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Biometric Recognition using Advanced Correlation Filters (special focus on Face Recognition)

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Systems Scientist
ECE & CyLab

Research: Biometric Recognition (Face, Iris, Palmprint, Fingerprint)

Teaching:
(Pattern Recognition Theory)-next semester

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Outline

- Biometric verification
- Correlation filters
- Biometric verification examples
  - Face
  - Fingerprint
  - Iris
- Cancelable Biometrics
- Summary

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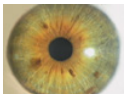
Motivation

- Recognizing the identity of a person can improve security of access to physical and virtual spaces
- Continuous recognition prevents unauthorized access when a legitimate user forgets to log off.
- Most current methods rely on passwords, ID cards that can be easily forgotten or stolen
- Vision: identity recognition based on
  - Biometrics (e.g., Fingerprints, face, voice, iris, etc.)
  - Intelligent fusion of information from multiple biometrics


Face


Fingerprint


Voiceprint


Iris

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Terminology

- Detection
  - Locating all faces in an image
- Verification (1:1 matching)
  - Am I who I say I am?
  - Example Application: Trusted Traveler Card
- Identification (1:N matching)
  - Does this face match to one of those on my watch list?
  - Example Application: Passenger screening at airports
- Recognition = Verification + Identification

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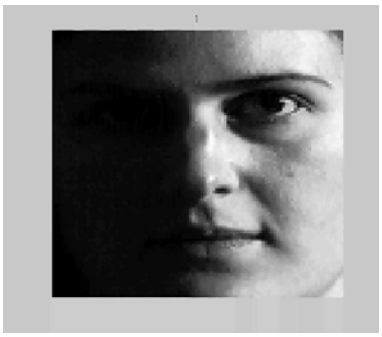
Pattern Variability

- Facial appearance may change due to illumination
- Fingerprint image may change due to plastic deformation



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Face Recognition/verification – challenges

- Expression changes

- Illumination variations

- Pose variations

- For biometric applications we focus more on illumination and facial expression variations.
- We explore advanced correlation filter designs to achieve tolerance to such distortions

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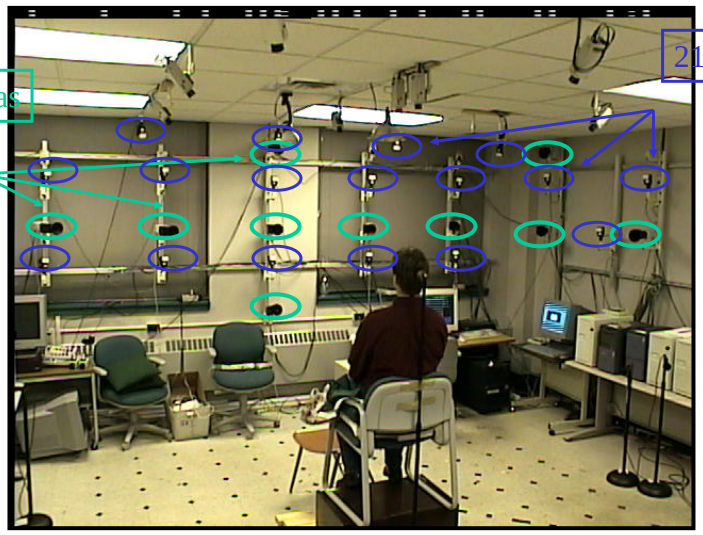
CMU PIE Database



The 3D Room (v. 2.0)

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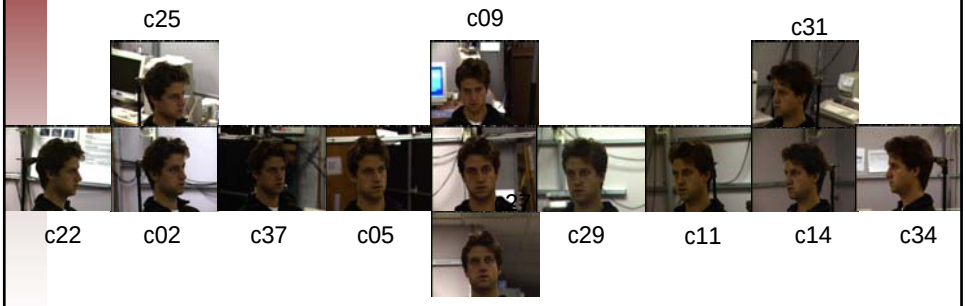
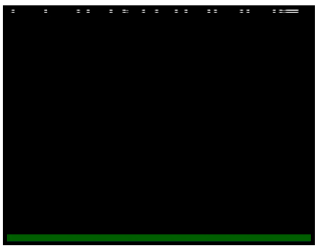
CMU PIE Pose and Illumination Variation





