SCiFI – A system for Secure Computation of Face Identification

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Face recognition technology

face identification
(surveillance)
arbitrary conditions

face identification
(login)
controlled conditions

We focus on the surveillance problem

surveillance

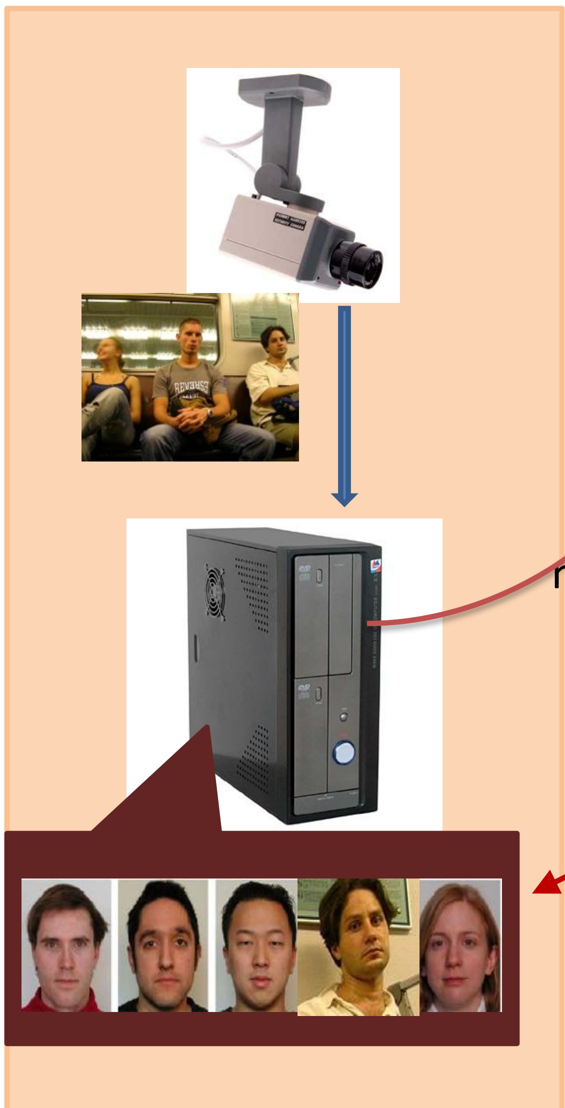
Example scenario:

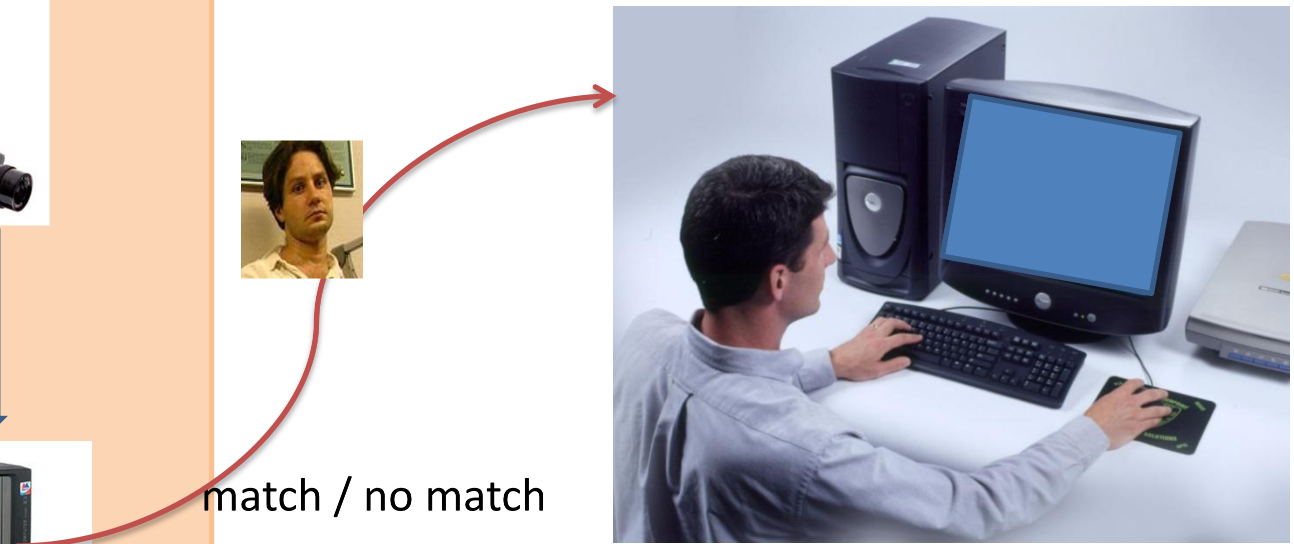
- a government has a list of suspects
- wants to identify them in a crowd

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)

