Recent Progress of Iris Recognition

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Outline of Talk

- Preamble
- Iris image acquisition
- Iris image preprocessing
- Iris pattern recognition
- Roadmap of iris recognition
- Resources and conclusions

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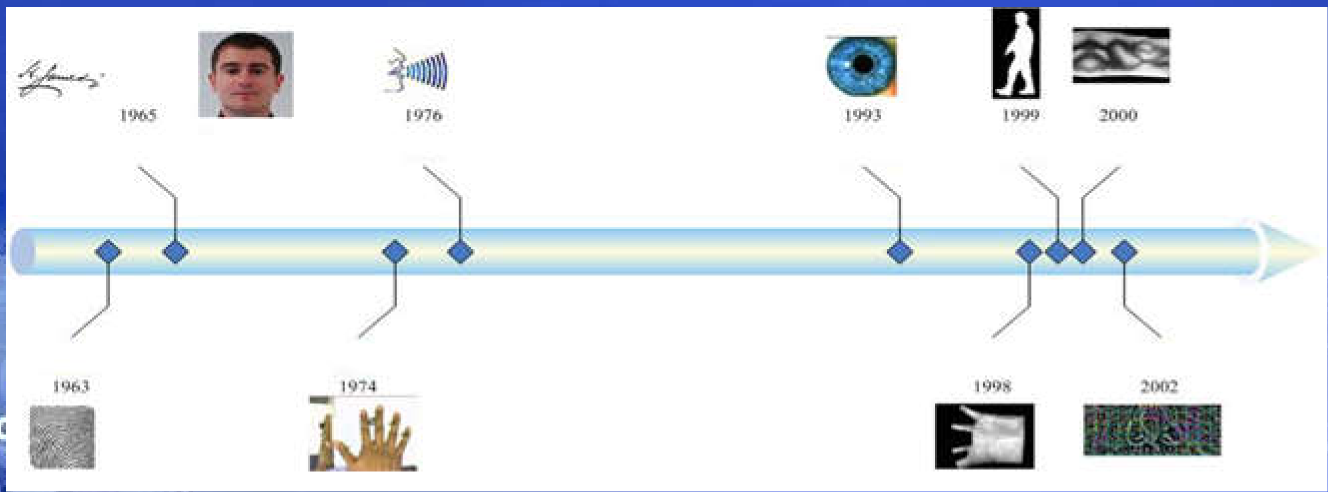
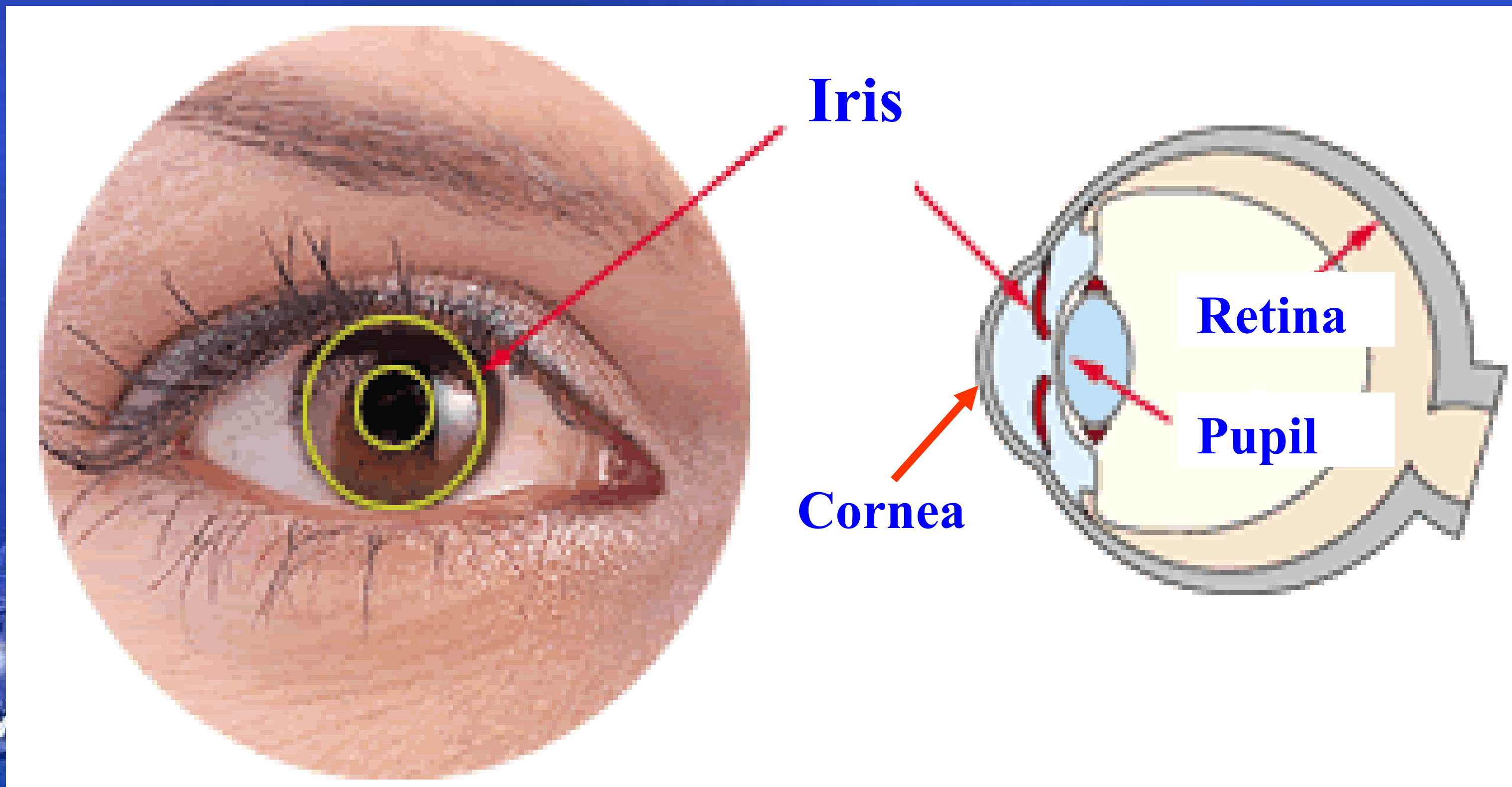
Iris in the context of biometrics



What is iris?

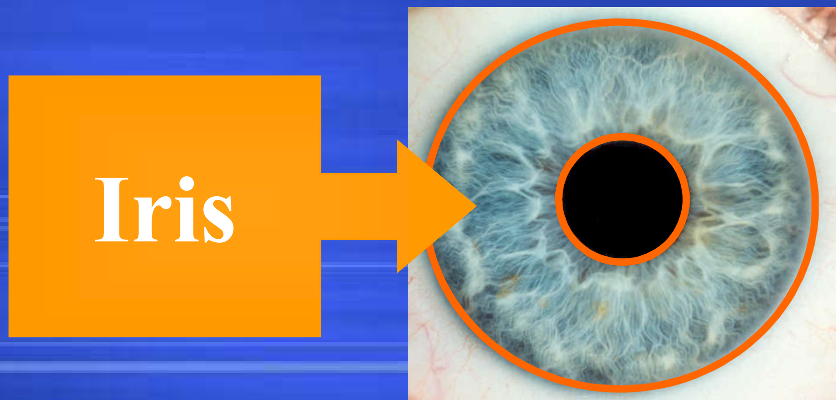
- The iris of your eye is the circular, colored membrane that surrounds the pupil.
- It controls light levels inside the eye similar to the aperture on a camera.
- Highly protected by cornea but externally visible at a distance



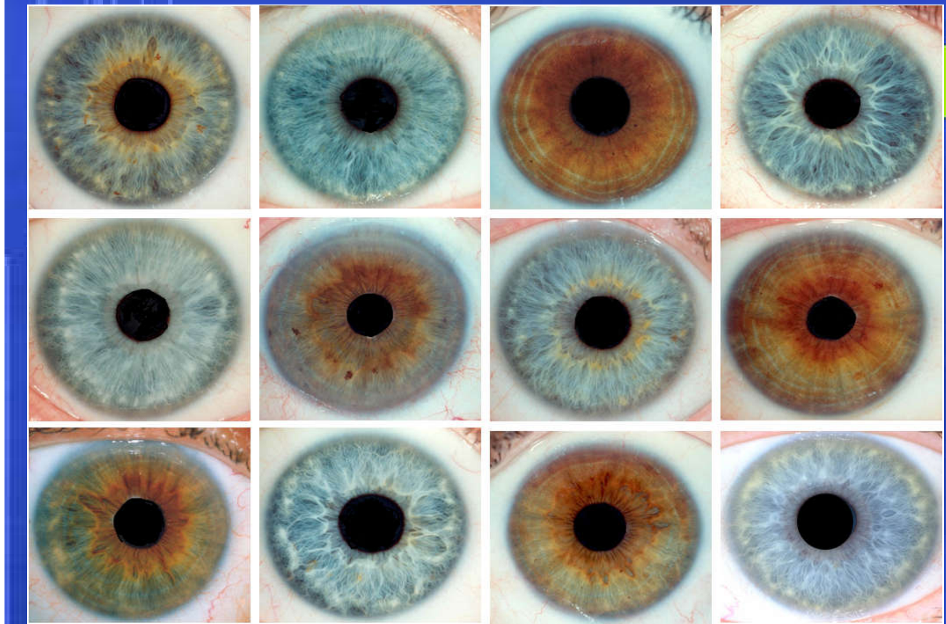
Iris Recognition

Acquisition, processing, analysis and comparison of iris patterns for personal identification

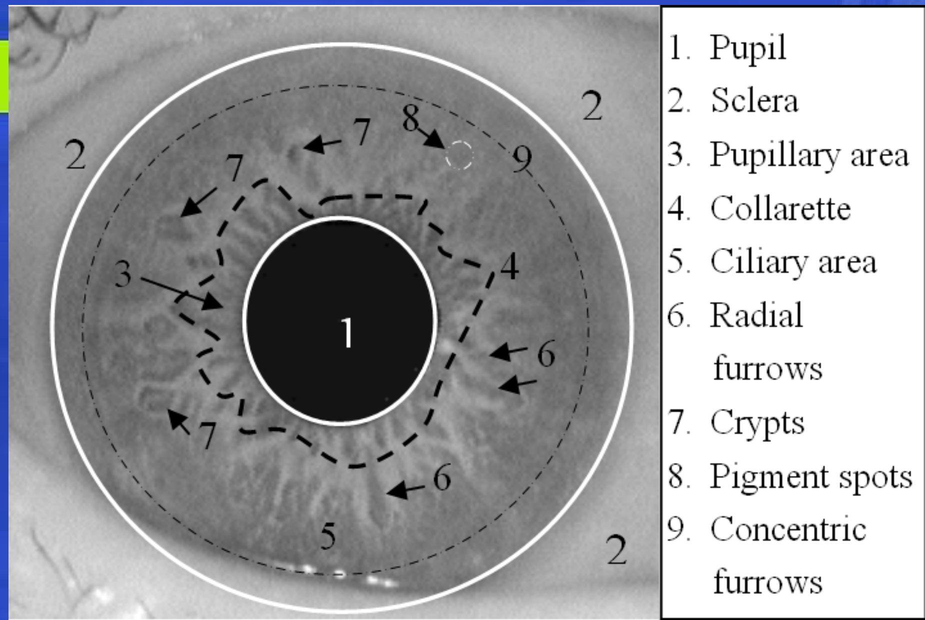
Who are you?



Human iris is small in size but rich of texture in visual appearance



Visible illumination



Near infrared illumination

- The uniqueness of iris texture comes from the random and complex structures such as furrows, ridges, crypts, rings, corona, freckles etc. which are formed during gestation
- The epigenetic iris texture remains stable after 1.5 years old or so

Desirable characteristics of iris for personal authentication

- Uniqueness

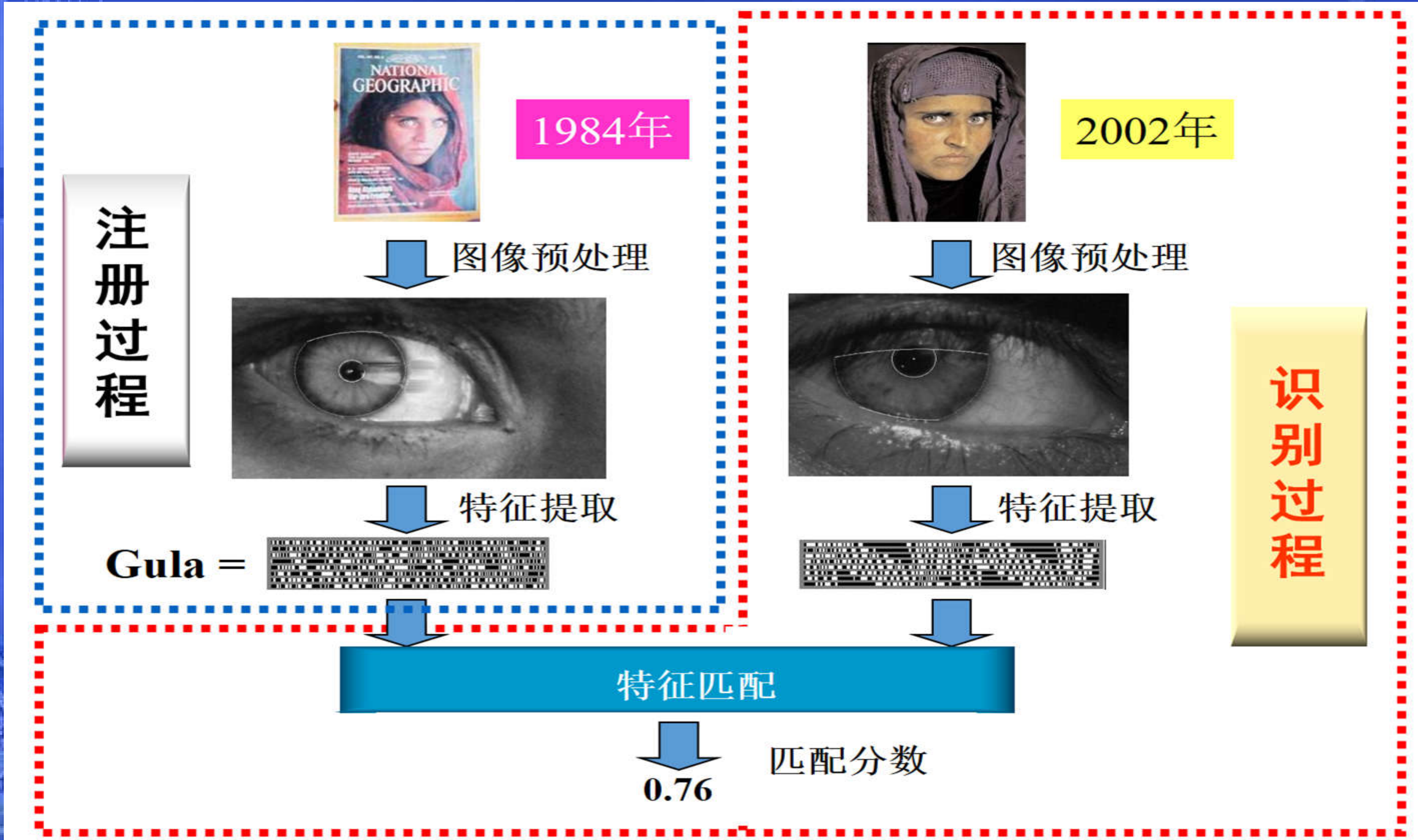
  phenotypic randomness, minute image features, rich information
- Stability

  stable through lifetime
- Non-intrusiveness

  imaging without touch

A Story on Iris Recognition

Identification of Gula Using Iris Recognition



Comparison with other modalities

Biometrics	Universality	Uniqueness	Stability	Collectability	Accuracy	Acceptability	Security
Face	High	Low	Medium	High	Low	High	Low
Fingerprint	Medium	High	High	Medium	High	Medium	High
Hand	Medium	Medium	Medium	High	Medium	Medium	Medium
Vein	Medium	Medium	Medium	Medium	Medium	Medium	High
Iris	High	High	High	Medium	High	Medium	High
Retina	High	High	Medium	Low	High	Low	High
Handwriting	Low	Low	Low	High	Low	High	Low
Voice	Medium	Low	Low	Medium	Low	High	Low
Thermogram	High	High	Low	High	Medium	High	High
Odor	High	High	High	Low	Low	Medium	Low
Gait	Medium	Low	Low	High	Low	High	Medium
Ear	Medium	Medium	High	Medium	Medium	High	Medium
DNA	High	High	High	Low	High	Low	Low

CESG/BWG Biometric Test Programme

accuracy of this matching process. By adjusting the decision criteria there can be a trade-off between false match and false non-match errors; so the performance is best represented by plotting the relationship between these error rates in a detection error trade-off graph.

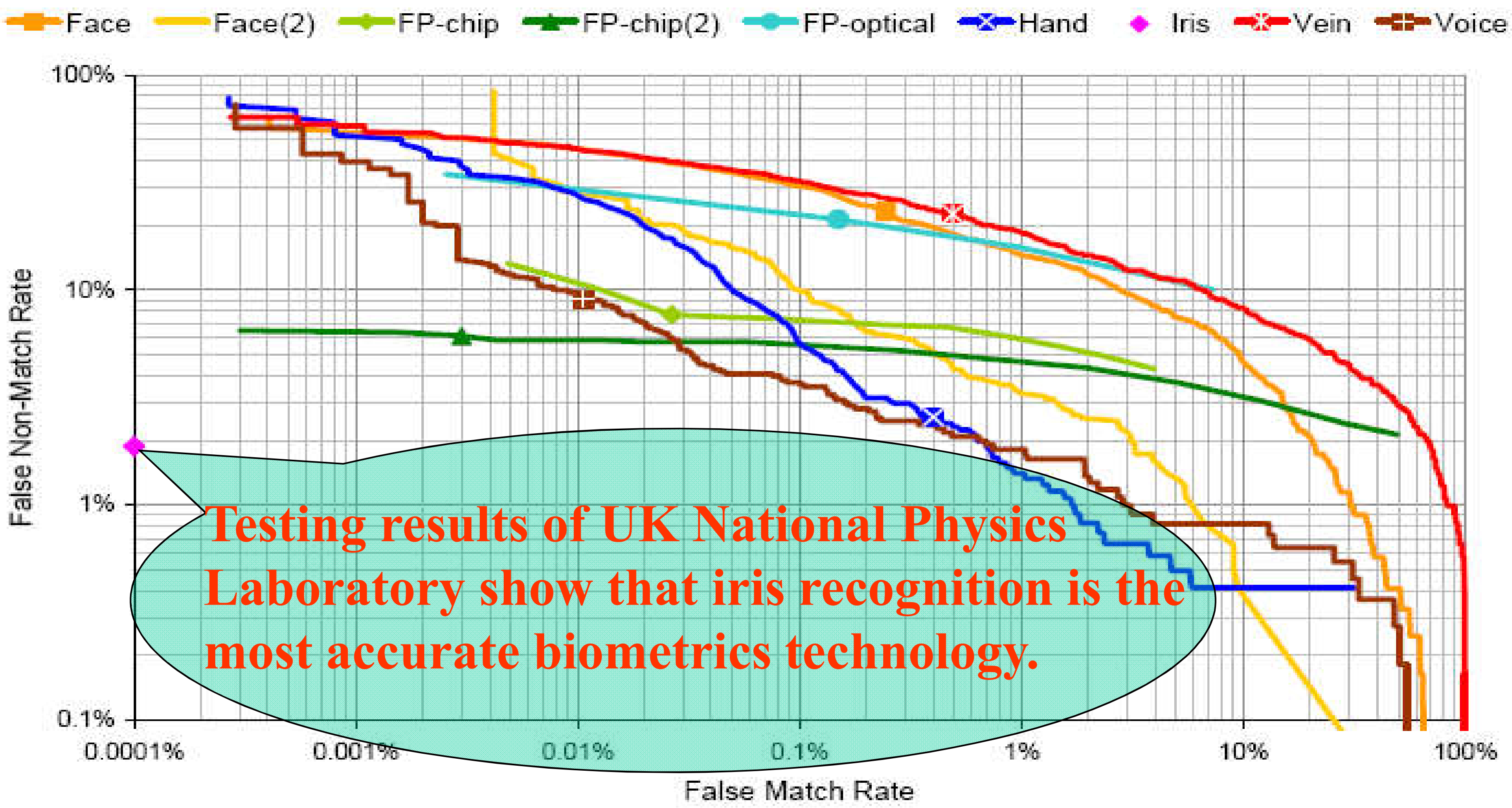


Figure 4. Detection error trade-off: FMR vs FNMR

History of Iris Recognition

1936
Frank Burch
Concept of using iris patterns for human identification

1985
Flom and Safir
First iris recognition patent

1991
John Daugman
Iris recognition patent

2001
UAE
Deployed iris recognition system for border control

2002
USA
Use of iris recognition in field operations

2003
Immigration clearance at Schiphol airport

2009
India
Aadhaar

2010
Mexico
National ID

2011
John Daugman
Patent expired

2011
Indonesia
National ID

2008
China
Coal miner management

1989
John Daugman
First iris camera

1995
IrisScanner System
One of the earliest commercial iris camera

2004
SecuriMetrics
Portable iris recognition device

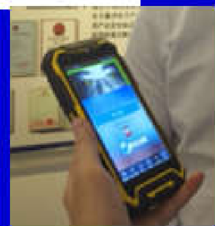
2006
Sarnoff
Iris on the Move

2013
AOptix
App & device for smartphone to capture iris

2013
DeltaID

1999
CASIA
The first iris recognition system in China

2009
CASIA
Iris recognition at a distance



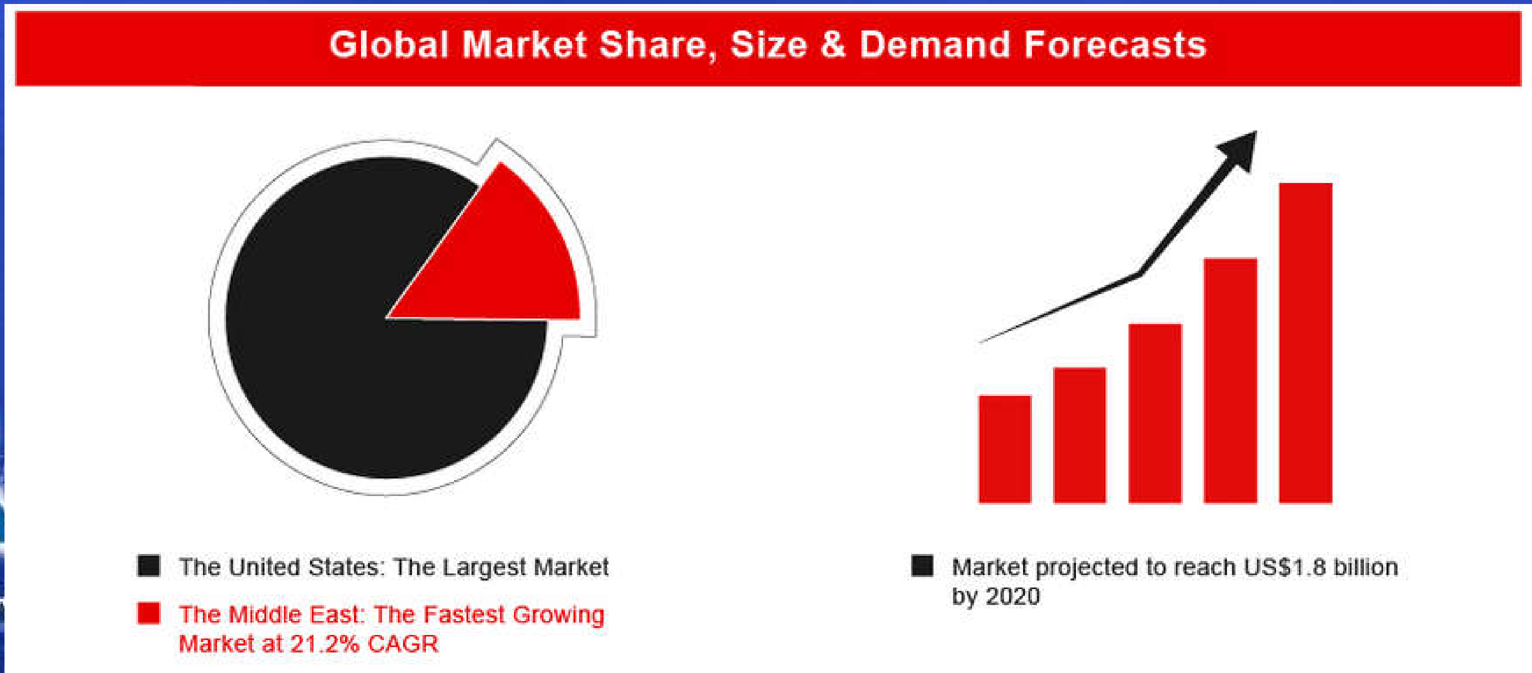
2015
IrisKing
Binocular Iris recognition on smartphones

A.K. Jain, K. Nandakumar and A. Ross, 50 Years of Biometric Research: Accomplishments, Challenges, and Opportunities. Pattern Recognition Letters, 2015

Global Market of Iris Recognition

Global Industry Analysts, Inc.
A Worldwide Business Strategy & Market Intelligence Source

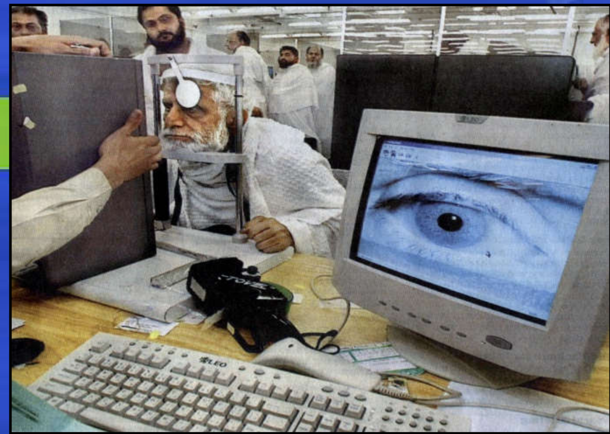
The global market for Iris Biometrics is projected to reach US$1.8 billion by 2020, driven by effervescent technology advancements and growing use in access, surveillance and identity applications.



Applications of iris recognition

Access control

Airport



Homeland security

Welfare distribution

Missing children identification

ATM

印度身份证管理

http://www.uidai.gov.in/

UID编码

Name

Address

Gender

Date of birth

+

Photo

Both iris

10 finger-prints

=

AADHAAR

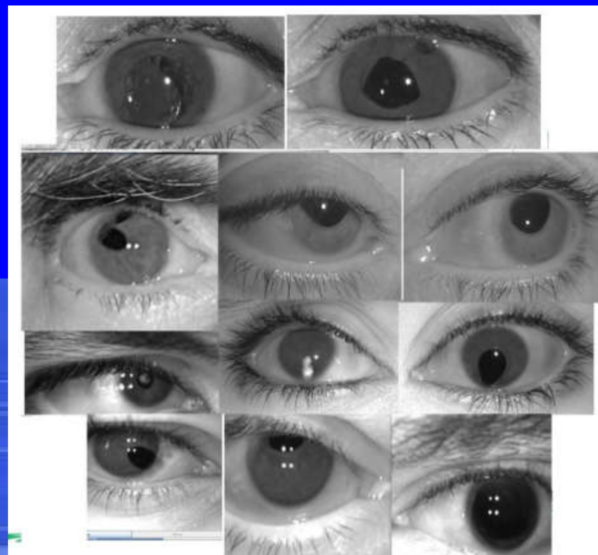
आपकी आधार संख्या / Your Aadhaar No.

1234 4678 9011

1 person⇔1 number

Progress of UID

- 2010.9-2016.4 Enrollment of one billion subjects
- Accuracy： False reject rate (FPIR) = 0.057%
  False accept rate (FNIR) = 0.035%
- FTE: 0.14%
- Usability： >99.5%
- EER： 99.73%



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Importance of Iris Biometrics in UID

Raj Mashruwala, Chief Biometric Coordinator of UID

The iris decision alone turned the UID system into a roaring biometrics success and averted a potentially catastrophic failure.

NIST reports FPIR rate of ten-finger identification to be between 1.5 to 3.5% on a gallery size of approximately one million. UIDAI reports FPIR rate of 0.057% over a gallery size of 100 million. This is a 50 times accuracy improvement despite a 100-times larger database.

UIDAI reports 2.9% of people have biometrically poor quality fingerprints but only 0.23% have biometrically poor quality fingerprints and iris. A third metric would reinforce this point. It is not uncommon in the literature to see estimations of 1 to 5% failure to enrol (FTE) fingerprint rate. UIDAI reports FTE rate of 0.14%, another 10X improvement.

Iris Recognition for Border Control

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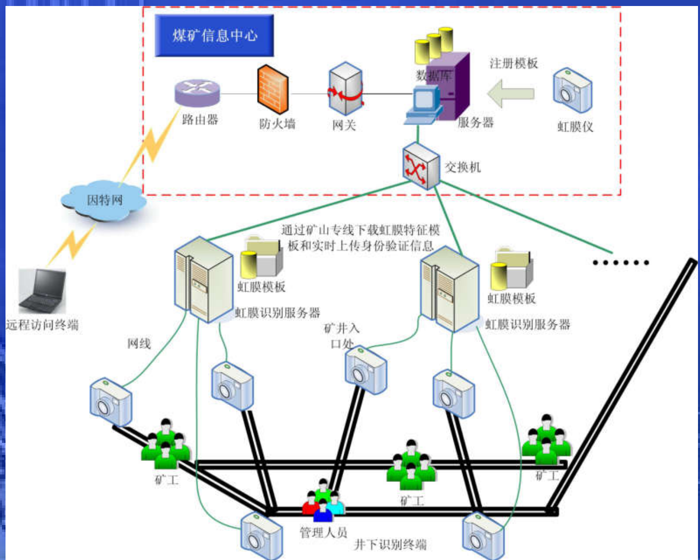
Iris Recognition for Criminal Investigation





Iris Recognition for Coal Miner Identification



http://www.IrisKing.com

Iris Recognition for Secure Bank Transactions

Cairo Amman Bank
Egypt

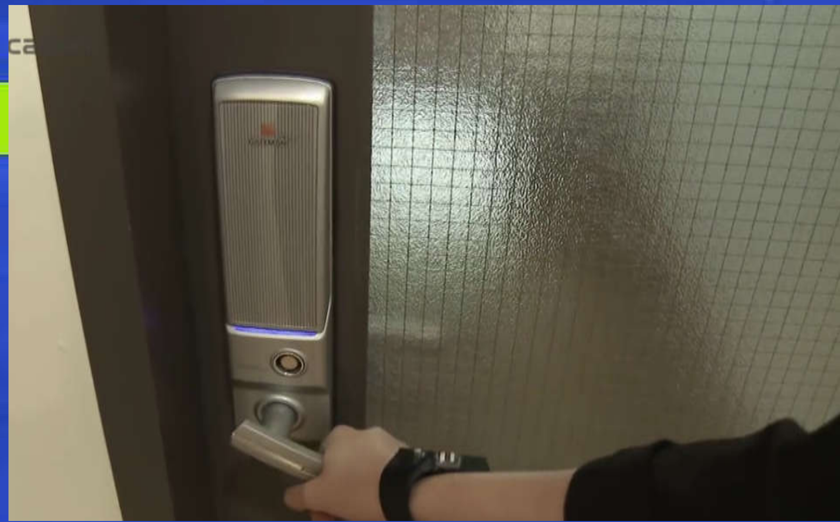
Cooperative & Agricultural Credit Bank
Yemen

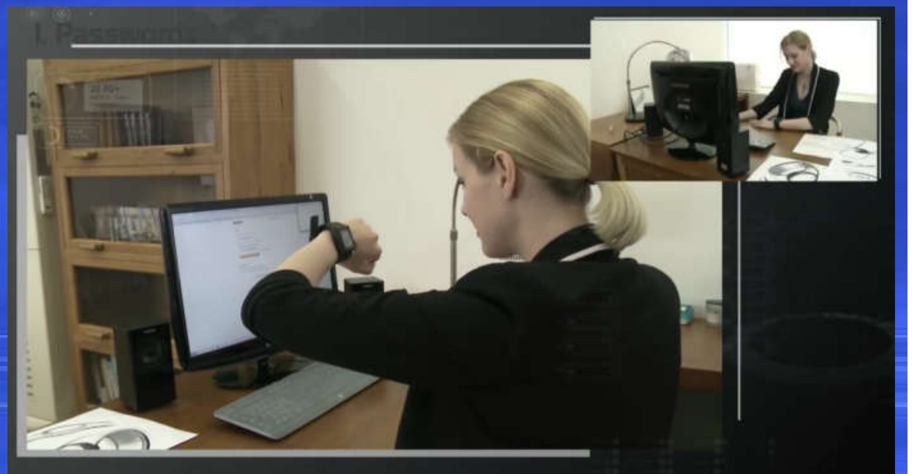
//www.ia.ac.cn

Iris Recognition for Prison Management

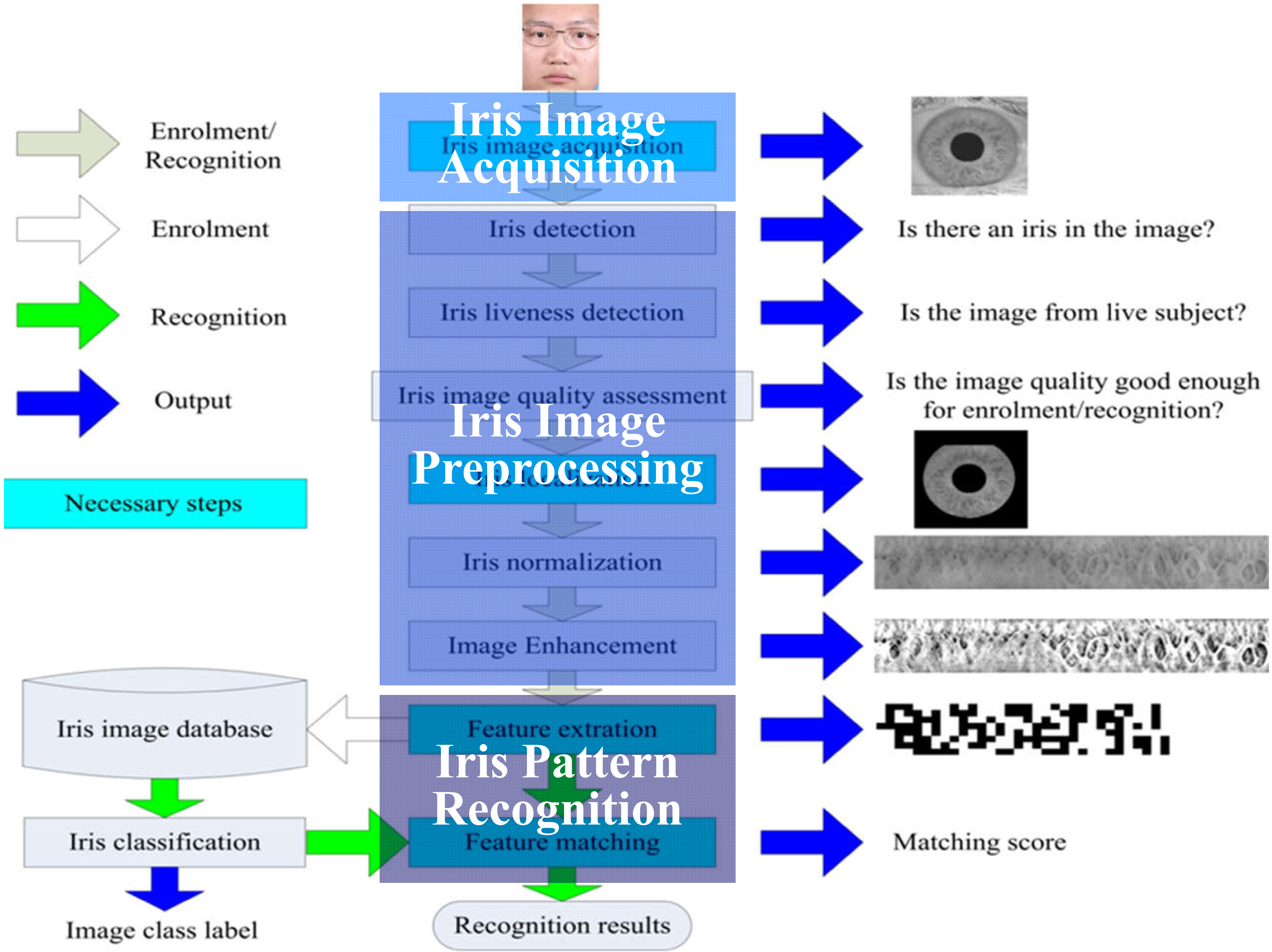
Iris Recognition on Mobile Devices

Iris Recognition in Smart Watch





Basic Modules of IR System



Iris Image Acquisition
Iris image acquisition
Iris detection
Iris liveness detection
Iris image quality assessment
Iris Image Preprocessing
Iris normalization
Image Enhancement
Feature extration
Iris Pattern Recognition
Feature matching
Recognition results
Enrolment/ Recognition
Enrolment
Recognition
Output
Necessary steps
Iris image database
Iris classification
Image class label
Is there an iris in the image?
Is the image from live subject?
Is the image quality good enough for enrolment/recognition?
Matching score

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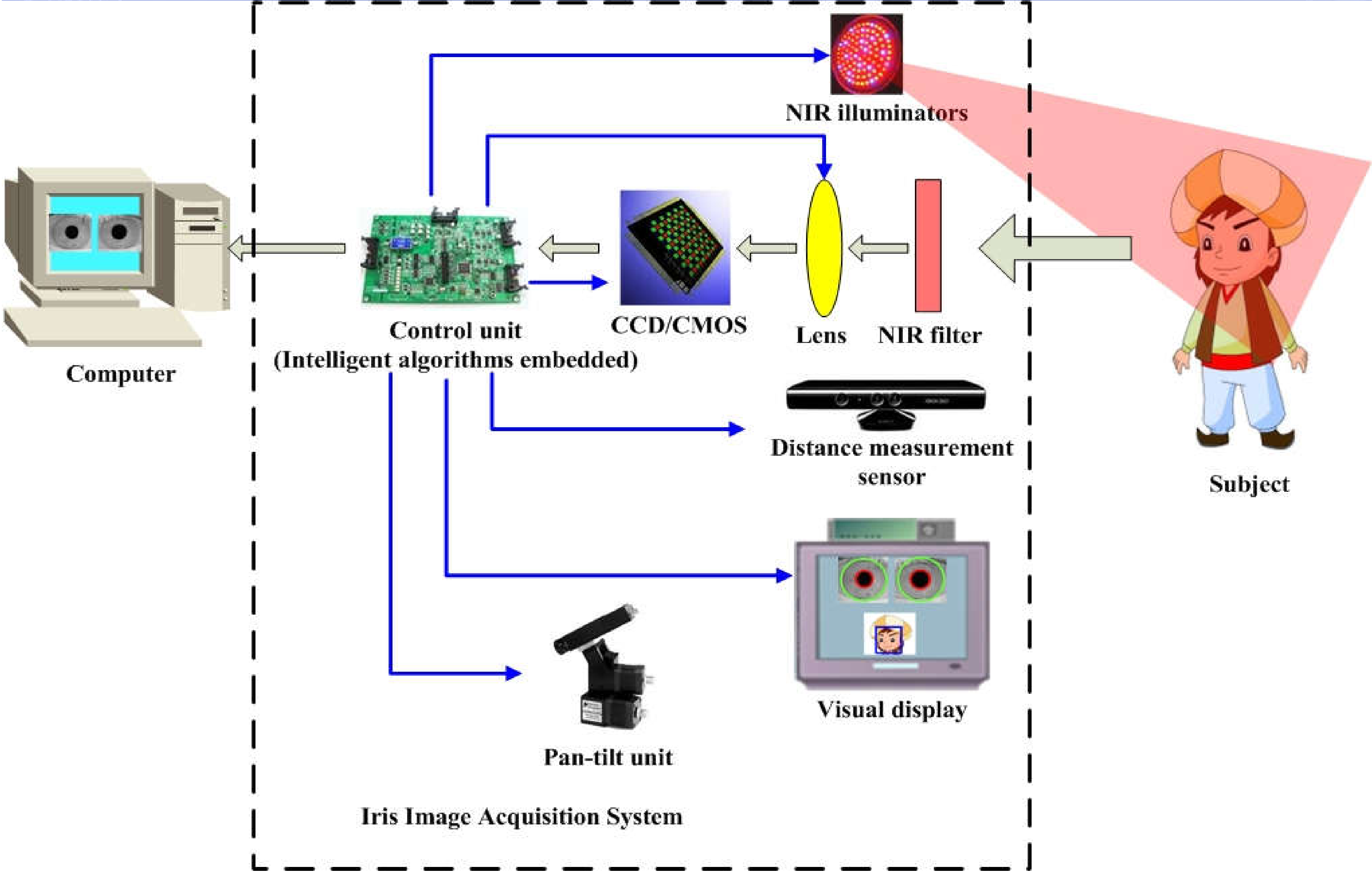
Difficulties of iris image acquisition

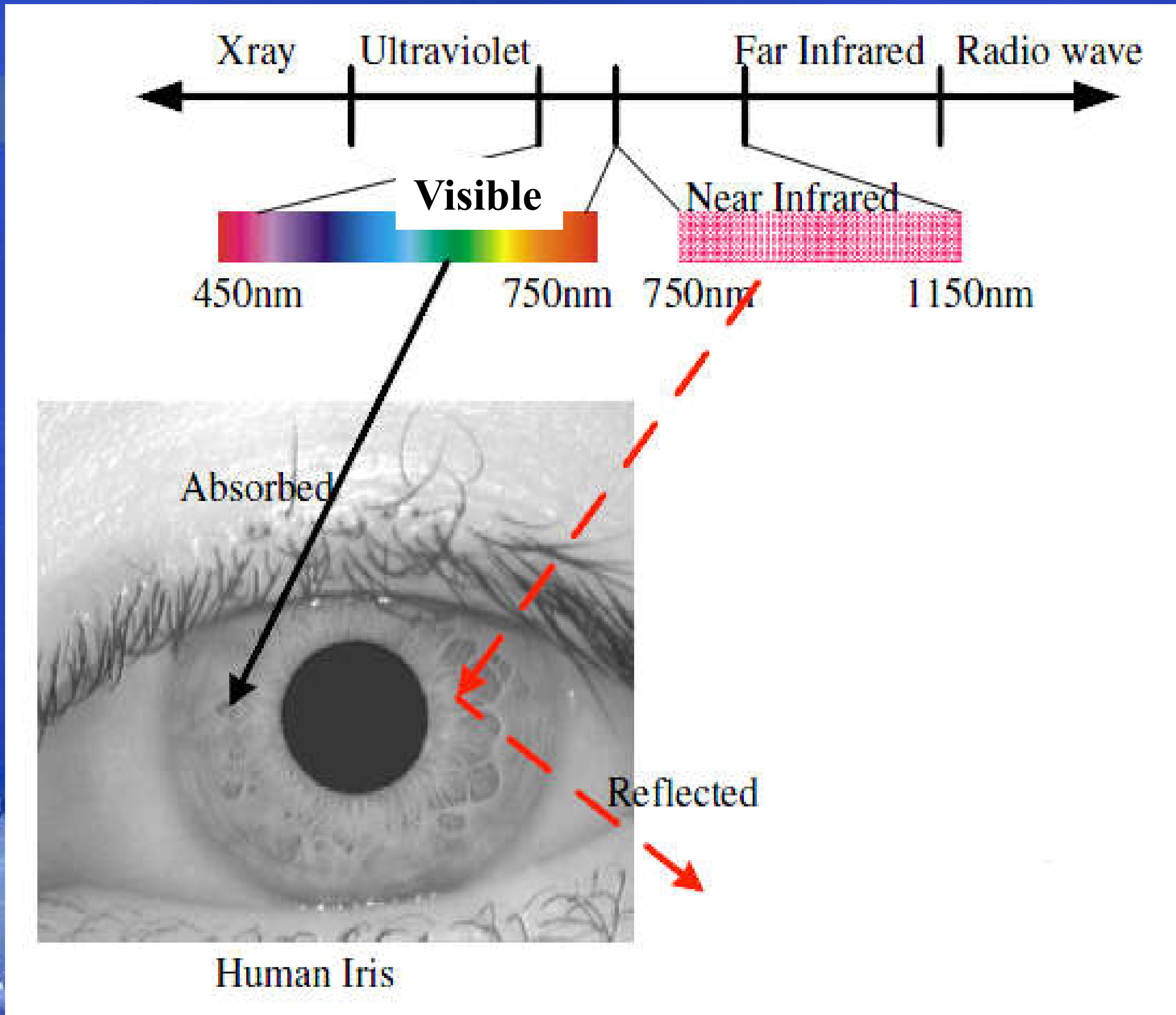
- Small size (11mm)
- Sufficient resolution (200 pixels)
- Narrow depth of field
- Must be optically on-axis
- Stop and stare
- Eyeglasses

How to capture clear iris images with low-cost, user-friendly cameras is still the most challenging problem in IR.