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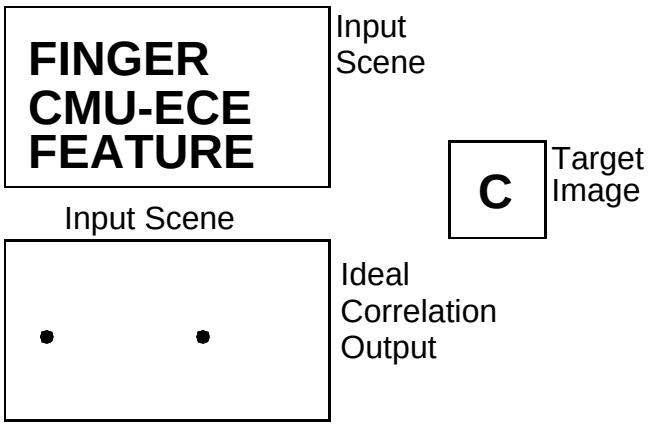
Cross-Correlation Function

$$c(\tau) = \int r(x)\, s(x-\tau)\, dx$$

- Determine the cross-correlation between the reference and test images for all possible shifts
- When the target scene matches the reference image exactly, output is the *autocorrelation* of the reference image.
- If the input r(x) contains a shifted version s(x-x_0) of the reference signal, the correlator will exhibit a peak at x=x_0.
- If the input does not contain the reference signal s(x), the correlator output will be low
- If the input contains multiple replicas of the reference signal, resulting cross-correlation contains multiple peaks at locations corresponding to input positions.

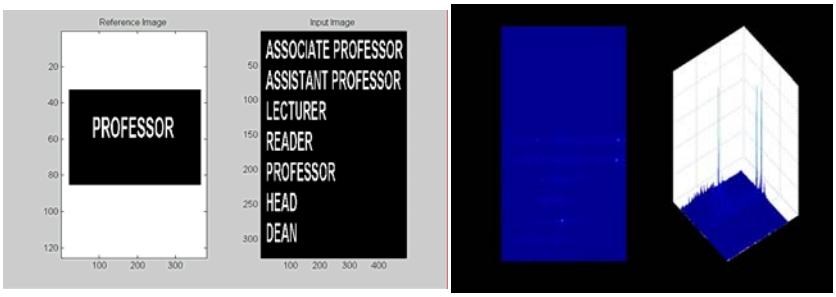
Object Recognition



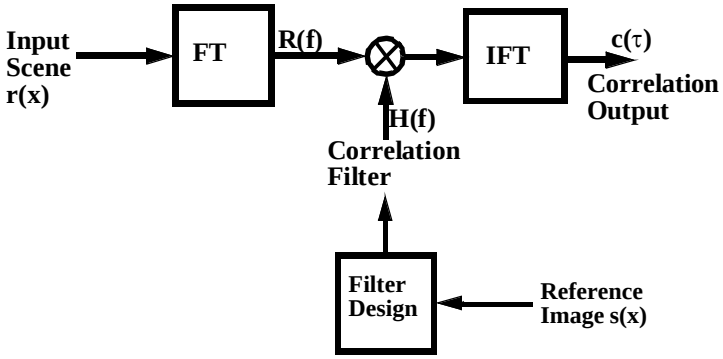
Goal: Locate all occurrences of a target in the input scene

Shift-Invariance

- Desired Pattern can be anywhere in the input scene.
- Multiple patterns can appear in the scene.
- Pattern recognition methods must be shift-invariant.

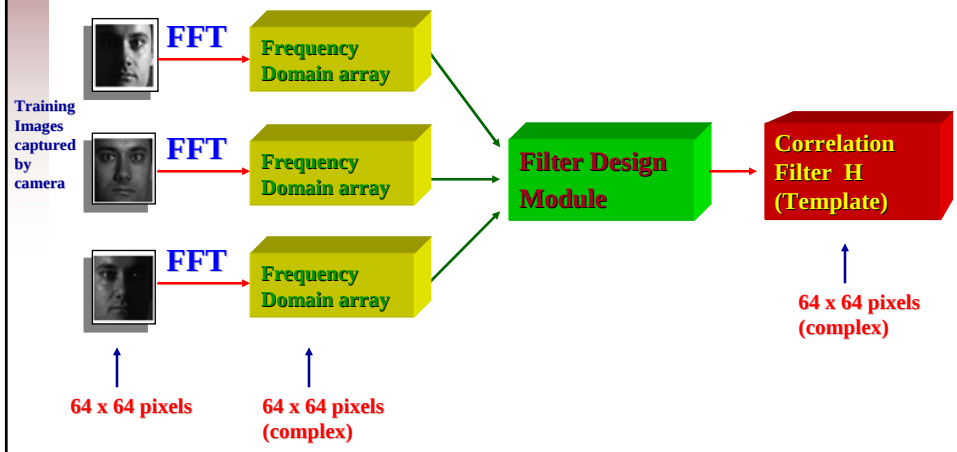


Cross-Correlation Via Fourier Transforms



- Fourier transforms can be done digitally or optically

Enrollment for Face Verification



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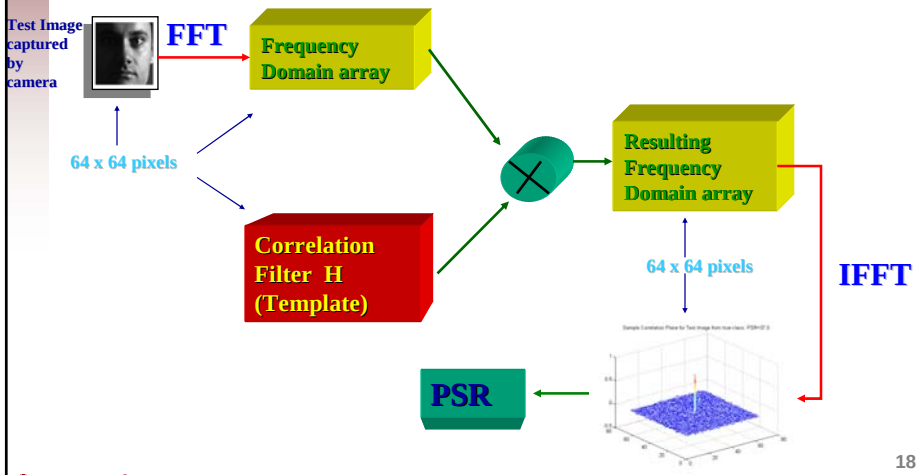
Face Verification