A solution to the privacy concern



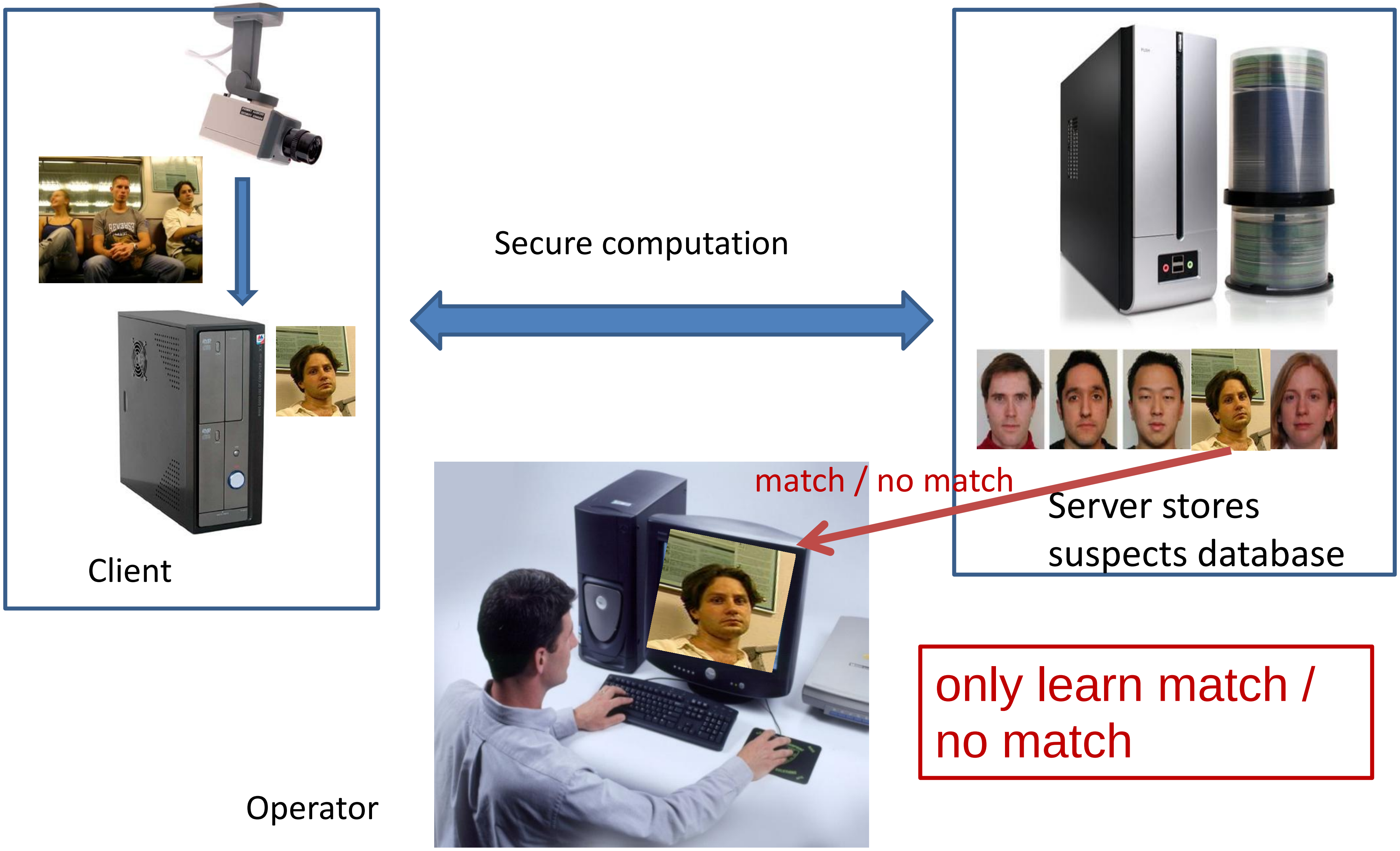


Operator

Store the suspects database at the client

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

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



System architecture

Client

Acquires an image

Generates representation of image

Runs secure protocol

Output: match / no-match

Server

Input: set of images of suspects

Runs secure protocol

Output: match / no-match

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

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.

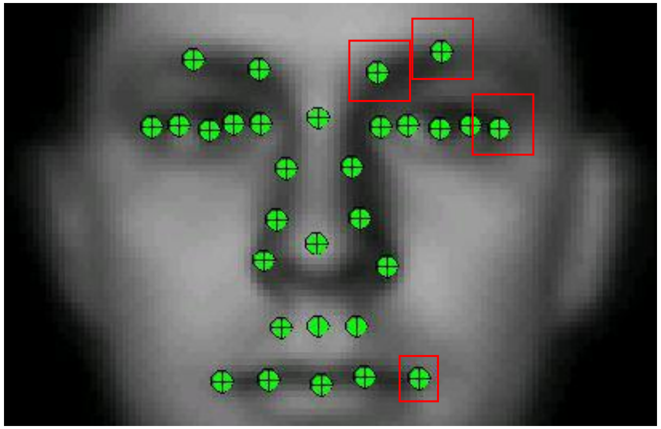
Our Contributions

- 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.

New Face Representation: Patch-Based Face Representation

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



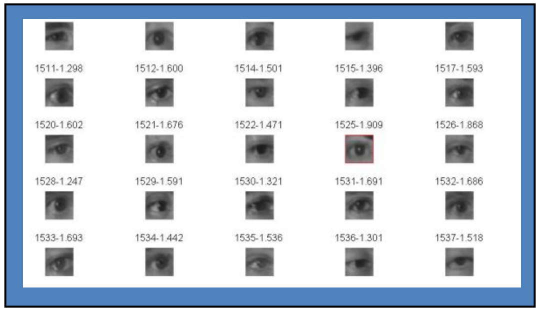
Patch centers

Patch size – could vary

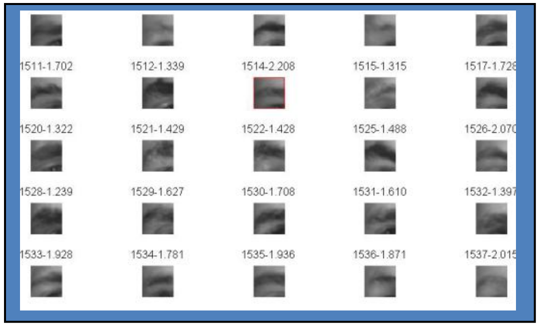
- Assume that the face is represented by *p* patches.

