r|l} 1 & 5, 8, 9, 14 \\ 2 & 3, 8, 10, 11 \\ 3 & 7, 9, 12, 18 \\ & \vdots \\ p & 4, 6, 10, 12 \end{array}$$

For each of the *p* patches, store indices of the 4 closest patches in the dictionary.

Indexing

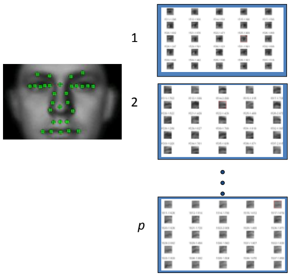


Each patch is represented by the 4 closest patches in the dictionary.

Similarity between faces

- We define the difference between faces as the set difference between their representations $\Delta(A,B) = |A \cup B| - |A \cap B|$
- Set difference ≡ Hamming distance between binary representation of faces
- Secure computation of Hamming distance is easy [JP09]

Representing a face



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Representation: vector with *p* entries, each with 4 values in the range of [1,N]. Alternatively, a binary representation: a binary vector of $p \cdot N$ bits, where *4p* of the bits equal 1.

The protocol in a nutshell
(details and proof in the paper)

- Inputs are vectors $w=w_0,\dots,w_{m-1}$; $w'=w'_0,\dots,w'_{m-1}$.
- Client sends $E(w_0),\dots,E(w_{m-1})$
- Server uses homomorphic properties
  - To compute $E(w_0 \oplus w'_0),\dots,E(w_{m-1} \oplus w'_{m-1})$
  - To sum these values and obtain $E(d_H(w,w')) = E(d)$
- Server chooses random R; sends $E(d+R)$ to client
- Client decrypts $E(d+R)$, reduces the result mod $m+1$.
- Both parties run a 1-out-of-($m+1$) OT, where client learns 1 if Hamming distance < threshold.

Cryptographic Protocol

- Functionality:
  - Client and server each have a binary vector representing a face.
  - Output 1 iff Hamming distance < threshold.
- Tools
  - Additively homomorphic encryption
    - Given E(x), E(y) can compute E(x+y)
  - Oblivious transfer
    - A two-party protocol where receiver can privately obtain one of two inputs of a sender

Online overhead

- A face is represented by a 900 bit vector.
- Overhead after the client captures an image:
  - Client sends 900 bits to server
  - For every image in server's database
    - Server performs 450 homomorphic additions
    - Server sends a single encryption to client
    - Client decrypts the encrypted value
    - Run a *preprocessed* OT: client sends 8 bits to server; server sends 180 bits to client.

Optimizations

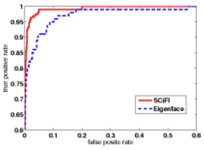
- Main goal: minimize *online* latency, to identify suspects in real time.
- Methods used:
  - Change protocol s.t. oblivious transfer and most communication can be done before image is recorded.
  - Prefer more efficient homomorphic operations *addition << encryption < subtraction*

Implementation

- Face recognition part (generating representations of images)
  - Implemented in Matlab, ran using Matlab Java builder.
- Cryptographic protocol
  - Implemented in Java, using Paillier and ElGamal based OT.
- Timing on Linux servers:
  - ~0.3 sec to compare to a single image in the database
  - An Implementation in C will be much faster
  - Easily parallelizable

Recognition experiments

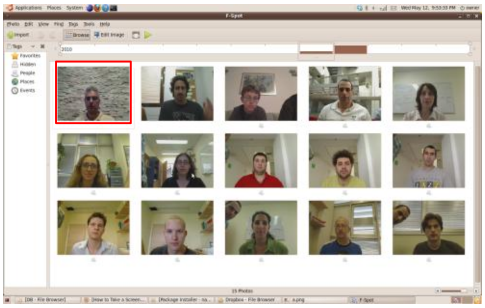
- Ran experiments with *standard databases* used by the face recognition community.
- Tested robustness to illumination changes, small changes in pose, and partial occlusions.