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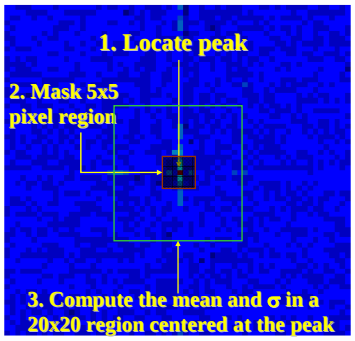
Peak to Side Lobe Ratio metric for Correlation filters



$$PSR = \frac{Peak - mean}{\sigma}$$

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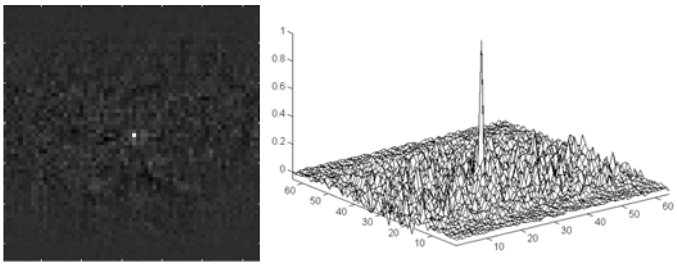
MACE Filter Output



(a) (b)

- MACE filter yields sharp correlation peaks

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Facial Expression Database

- Facial Expression Database (AMP Lab, CMU)
  - 13 People
  - 75 images per person
  - Varying Expressions
  - 64x64 pixels
  - Constant illumination
- 1 filter per person made from 3 training images

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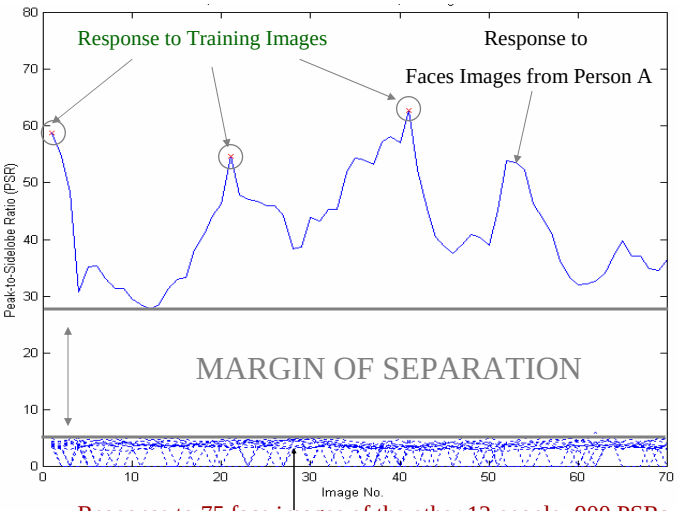
PSRs for the Filter Trained on 3 Images



PSR

Response to 75 face images of the other 12 people=900 PSRs

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49 Faces from PIE Database illustrating the variations in illumination

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Training Image selection

- We used *three* face images to synthesize a correlation filter
- The three selected training images consisted of 3 extreme cases (dark left half face, normal face illumination, dark right half face).

n = 3

n = 7

n = 16

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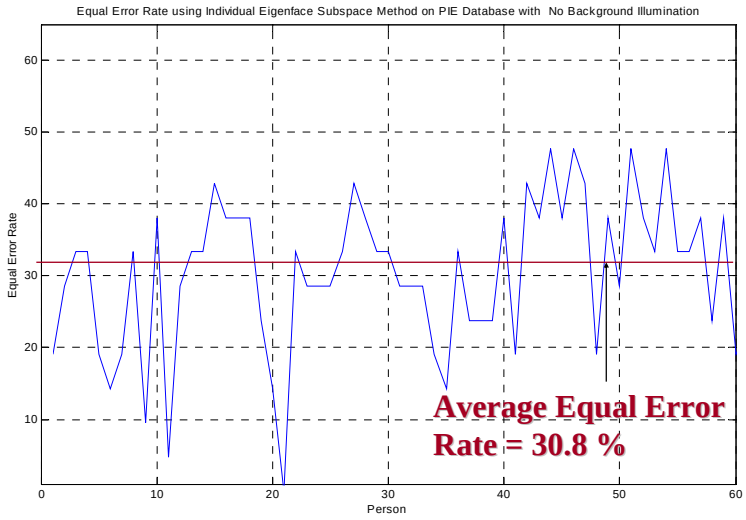
EER using MIT's EIGENFACE algorithm