Gallery / Dictionary

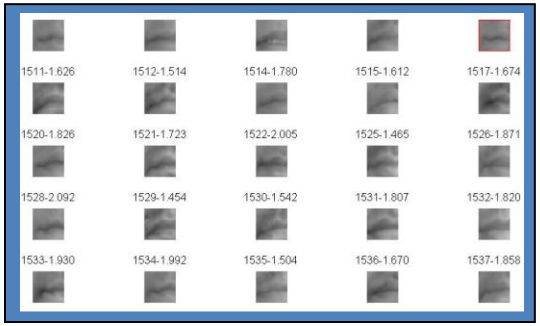
1



2



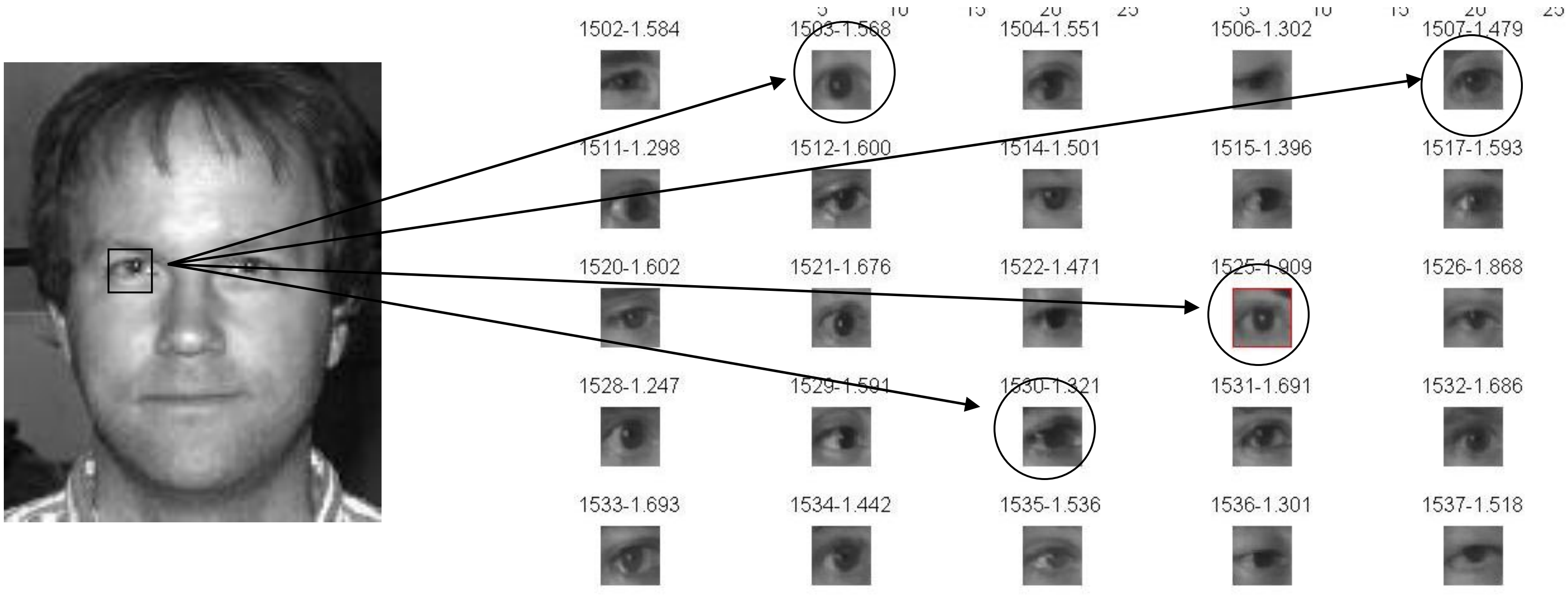
p



A public database (gallery) of *N* faces

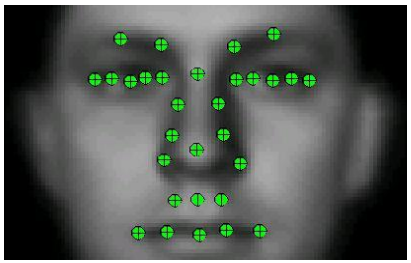
$\Rightarrow$ A dictionary of *N* values for each patch

Indexing

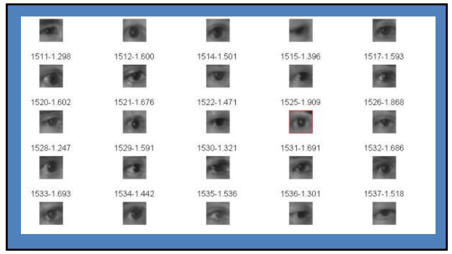


Each patch is represented by the 4 closest patches in the dictionary.