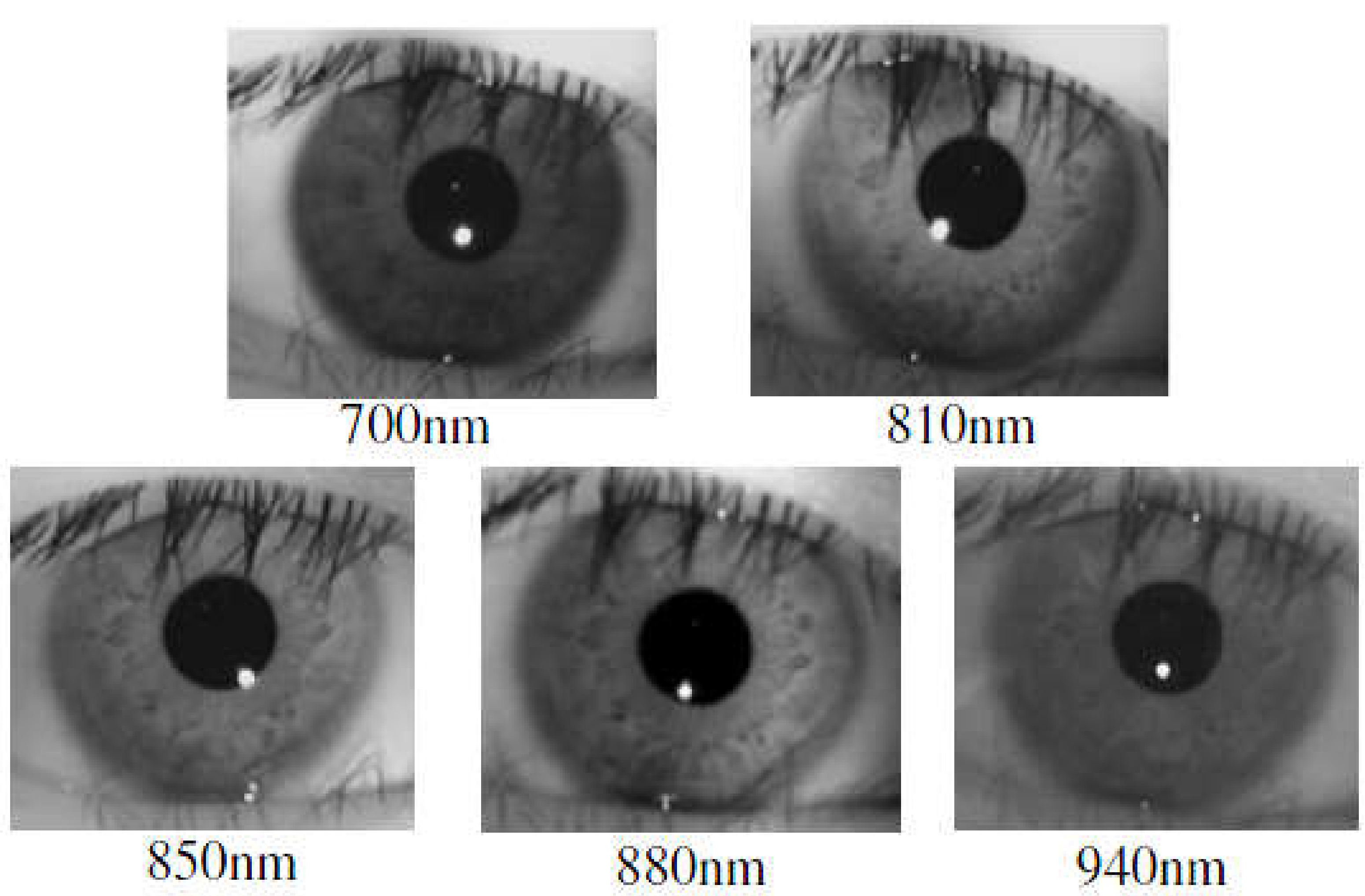
Basic Components of Iris Sensor



Optical characteristics of human iris



Iris images captured at different wavelength



Close-range iris devices


OKI IrisPass-H


OKI IrisPass-M


IrisID iCAM T10


IrisID iCAM 7000


Panasonic BM-ET300

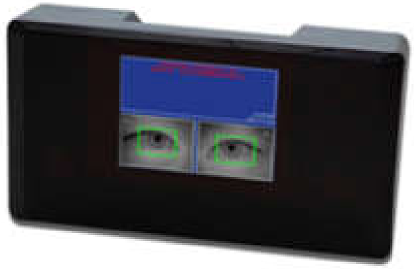

Panasonic BM-ET500


IrisGuard IG-H100


IrisGuard IG-AD100


SecuriMetrics PIER 2.3

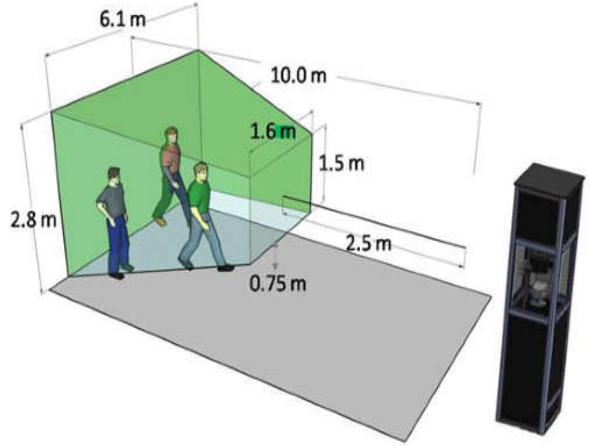

Crossmatch I SCAN2


IrisKing IKEMB-110

Long-range iris devices

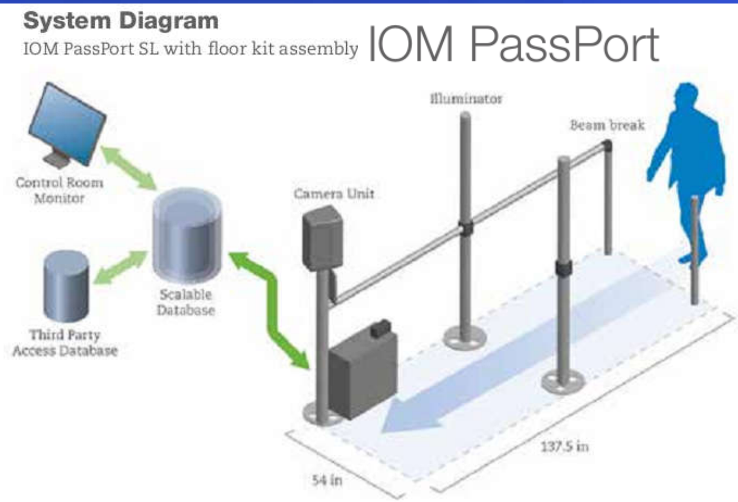

Aoptix InSight


EyeLock HBOX



Eagle-eyes


IOM PassThru




IrisID iCAM D1000


CASIA

Iris image acquisition devices of CASIA

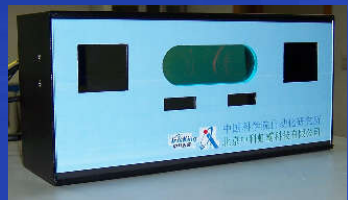
1999

2000

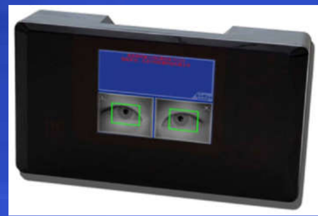
2001

2004

2005



2007



2008

2009

2014

2015

Technology Roadmap of Iris Recognition

从无到有

1999：打破国外技术封锁，实现零的突破

2001：虹膜图像质量达到国际先进水平

从单目到双目

2006：双目、声光引导用户自定位

2008：液晶实时反馈、嵌入式、网络化

由近及远

2009：远距离虹膜人脸一体化成像

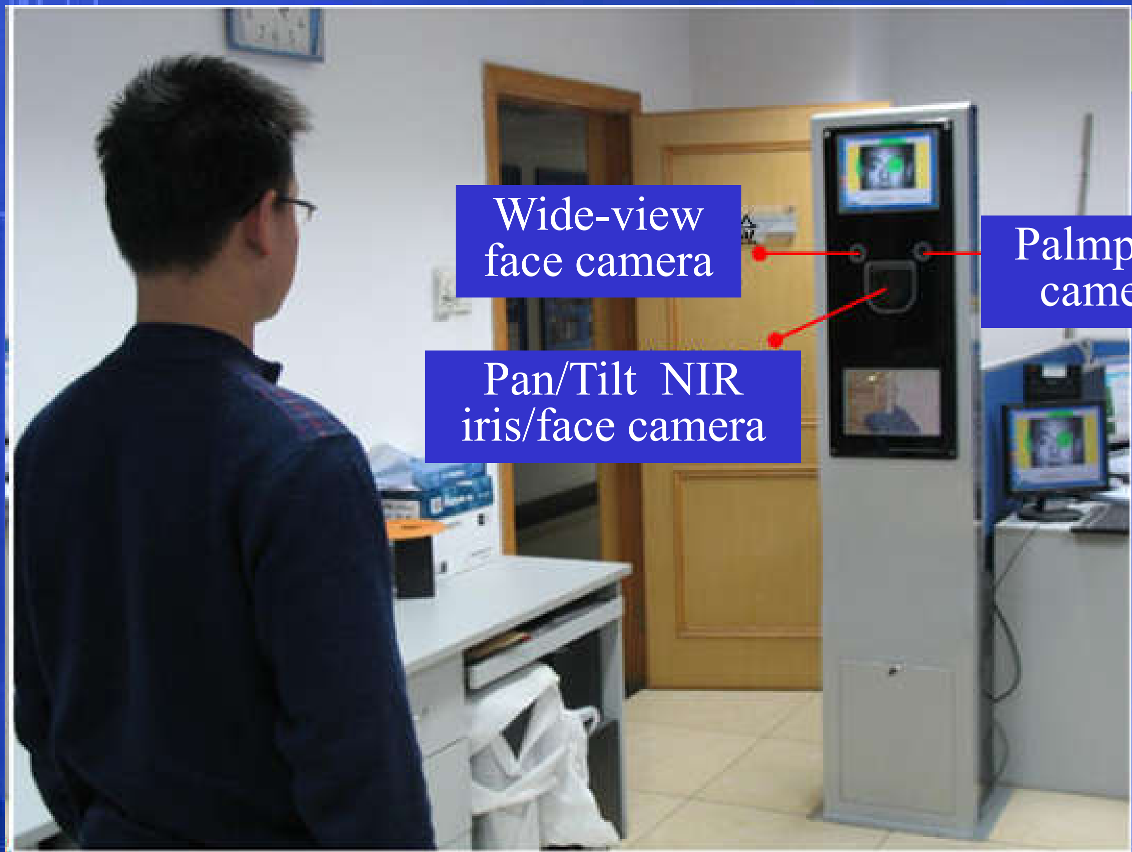
2013：多目标虹膜人脸光场成像

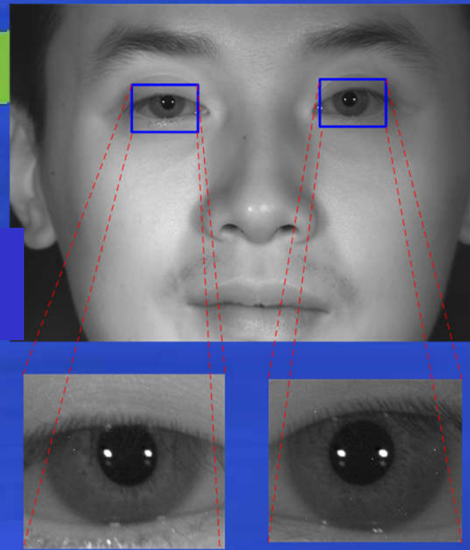
从固定到移动

2014：便携式虹膜识别仪

2015：虹膜识别手机

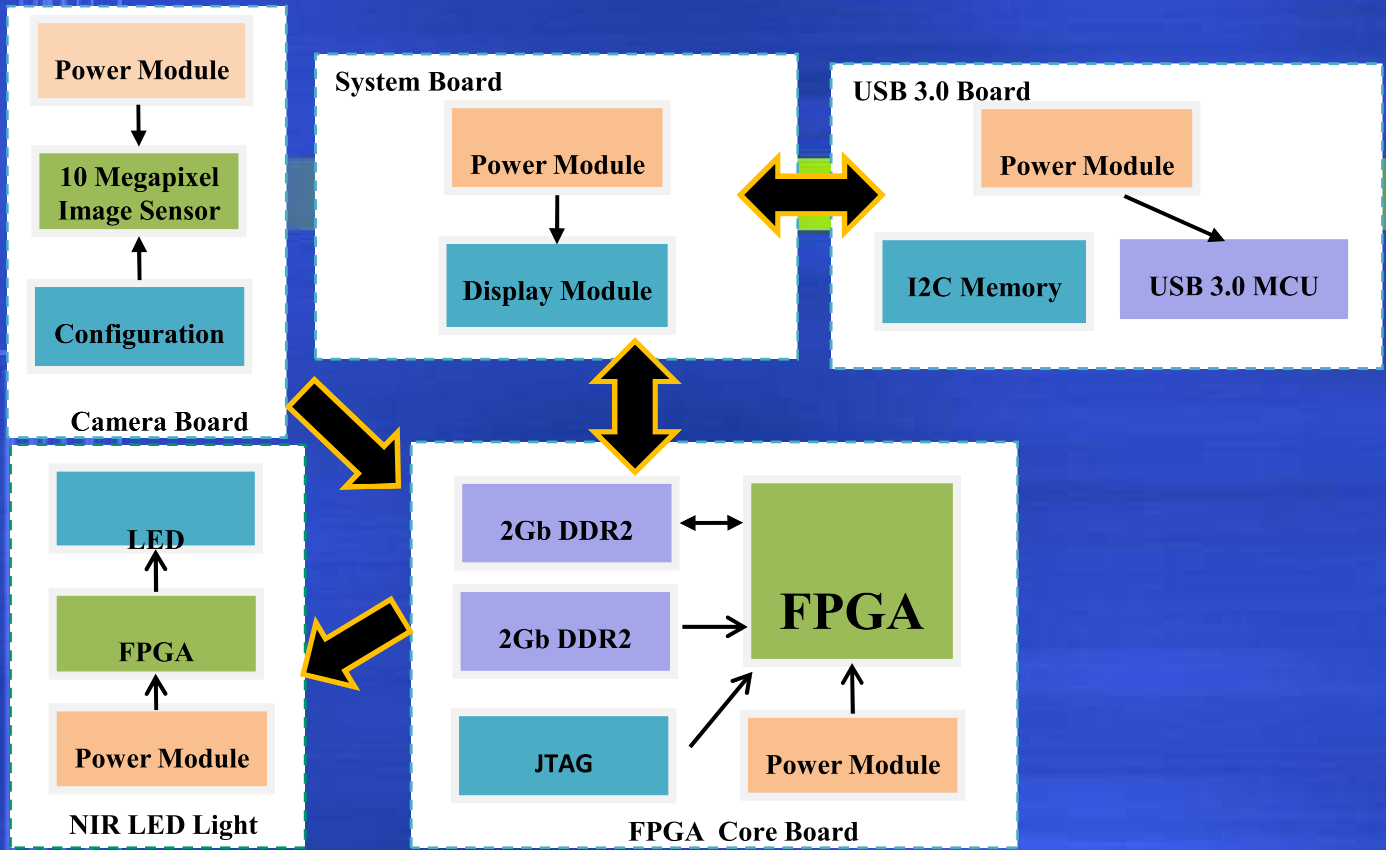
Multi-modal biometric recognition at a distance





Iris/Face/Palmprint recognition for friendly personal identification

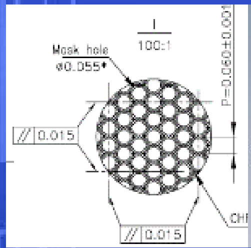
Long-range Iris/Face Recognition System

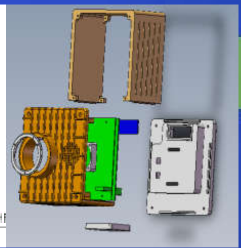


- High Resolution Iris Camera
- High-Speed Iris Image Acquisition
- NIR Illumination Optimization
- Fast Recognition Procedure

Demo of Iris Recognition at a Distance

Computational light field imaging





One shot of multiple well-focused subjects: refocusing, 3D reconstruction algorithms are integrated into the sensor

Techniques to improve user interface of iris cameras

- Use extremely high resolution CCD
- Well-designed optical system to improve DOF (Depth of Field)
- Cold mirror to let user adjust his eye optically on-axis
- Auto-focus system adaptive to the distance between eye and camera
- Distance sensor or image content based distance estimation
- Visual or audio feedback for user
- Dual-eye iris camera
- Active pan/tilt camera optics to accommodate different heights and poses
- Use facial feature detection and tracking to guide iris image acquisition
- Light-field imaging with computational refocusing

Iris Image Synthesis

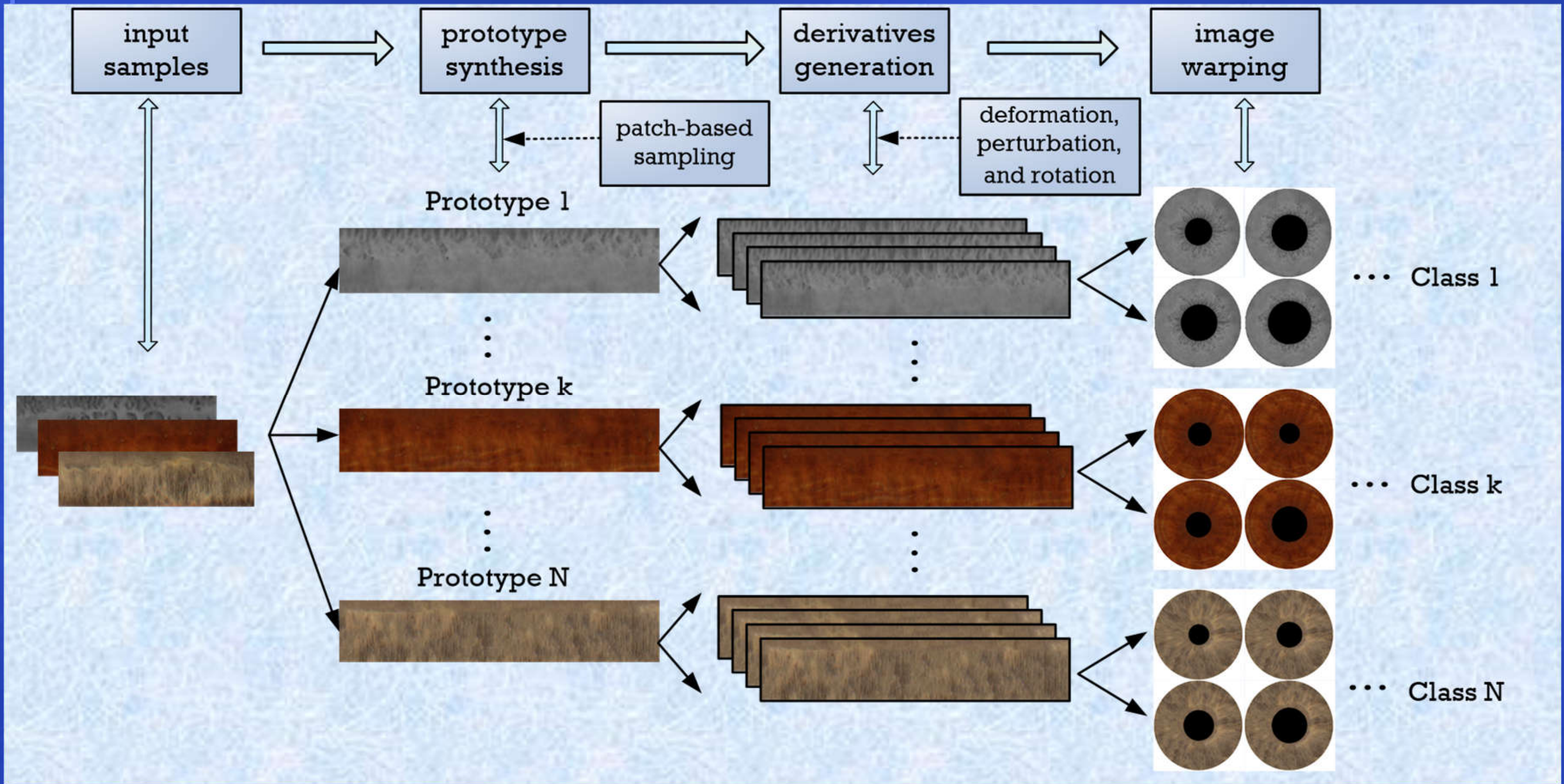
Motivation:

1. Construct large-scale databases to evaluate iris recognition algorithms
2. Construct iris databases of controllable quality
3. Understand how iris texture is formed

Challenges of Iris Image Synthesis

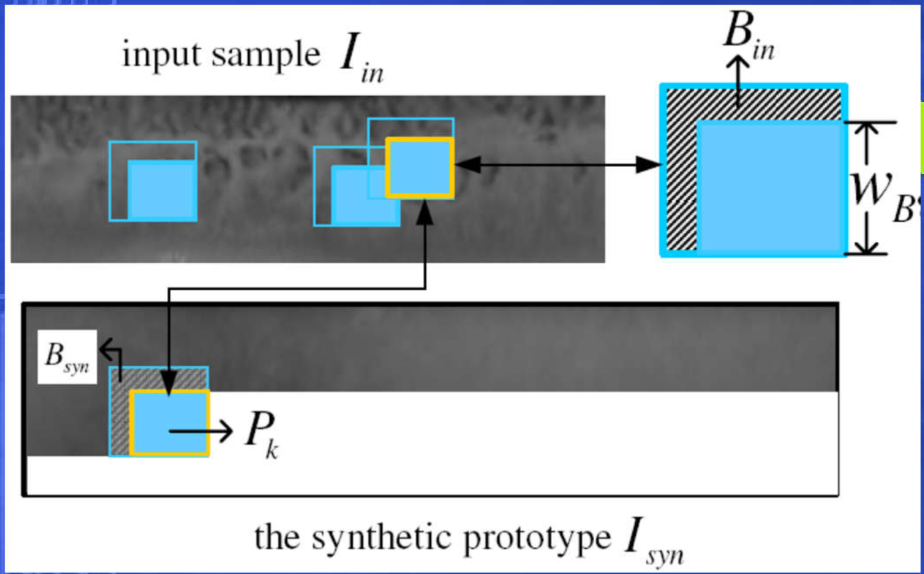
1. Anatomical structures of iris pattern
2. Visual similarity
3. Numerous iris classes
4. Complex intra-class variations
   e.g., eyelashes and eyelids, illumination, deformation, eyeglasses, etc.
5. Independent of representation methods
6. Usefulness for IR algorithm evaluation

Iris image synthesis from exemplars

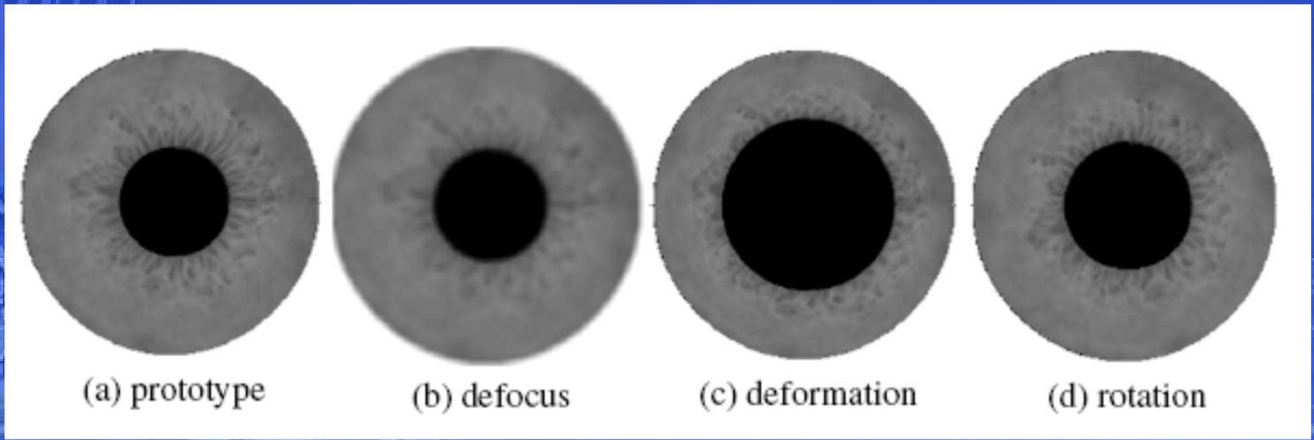


1) An input sample image is formed.
2) A prototype image is created.
3) Multiple images with intra-class variations are generated from the prototype.
4) The generated images are warped into annular shape.

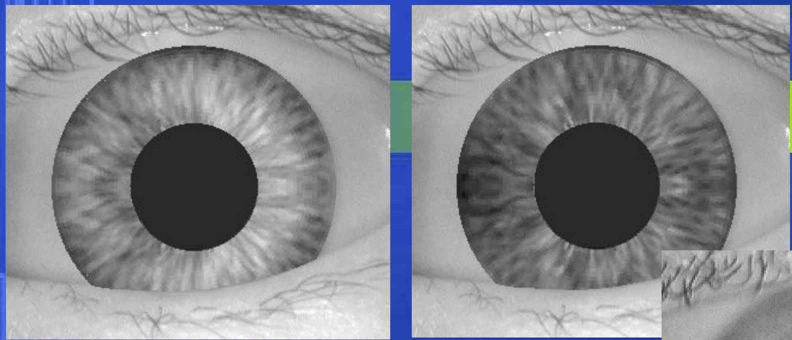
Techniques of iris image synthesis

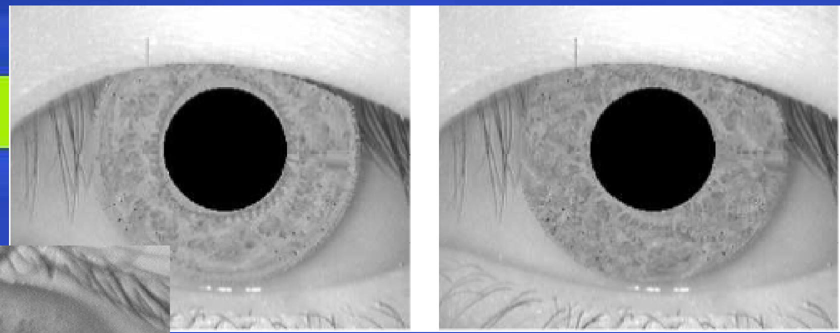


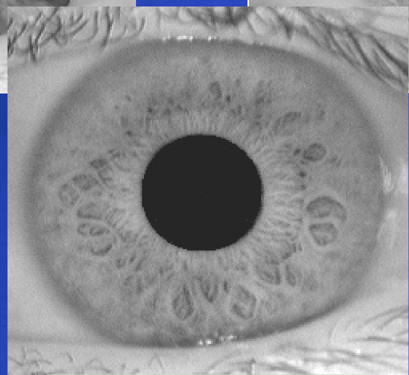
- Patch-based sampling is applied to synthesize iris prototype;
- Different strategies are deployed to create multiple samples.

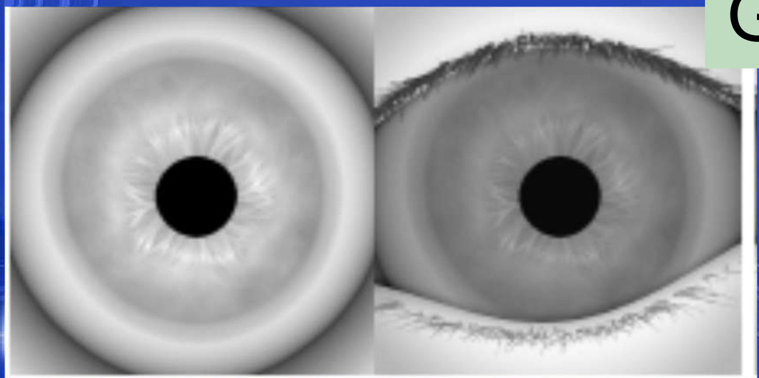


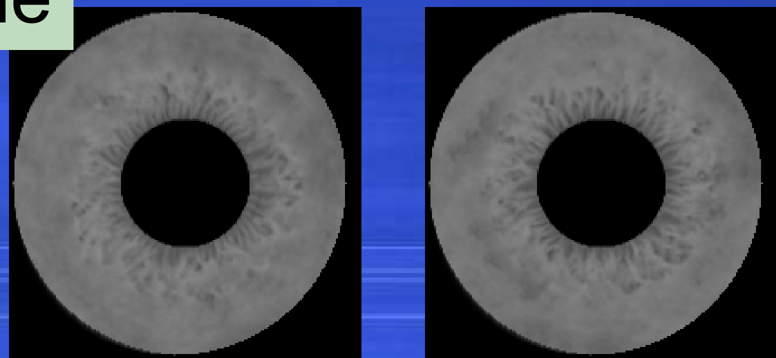
Realism of Synthetic Iris Images

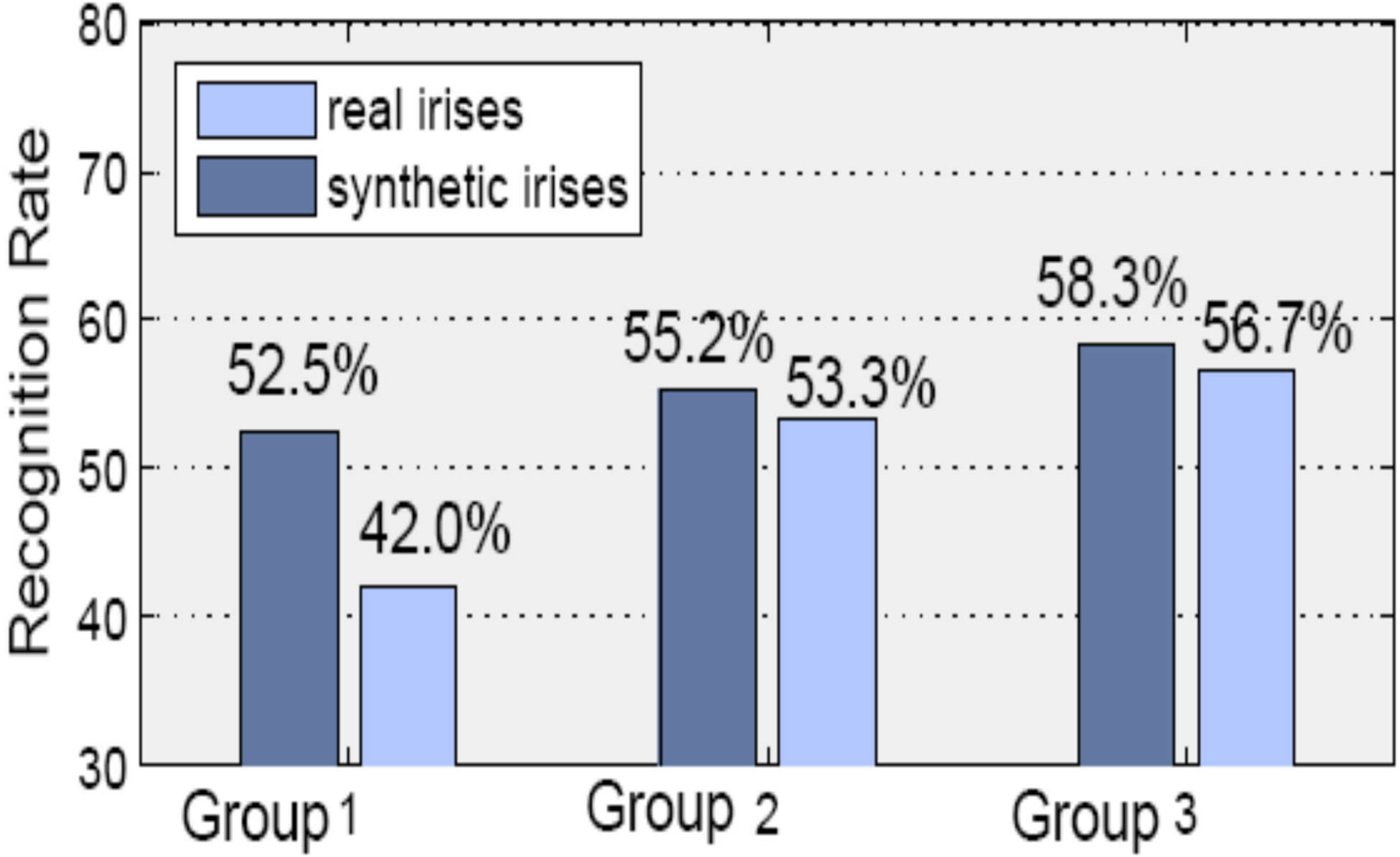

PCA


MRF


Genuine


Model based

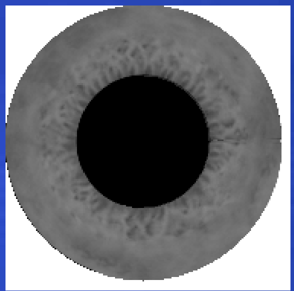
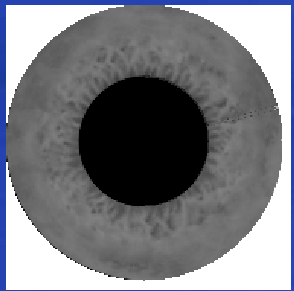
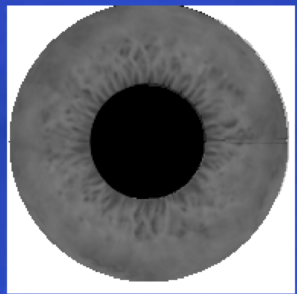
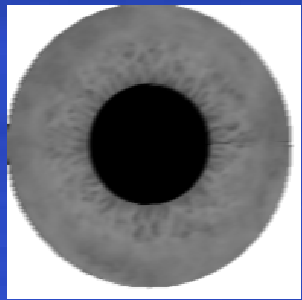
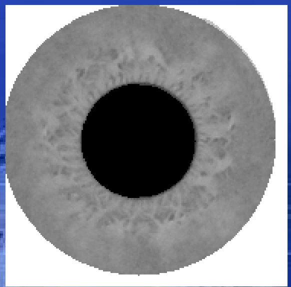
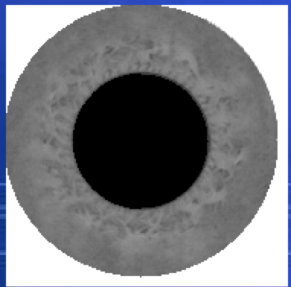

Patch sampling



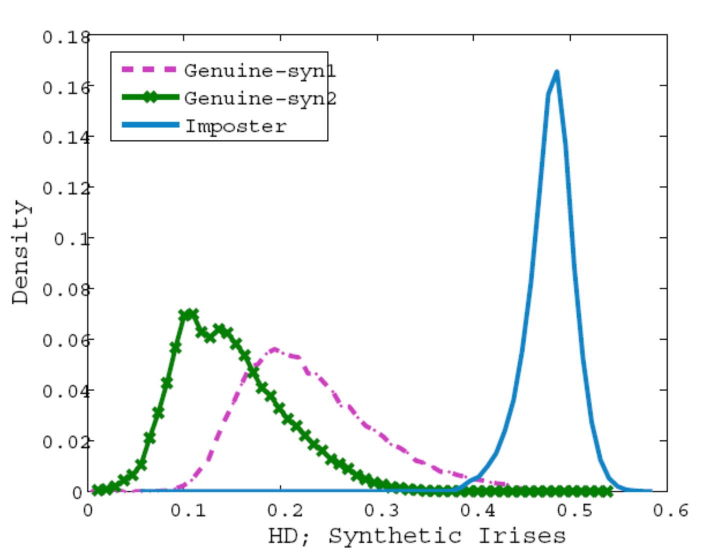
Recognition Rate
80
70
60
50
40
30
real irises
synthetic irises
52.5%
42.0%
55.2%
53.3%
58.3%
56.7%
Group 1
Group 2
Group 3

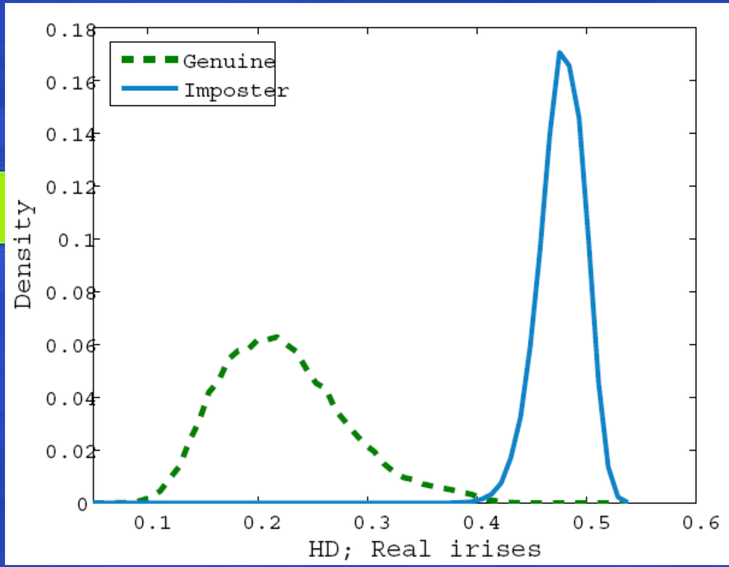
Database synthesis

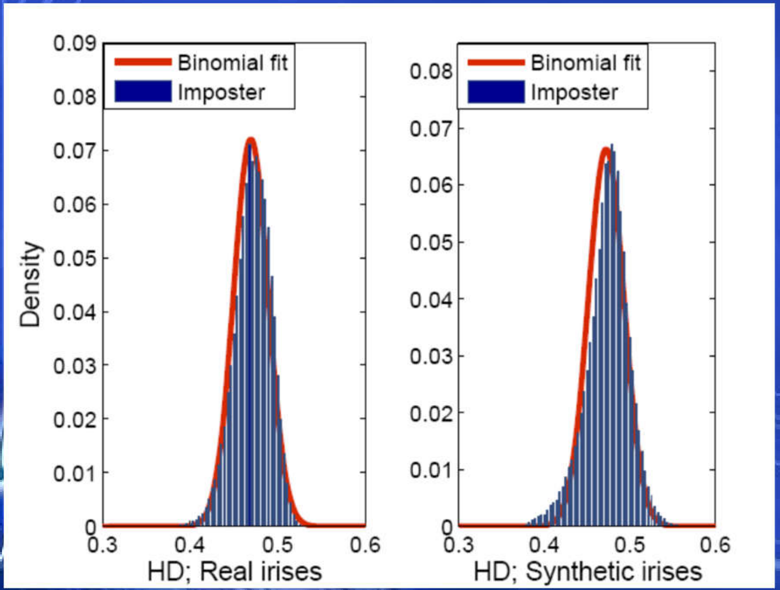
- 1000 classes, 10 images per class, intra-class variations include: deformation, rotation, blurred, and mixture of the above