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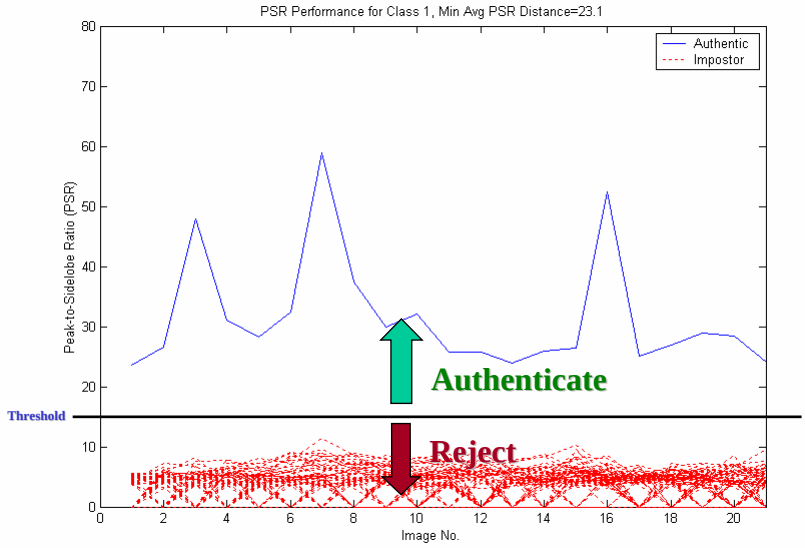
EER using Correlation Filter Approach



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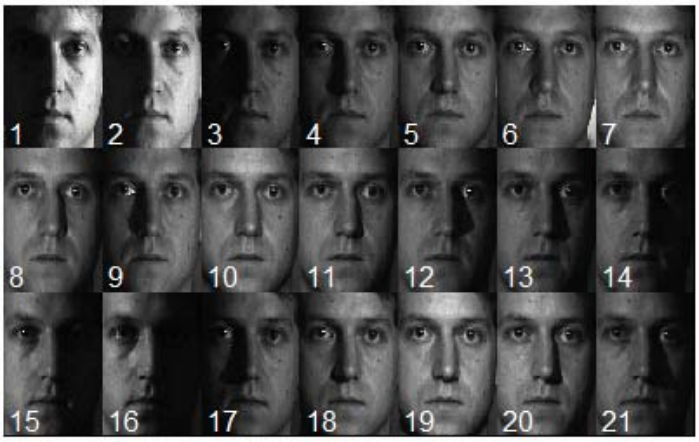
PIE Database Illumination Subset

- No background lighting



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Face Identification – Experiments

- **Use training images (with /without illumination variations to analyze face identification accuracy**
- **Choose images with illuminations variations (i.e.left shadow, frontal lighting, right shadow)**
- **Use frontal lighting images and test on illumination variation (most plausible enrollment scenario).**
- **Use various size length training datasets.**

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Face Identification – Results on PIE dB with *NO* Background lighting (harder dataset).-Train on Frontal Illumination, Test on unknown lighting variation

Training Images (selected for each person)	No. misclassifications	% Accuracy
5,6,7,8,9,10,11,18,19,20	0	100%
5, 6, 7, 8, 9, 10, 11, 12	1	99.9%
5, 6, 7, 8, 9, 10	1	99.9%
5, 7, 9,10	1	99.9%
7,10,19	10	99.1%
6,7,8	2	99.8%
8,9,10	1	99.9%
18,19,20	2	99.9%

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Face Identification – Results on PIE dB with *NO* Background lighting (harder dataset).-Train with some illumination variation, test on all.

Training Images (selected for each person)	No. misclassifications	% Accuracy
3, 7,16	0	100%
1,10,16	0	100%
2, 7, 16	0	100%
4, 7, 13	0	100%
1, 2, 7, 16	0	100%
3, 16	1	99.9%

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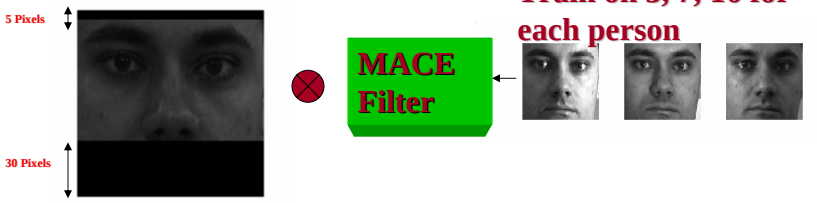
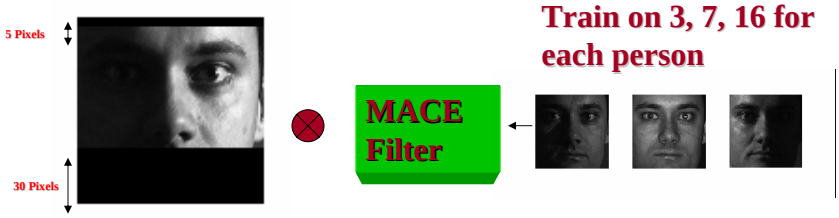
Partial Face Identification-test on cropped DB

Accuracy = 100 %



Accuracy = 99.5 % (7 misses)