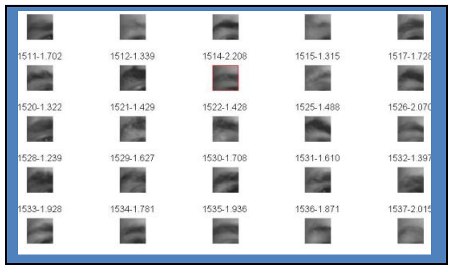
Representing a face



1

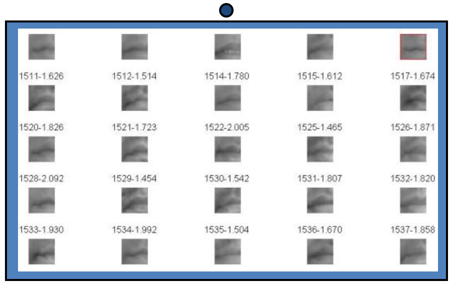


2



⋮

p

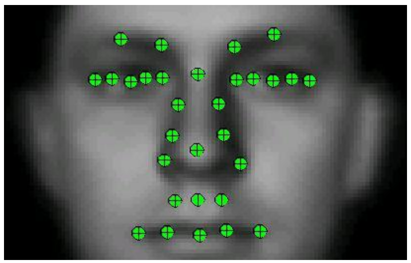


V=

1 | 5, 8, 9, 14
2 | 3, 8, 10, 11
3 | 7, 9, 12, 18
⋮
p | 4, 6, 10, 12

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

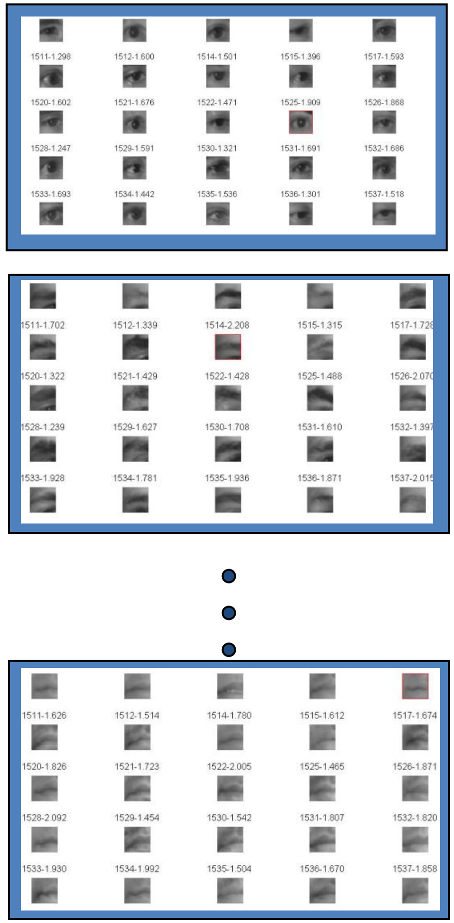
Representing a face



1

2

p



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

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.

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 $\equiv$ Hamming distance between binary representation of faces
- Secure computation of Hamming distance is easy [JP09]

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

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

- Inputs are vectors $w=w_0,\ldots,w_{m-1}$; $w'=w'_0,\ldots,w'_{m-1}$.
- Client sends $E(w_0),\ldots,E(w_{m-1})$
- Server uses homomorphic properties
  - To compute $E(w_0 \oplus w'_0),\ldots,E(w_{m-1} \oplus w'_{m-1})$
  - 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.

Optimizations

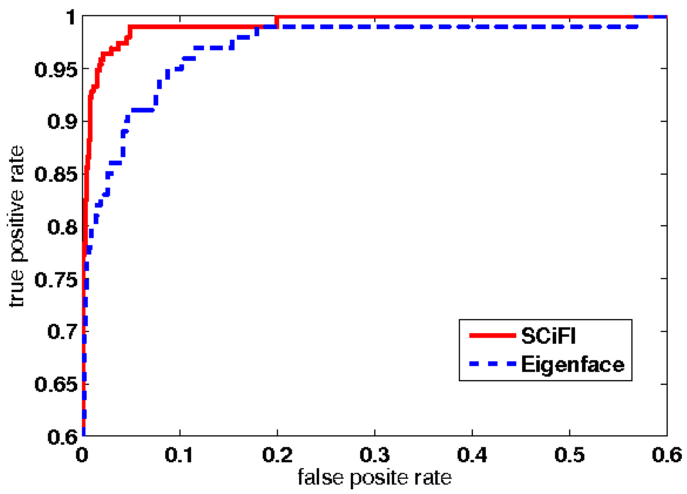
- Main goal: minimize *online* latency, to identify suspects in real time.
- Methods used:
  - Change protocol s.t. oblivious transfer and most communication can be done before image is recorded.
  - Prefer more efficient homomorphic operations
    addition << encryption < subtraction

Online overhead

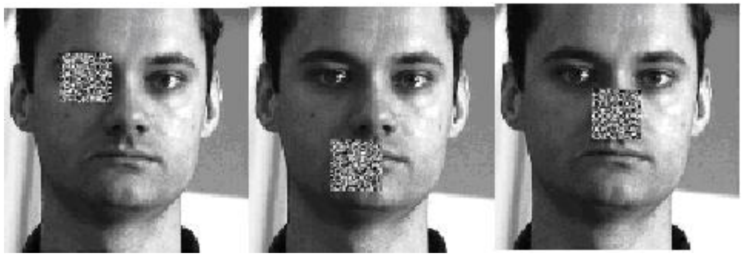
- A face is represented by a 900 bit vector.
- Overhead after the client captures an image:
  – Client sends 900 bits to server
  – For every image in server's database
    - Server performs 450 homomorphic additions
    - Server sends a single encryption to client
    - Client decrypts the encrypted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