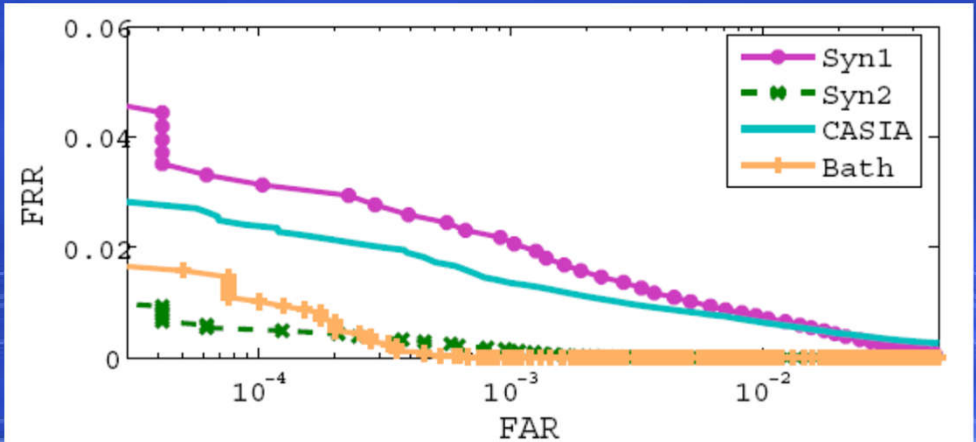







Statistical similarity









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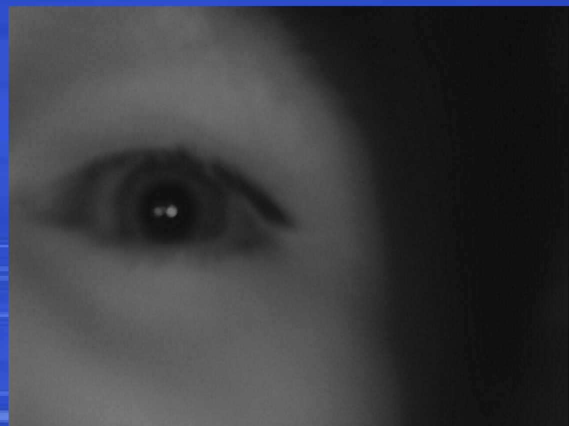
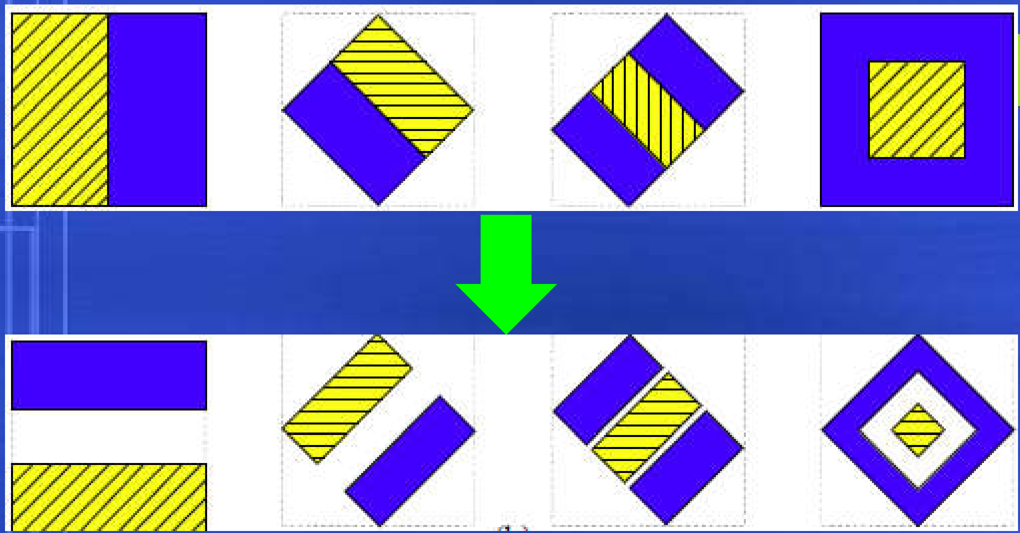
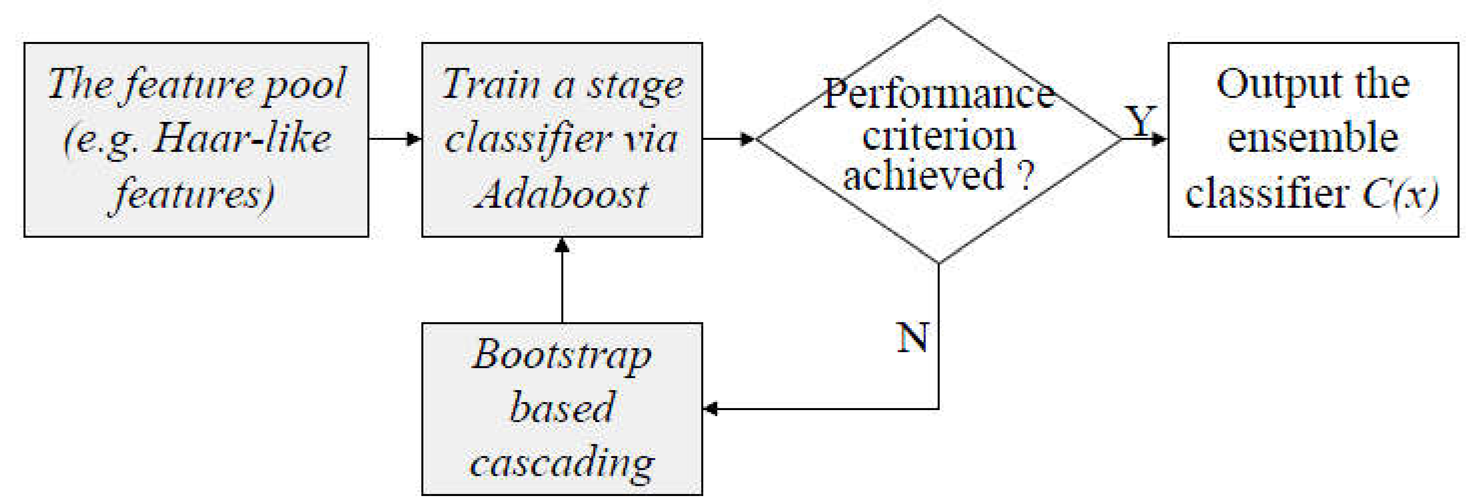
Iris detection

Is there an iris in the input image?

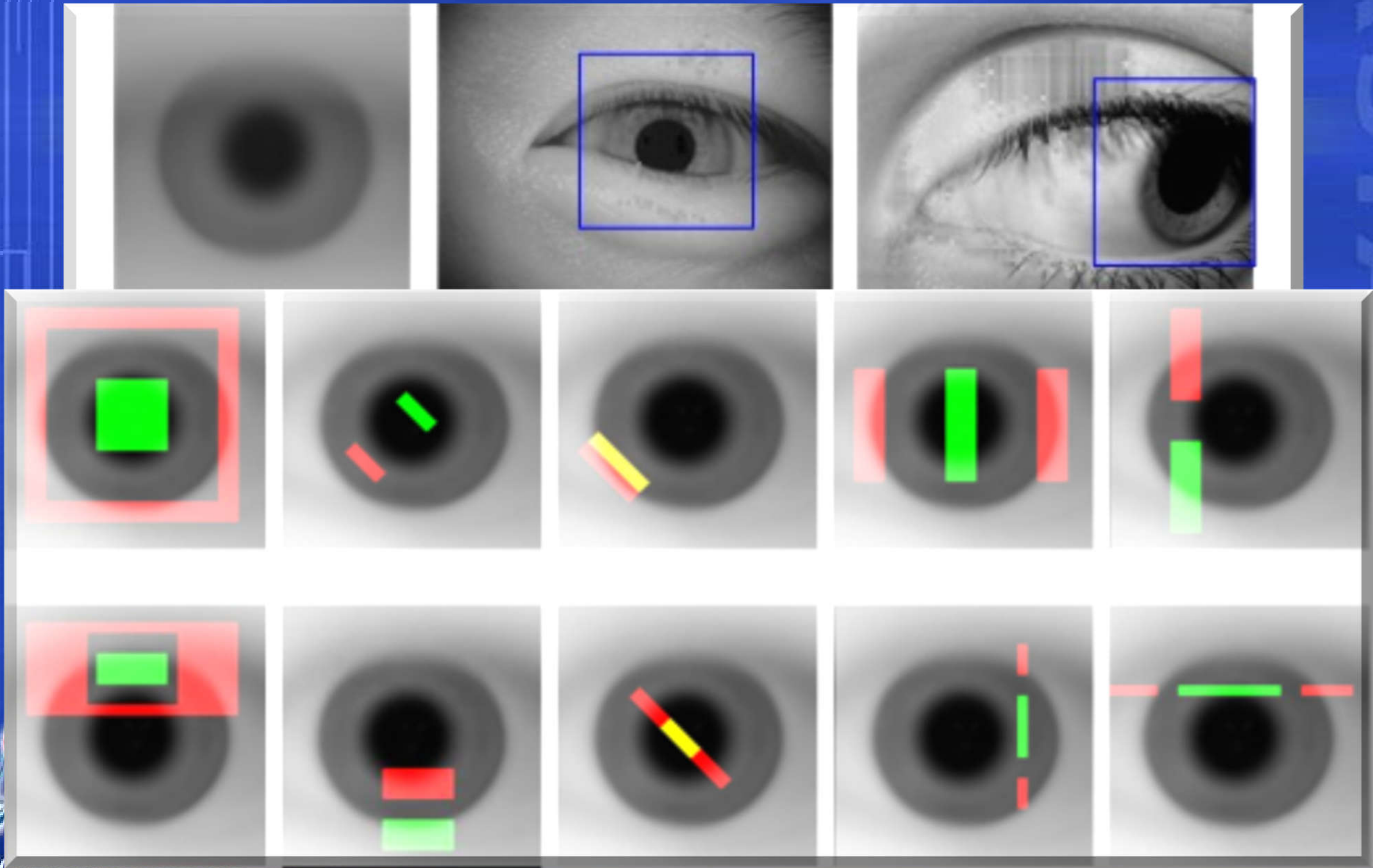


Solution to iris detection:
Extended Haar features + Boosting learning





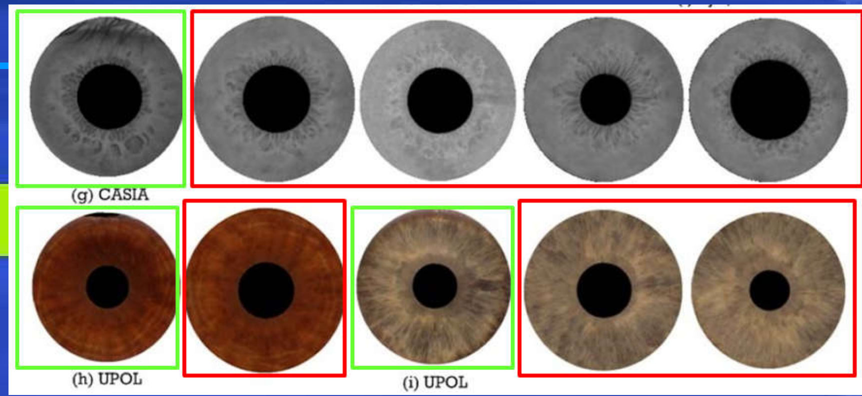
Iris detection results



Correct detection rate is 99.2% on a database of 60,000 iris images

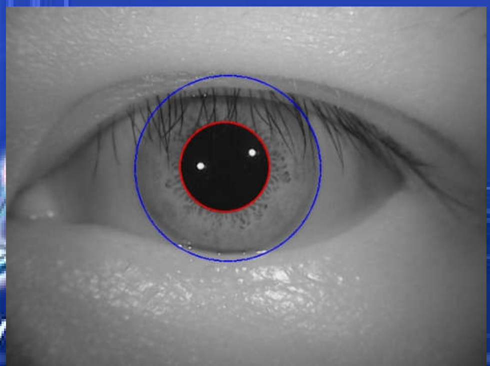
Risk of Fake Iris Attacks

Well-made eye model



Synthetic iris

Contact lens



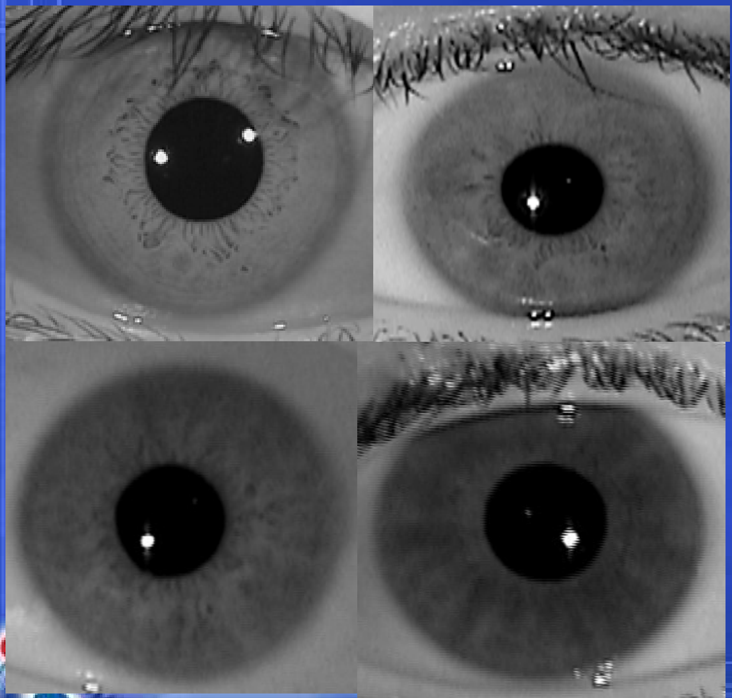
Video iris

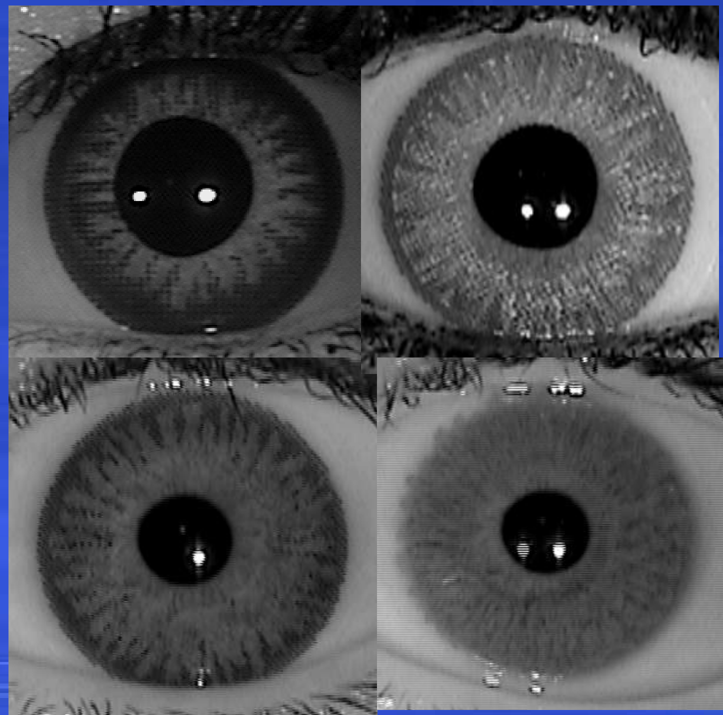
LCD iris

Printed iris

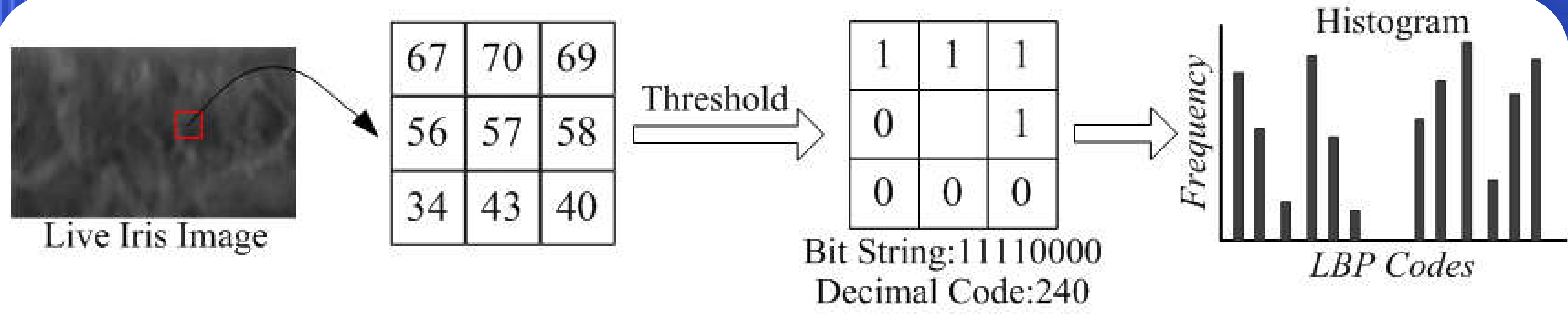
Iris liveness detection: a texture solution

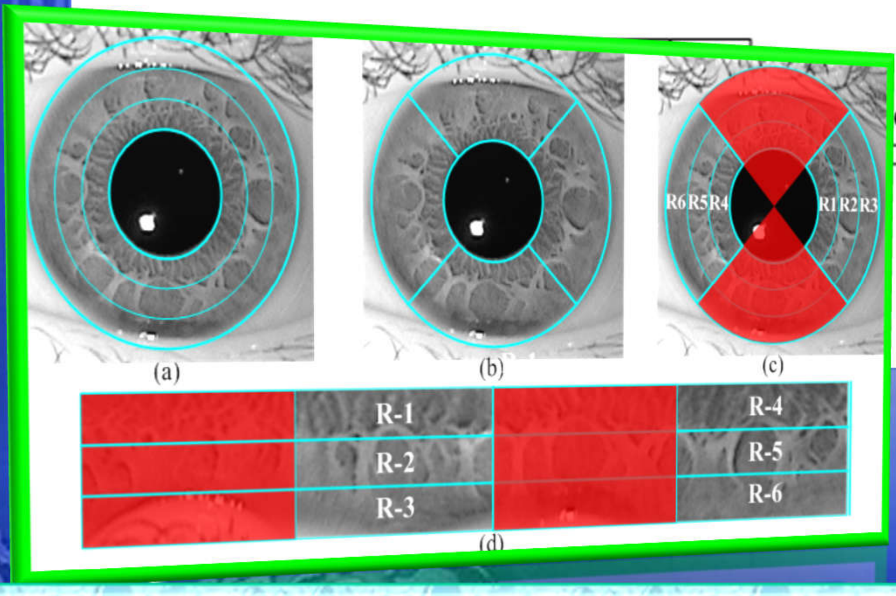
Smooth texture — Coarse texture

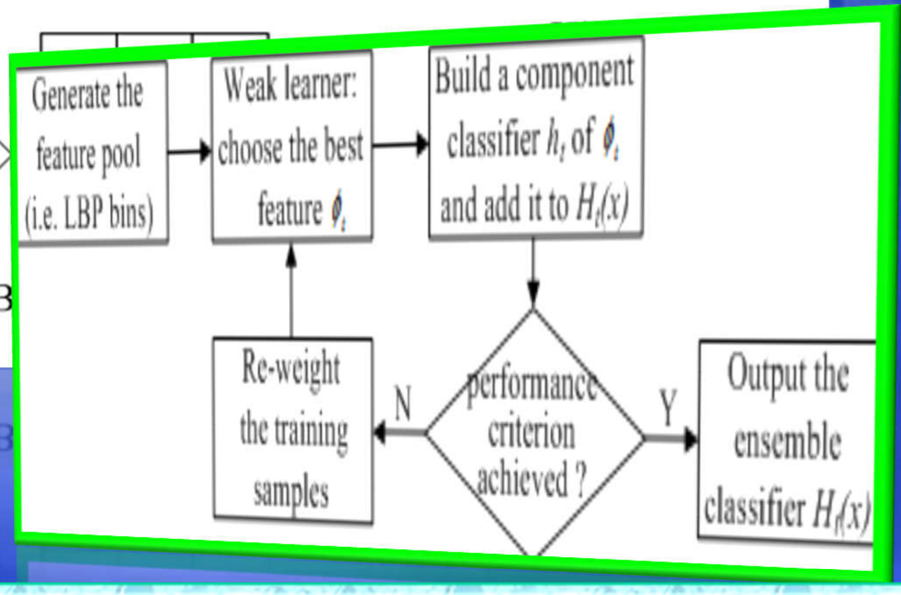




LBP+Boosting

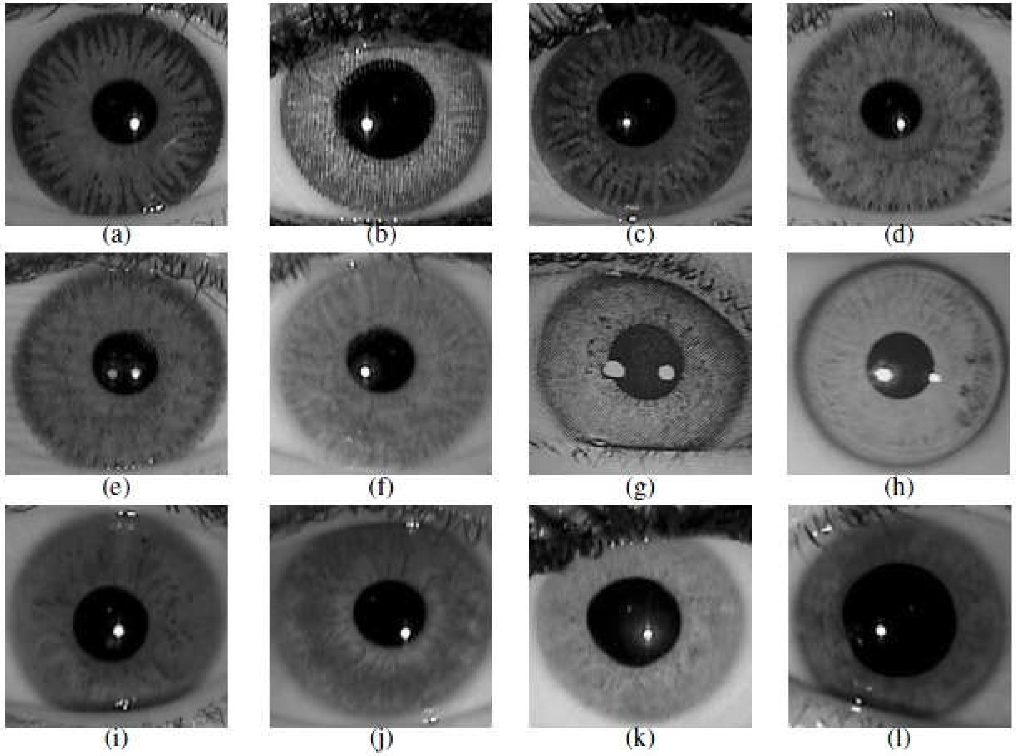






Iris Liveness Detection via Boosted Local Binary Patterns

Experimental results



Examples of training samples. (a)-(f): Contact lens wearing iris images. (g) Printed iris. (h) Glass eye. (i)-(l): Live iris images.

Training

- 300 fake iris images
- 6000 genuine iris images

Test

- 300 fake iris images
- 4000 genuine iris images

Algorithm	FAR (%)	FRR (%)	Speed(ms)
GLCM	4.33	6.84	230
Iris texton	3.67	6.91	340
LBP+Boosting	0.67	2.64	160

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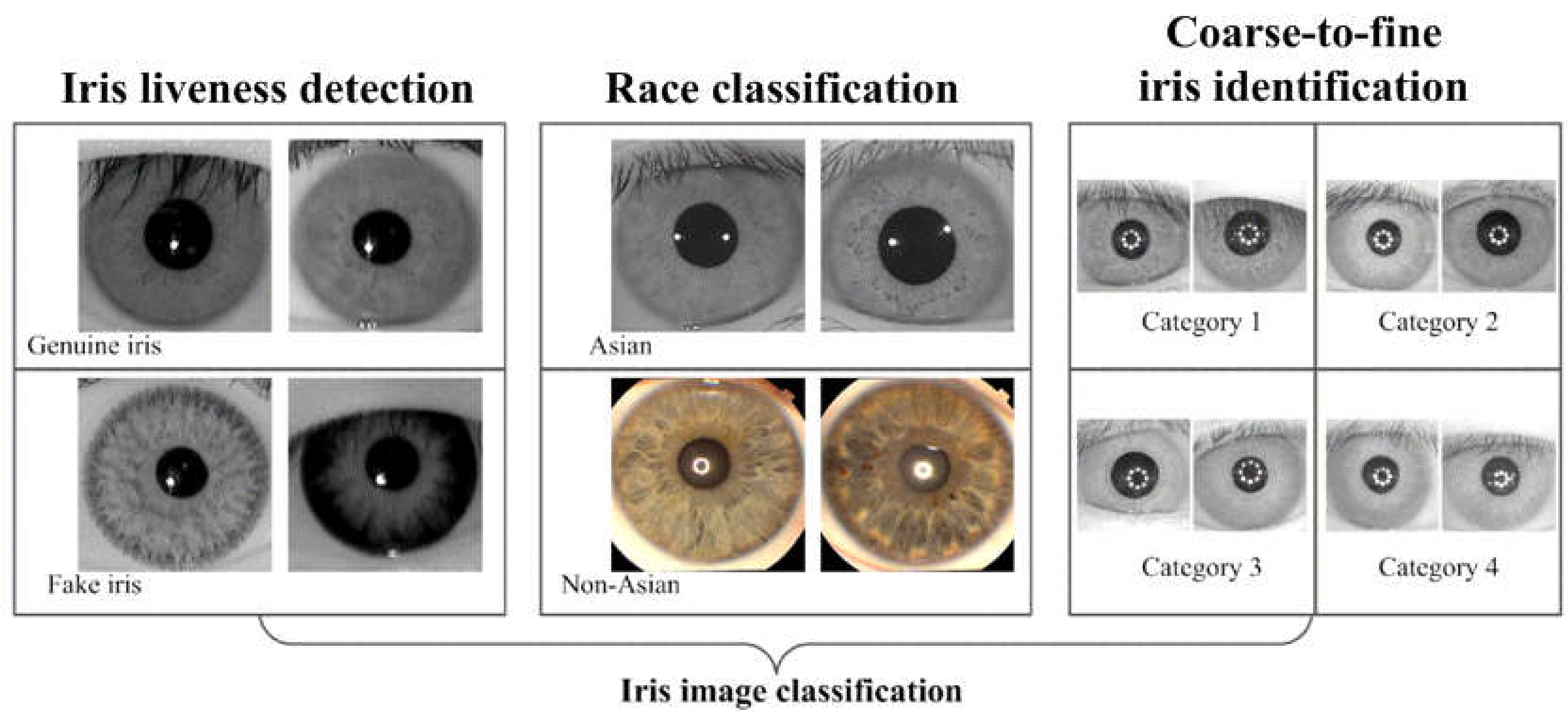
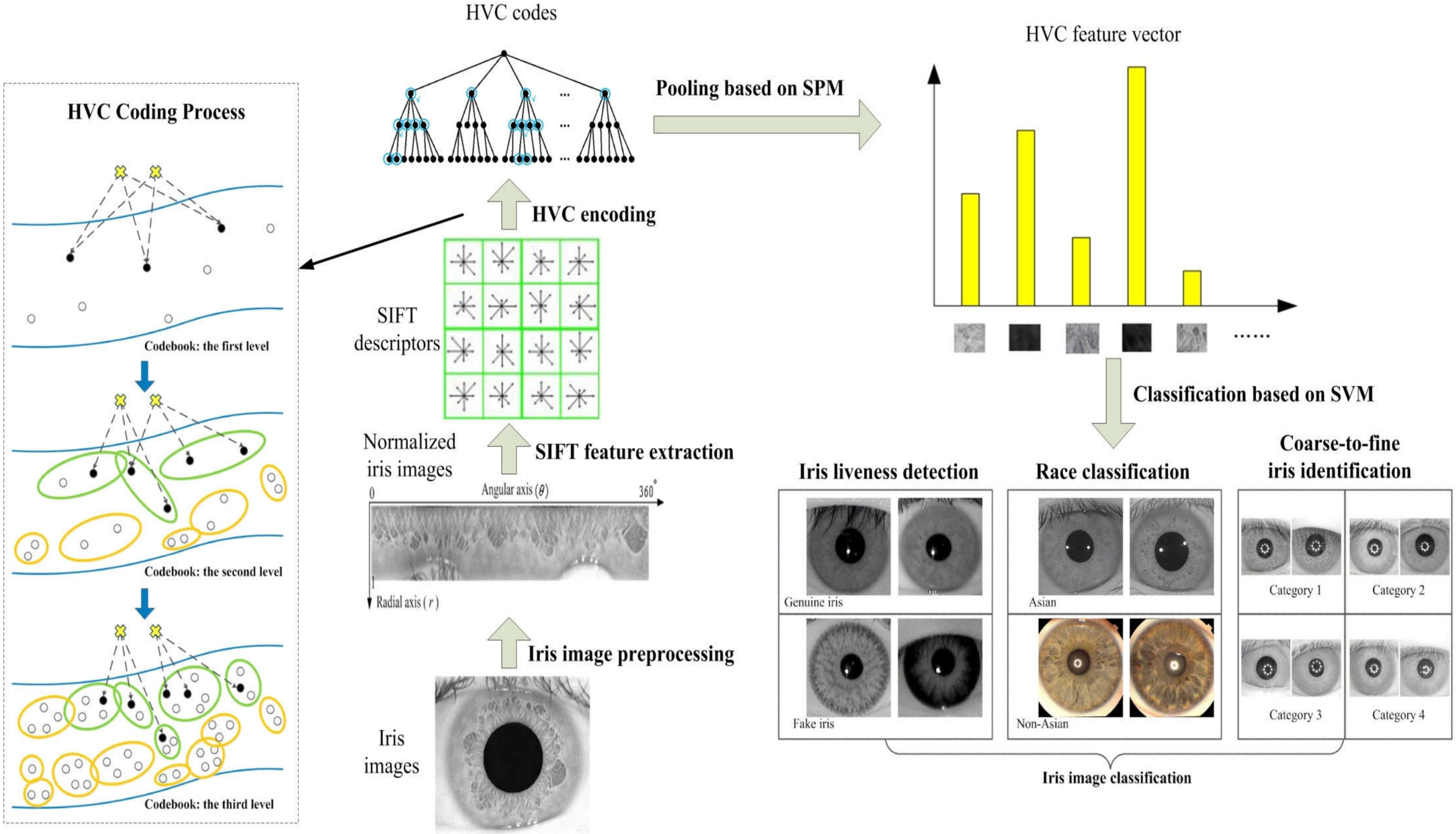
Iris image classification: one solution to multiple problems



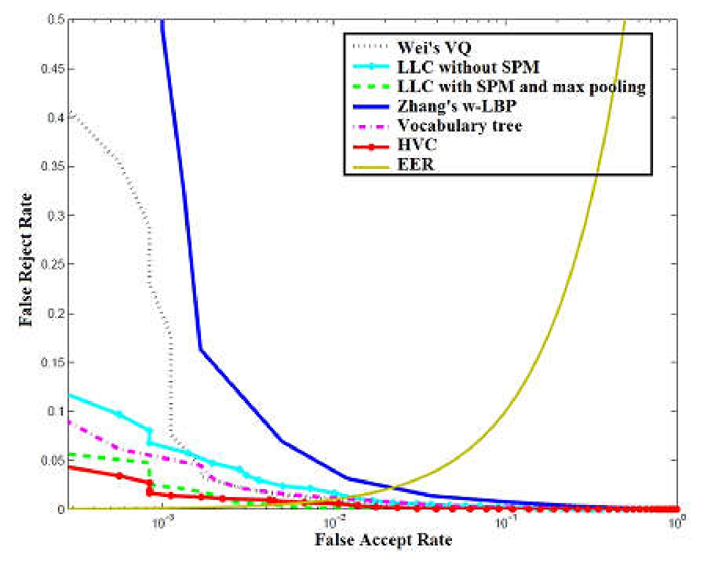
Iris image classification:

- Classify iris image into application specific category
- Different from iris recognition

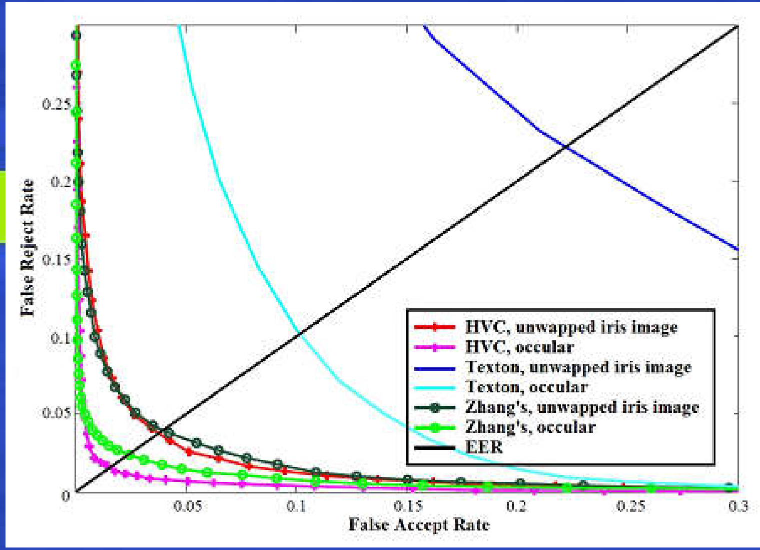
Iris Image Classification Based on Hierarchical Visual Codebook (HVC)



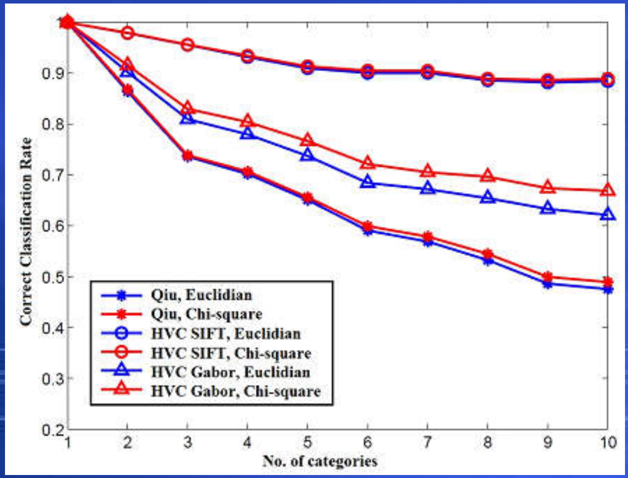
Experimental results



Iris liveness detection

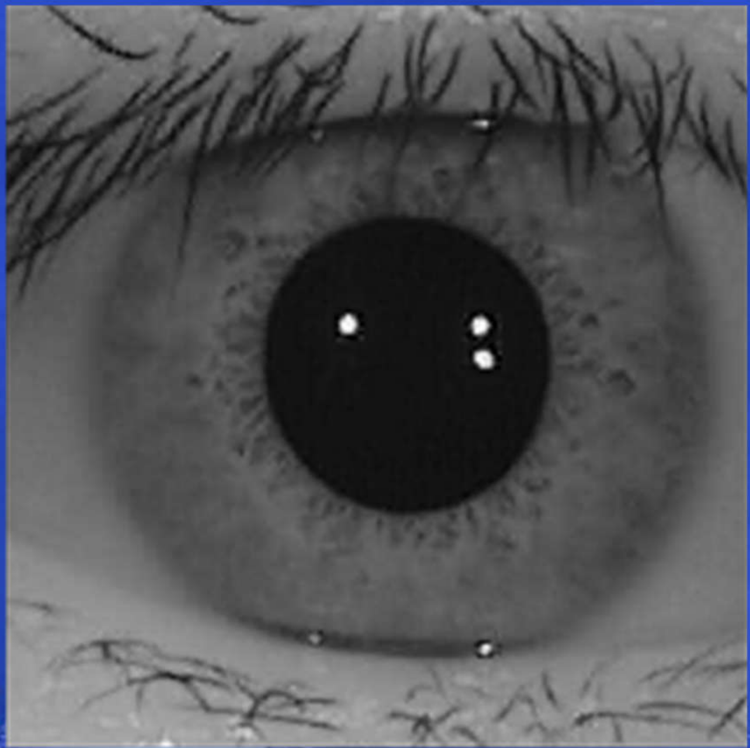


Race classification



Classification of iris images in large database

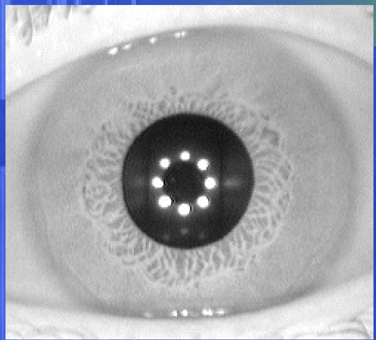
The success of race classification based on iris images indicates that an iris image is not only a phenotypic biological signature but also a genotypic biometric pattern.