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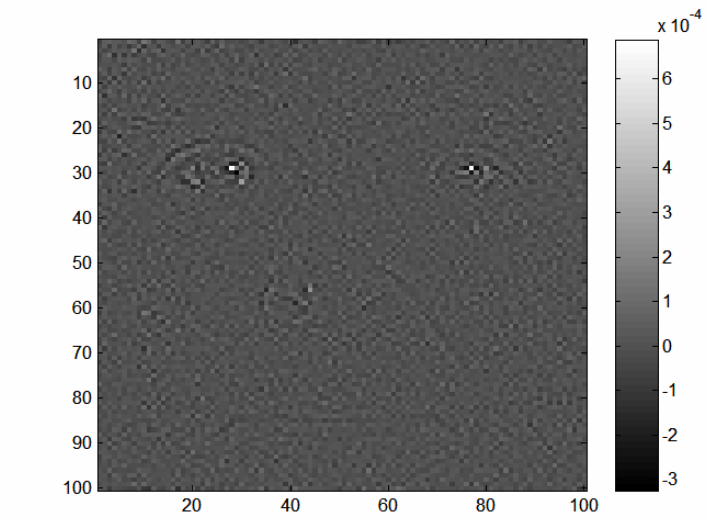
2D Impulse Response of MACE Filter



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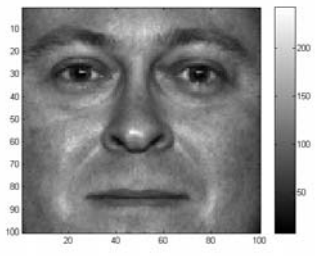
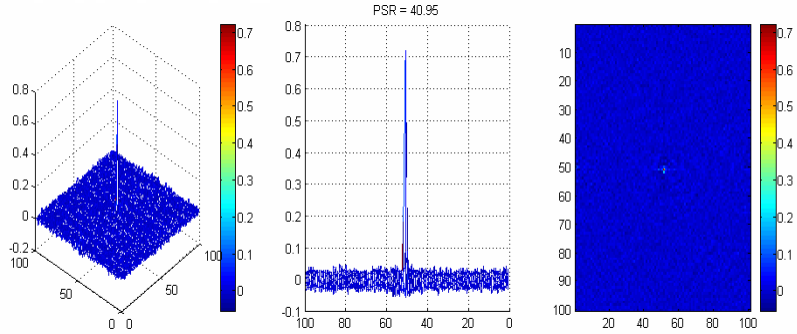


Train on 3, 7, 16, -> Test on 10.



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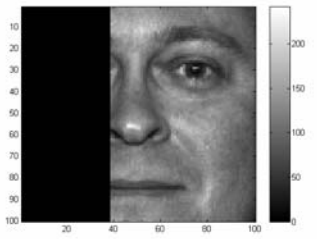
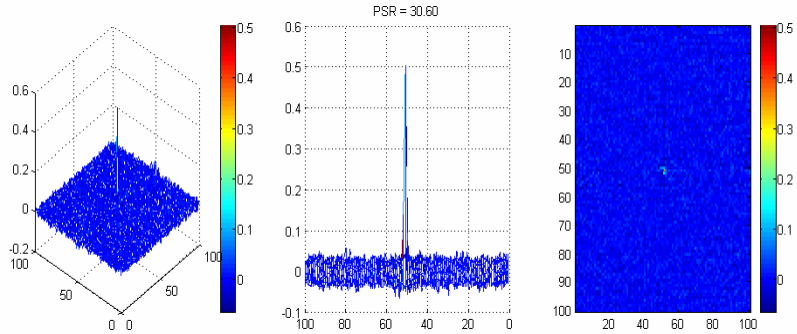


Using same Filter trained before,

Perform cross-correlation on cropped-face shown on left.



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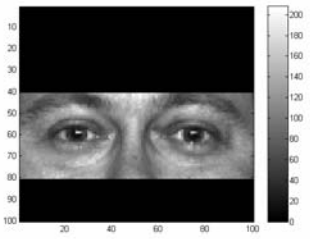
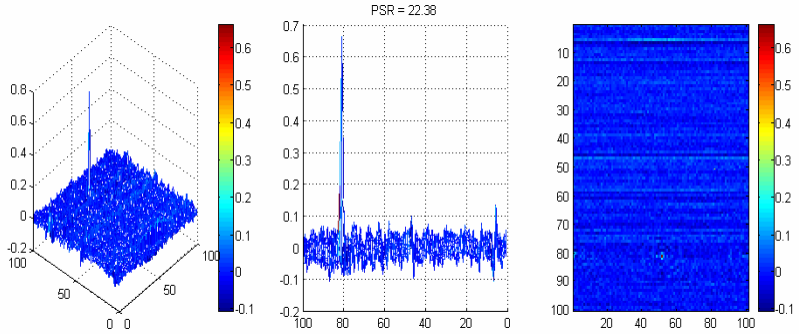
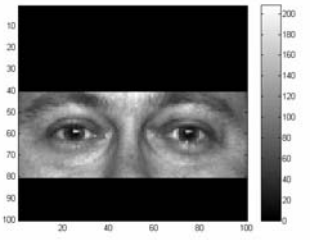
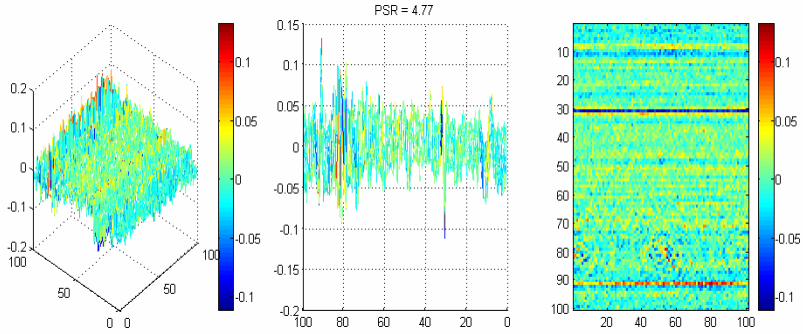