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

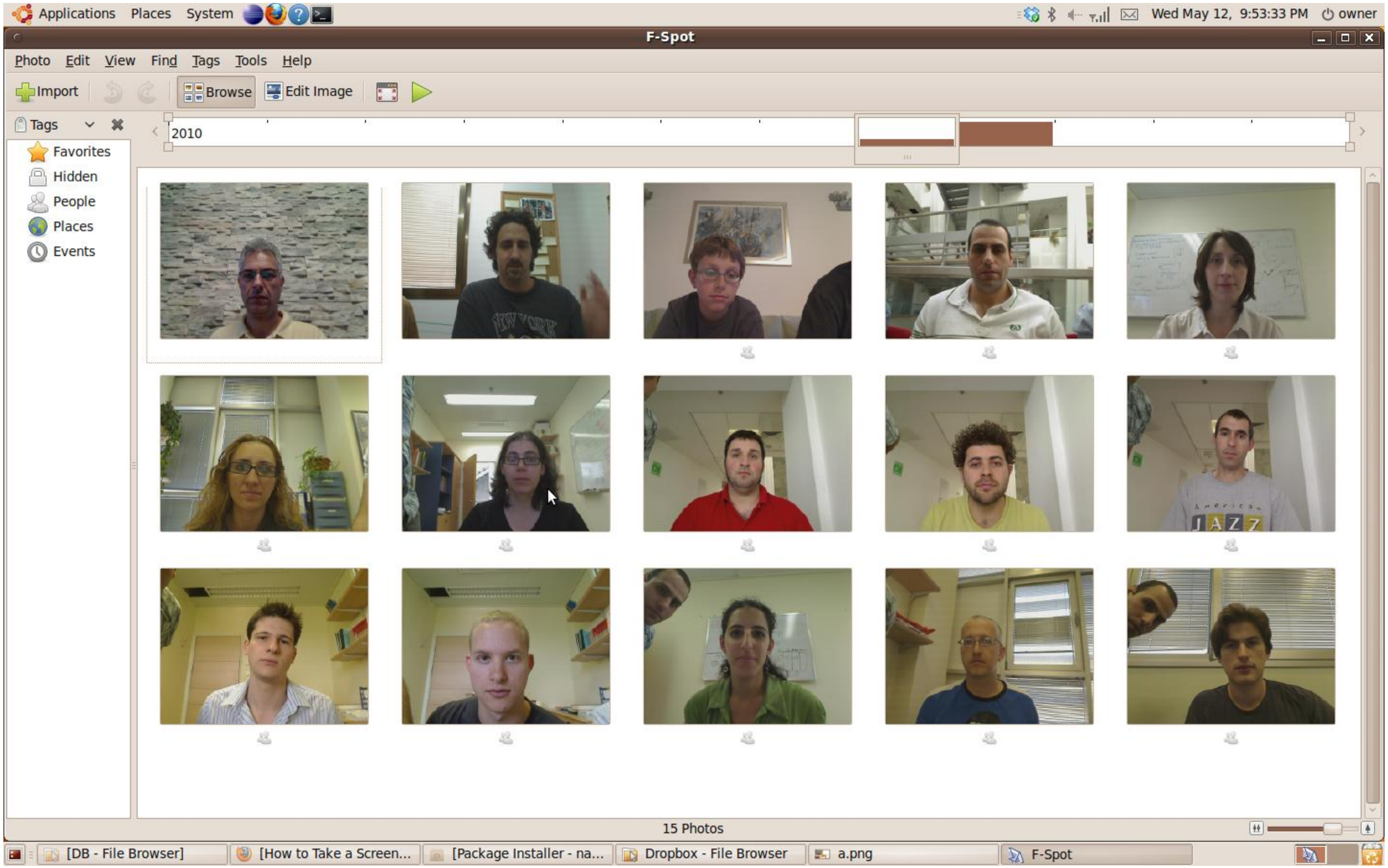


Robustness to partial occlusions

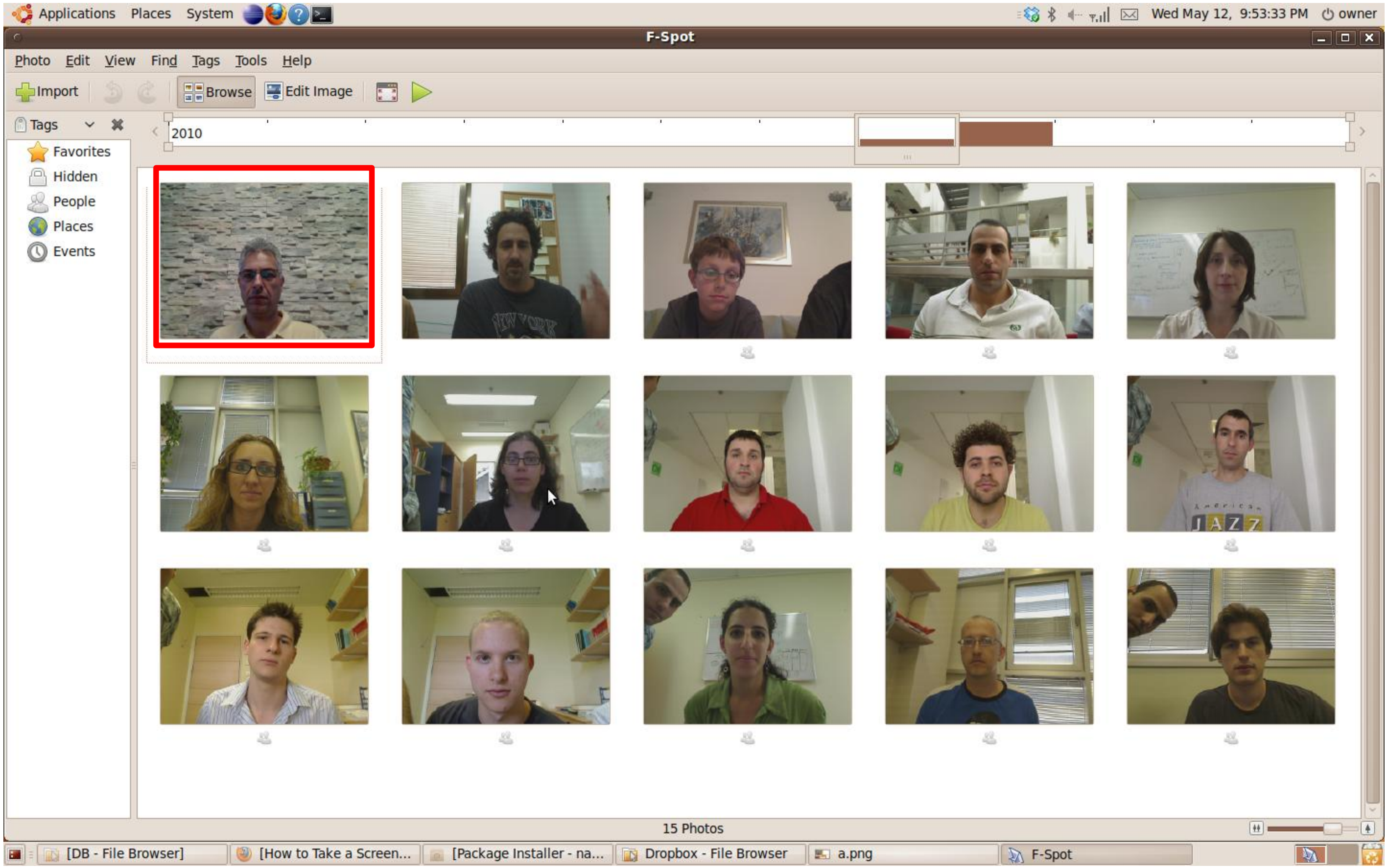
Implementation

- 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

The database



The suspect


Applications Places System
Wed May 12, 9:53:33 PM owner
F-Spot
Photo Edit View Find Tags Tools Help
Import
Browse
Edit Image
Tags
Favorites