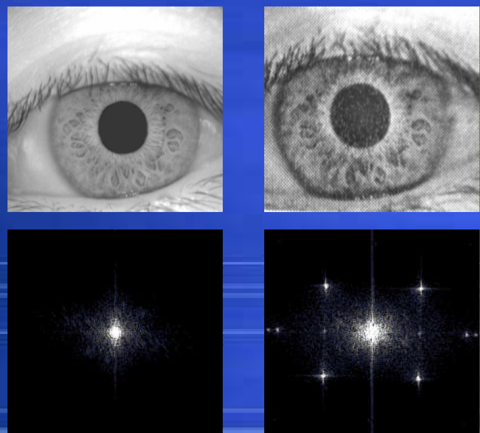
Asian

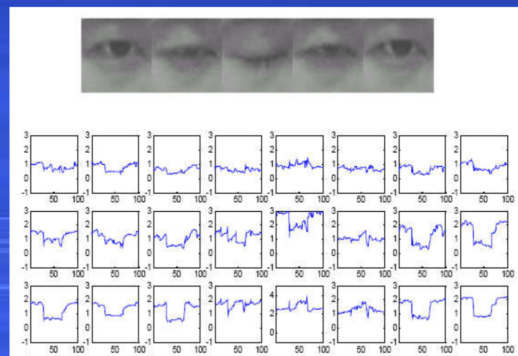
Non-Asian

Other possible ways for iris liveness detection



1. Spectrographic properties of physiological components of eye
2. Specular reflections caused light spots
3. Eyelid movement
4. Challenge-response
5. Facial features, head movement, body sway, etc.
6. Multi-biometrics





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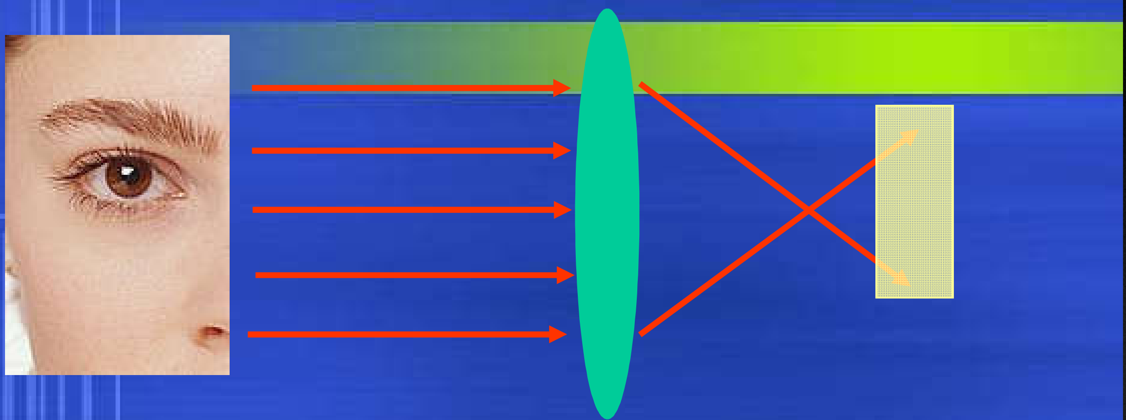
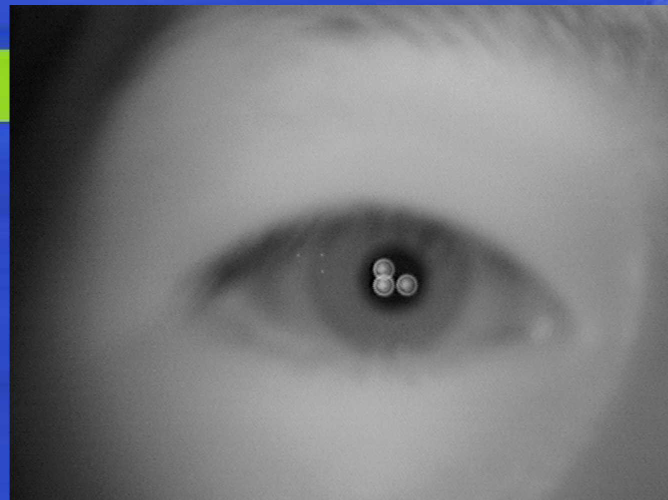
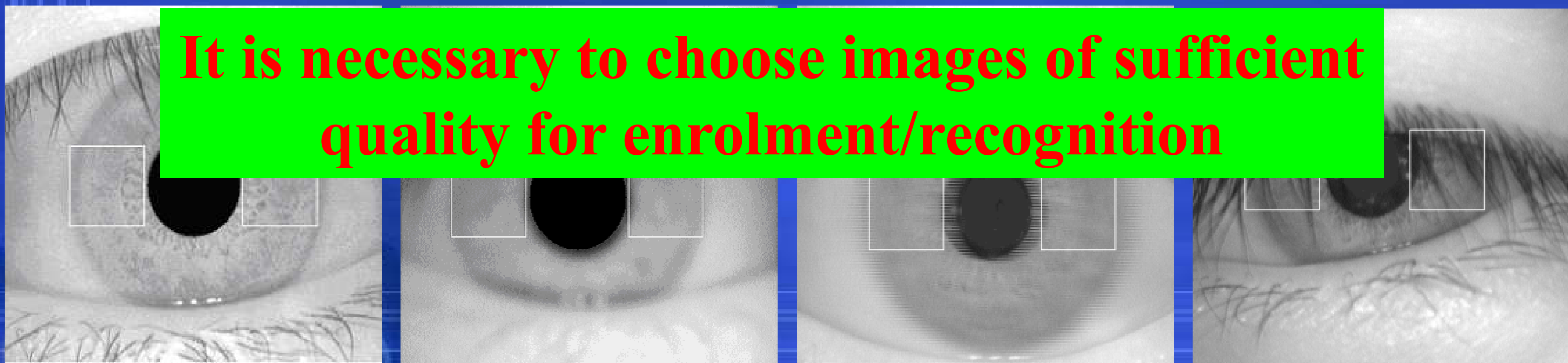
Iris image quality assessment



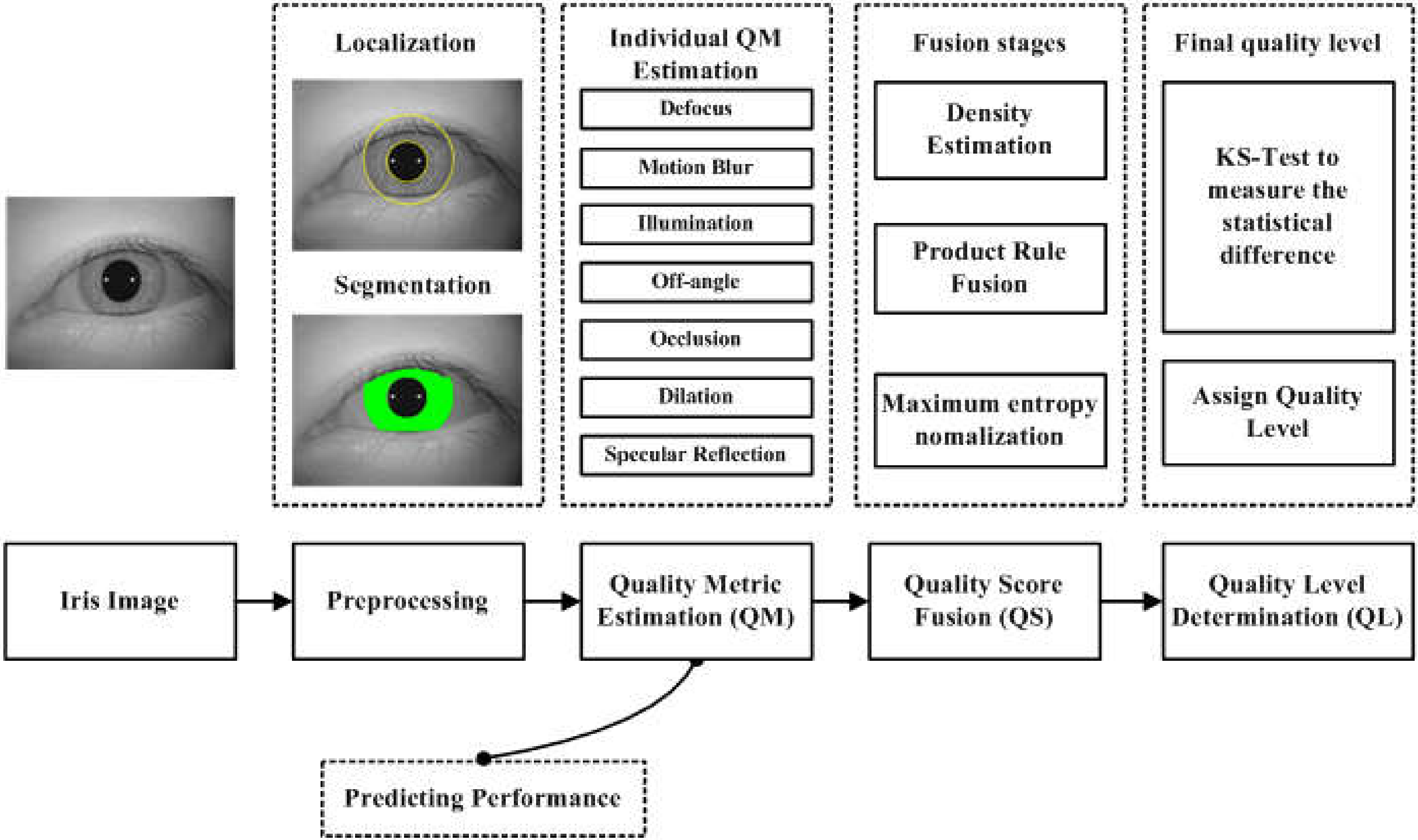




It is necessary to choose images of sufficient quality for enrolment/recognition

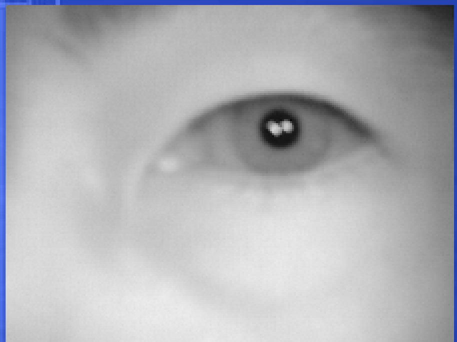
Clear | Defocused | Motion blurred | Occluded

A framework of iris image quality assessment (3Q model)

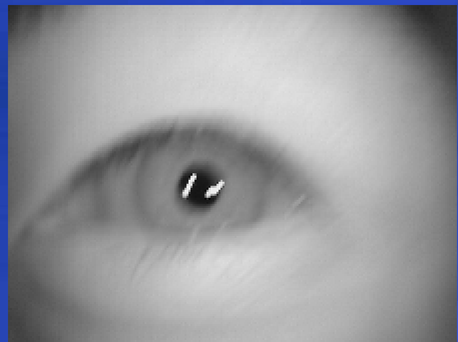


The first Q: quality metric estimation

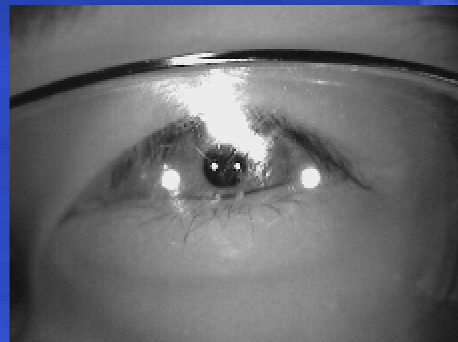
Defocus



Motion blur

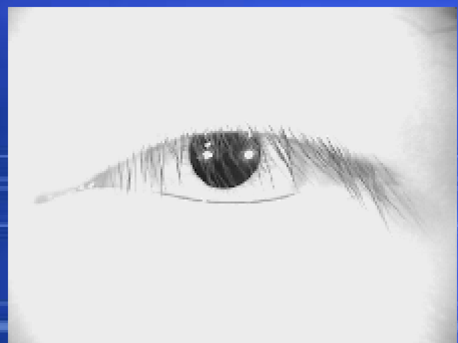


Valid area



Off-angle

Illumination

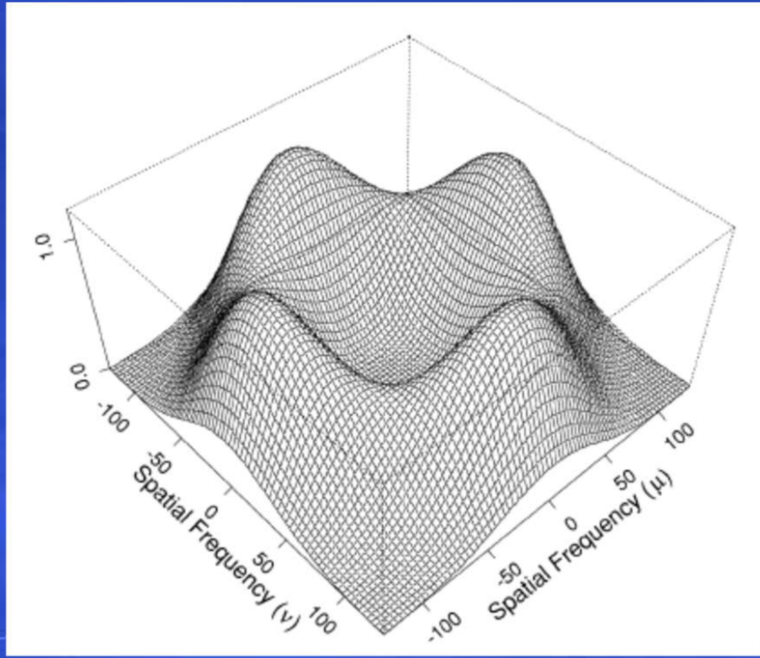


Dilation

Defocused blur assessment

- **Daugman：High-frequency power in the 2D Fourier spectrum**

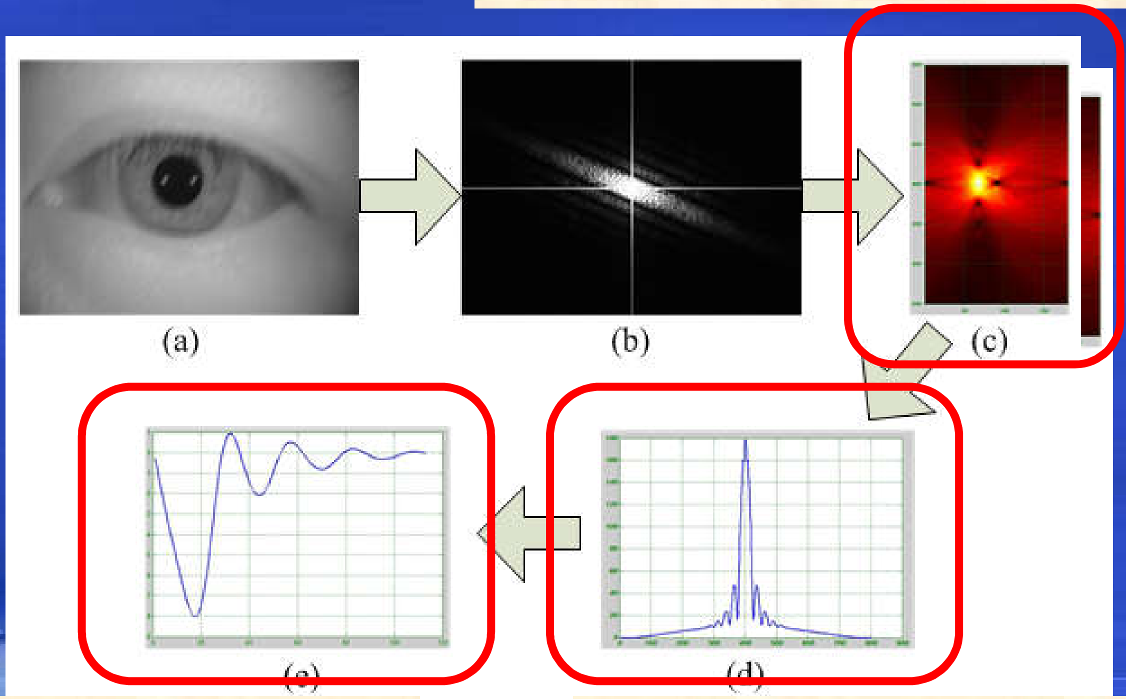
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1



J. Daugman. *How Iris Recognition Works*, IEEE Trans. on Circuits and Systems for Video Technology, vol. 14, no.1 pp. 21-30, (2004)

Motion blur estimation based on Radon transform

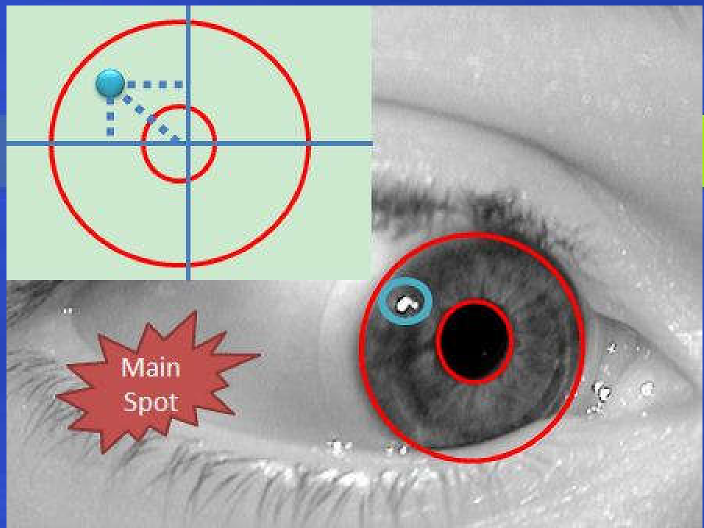
$$R_{p,\theta} = \iint_D f(x,y)\delta(P - x\cos\theta - y\sin\theta)\,dx\,dy$$



$$\hat{P} = \arg\min\{\frac{\partial R_{p,\hat{\theta}} * G_\sigma(r)}{\partial x} = 0\}$$

$$\hat{\Theta} = \arg\max_{\theta\in[0:180]}\{\int_0^{a\sin\theta + b\cos\theta} R_{p,\theta}\,dp\}$$

Off-angle iris image identification



Geometric Information

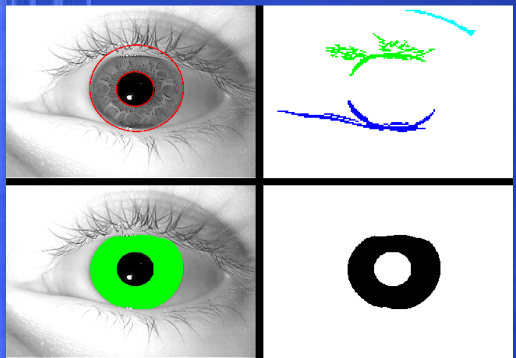
Classifier

Frontal iris images

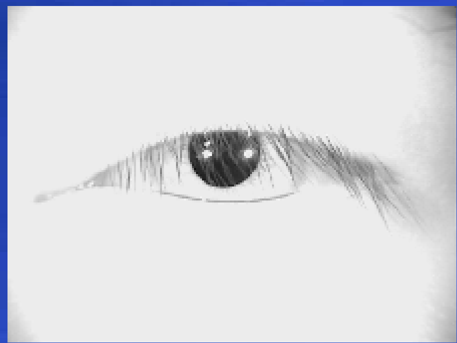
Off-angle iris images

Other quality metrics

Valid area



Illumination



Mean gray value in the valid iris region

Dilation

$$Q_{dilation} = \frac{IrisArea}{IrisArea + PupilArea}$$

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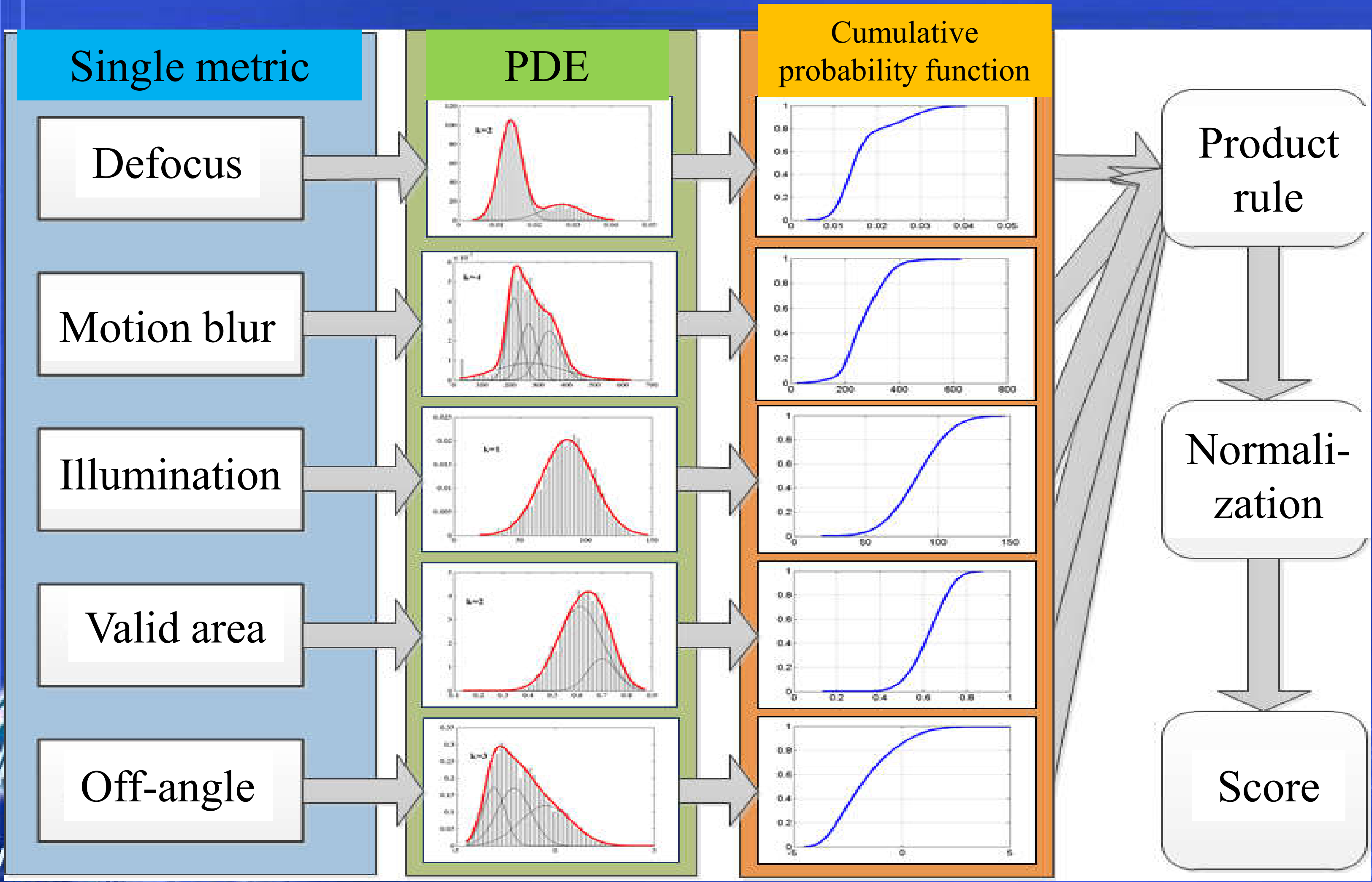
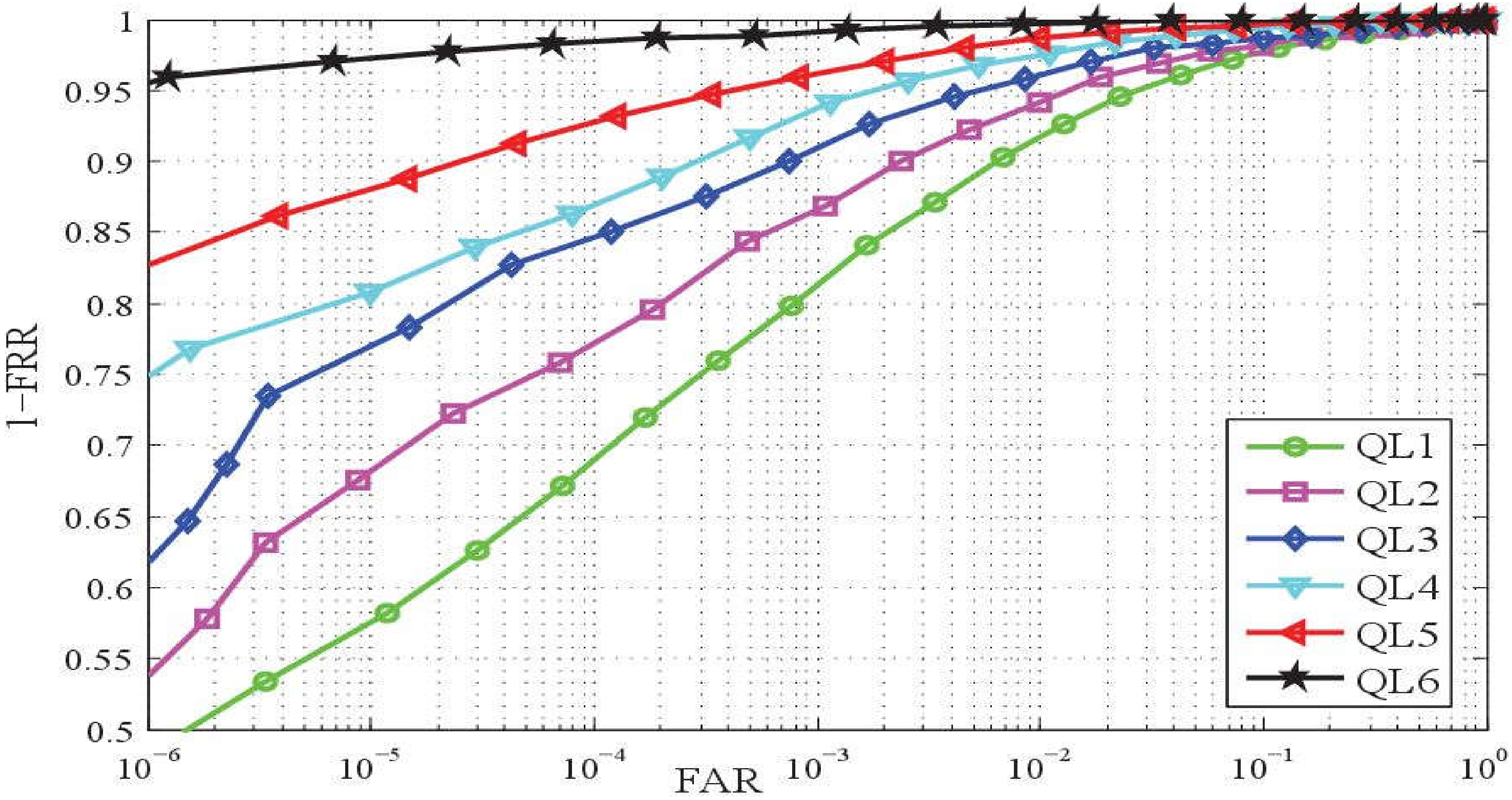
The second Q: quality score fusion from multiple metrics



The third Q: quality level determination

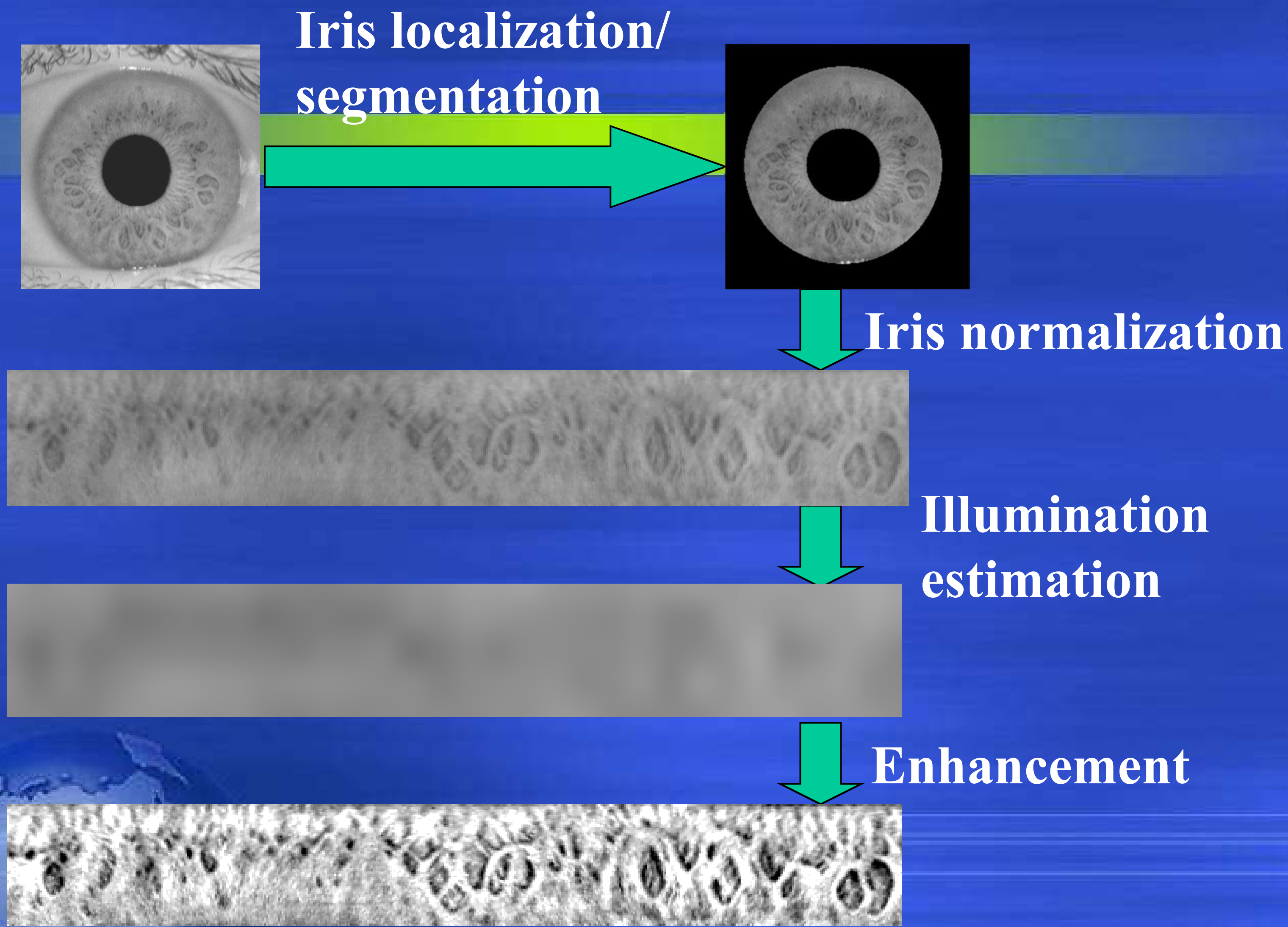
Iris recognition performance as a function of QL on the CASIA database



Applications of iris image quality assessment

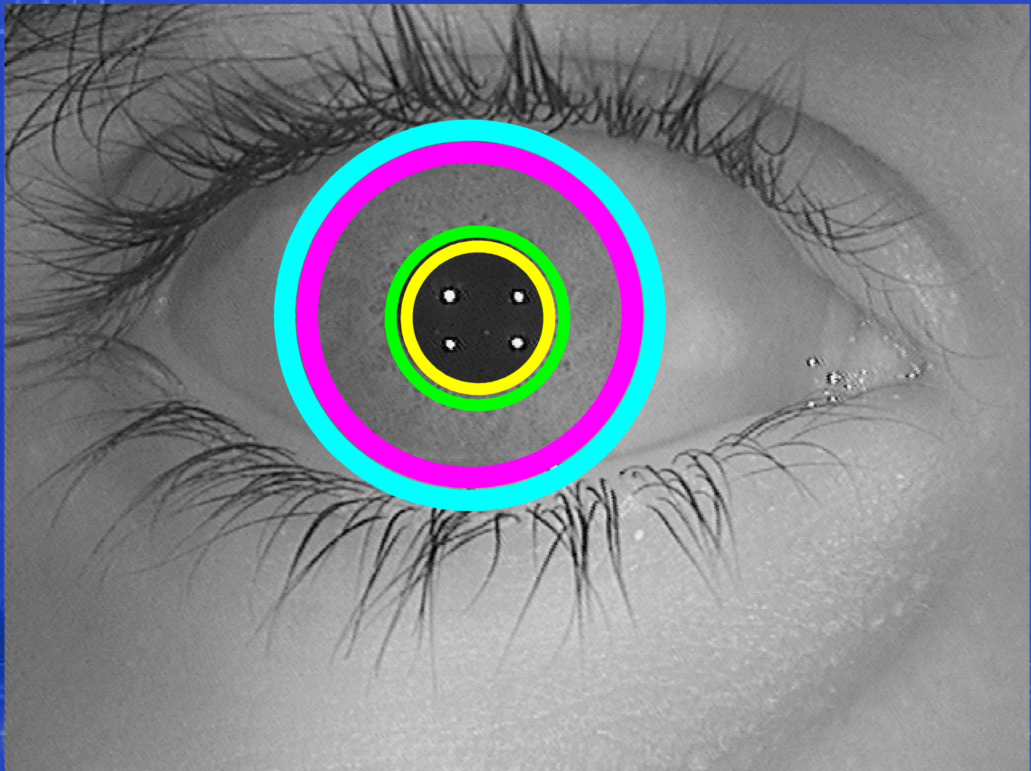
- Prediction of iris recognition performance
- Design of adaptive iris recognition algorithms
- Smart interface of iris devices
- ……

Iris image preprocessing



Iris localization

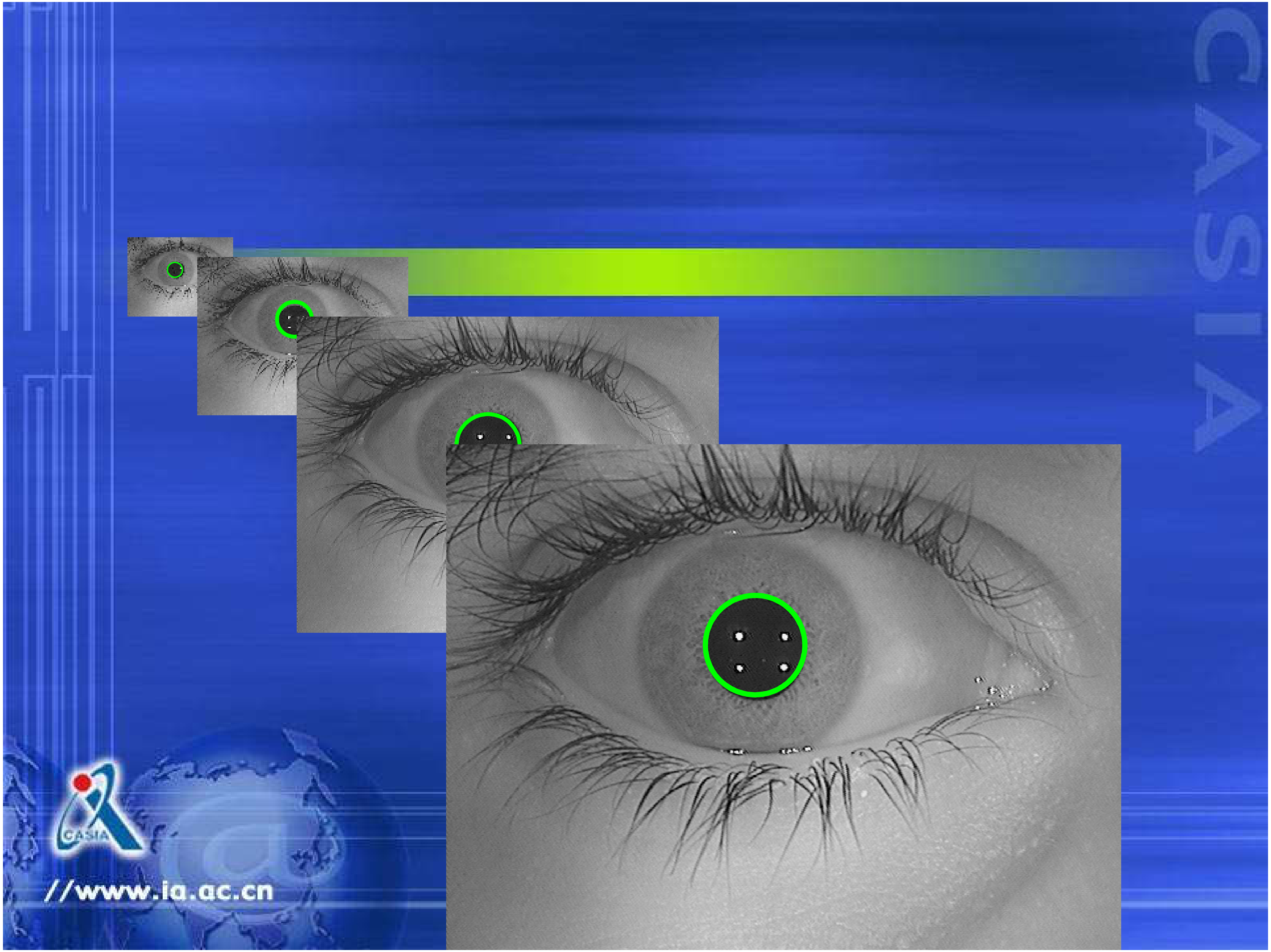
—Daugman's algorithm—



Integral-differential operator

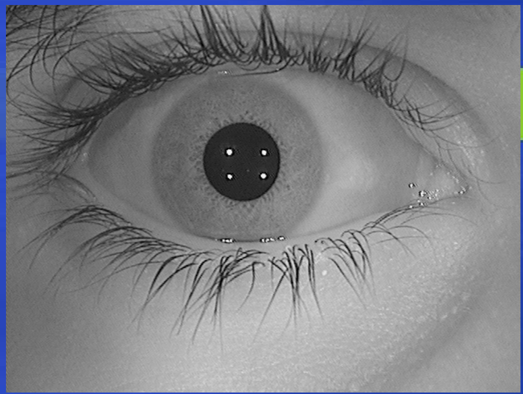
$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r,x_0,y_0} \frac{I(x,y)}{2\pi r} ds \right|$$

Coarse to fine strategy

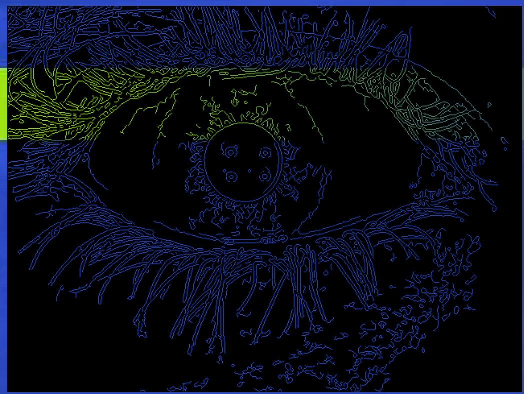

CASIA
//www.ia.ac.cn

Iris localization

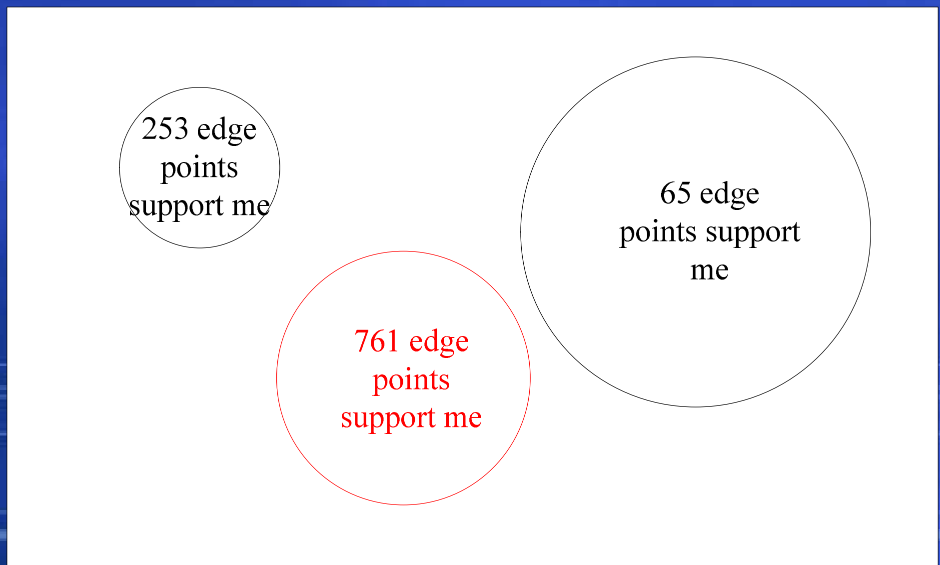
—Wildes' algorithm—



Edge detection



Hough transform



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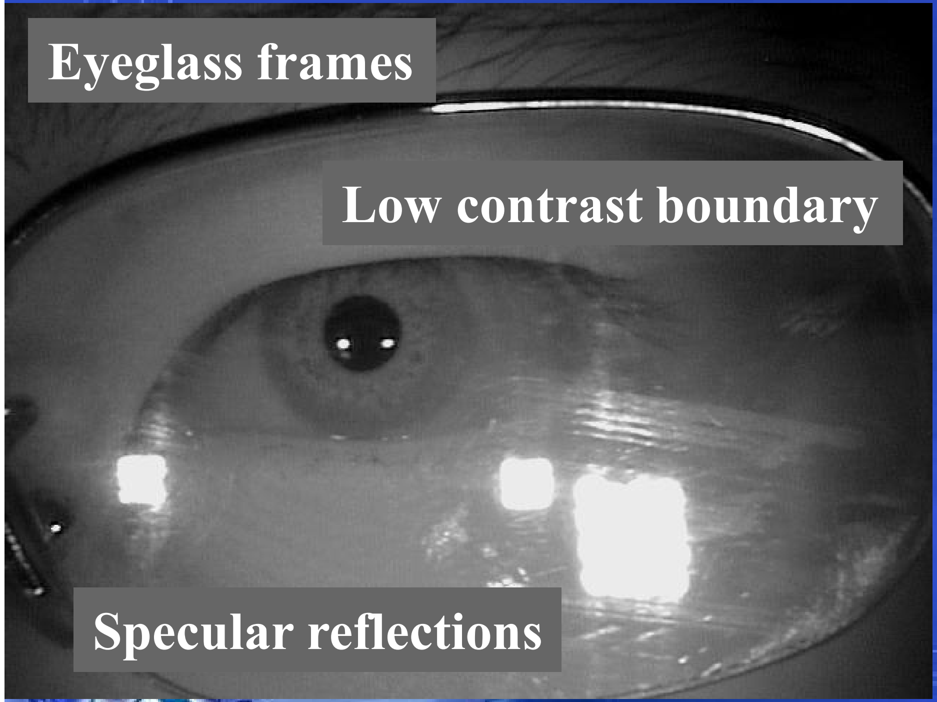
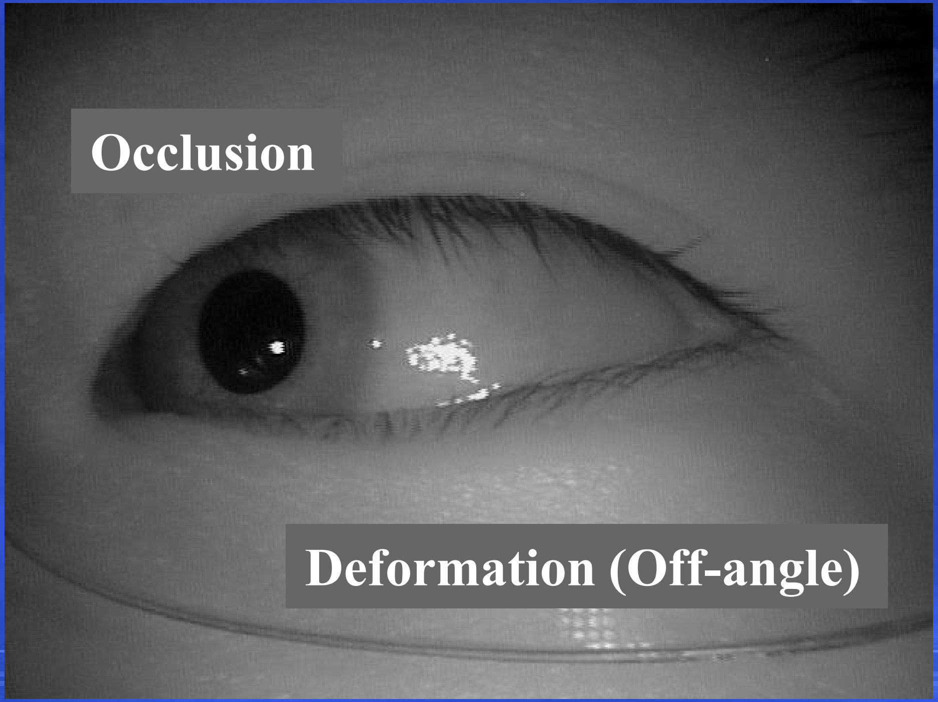
The main challenges of iris image segmentation