- **CORRELATION FILTERS ARE SHIFT-INVARIANT**
- **Correlation output is shifted down by the same amount of the shifted face image, PSR remains SAME!**





- **Using SOMEONE ELSE'S Filter,…. Perform cross-correlation on cropped-face shown on left.**
- **As expected very low PSR.**



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Features of Correlation Filters

- Shift-invariant; no need for centering the test image
- Graceful degradation
- Can handle multiple appearances of the reference image in the test image
- Closed-form solutions based on well-defined metrics

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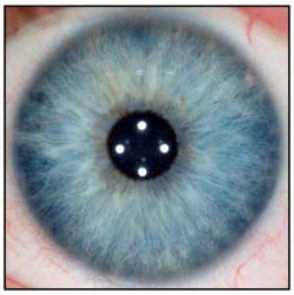
Iris as a Biometric

As a biometric, the iris offers the following advantages:



• It has an intricate biological structure, making it unique.

• It is protected by the cornea, and it is thought to remain stable over a person's lifetime.

• With subject cooperation, its information can be captured externally as an image.

• The left and right irises of an individual can be treated as separate, unique identifiers.

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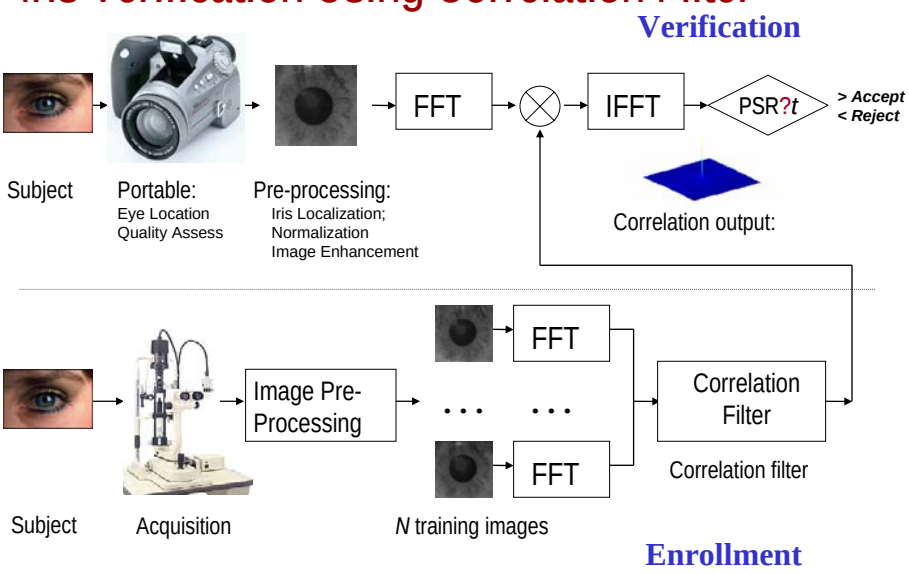
Iris Verification Using Correlation Filter



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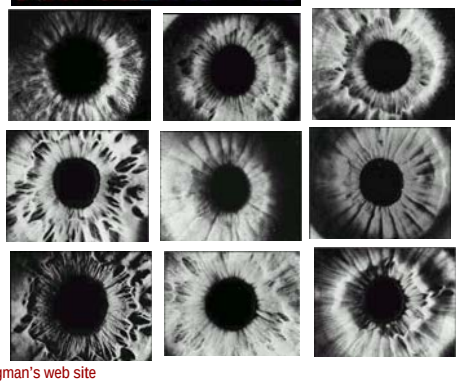
Iris Verification

- High-quality iris images yield low error rates
- Challenge is to acquire high-quality iris images
- Correlation filters yield zero verification errors with the 9 iris images

Source: National Geographic Magazine



Source: Dr. J. Daugman's web site

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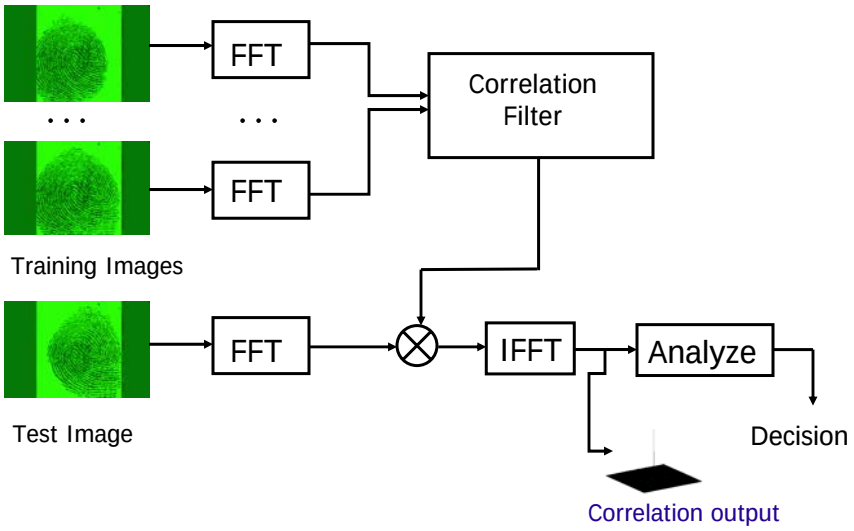
Variability in Fingerprints