Hidden
People
Places
Events
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15 Photos
[DB - File Browser]
[How to Take a Screen...
[Package Installer - na...
Dropbox - File Browser
a.png
F-Spot

The suspect


Applications Places System
Wed May 12, 9:55:09 PM
owner
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Photo Edit View Find Tags Tools Help
Import
Browse
Edit Image
1 of 15
Edit
Crop
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Desaturate
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Straighten
Soft Focus
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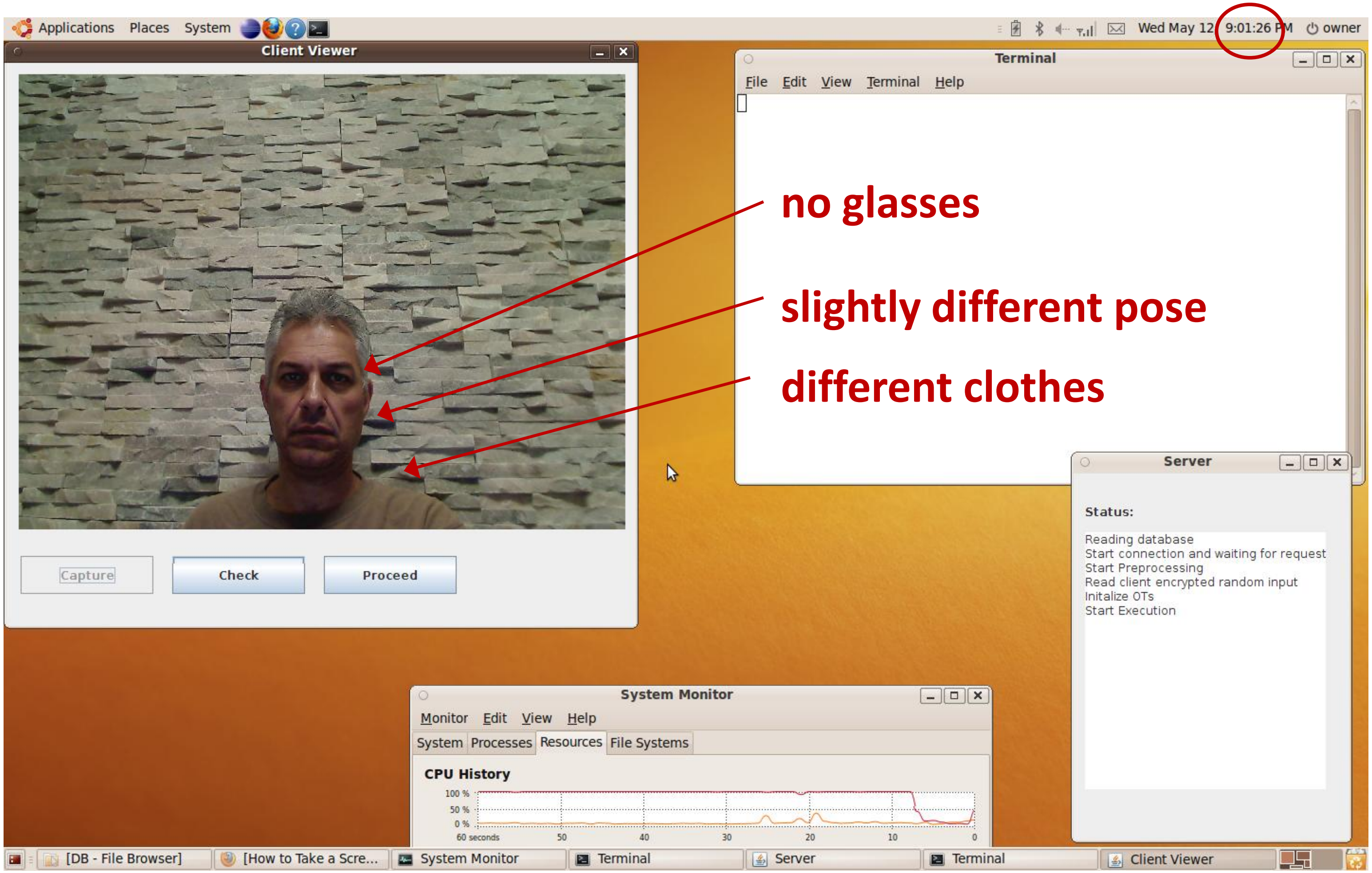
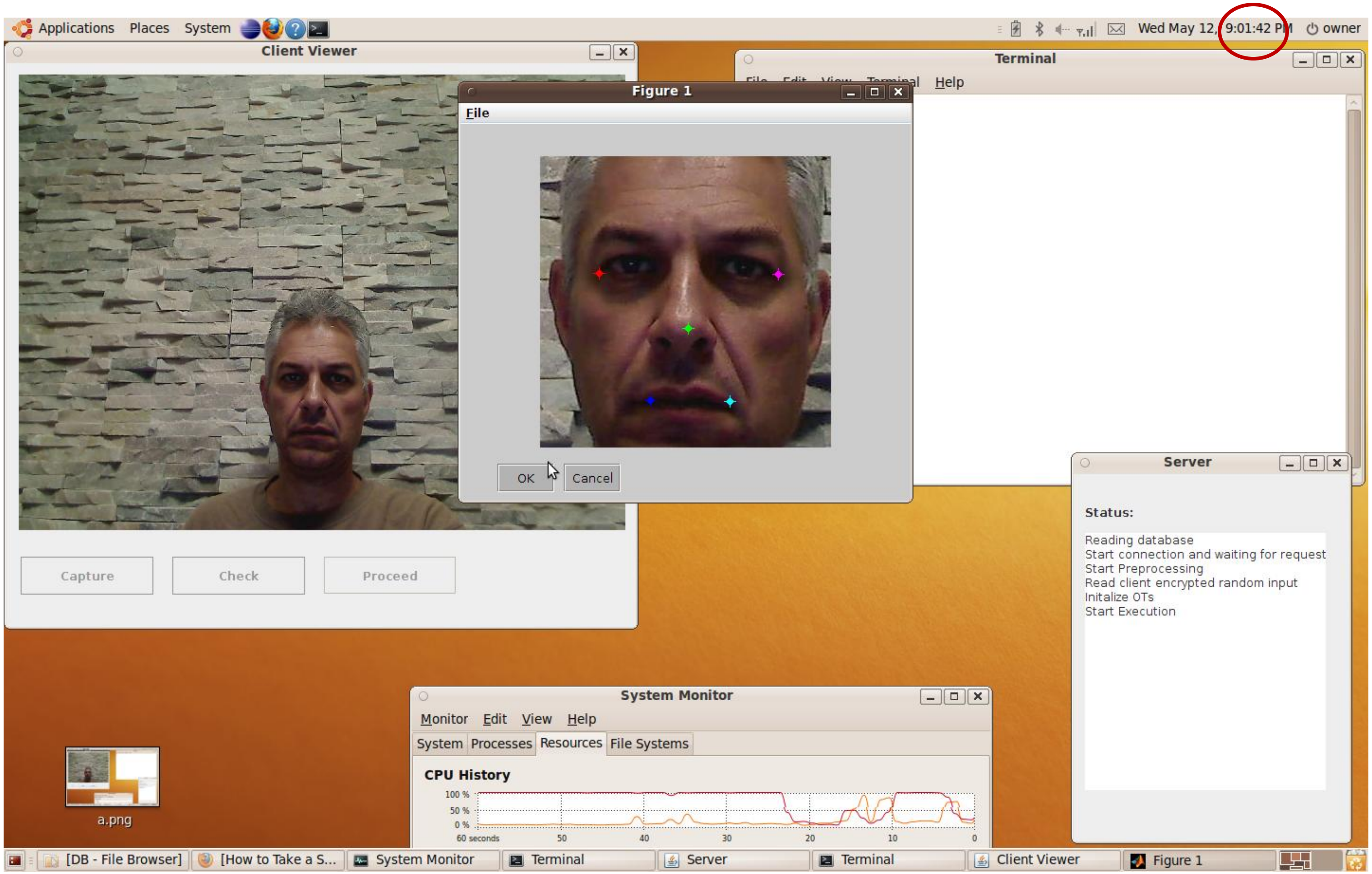
Comment:
15 Photos (1 selected)
[DB - File Browser]
[How to Take a Screen...
[Package Installer - na...
Dropbox - File Browser
a.png
F-Spot
glare