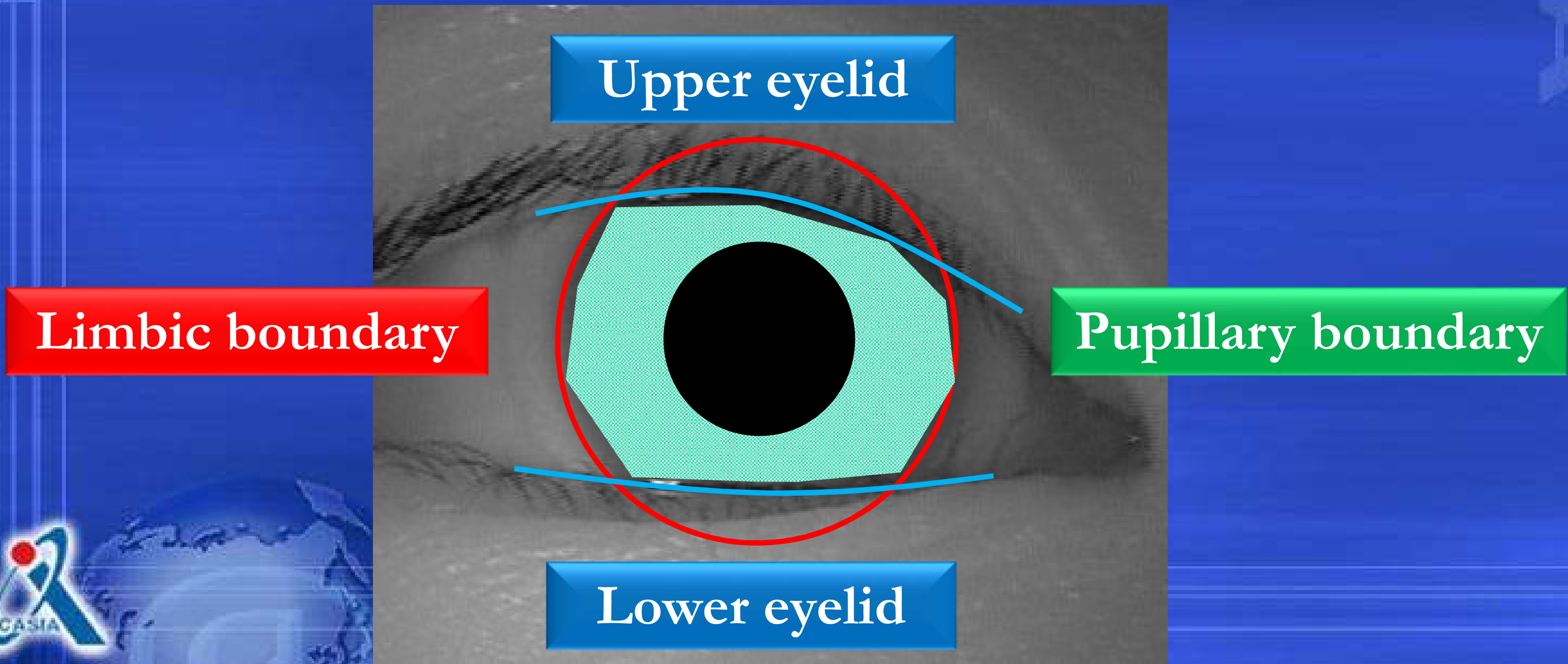
Related works

Region Based Methods

Pixel classification (Proença, TPAMI'10)
Pixel clustering (Tan, IVC'10)

Edge Based Methods

Integrodifferential operator (Daugman, TCSVT'04)
Hough transform (Wildes, Proc. of IEEE'97)
Active contours (Shah and Ross, TIFS'09)
Pulling and pushing (He, Tan et al., TPAMI'09)



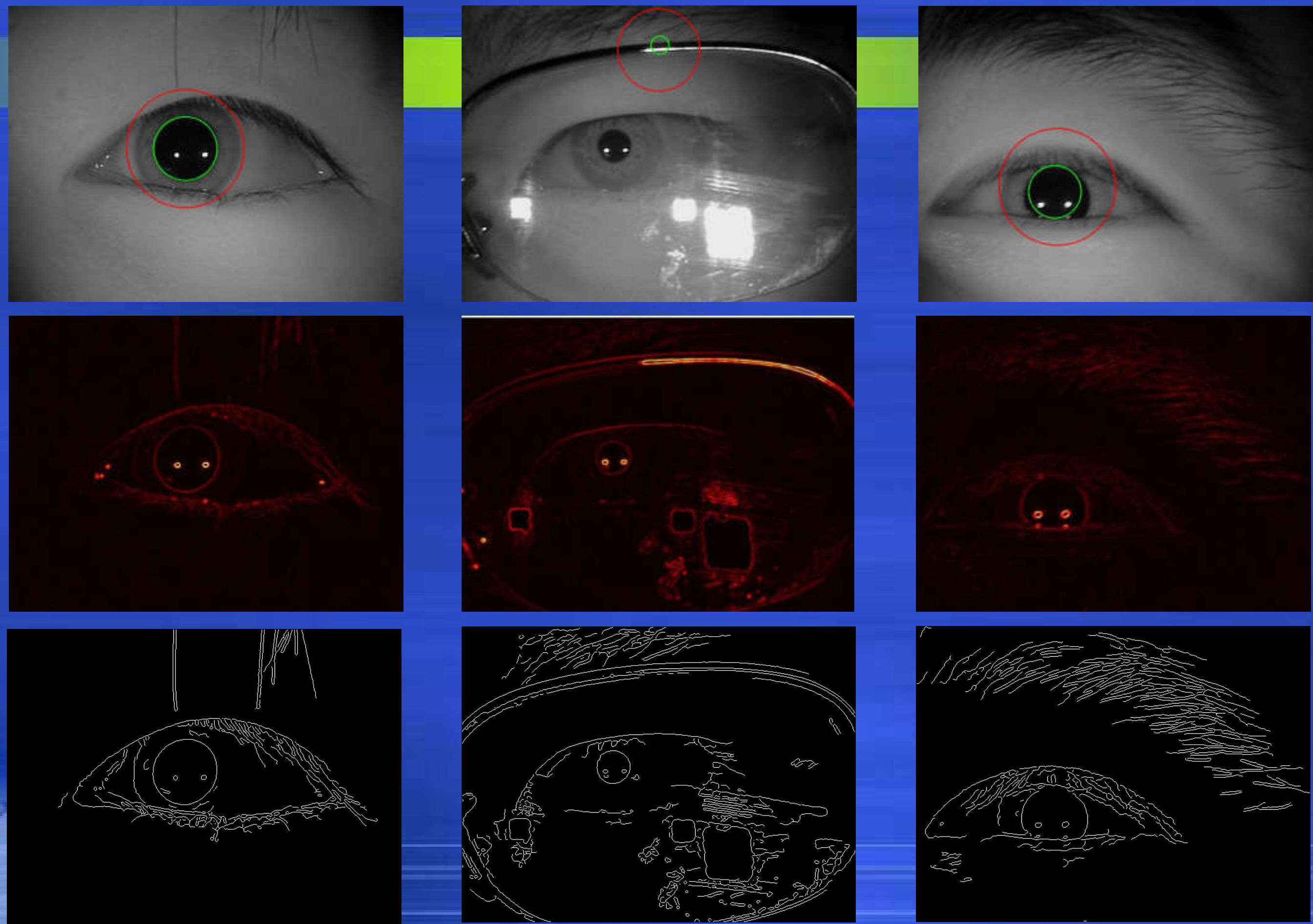
The main problems of edge based methods

Unclear boundary | Eyeglasses | Occlusion

Original

Gradient

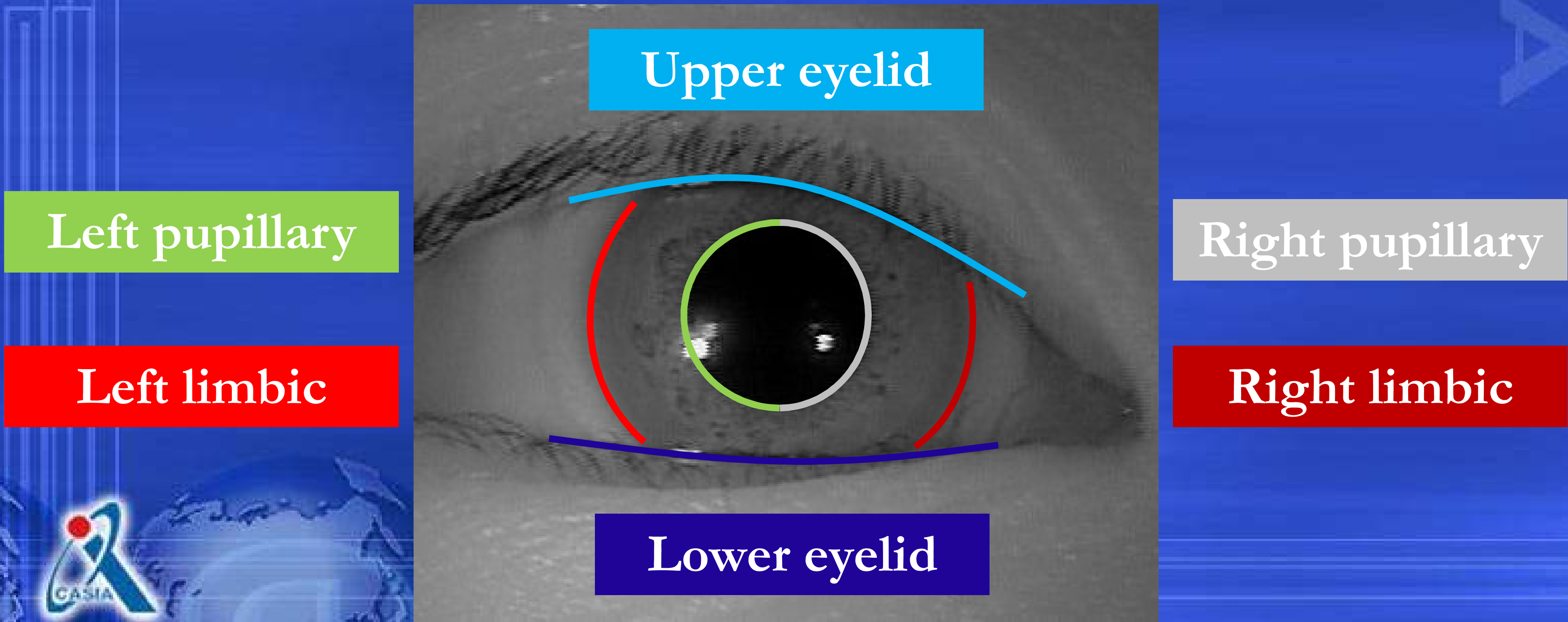
Canny edge



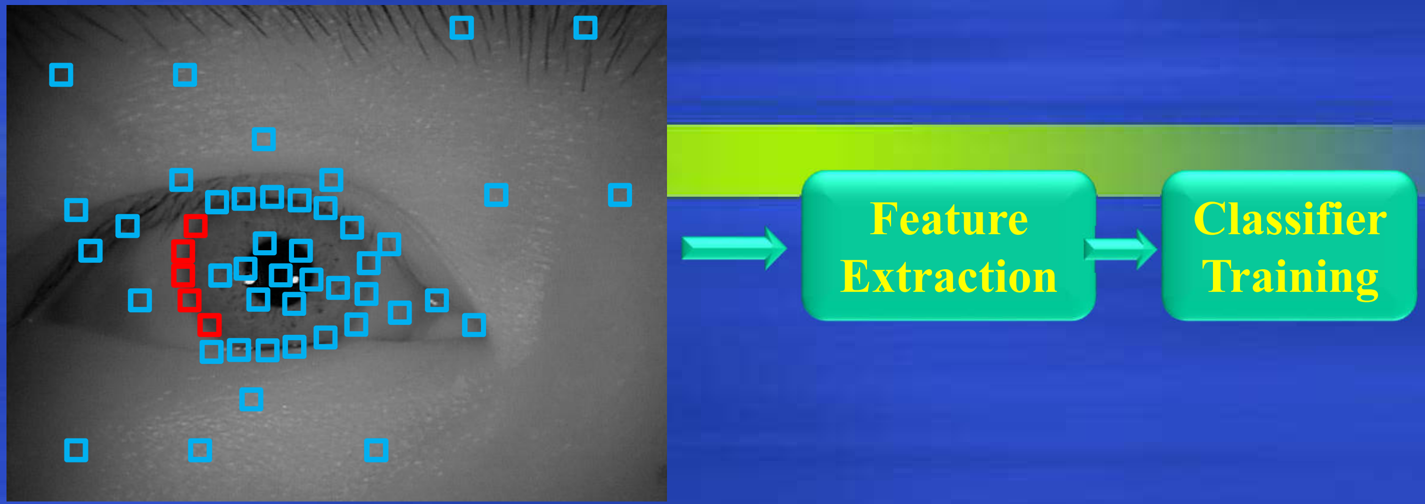
How to identify the edges on the iris boundaries ?

Our solution: specific edge detectors only sensitive to the edge points on iris boundaries

Learned Boundary Detectors (LBDs)
Main idea: **Generic** to **Specific** edge detector



Machine learning of the feature representations of iris boundary specific edge detectors



Patch size: 17*17

Features

- **Intensity:** mean, variance;
- **Gradient (x and y):** mean, variance
- **Structure:** Haar-like

  at multiple locations, scales and aspect ratios

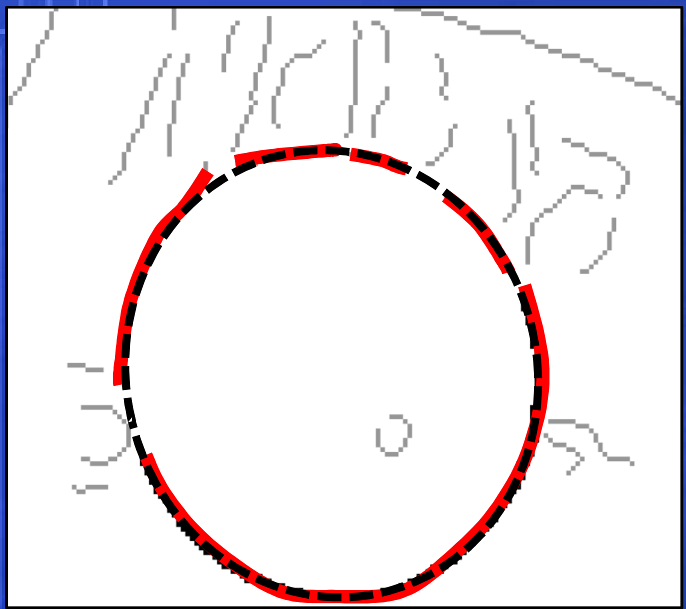
} 14091 features in total

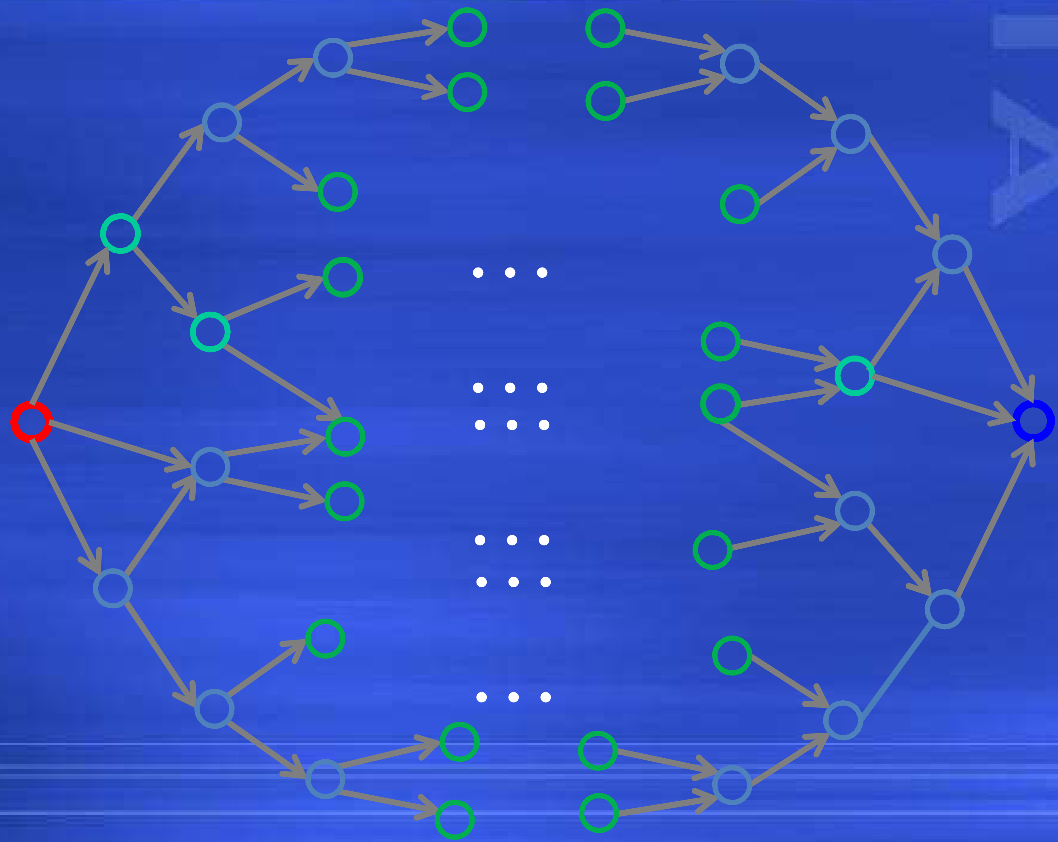
Integer intensities

All features can be computed efficiently

Contour connection based on energy minimization

$$c = w_{LBD}c_{LBD} + w_d c_d + w_\theta c_\theta$$





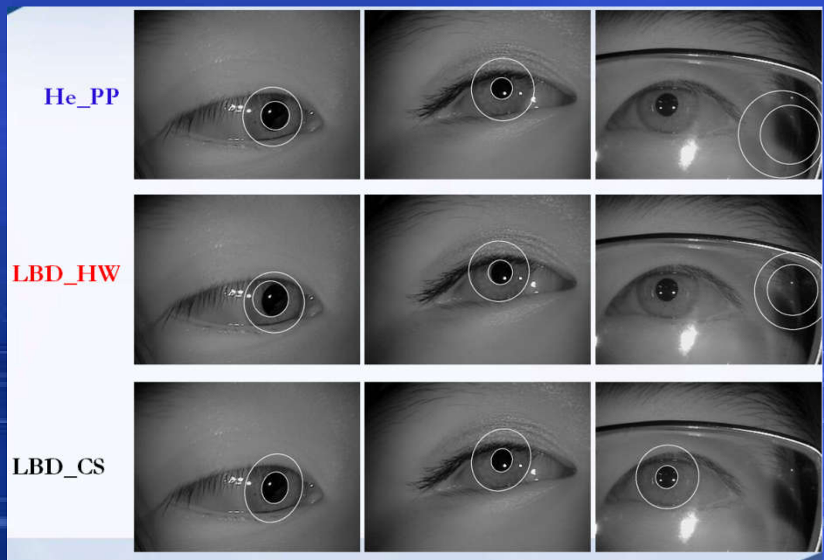
Performance of iris localization

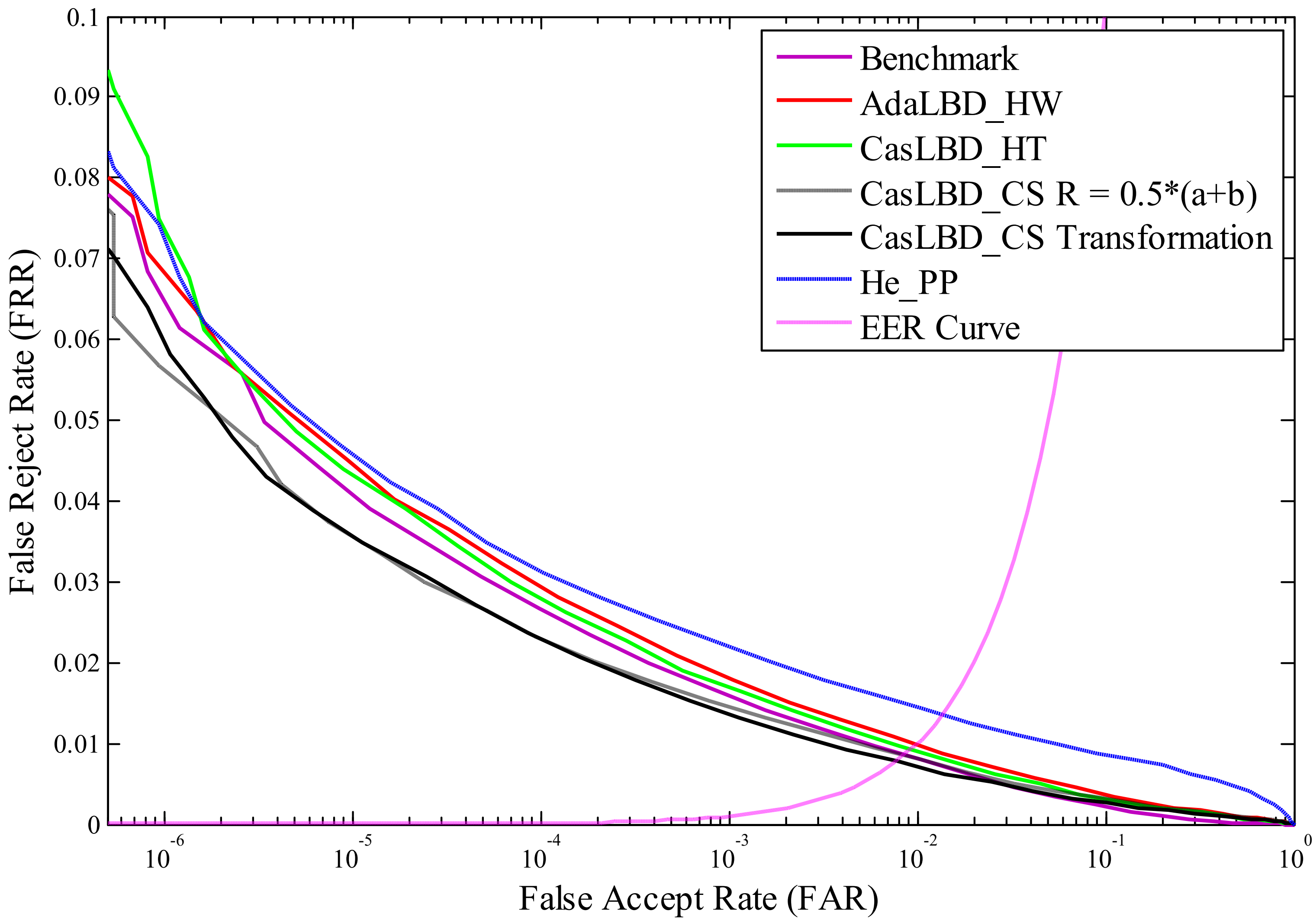
CASIA-Iris-Thousand: 20,000 iris images from 2,000 eyes of 1,000 persons.

Accuracy Rate:

$$AR(DR \le Th) = \frac{1}{N}\sum_{n=1}^{N}\delta(DR_n \le Th)$$

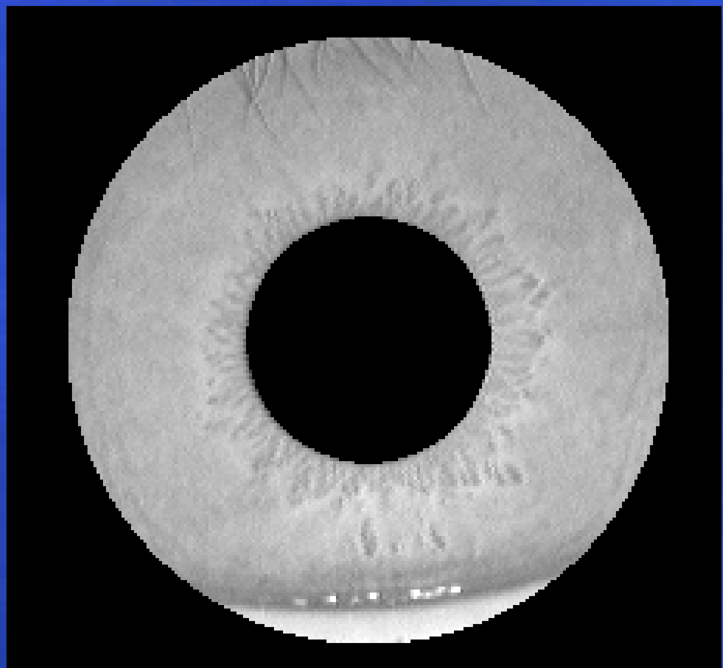
He_PP (He, Tan et al. TPAMI 2009)	**95.30%**
CasLBD_HT (Cascaded LBDs + Hough Transform; ICB 2012)	99.13%
CasLBD_CS (Cascaded LBDs + Contour Segments; ICPR 2012)	99.28%



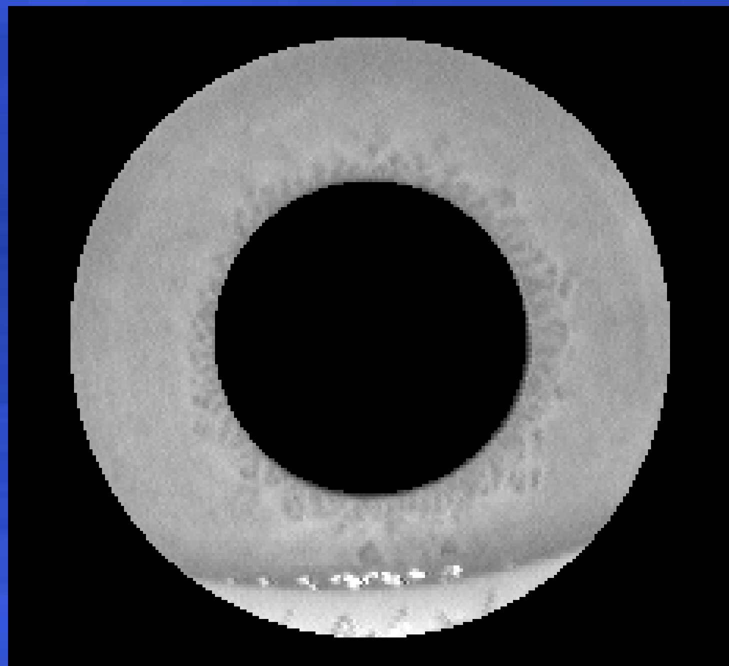


Benchmark
AdaLBD_HW
CasLBD_HT
CasLBD_CS R = 0.5*(a+b)
CasLBD_CS Transformation
He_PP
EER Curve
False Reject Rate (FRR)
False Accept Rate (FAR)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0

Nonlinear iris deformation

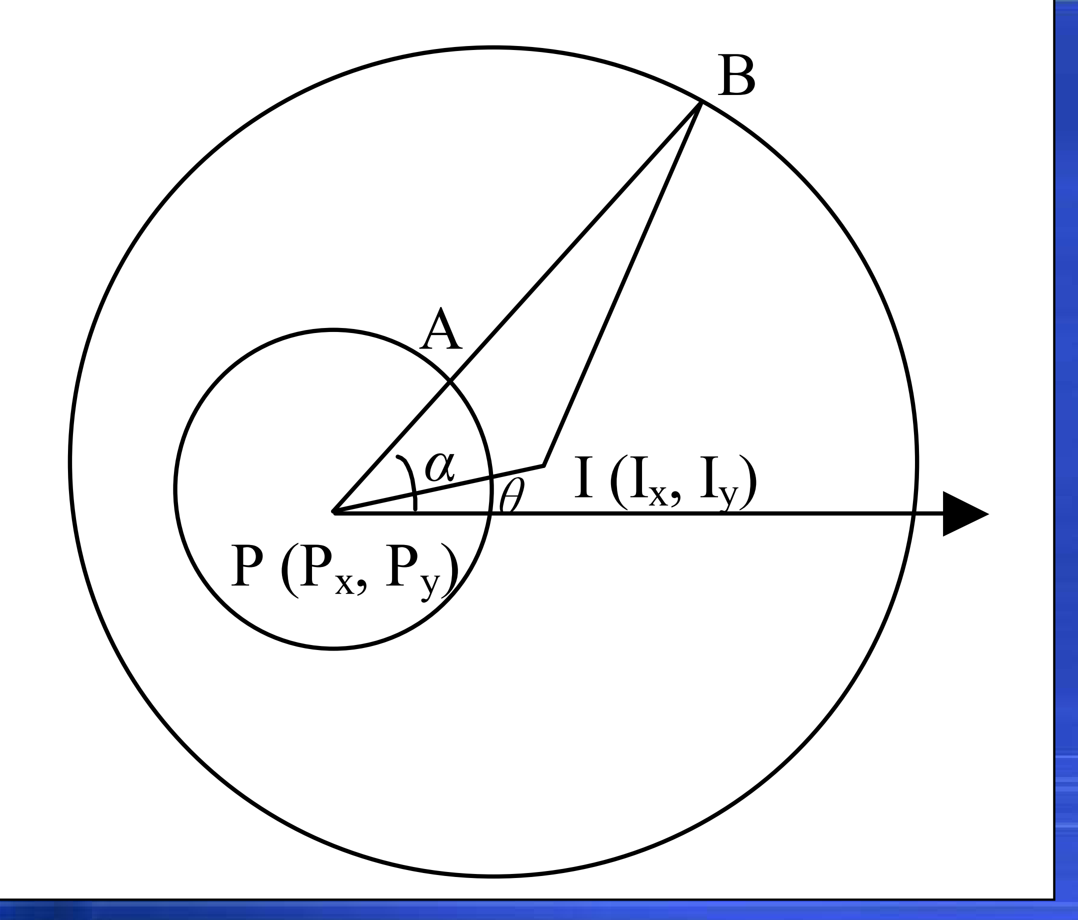


Normal illumination



Weak illumination

Iris normalization



Iris normalization model

Linear mapping model：

$$f(x) = \frac{R}{r}x$$

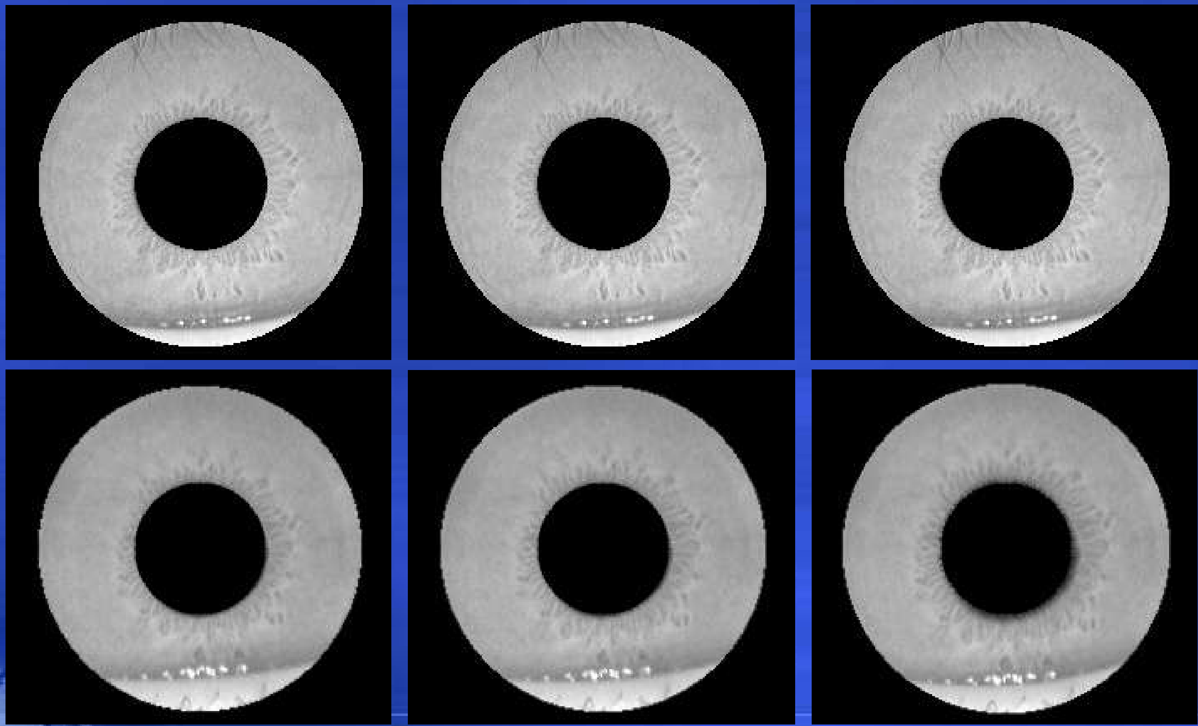
Piecewise-linear mapping model：

$$f(x) = \begin{cases} \dfrac{nkR + (1-k)(R-r)}{nkr}x & x \in [0, kr] \\ \dfrac{R-r}{n} + \dfrac{nR-(R-r)}{nr}x & x \in (kr, r] \end{cases}$$

Nonlinear mapping：

$$f(x) = \frac{R-br}{\ln(ar+1)}\ln(ax+1) + bx$$

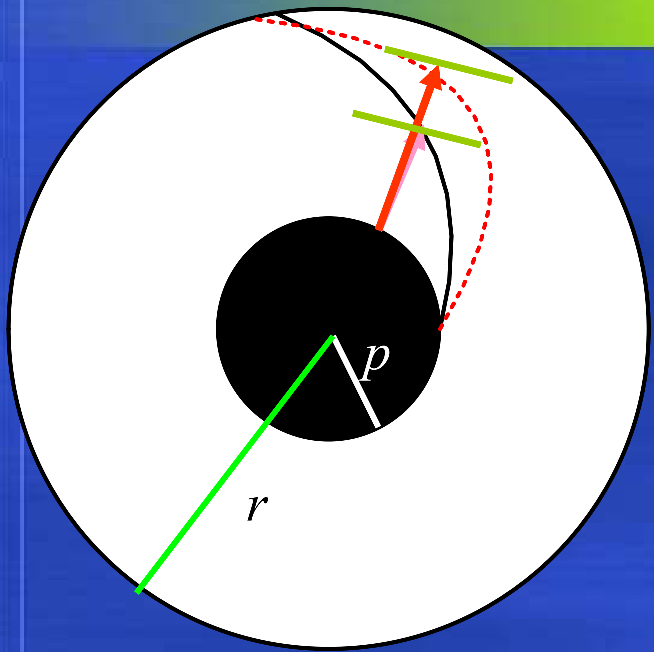
Iris normalization results



Linear Piecewise-linear Nonlinear

Nonlinear iris deformation correction

(In Harry J. Wyatt's work: A 'minimum-wear-and-tear' meshwork for the iris)



A point in any position of iris region can be described as:

$$R_{nonlinear} = R_{linear} + \square R(p,r)$$

R_{linear} Linear stretch position

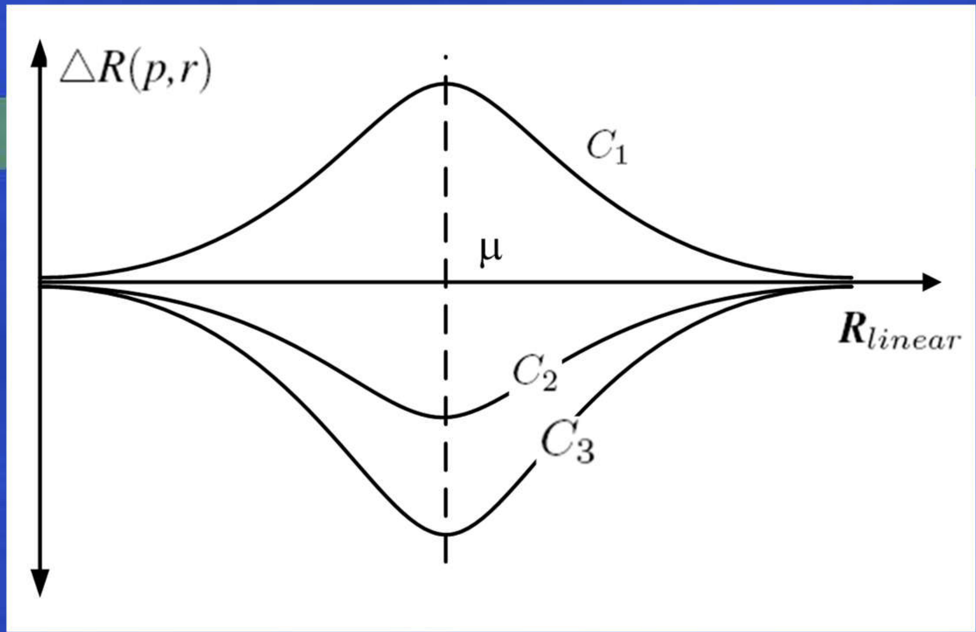
$R_{nonlinear}$ Nonlinear stretch position

$\square R(p,r)$ Additive item

Iris linear stretch

Iris nonlinear stretch

Our solution: Gaussian function to model the additive component

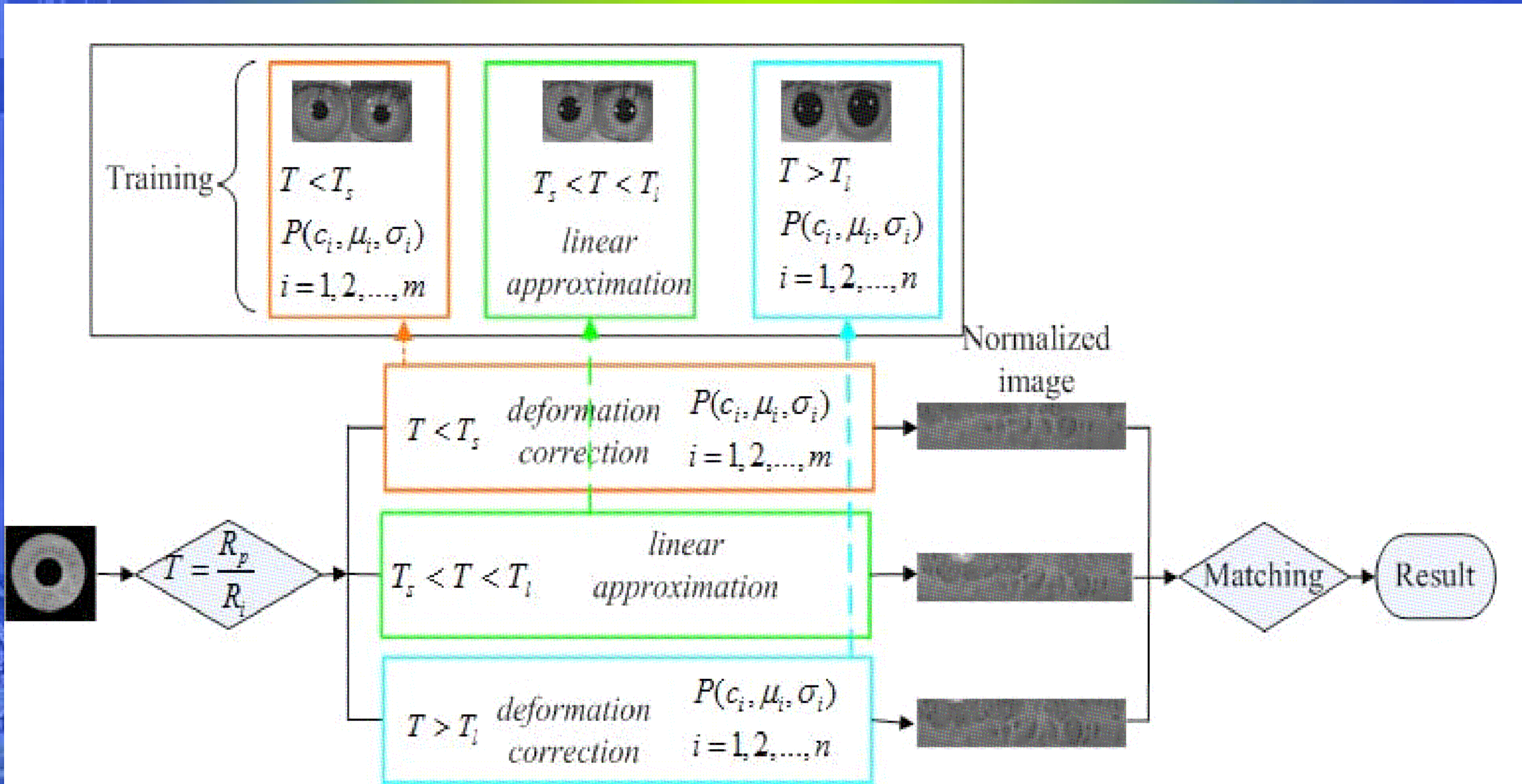


$$\Delta R = C \times \exp[-\frac{1}{2} \times \frac{(R_{linear} - \mu)^2}{\sigma^2}]$$