- Fingerprint ridges get displaced
- Lots of variability
- Error rates of 1% to 2%

Class 3
Less variation

Class 10
Lot of variation

Fingerprint Recognition



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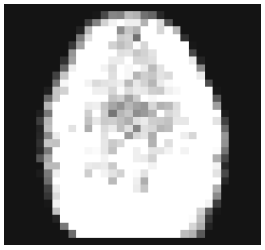
Do We Need 512x512 Images?

Original (512x512)

(256 x 256)

(128 x 128)

(64 x 64)



(32 x 32)

Fewer pixels means
- **Less storage**
- **Less computation**
- **Less Transmission**

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Error Rates using Correlation Filters

Image Resolution	Equal Error Rate
512x512	2%
256x256	1.3%
128x128	1.5%
64x64	5%
32x32	7%

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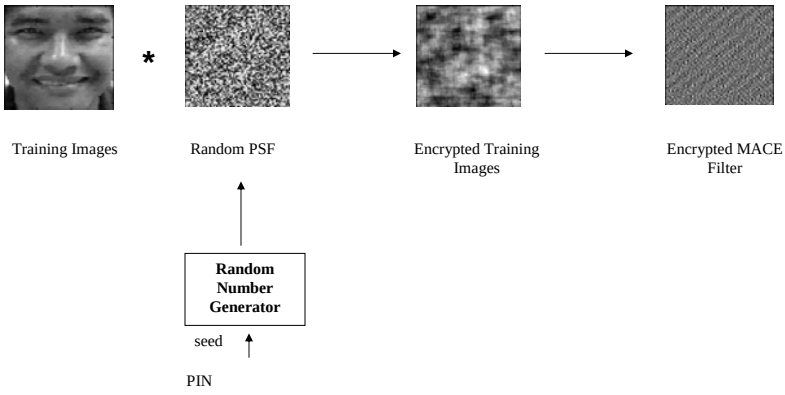
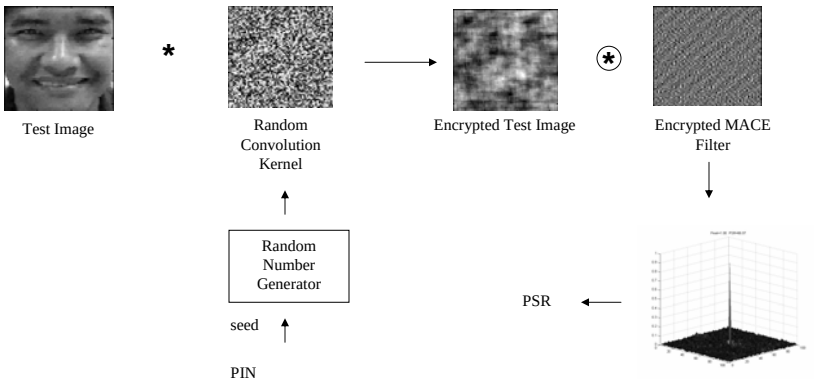
Cancellable Biometric Filters

- A biometric filter (stored on a card) can be lost or stolen
  - Can we re-issue a different one (just as we re-issue a different credit card)?
  - There are only a limited set of biometric images per person (e.g., only one face)
  - We have figure out a way to encrypt them and 'work' or authenticate in the encrypted domain and NOT directly in the original biometric domain.

Enrollment Stage



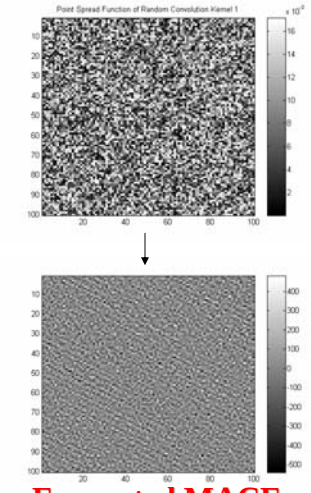
Authentication Stage



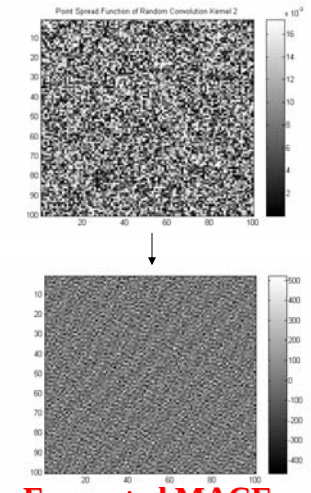
What about performance?