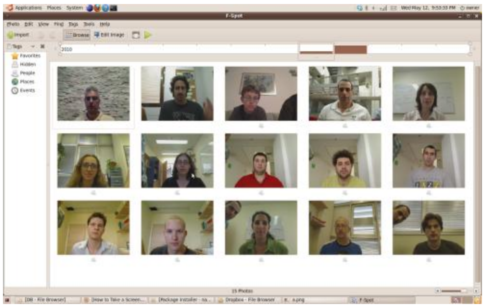
Robustness compared to Eigenfaces

Robustness to partial occlusions

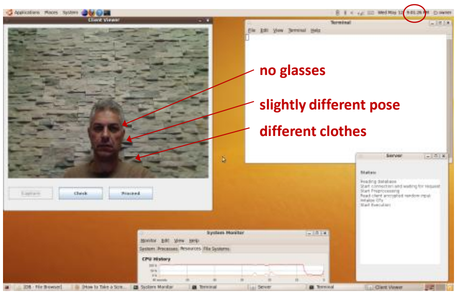
The suspect



The database



An image is obtained by the client



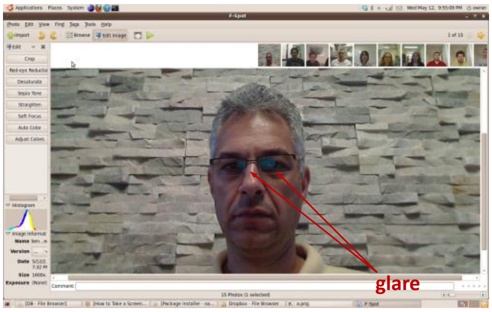
no glasses

slightly different pose

different clothes

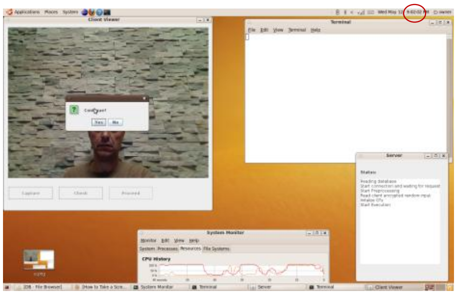
Status:
Reading database
Start connection and waiting for request
Start Preprocessing
Read client encrypted random input
Initialize OTs
Start Execution

The suspect

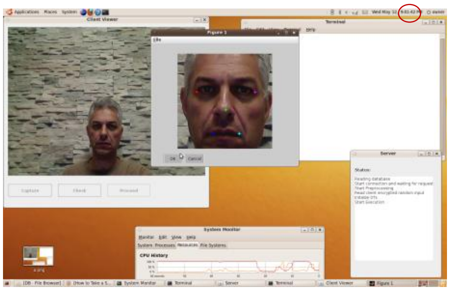


glare

Face representation is ready

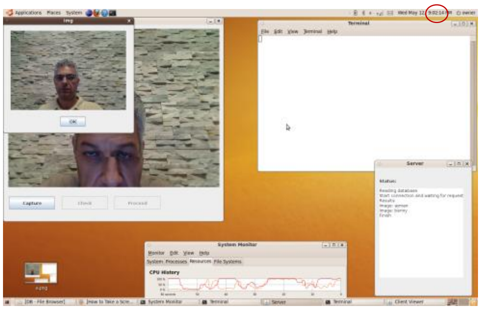


Facial features are recognized

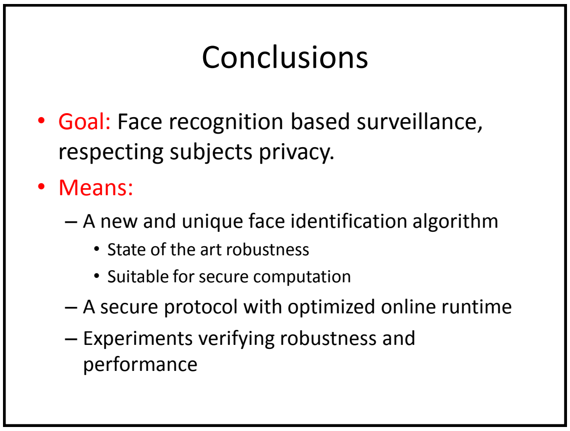


Live demo available upon request

Secure protocol is run, a match is found



Status:
Reading database
Start connection and waiting for request
Results:
Image: simon
Image: benny
Finish



Conclusions

- Goal: Face recognition based surveillance, respecting subjects privacy.
- Means:
  - A new and unique face identification algorithm
    - State of the art robustness
    - Suitable for secure computation
  - A secure protocol with optimized online runtime
  - Experiments verifying robustness and performance