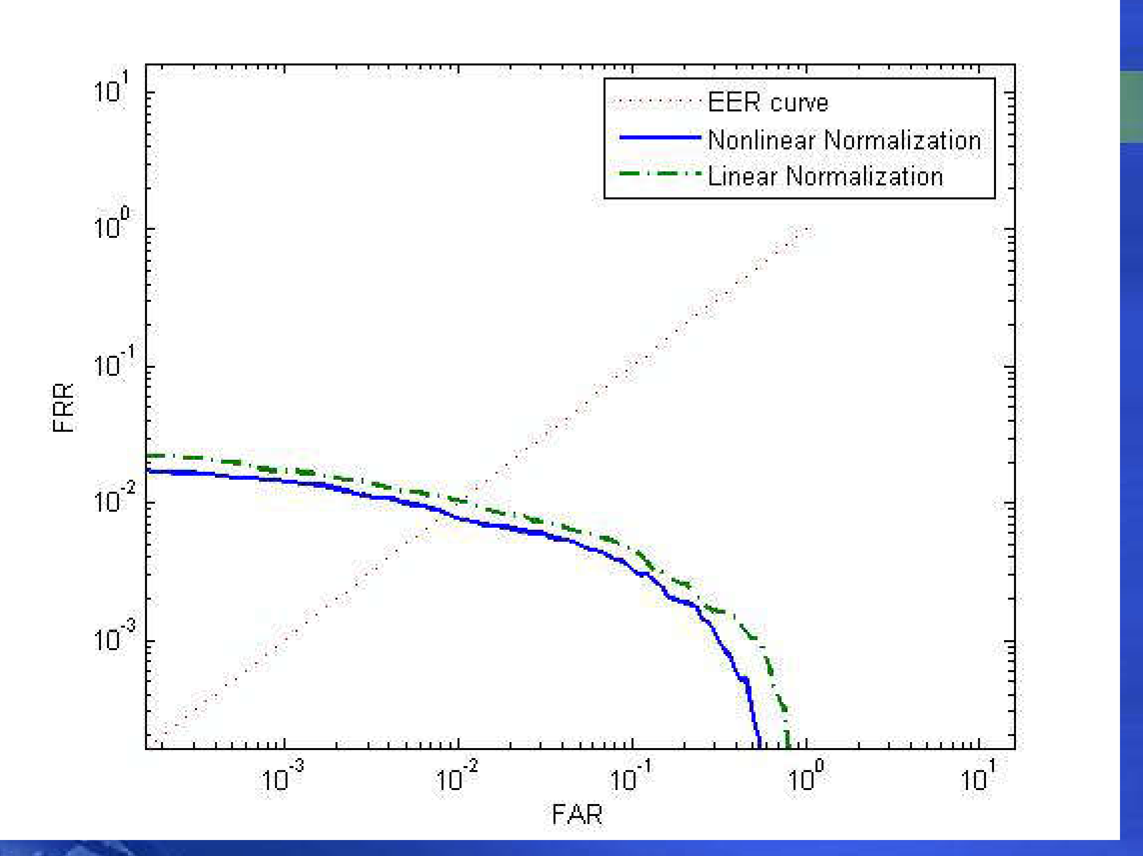
$$C = \lambda - \frac{p}{r}$$

where λ is the standard ratio of pupil radius per iris radius

Flowchart of nonlinear iris deformation correction



Recognition using different normalization methods



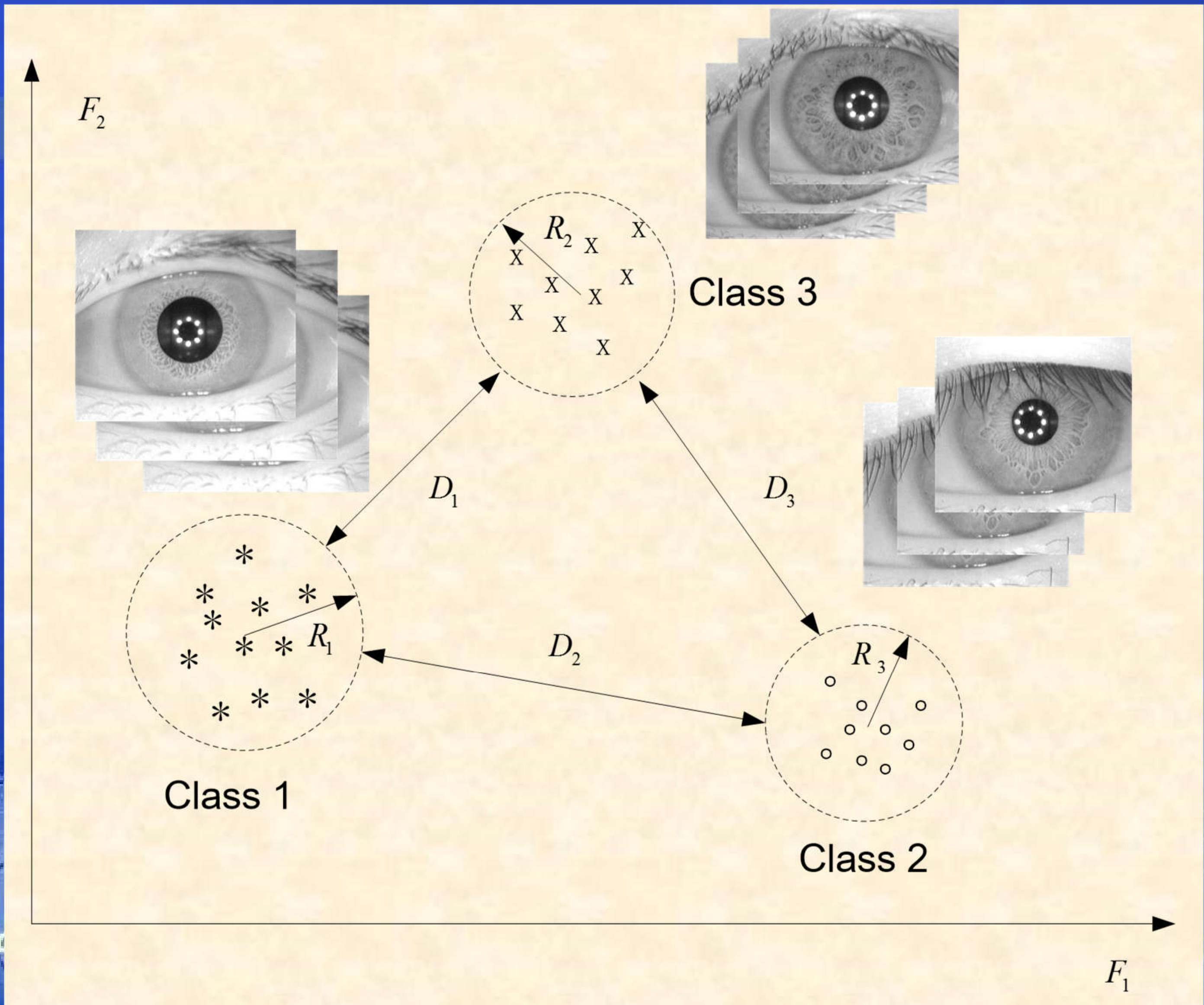
	EER	Discri Index	Time (s)
Linear	1.0585%	4.7094	0.0862
Nonlinear	0.85067%	4.9913	0.0693

use look-up-table

Outline of Talk

- Preamble
- Iris image acquisition
- Iris image preprocessing
- **Iris pattern recognition**
- Roadmap of iris recognition
- Resources and conclusions

Objective of iris pattern recognition



Iris Feature Extraction

- **Phase-based method**
  (Daugman, PAMI 1993)
- **Correlation-based method**
  (Wildes, Machine vision and applications, 1996)
- **Zero-crossings representation**
  (Boles, IEEE Trans. SP 1998)
- **Texture analysis**
  (Tan et al, PAMI 2003)
- **Local intensity variation**
  (Tan et al, IEEE Trans. IP 2004 and PR 2004)
- **Ordinal measures**
  (Tan et al, PAMI 2009)

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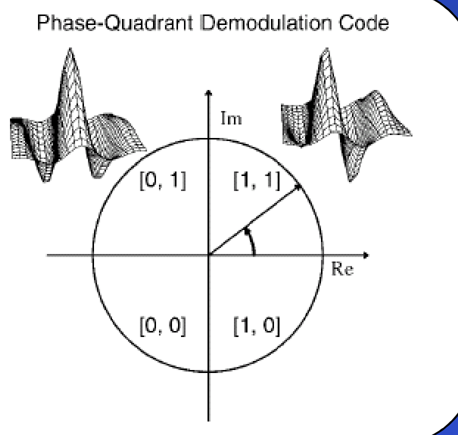
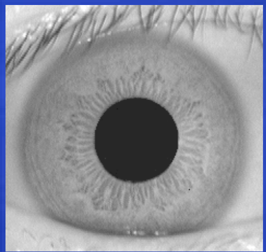
Email: John.Daugman at CL.cam.ac.uk

Daugman's method: IrisCode

Feature extraction



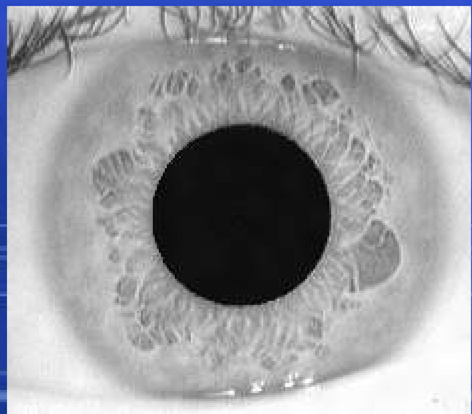


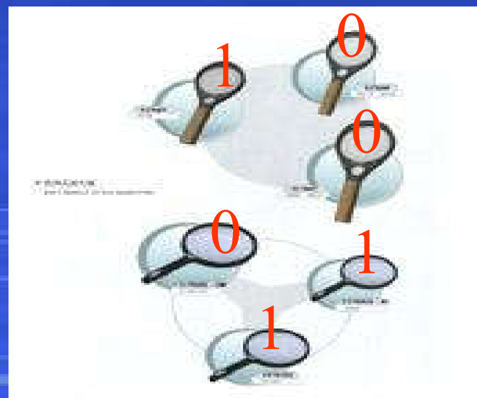
Multiscale Gabor filters

Filtered results

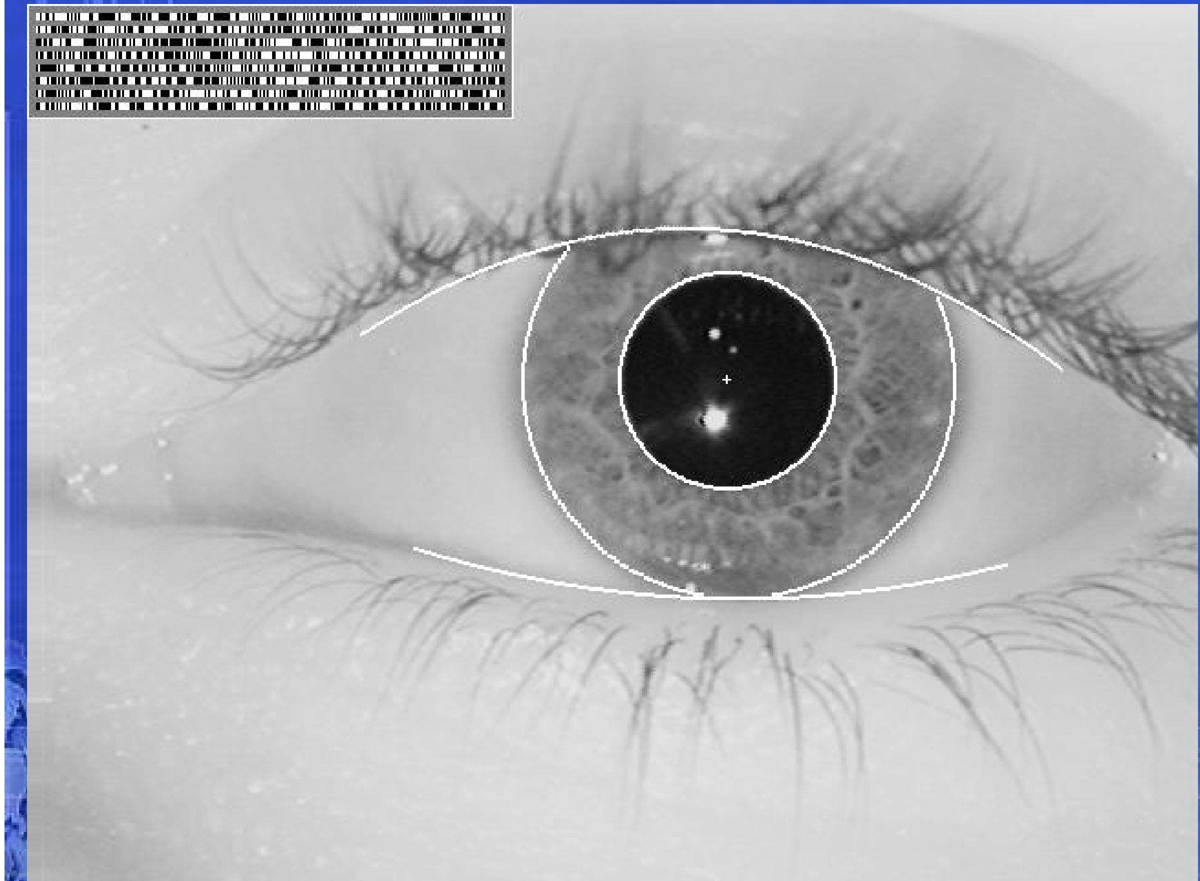
Quantization

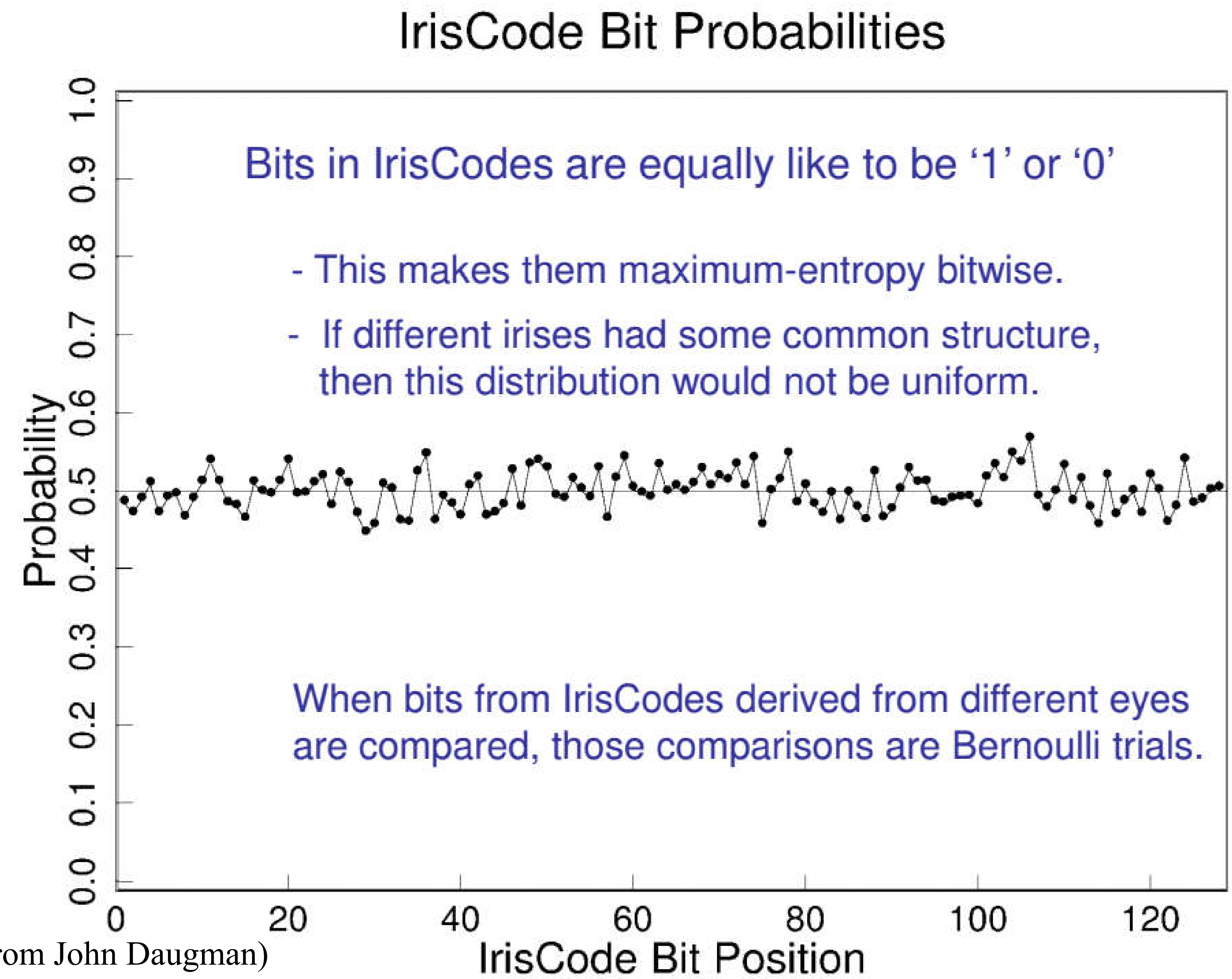
IrisCode



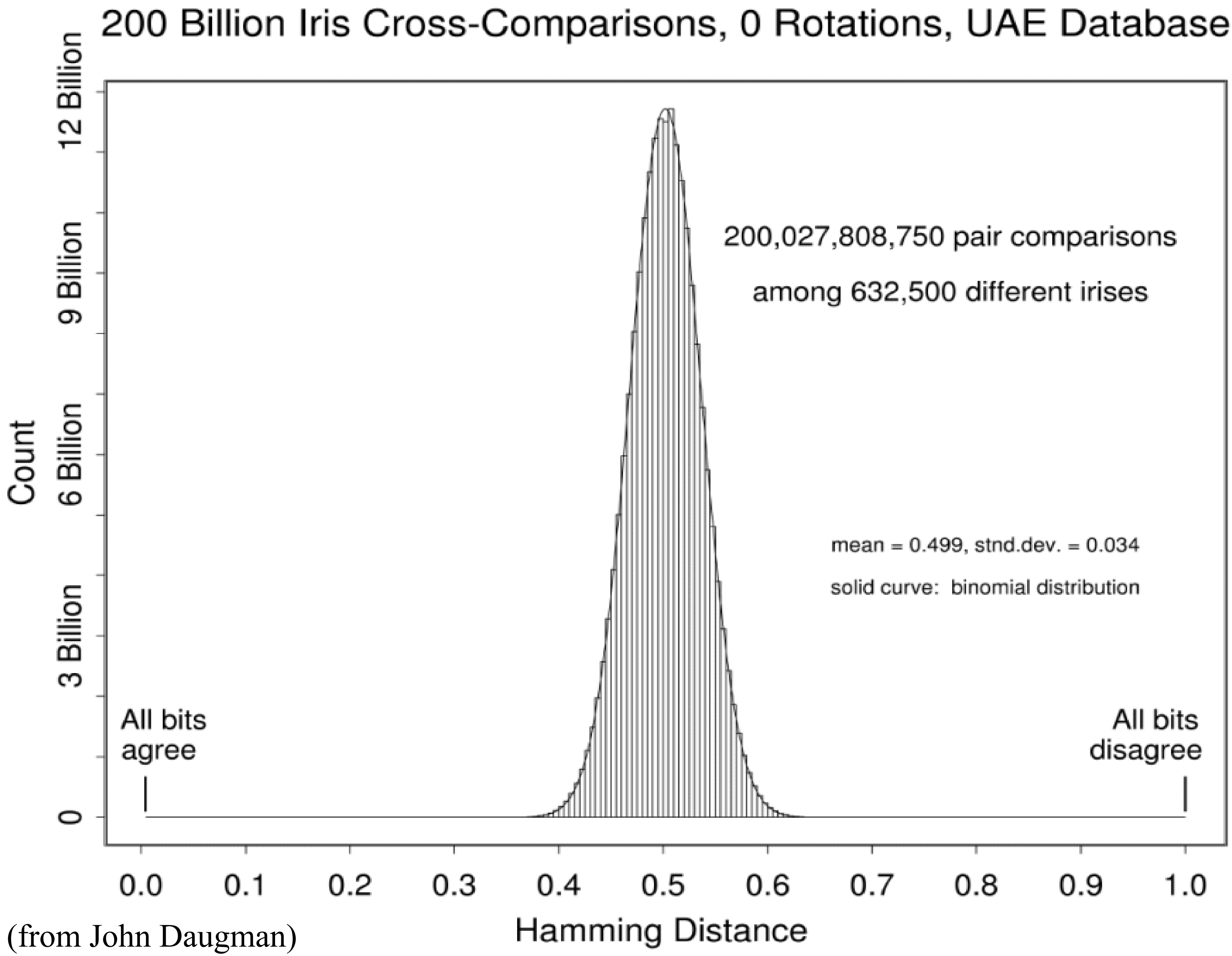


Examples of IrisCodes





(from John Daugman)



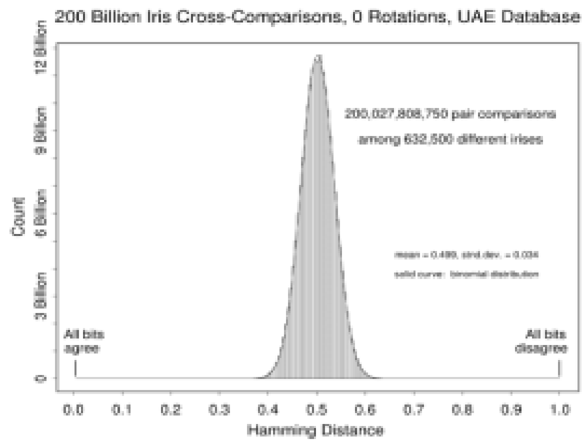
(from John Daugman)

IrisCode Bit Comparisons are Bernoulli Trials

Jacob Bernoulli (1645-1705) analyzed *coin-tossing* and derived the binomial distribution. If the probability of "heads" is p, then the likelihood that a fraction $x = m/N$ out of N tosses will turn up "heads" is:

University of Groningen

$$P(x) = \frac{N!}{m!(N-m)!}\, p^m \,(1-p)^{(N-m)}$$



(from John Daugman)

IrisCode Logic and Normalizations

Logic for computing raw Hamming Distance scores, incorporating masks:

$$HD_{\text{raw}} = \frac{\|(codeA \otimes codeB) \cap maskA \cap maskB\|}{\|maskA \cap maskB\|}$$

where $\otimes$ is Exclusive-OR, $\cap$ is AND, and $\| \quad \|$ is the count of 'set' bits.

Score re-normalisation to compensate for number of bits compared:

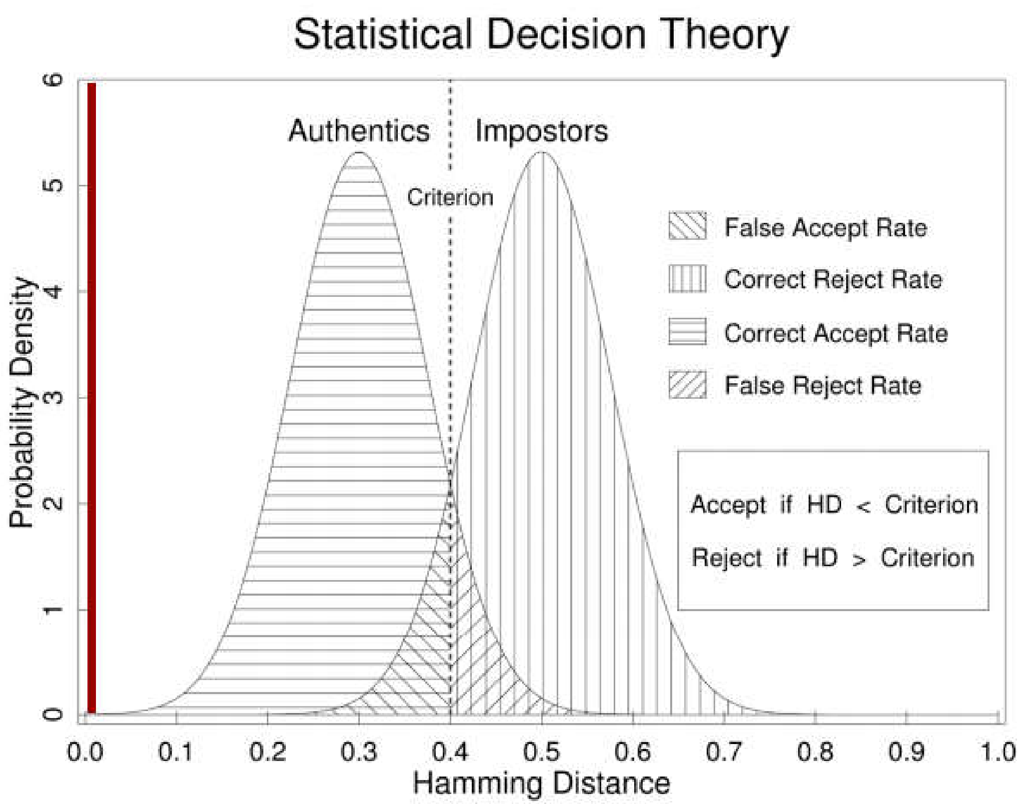
$$HD_{\text{norm}} = 0.5 - (0.5 - HD_{\text{raw}})\sqrt{\frac{n}{911}}$$

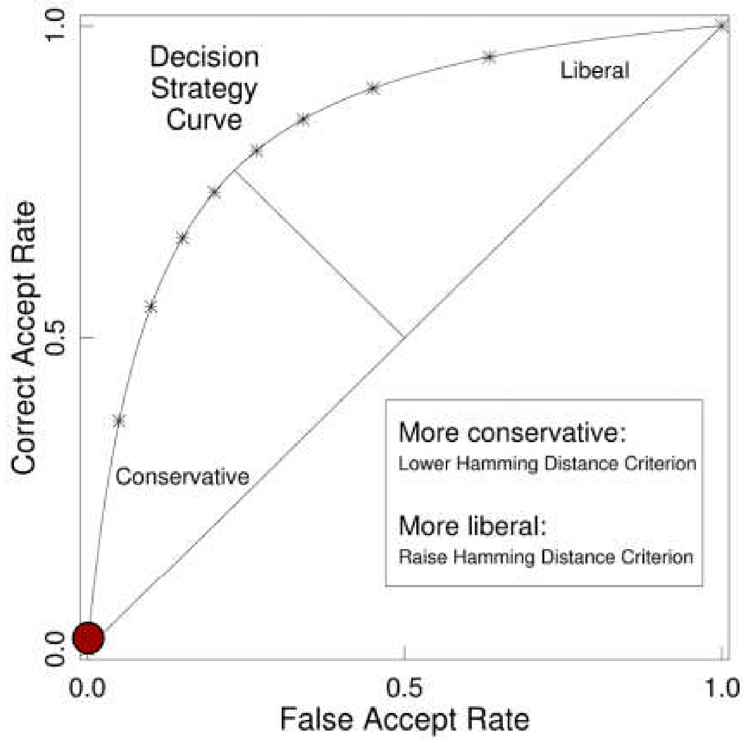
Decision Criterion normalisation by database size and query rate:

$$HD_{\text{Crit}} \sim 0.32 - 0.012 \ \log_{10}(N \times M)$$

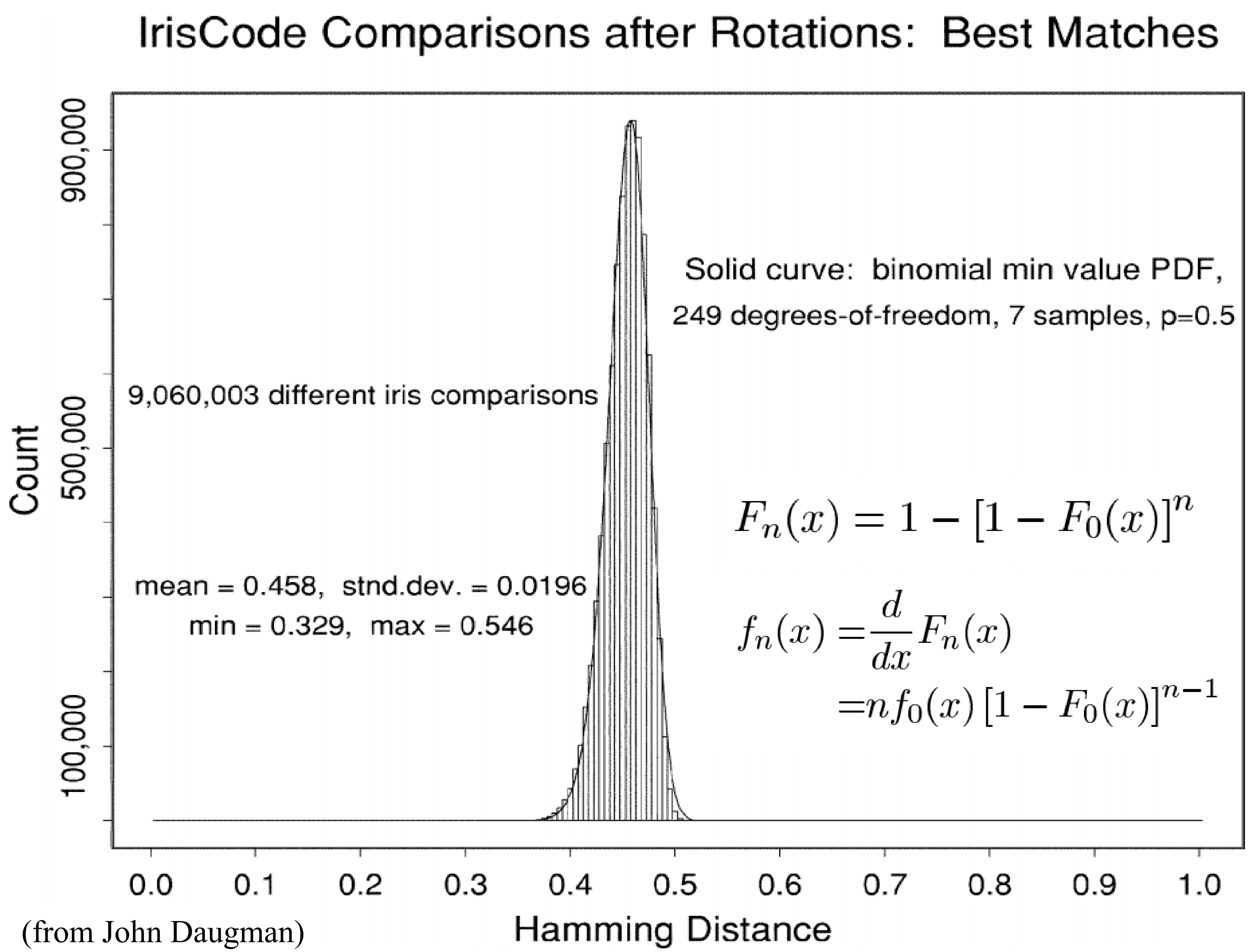
where N is the search database size, M is the number of queries to be compared against the full database, while requiring nil False Matches

Distribution of HDs and Decision



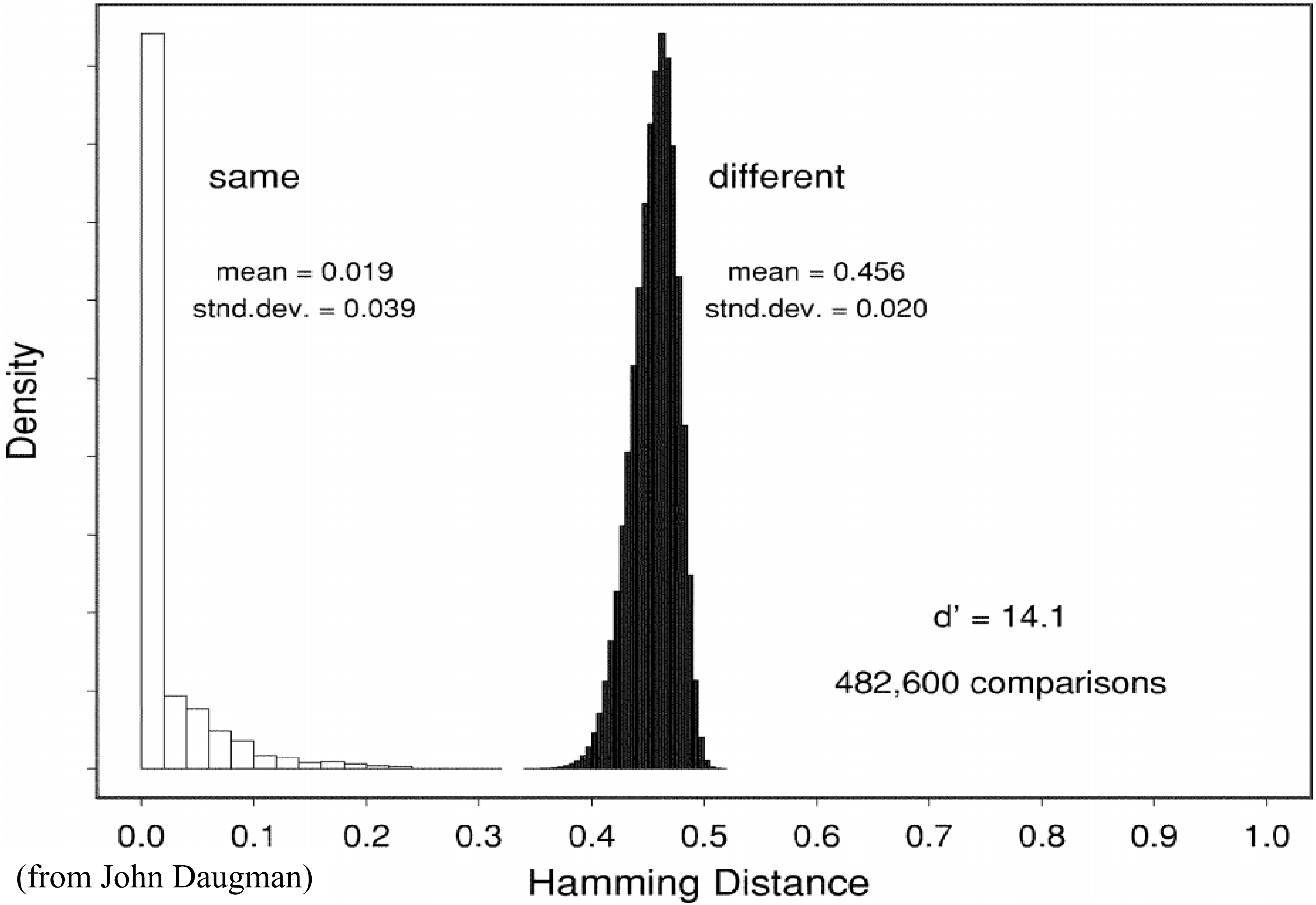


(from John Daugman)



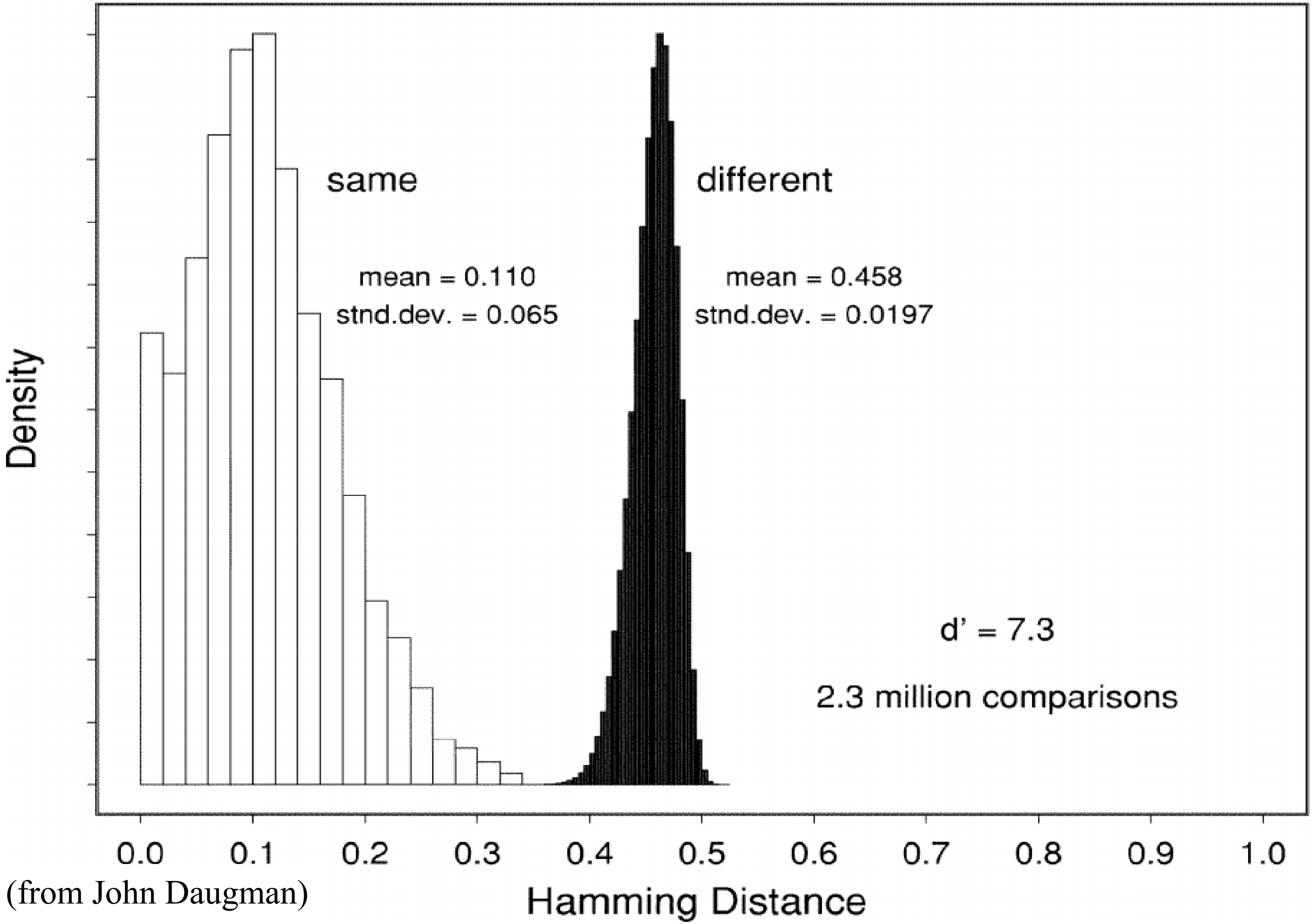
(from John Daugman)

Decision Environment for Iris Recognition: Ideal Imaging



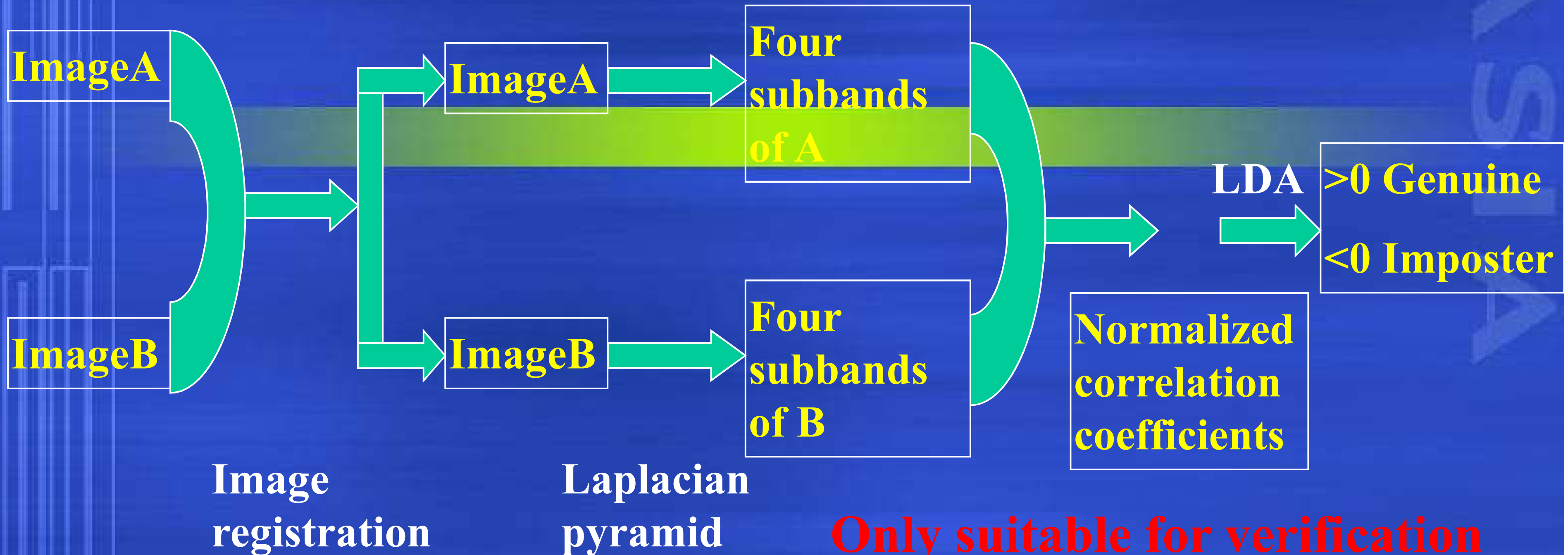
(from John Daugman)

Decision Environment for Iris Recognition: Non-Ideal Imaging

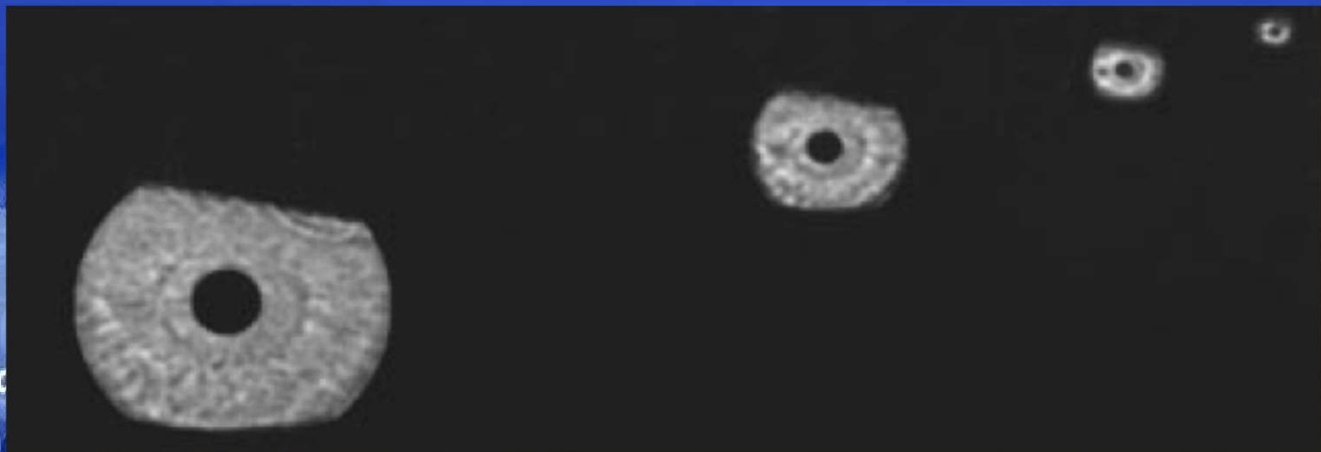


(from John Daugman)