- We can show theoretically that performing this convolution pre-processing step does not affect resulting Peak-to-Sidelobe ratios.
- Thus, working in this encrypted domain does not change the verification performance

Random Convolution Kernel 1



Random Convolution Kernel 2

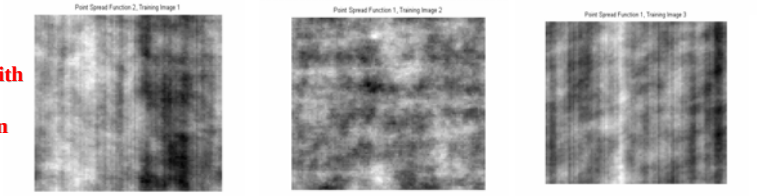


Encrypted MACE Filter 1

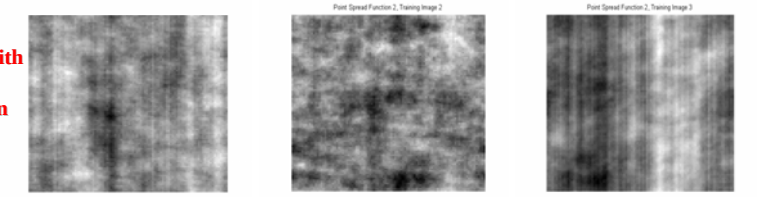
Encrypted MACE Filter 2

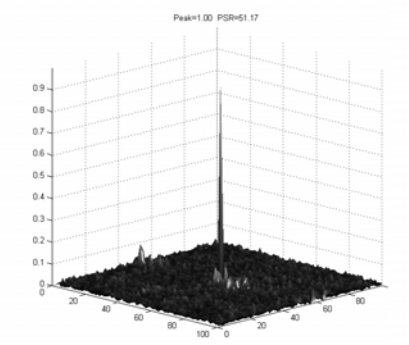
Original Training Images

Convolved with Random Convolution Kernel 1

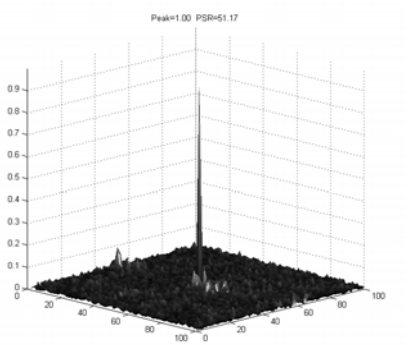


Convolved with Random Convolution Kernel 2



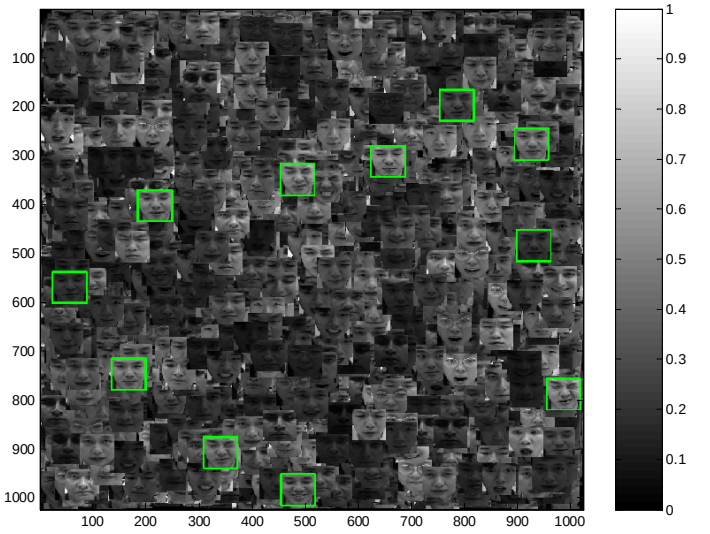


Correlation Output from Encrypted MACE Filter 1



Correlation Output from Encrypted MACE Filter 2

Detection of a specific Person's face



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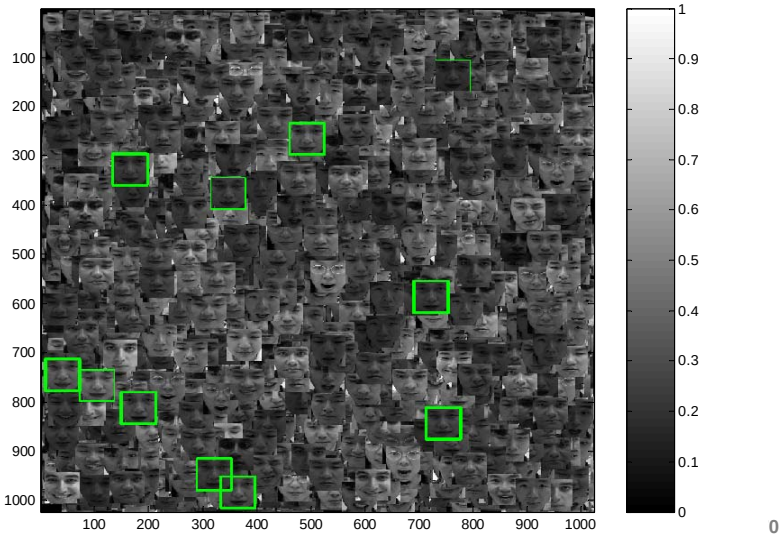
Detection of a different Person's face



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That's All Folks!

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