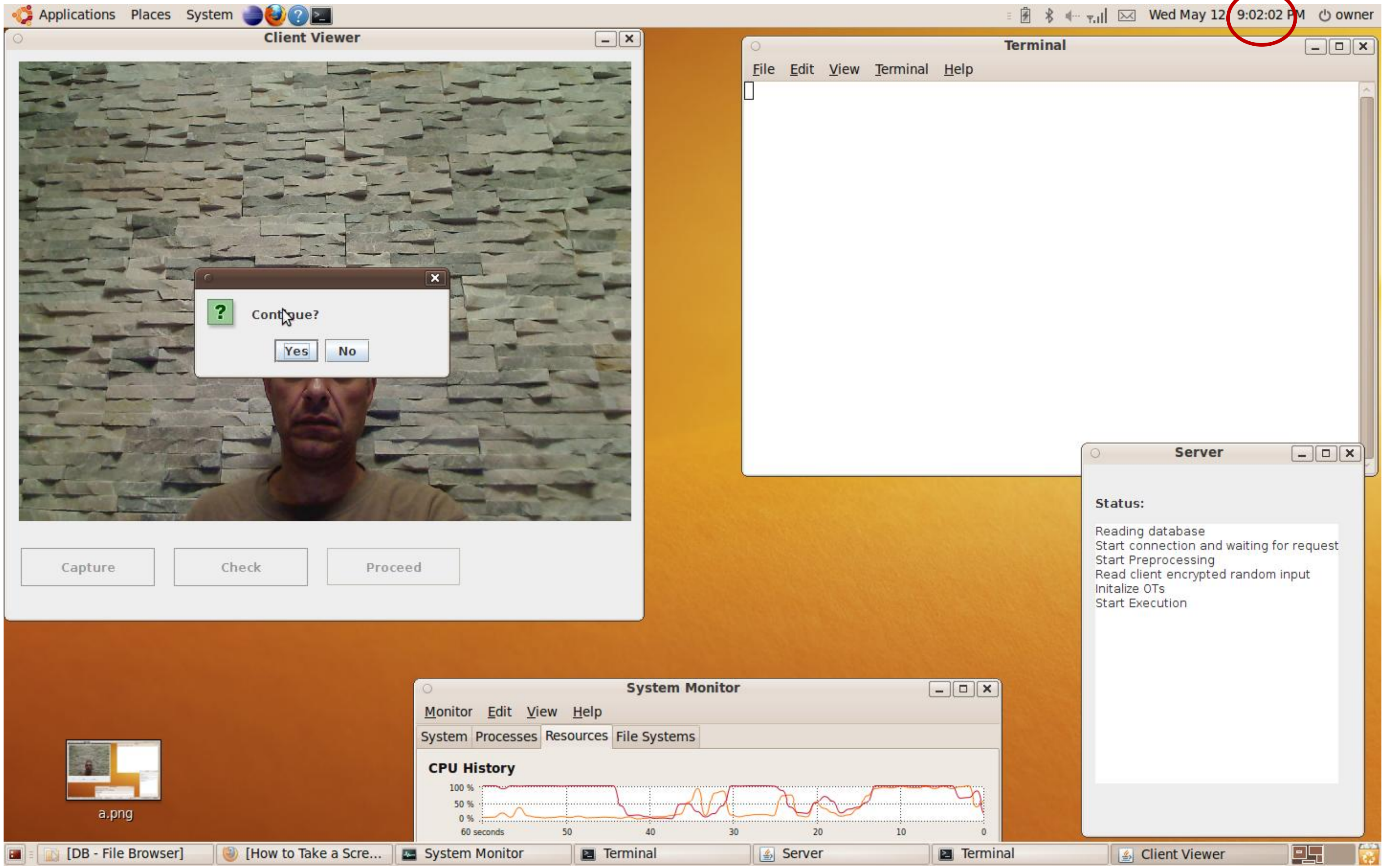
An image is obtained by the client



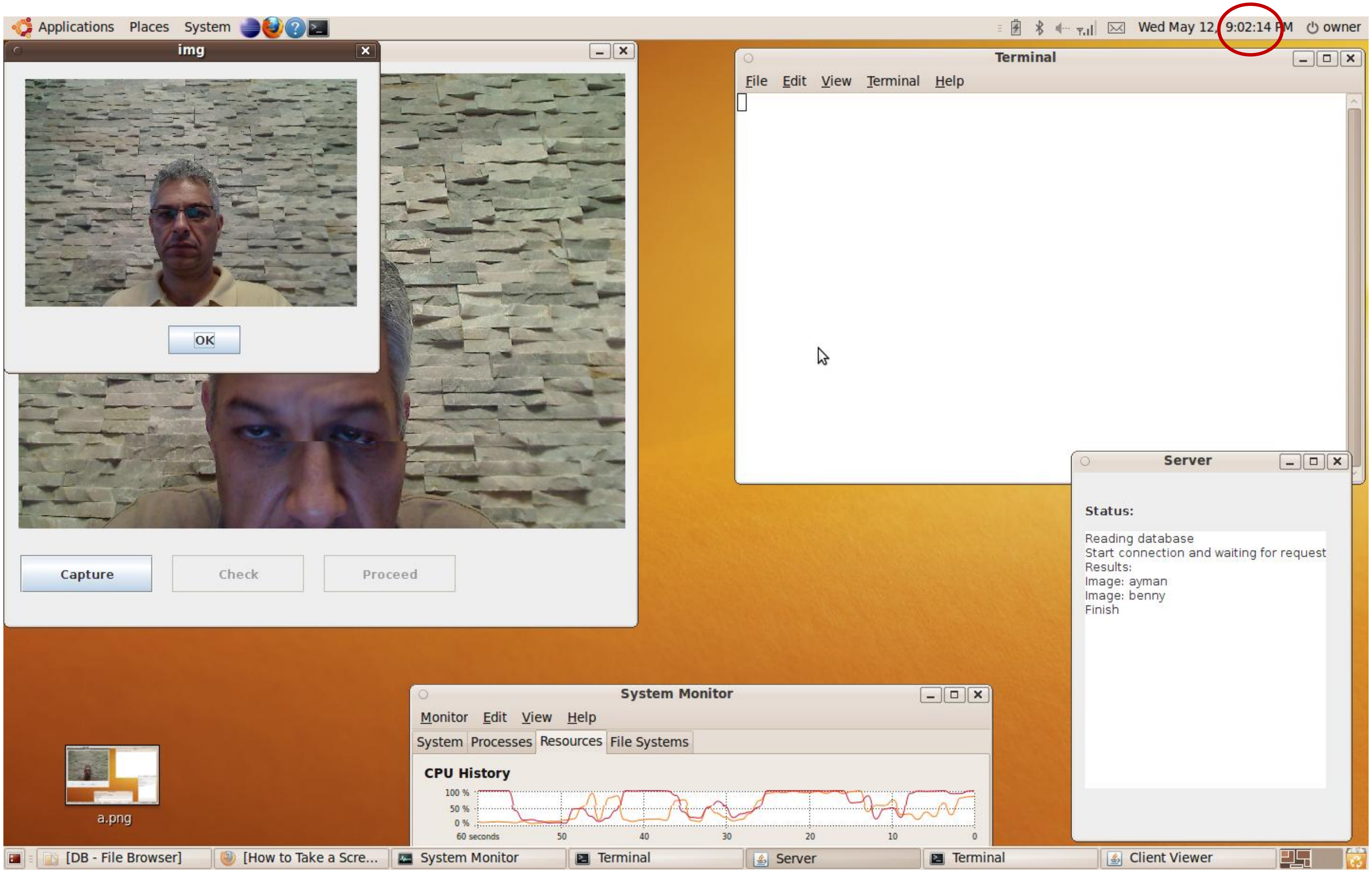
Facial features are recognized



Face representation is ready



Secure protocol is run, a match is found



Live demo available upon request

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