Wildes' method

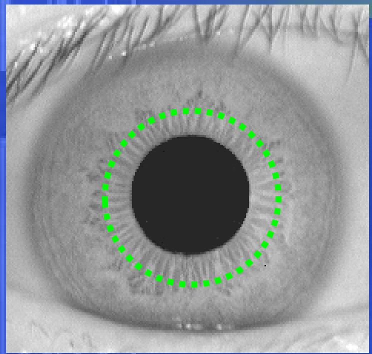


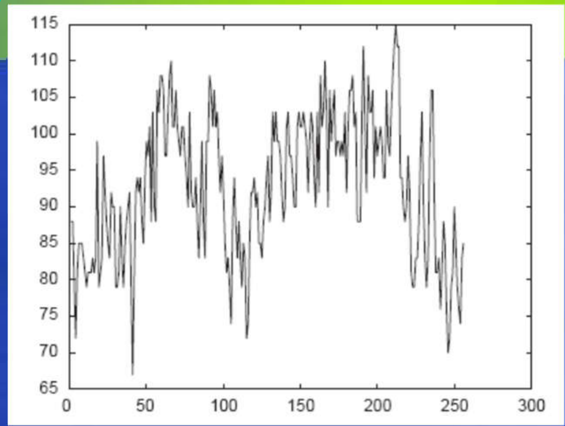
Only suitable for verification



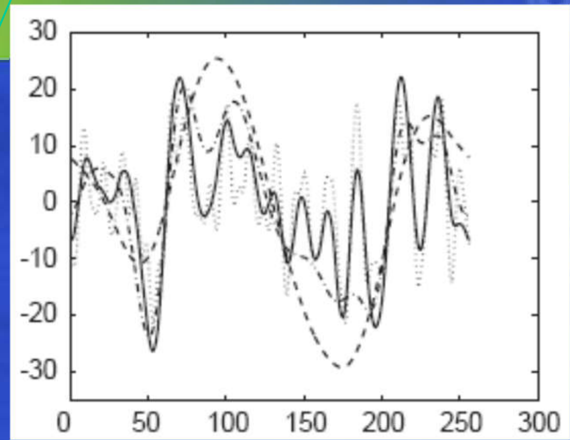
Boles' method

1D Signal Sampling

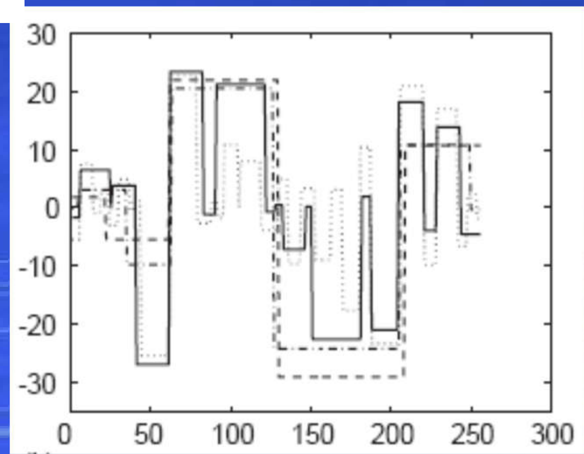




Wavelet transform



Zero-crossing representation



Feature matching

$$d_j^{(1)}(f, g) = \min_m \sum_{n=1}^{N} |Z_j f(n) - \Gamma Z_j g(n+m)|^2$$

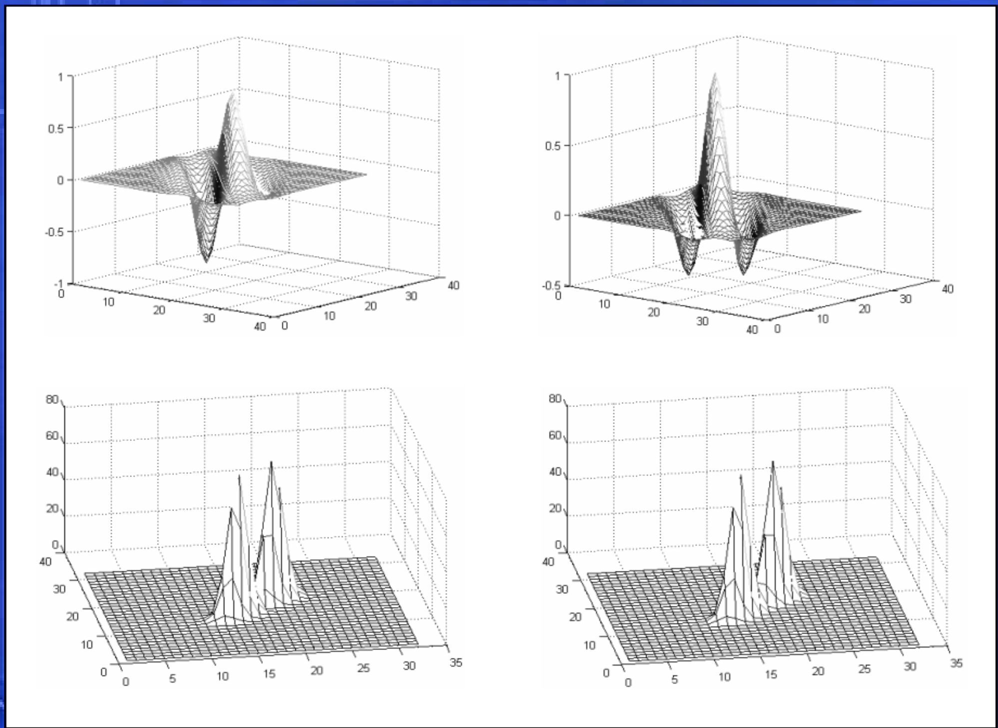
$$m \in [0, N-1]$$

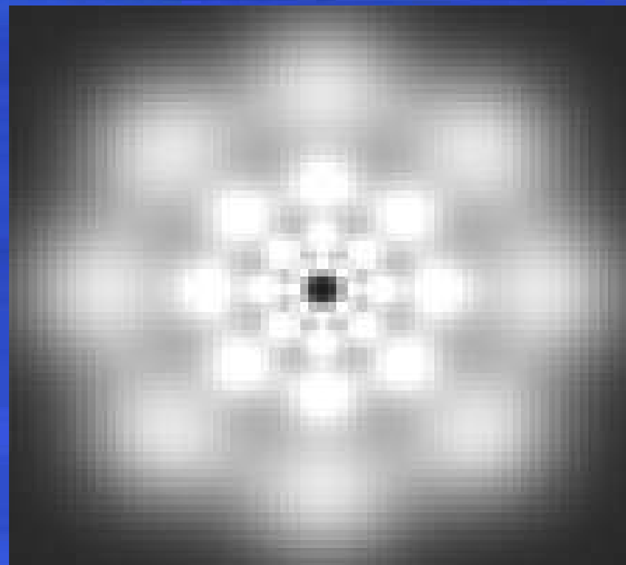
$$d_j^{(2)}(f, g) = \min_m \frac{\sum_{r=1}^{R_j} \{[\mu_j(r)]_f[\rho_j(r)]_f - \Gamma[\mu_j(r+m)]_g[\rho_j(r+m)]_g\}^2}{\Gamma \sum_{r=1}^{R_j} |[\mu_j(r)]_f[\rho_j(r)]_f| \, |[\mu_j(r)]_g[\rho_j(r)]_g|}$$

$$m \in [0, R_j - 1]$$

Gabor based iris texture analysis

—Multi-channel Gabor filtering—





Totally 16 Gabor channels
(4 orientations, 4 frequencies)

L. Ma, T. Tan, Y. Wang and D. Zhang, "Personal Identification Based on Iris Texture Analysis", IEEE Trans. on Pattern Analysis and Machine Intelligence (PAMI), Vol. 25, No. 12, pp.1519-1533, 2003.

Gabor based iris texture analysis

—Results—

Recognition results as a function of Gabor orientation

Orientation	0^0	45^0	90^0	135^0	All orientations
CCR	86.90%	81.89%	60.55%	82.22%	94.91%
DI	2.80	2.69	2.23	2.70	3.50

1. Iris texture feature along angular direction is the most informative.

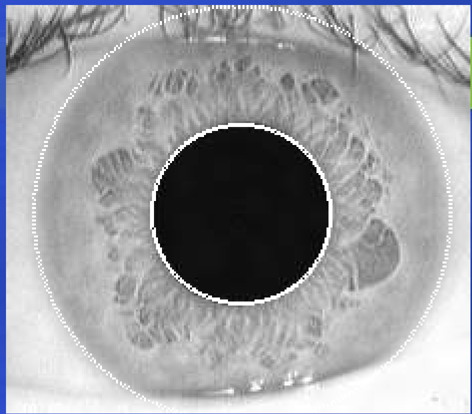
Recognition results as a function of Gabor frequency

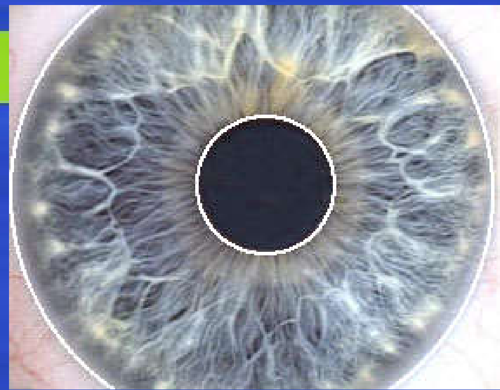
Frequency	$2\sqrt{2}$	$4\sqrt{2}$	$8\sqrt{2}$	$16\sqrt{2}$	All frequencies
CCR	90.14%	91.92%	79.71%	53.68%	94.91%
DI	3.35	3.28	2.46	1.91	3.50

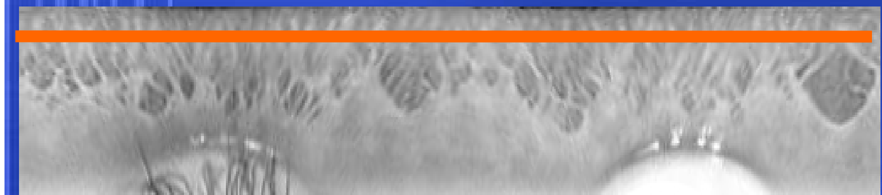
2. Most of the distinctive features of iris texture are in low- and medium- frequencies.

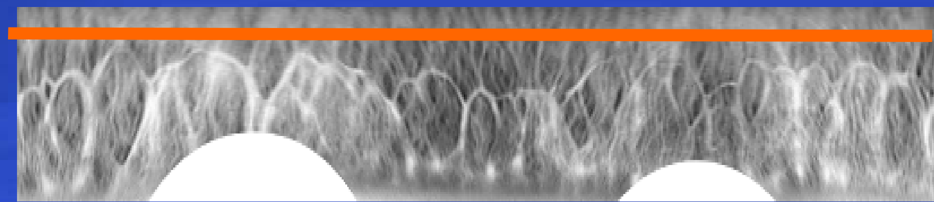
Gaussian-Hermite moments based method

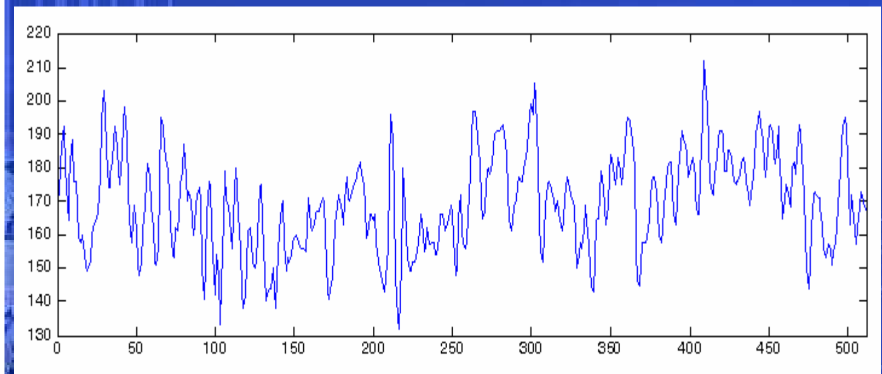
－1D signal representation－

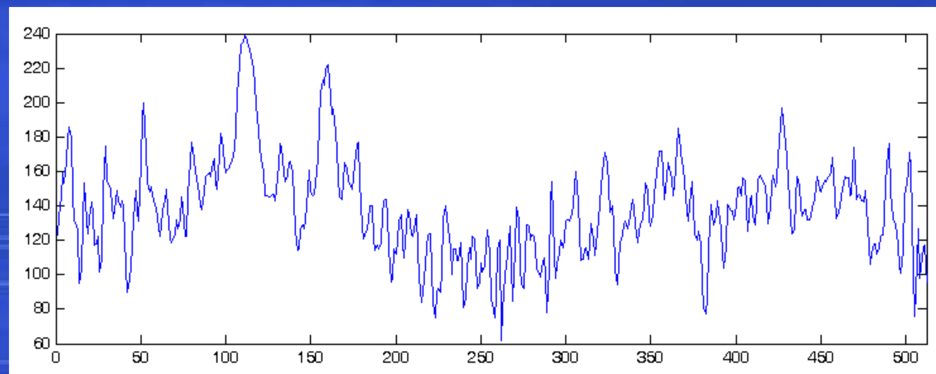






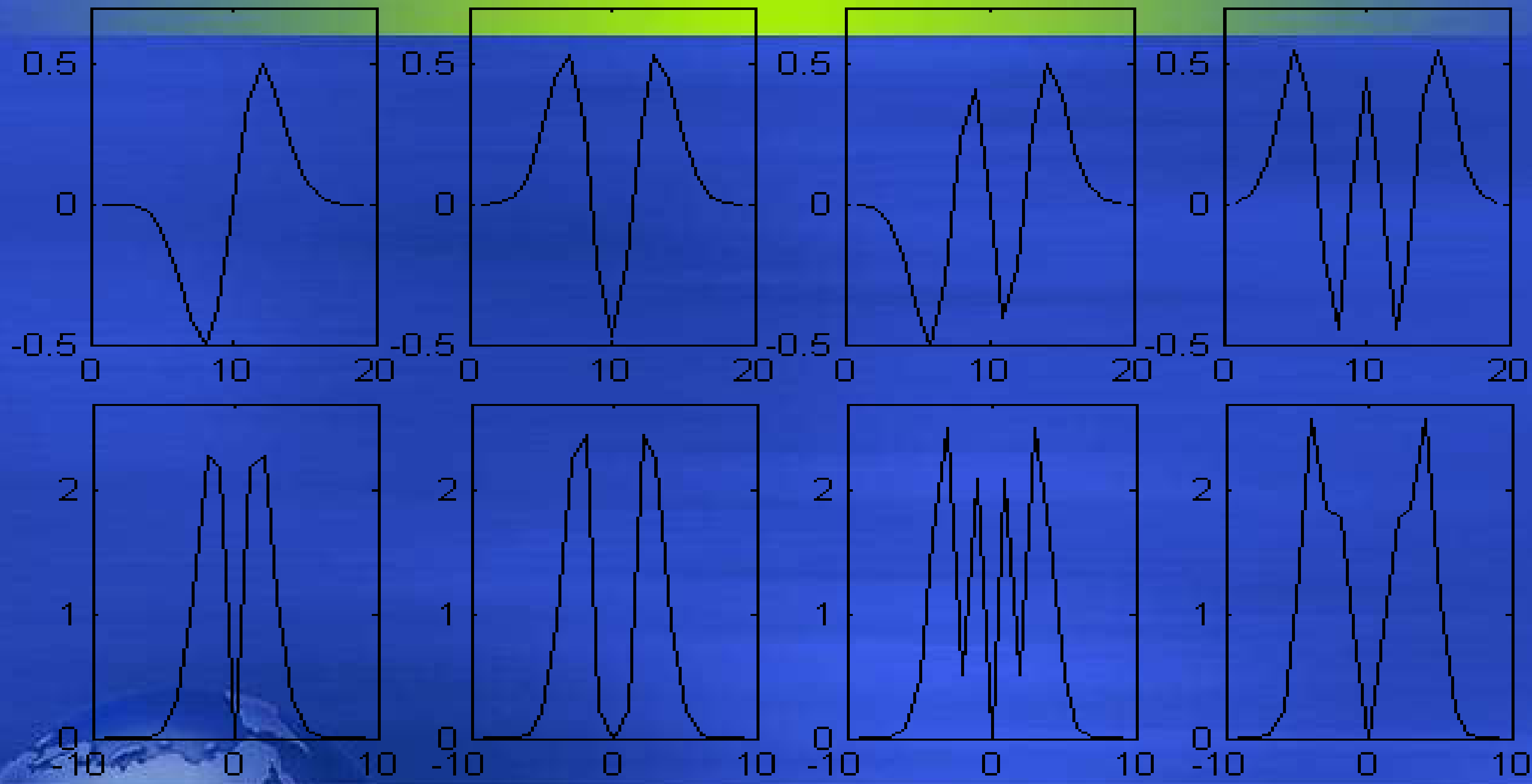






Gaussian-Hermite moments based method

—GH moments used for shape analysis—



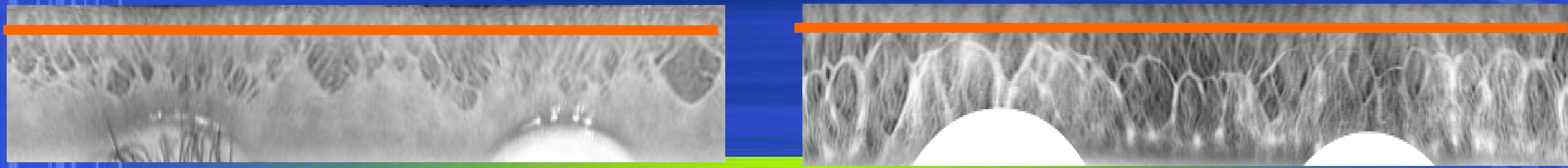
L. Ma, T. Tan, D. Zhang and Y. Wang, "Local Intensity Variation Analysis for Iris Recognition", Pattern Recognition, Vol.37, No.6, pp. 1287-1298, 2004.

Gaussian-Hermite moments based method

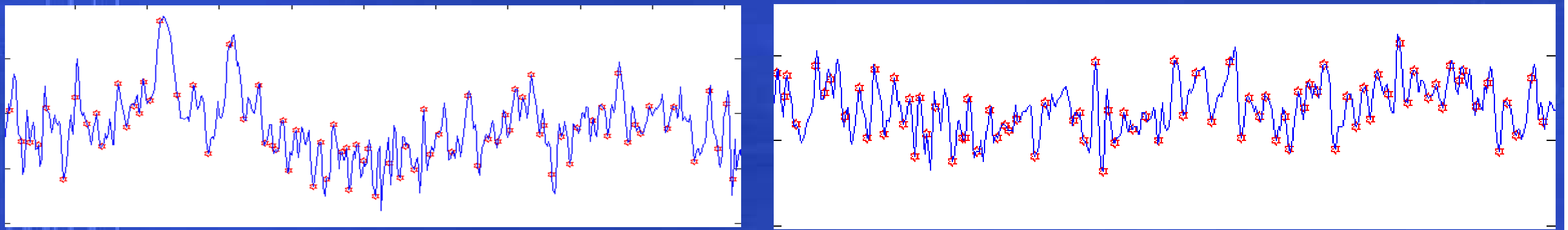
—Conclusions—

Compared with texture features, features based on local intensity variations are more effective for recognition. This is because texture features are incapable of precisely capturing local fine changes of the iris since texture is by nature a regional image property.

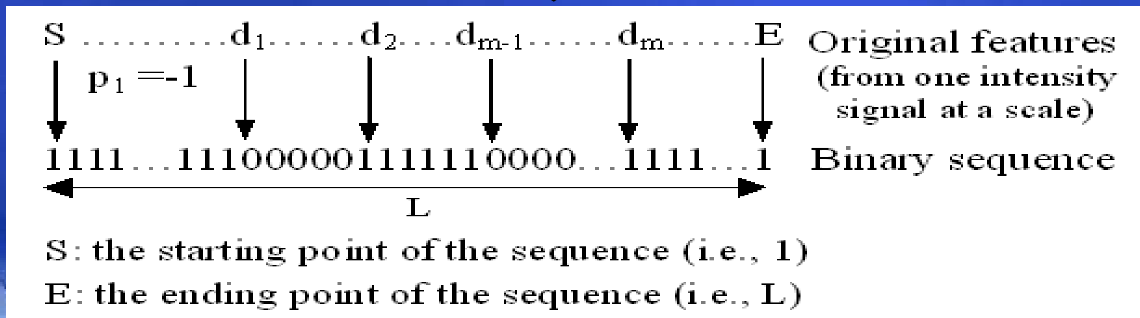
Local sharp variation based method



Sharp variation point detection



Feature transform



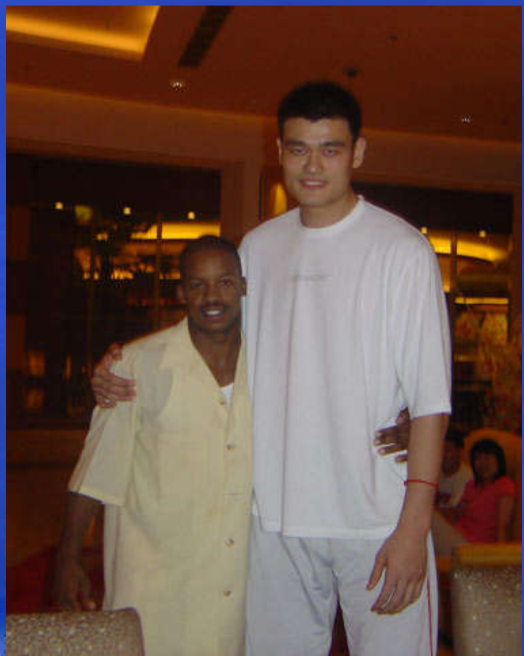
Li Ma, Tieniu Tan, Yunhong Wang and Dexin Zhang, "Efficient Iris Recognition by Characterizing Key Local Variations", IEEE Trans. on Image Processing, Vol. 13, No.6, pp. 739- 750, 2004.

Two important questions in iris recognition

- **Why do some iris recognition algorithms perform better (e.g., why is Daugman's IrisCode so good)?**
- **How to do better than the best (e.g., can we possibly outperform Daugman's IrisCode)?**

Ordinal Measures

Ordinal measures (OM) in everyday life



Height

Weight

D>B

C>E

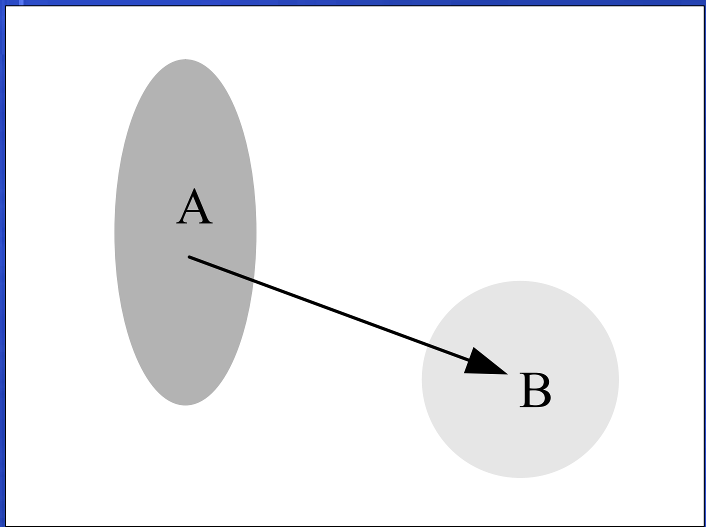
F>D

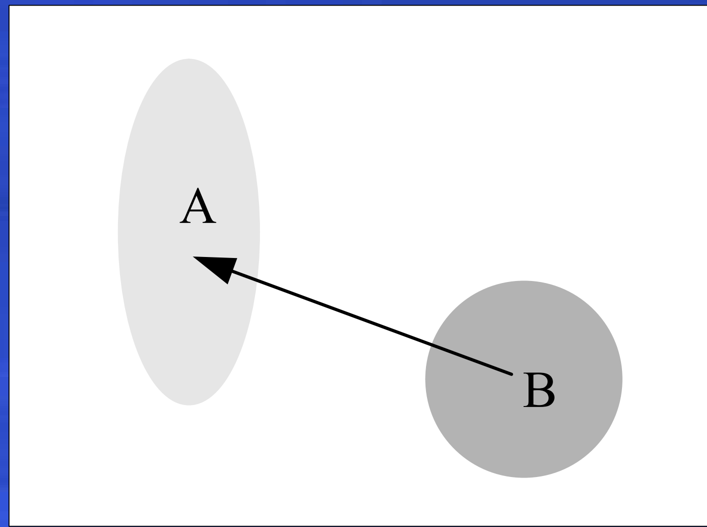
2C>B+D

C+D+F>A+B+E

……

Ordinal measures in visual images

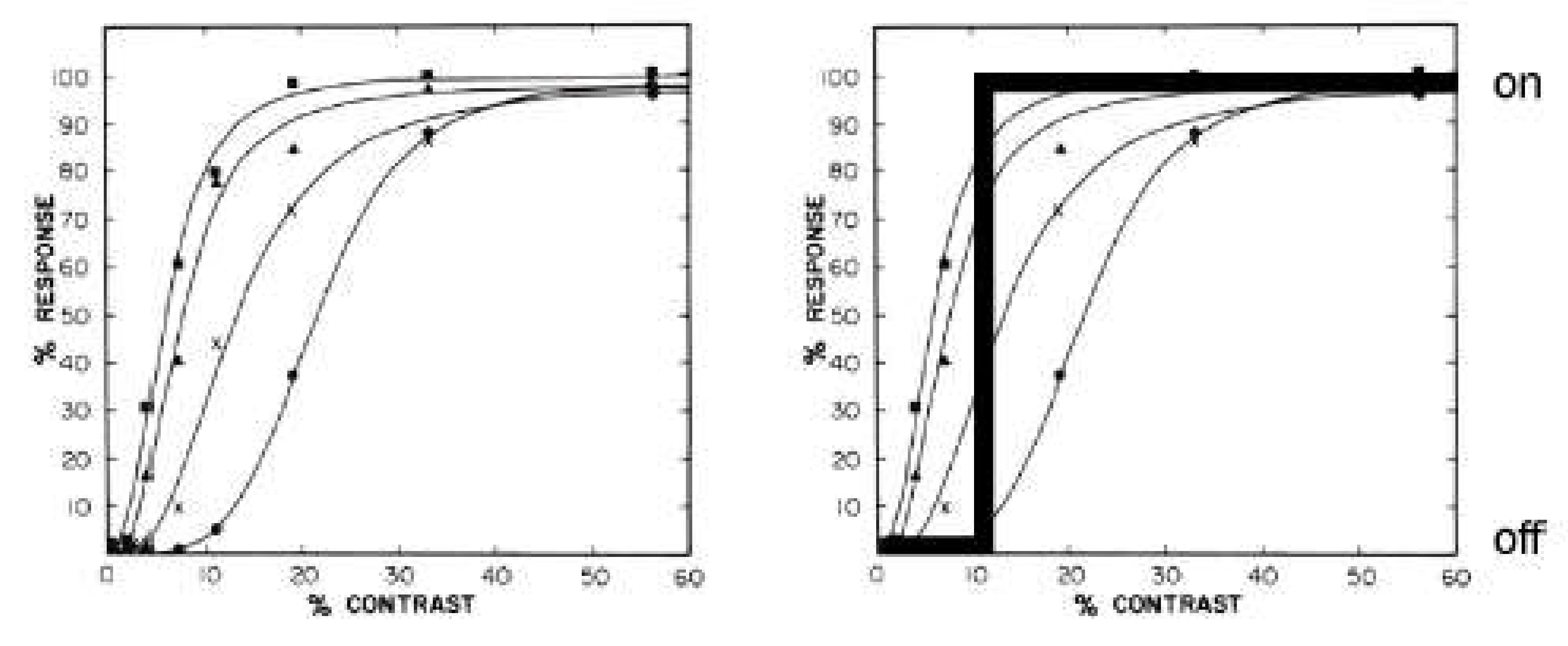




$A \prec B$ $\qquad$ $A \succ B.$

1 one bit code 0

OM in the biological vision system

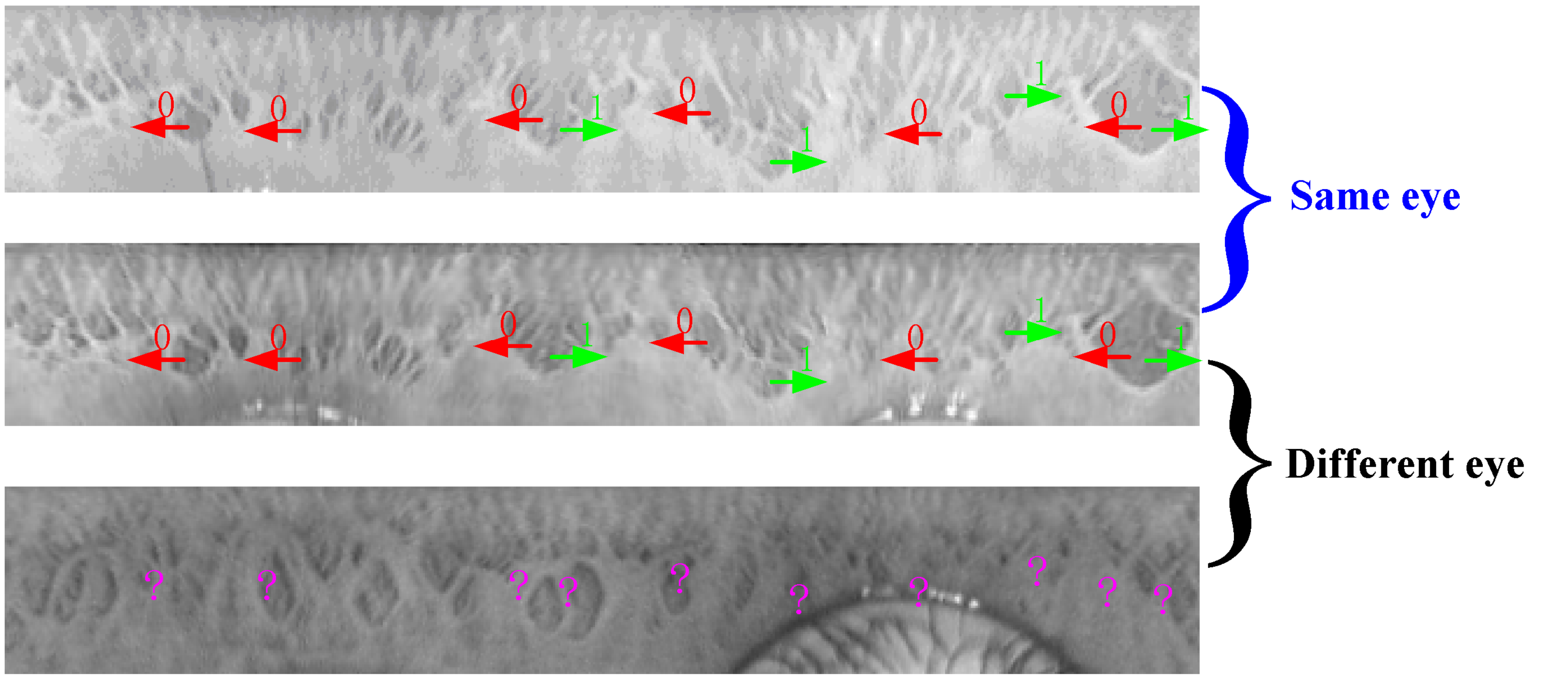


Duane G. Albrecht and David B. Hamilton. Striate cortex of the monkey and cat: Contrast response function. *Journal of Neuroscience*, 48(1):217–237, July 1982.

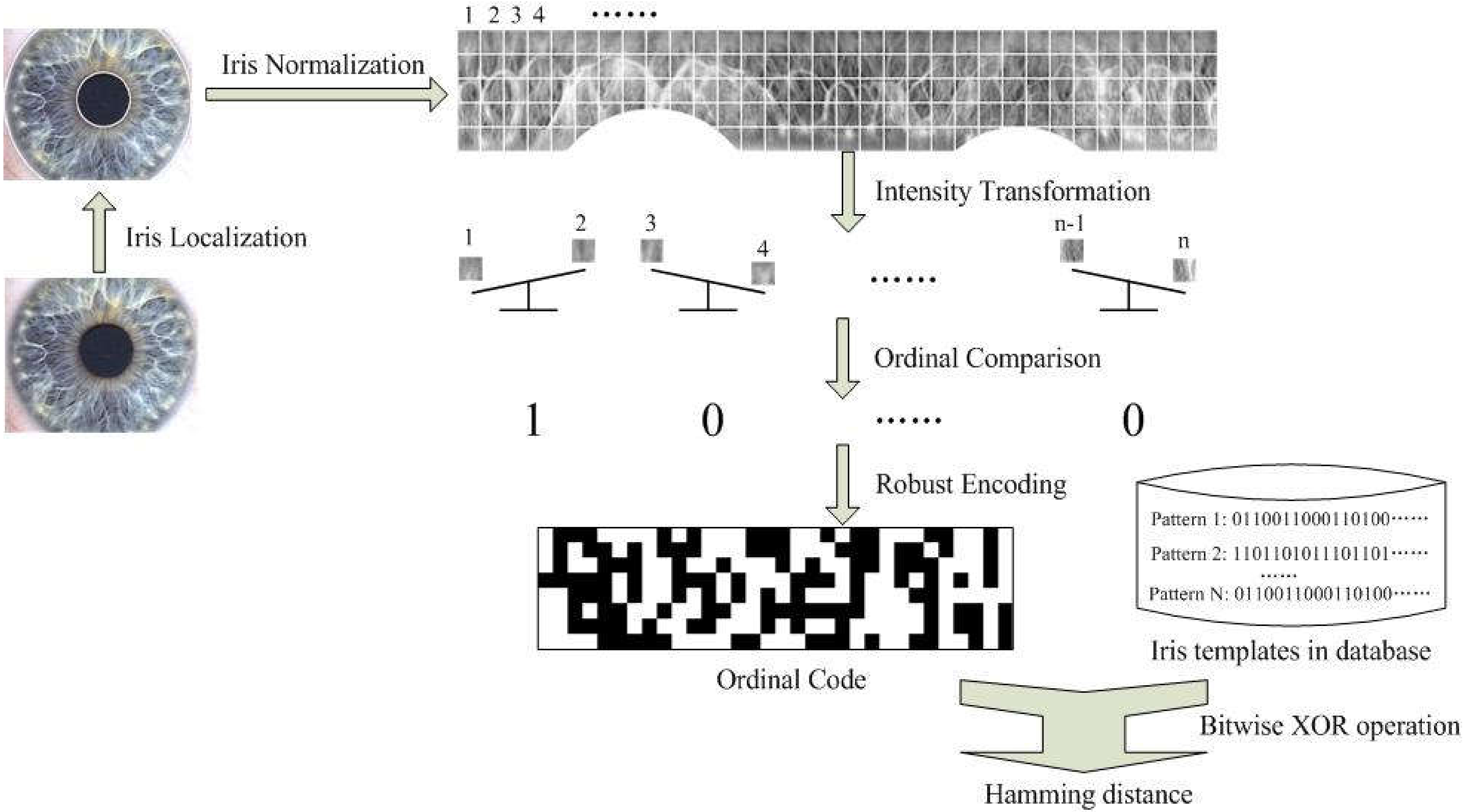
Desirable properties of ordinal representation

- Discriminating
- Robust
- Computationally simple
- Memory efficient
- Biologically plausible

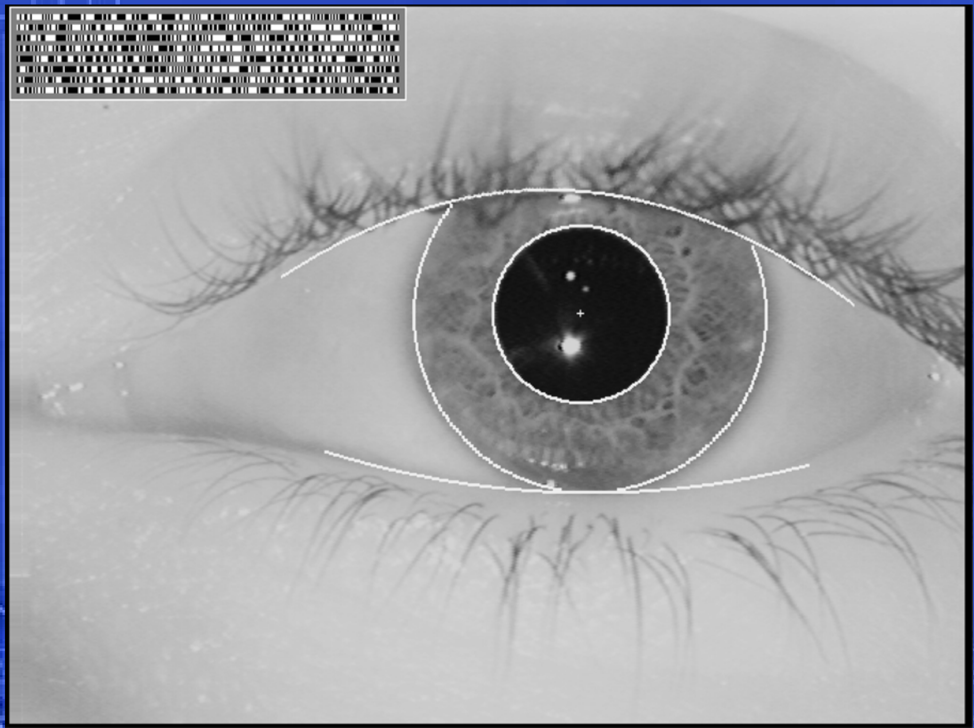
Ordinal measures in iris images

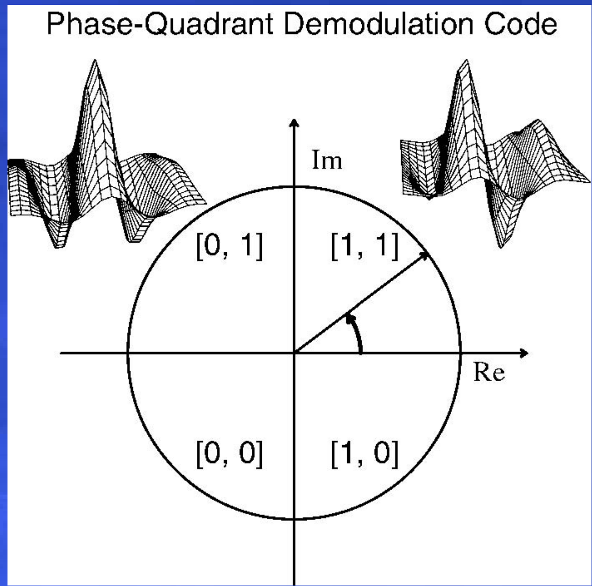


A General Framework for Iris Recognition Based on OM



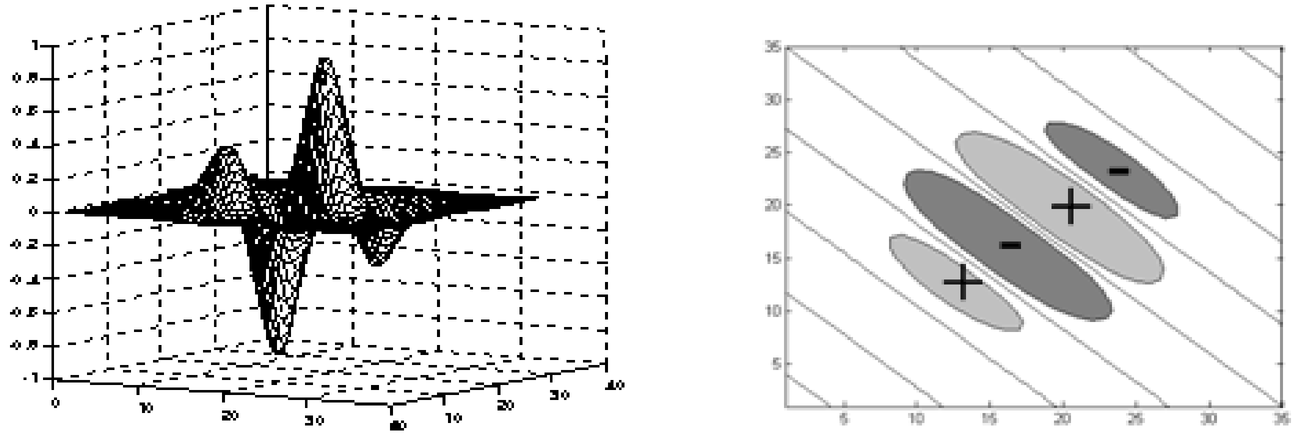
Phase demodulation based on Gabor filters (Daugman)



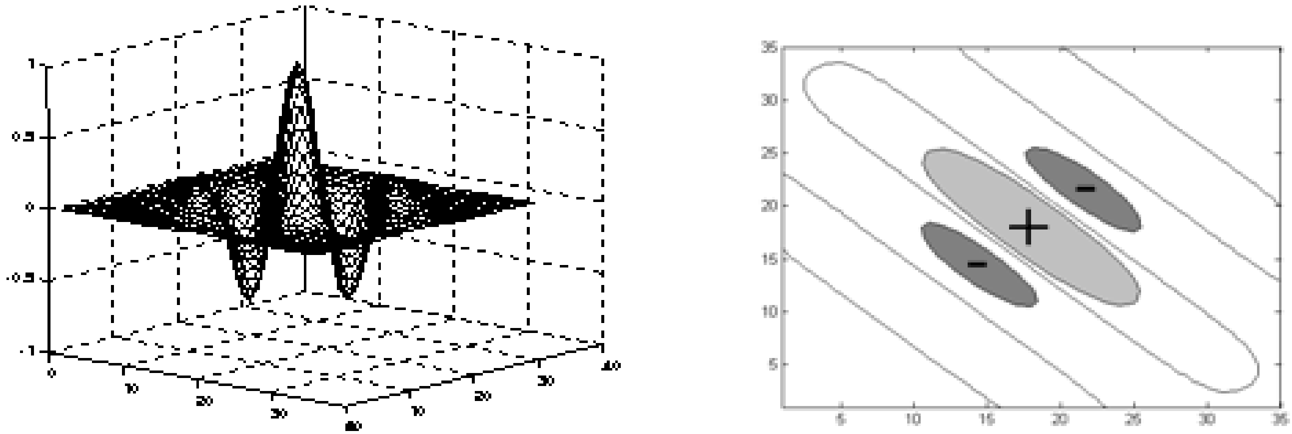


$$HD = \frac{\|(codeA \otimes codeB) \bigcap maskA \bigcap maskB\|}{\|maskA \bigcap maskB\|}$$

Gabor filter + phase demodulation is an ordinal operator



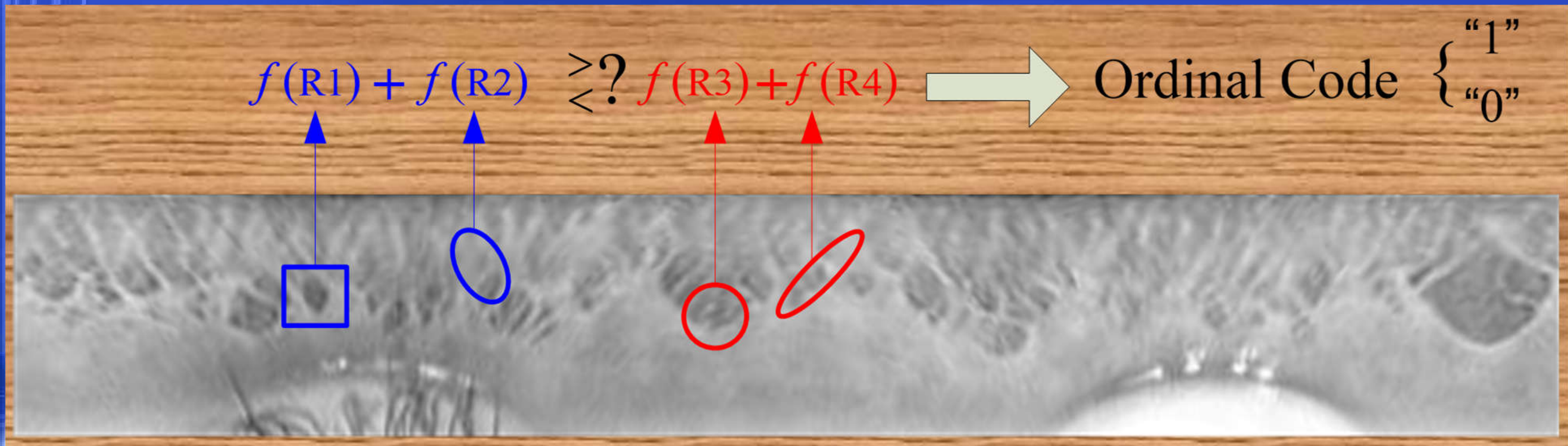
Odd Gabor filter



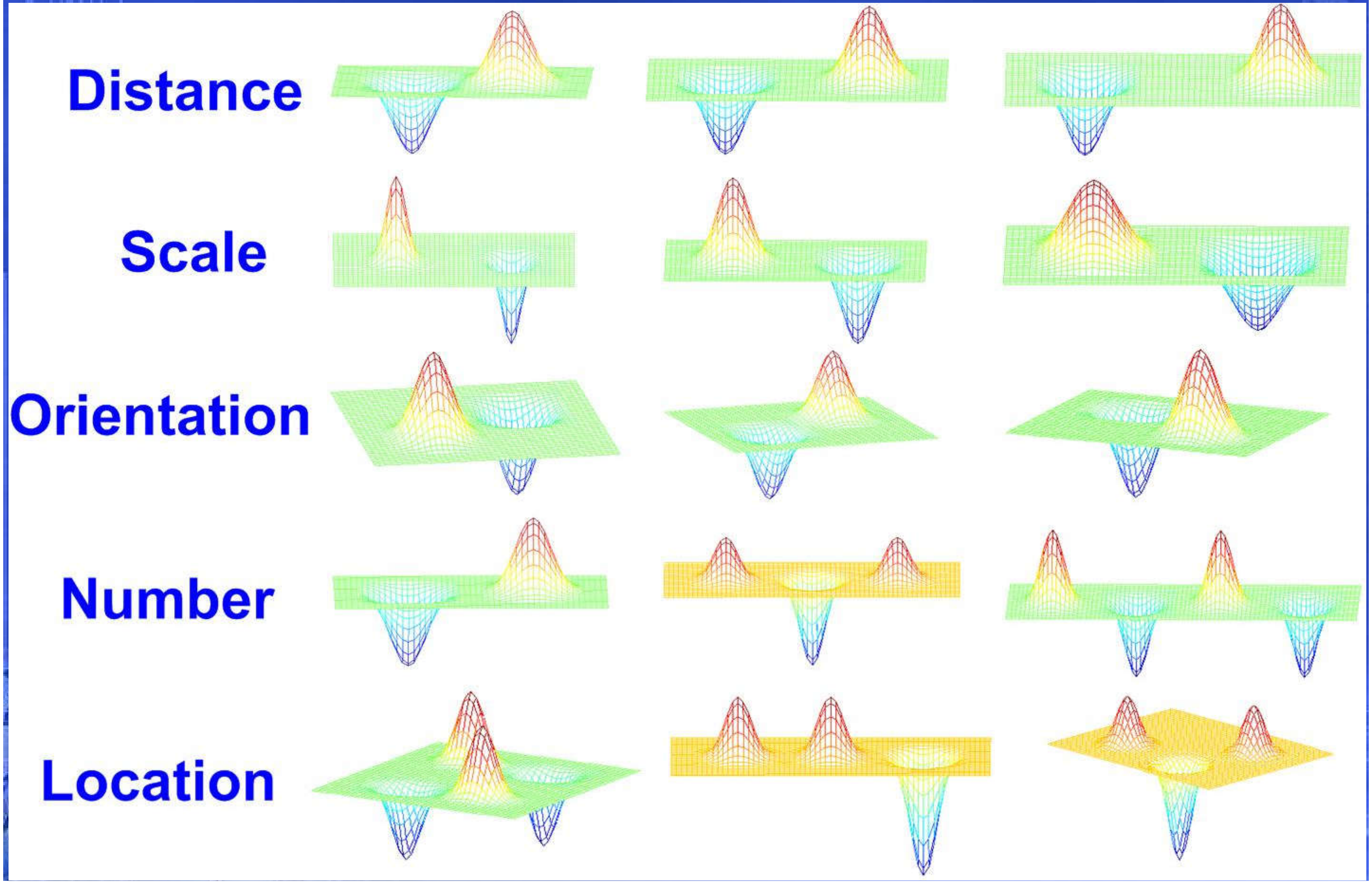
Even Gabor filter

Variables in ordinal feature extraction

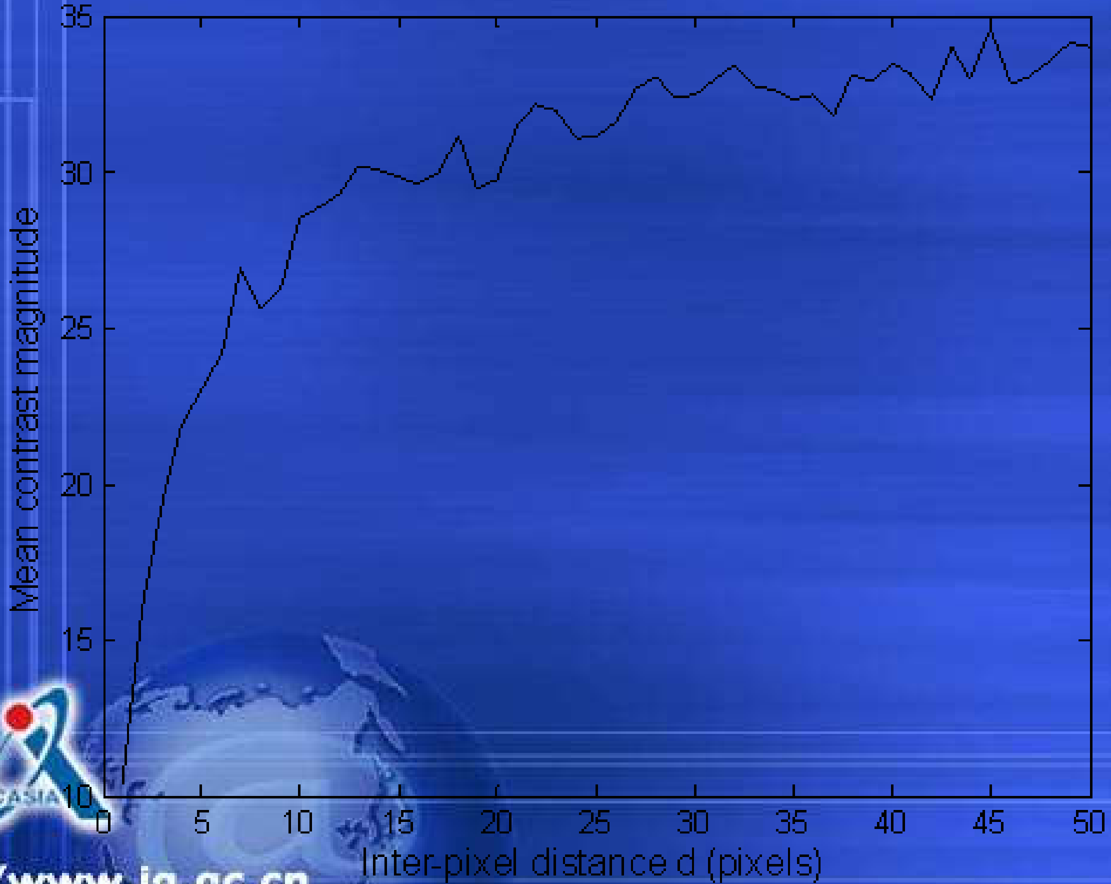
- Location of image regions
- Shape of image regions
- Features of image regions



Dissociated Multi-Poles



Inter-pixel contrast magnitude of iris image as a function of inter-pixel distance



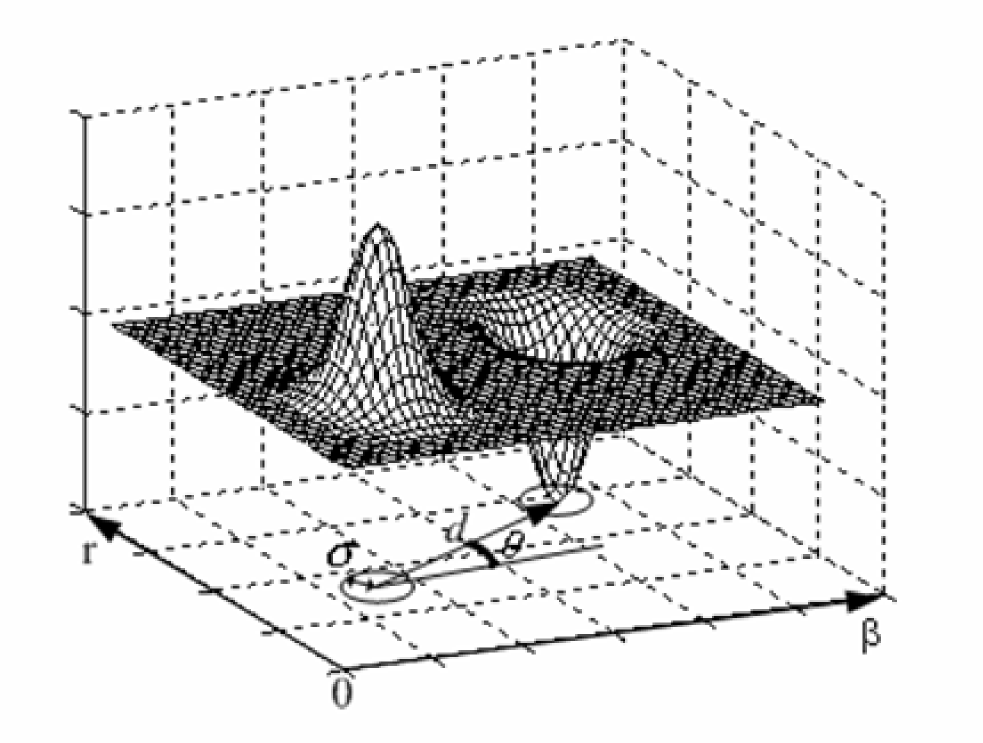
Larger distance

Less correlation

Higher contrast

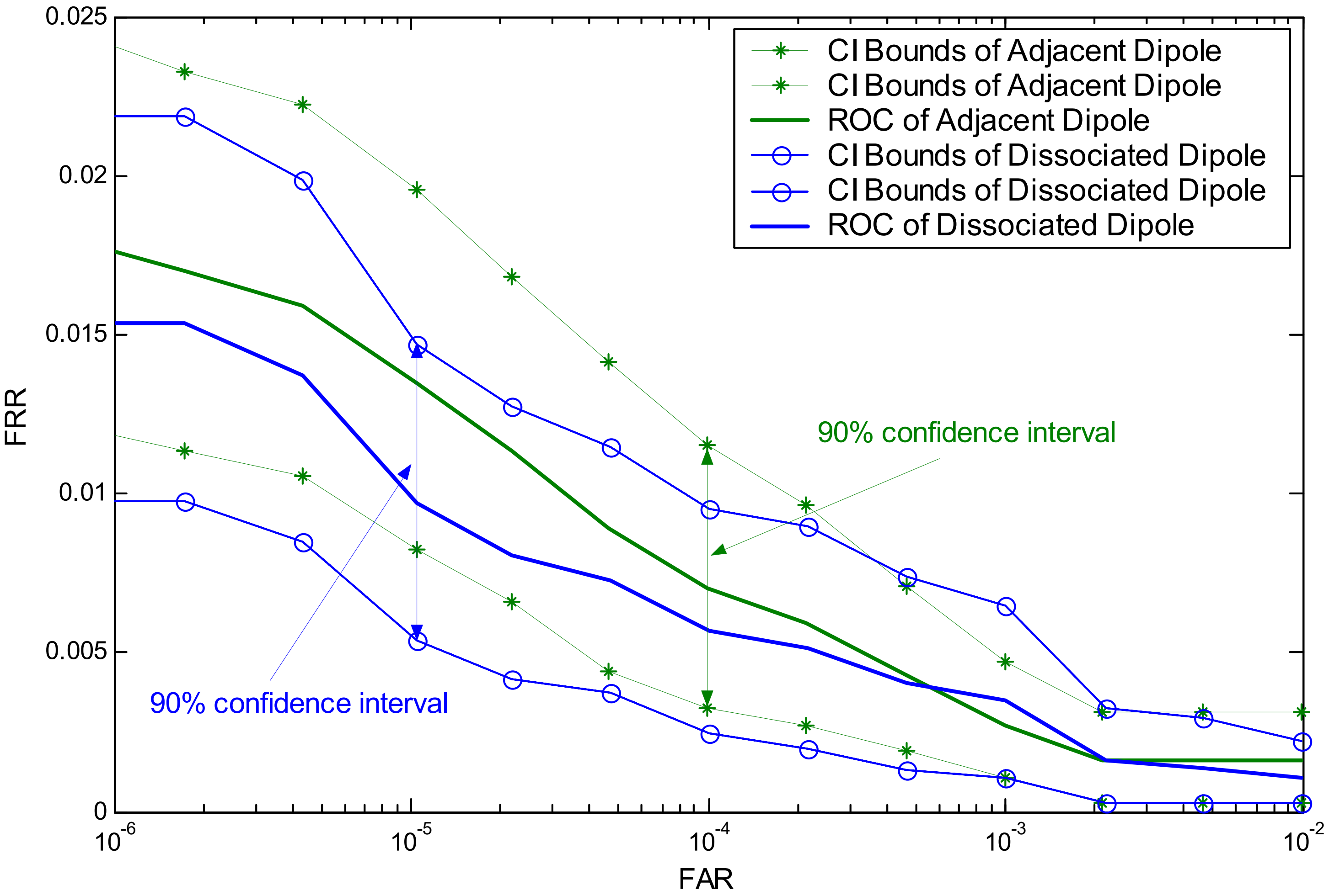
More robust OM

Local ordinal measures vs. Non-local ordinal measures

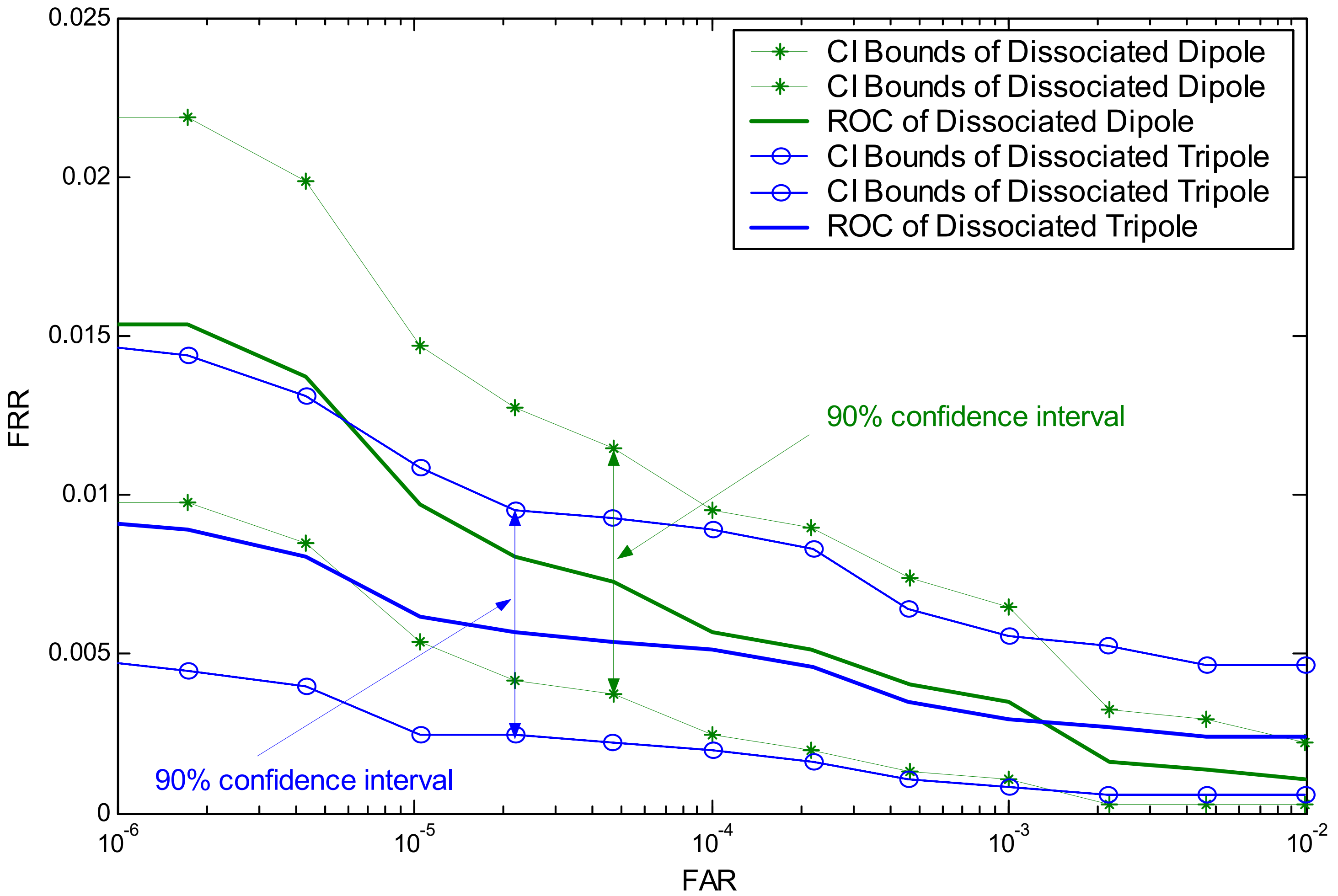


Dissociated Dipoles (from P. Sinha)

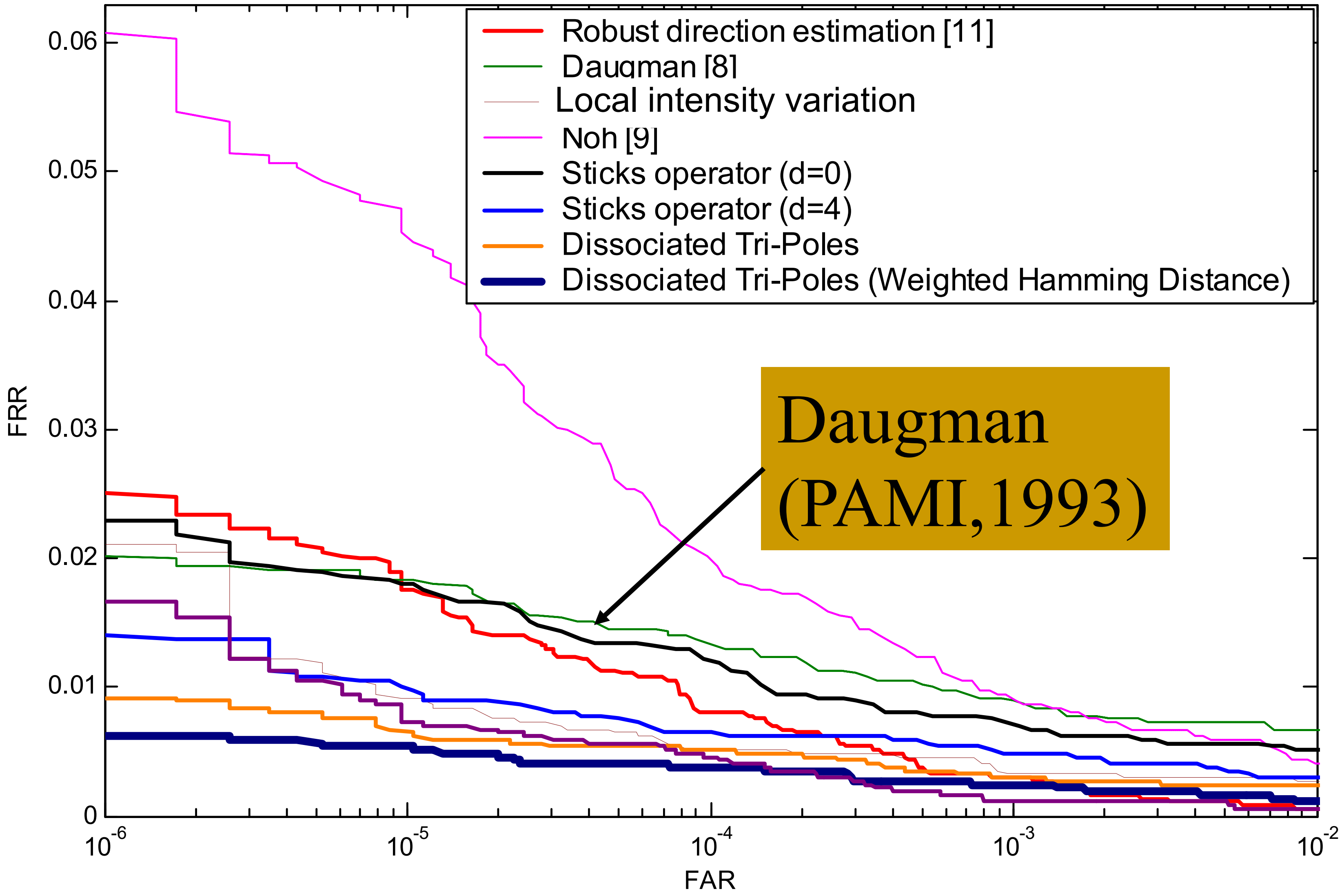
Local ordinal measures vs. Non-local ordinal measures

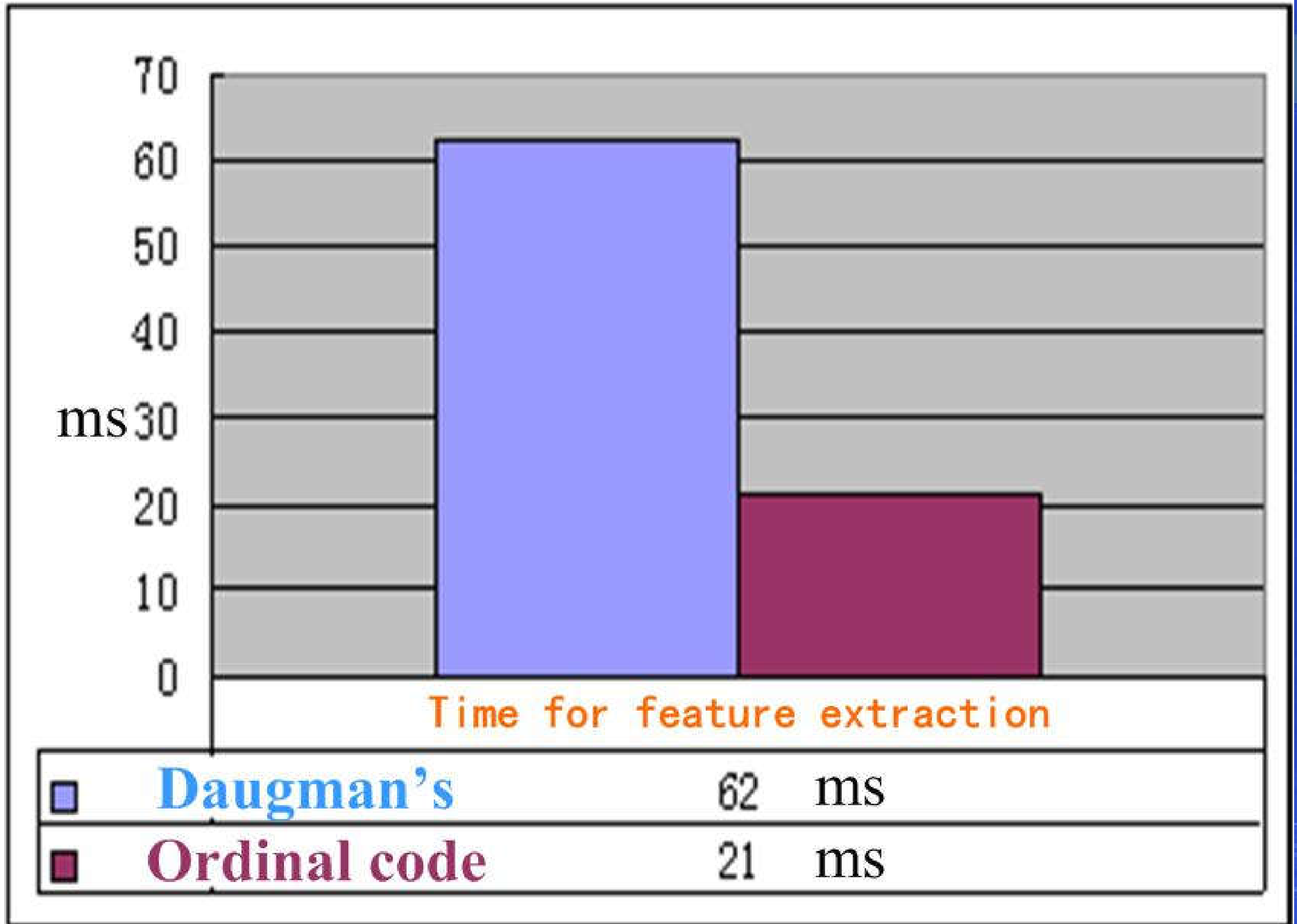


Dissociated Dipoles vs. Dissociated Tri-poles



State-of-the-art iris recognition performance

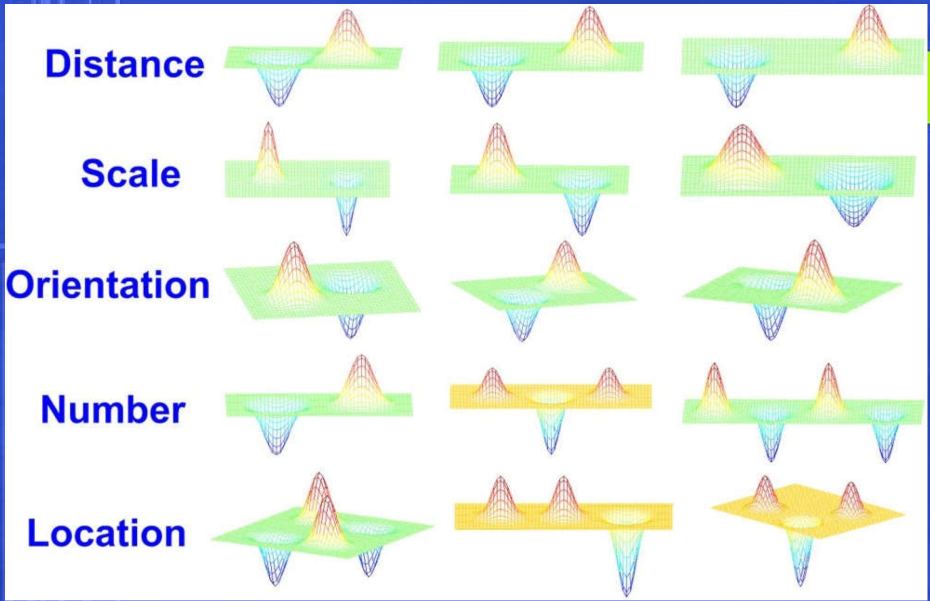


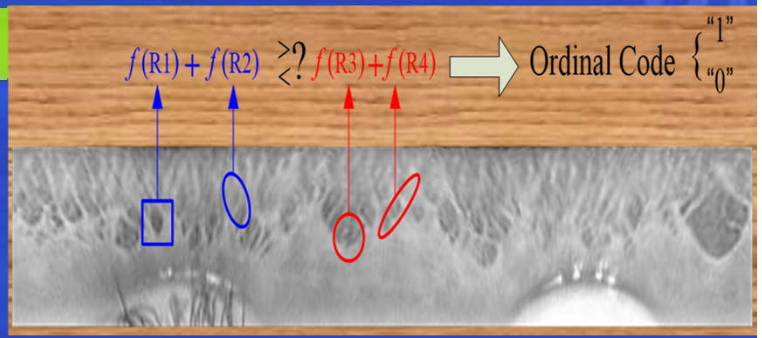

70
60
50
40
ms 30
20
10
0
Time for feature extraction
Daugman's 62 ms
Ordinal code 21 ms

Ordinal Iris Representation: Conclusions

- Ordinal measures appear to be a very promising iris representation scheme.
- Based on OM, some of the best iris recognition algorithms may be unified into a general framework.
- Non-local OM outperforms local OM.
- How to select an optimal subset of OM from the pool of DMP ordinal filters to construct a strong classifier is an important problem to study in the future.

The importance of feature selection

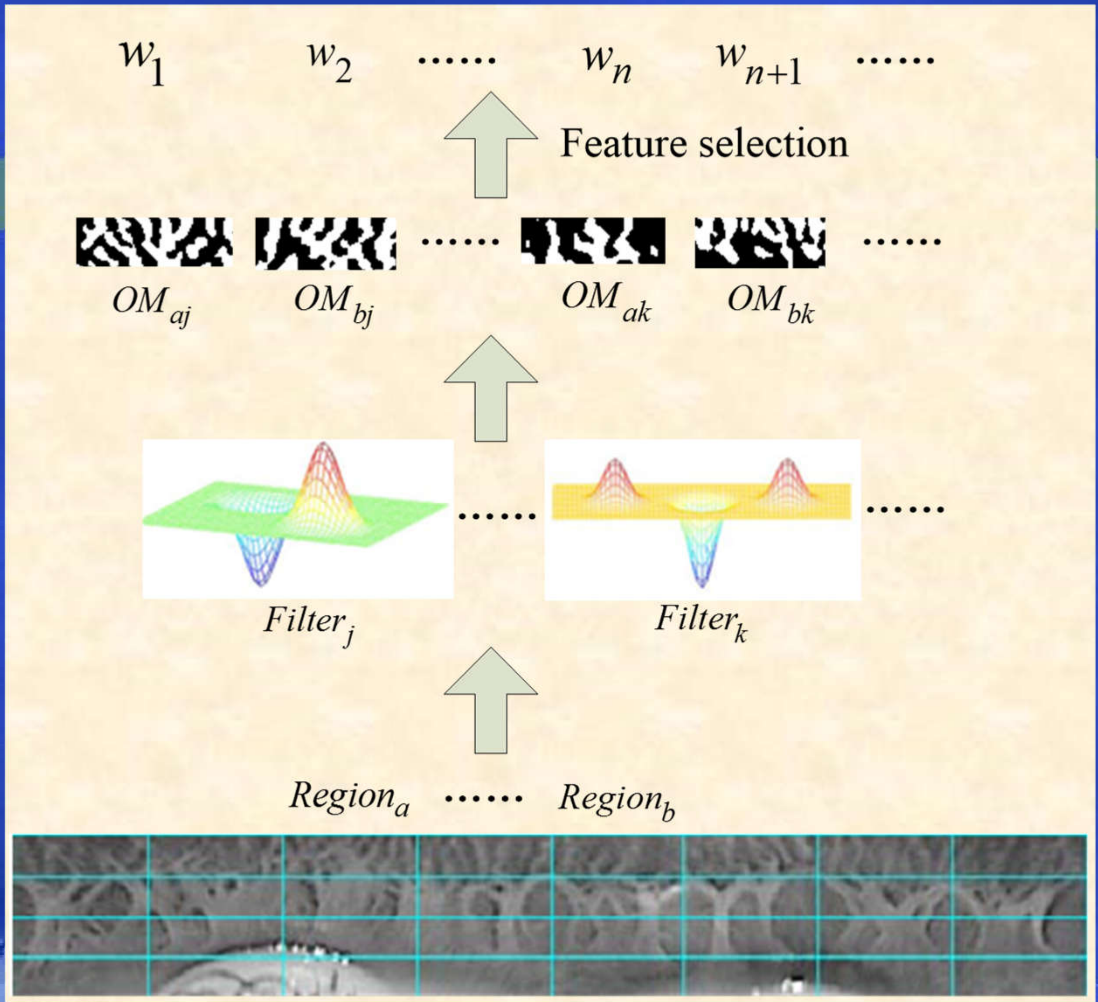




A huge feature set

- Significant difference between various ordinal features in terms of distinctiveness and robustness.
- Redundancy in the complete set of ordinal feature representation.

The objective of feature selection



Finding a compact ordinal feature set for accurate classification of intra- and inter-class matching pairs

Related work: feature selection

- **Boost**

It can not obtain a globally optimal feature set

Overfitting of training data

- **Lasso based sparse representation**

Non-linear optimization (time-consuming, sensitive to outliers)

The optimization does not take into account the characteristics of image features and biometric recognition

$$f_L = \arg\min_f \{ \|g - Af\|_2^2 + 2\tau |f|_1 \}$$

Ordinal feature selection based on linear programming

IEEE-TIP2014.

Minimize the misclassification errors of intra- and inter-class matching samples

Enforce weighted sparsity of ordinal feature components

Objective function:

$$\min\left\{\frac{\lambda^{+}}{N^{+}}\sum_{j=1}^{N^{+}}\xi_{j}^{+}+\frac{\lambda^{-}}{N^{-}}\sum_{k=1}^{N^{-}}\xi_{k}^{-}+\sum_{i=1}^{D}P_{i}w_{i}\right\}$$

Subject to:

$$\sum_{i=1}^{D}w_{i}x_{ij}^{+}\leq\alpha+\xi_{j}^{+},\quad j=1,2,\cdots,N^{+}$$

$$\sum_{i=1}^{D}w_{i}x_{ik}^{-}\geq\beta-\xi_{k}^{-},\quad k=1,2,\cdots,N^{-}$$

$$\xi_{j}^{+}\geq 0,\quad j=1,2,\cdots,N^{+}$$

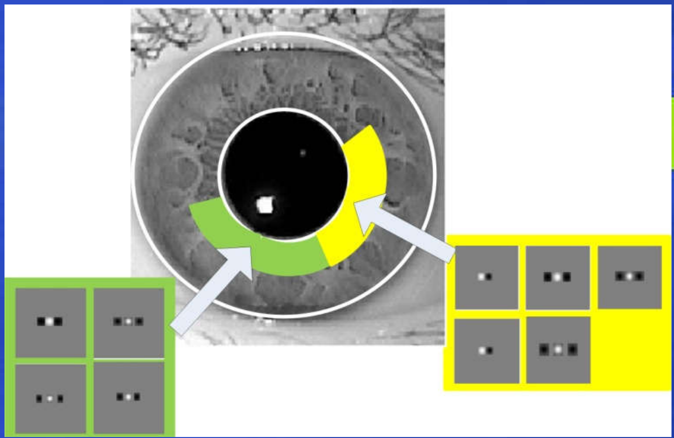
$$\xi_{k}^{-}\geq 0,\quad k=1,2,\cdots,N^{-}$$

$$w_{i}\geq 0,\quad i=1,2,\cdots,D$$

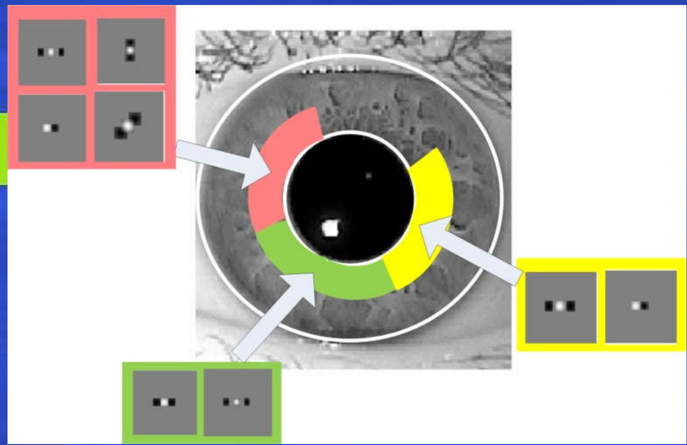
All intra- and inter-class matching samples should be well separated based on a large margin principle

Slack variables

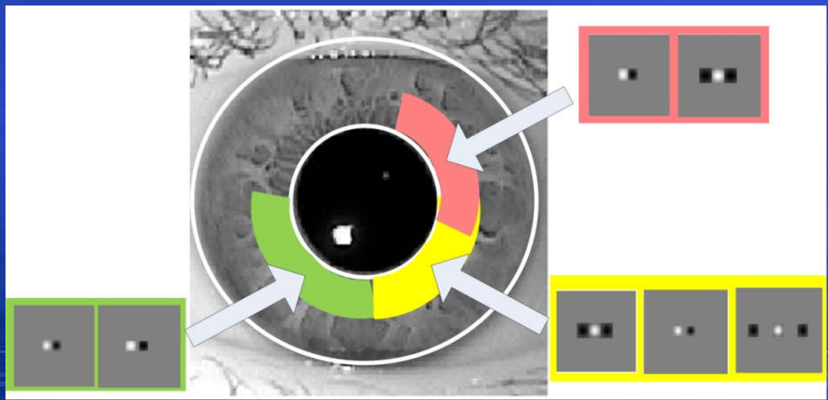
Feature selection results for iris biometrics



LP-OM

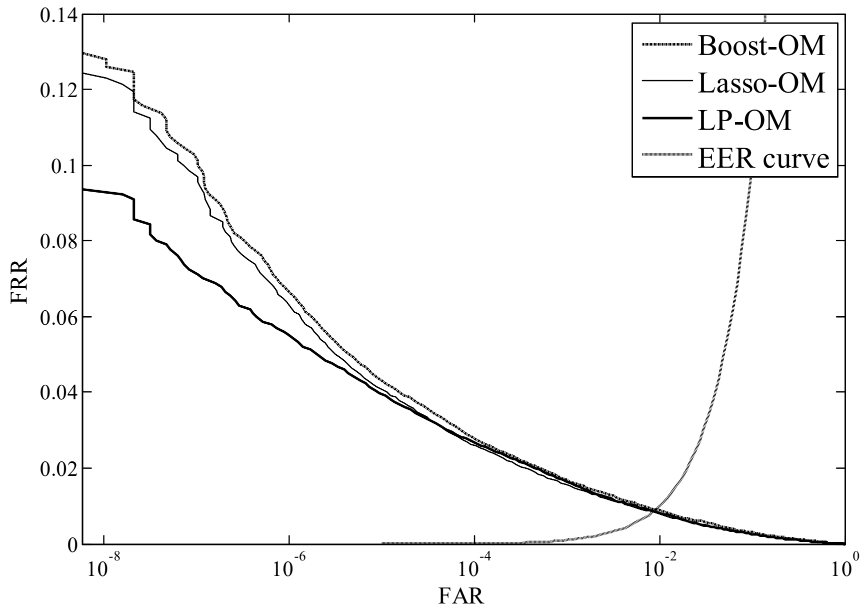


Lasso-OM

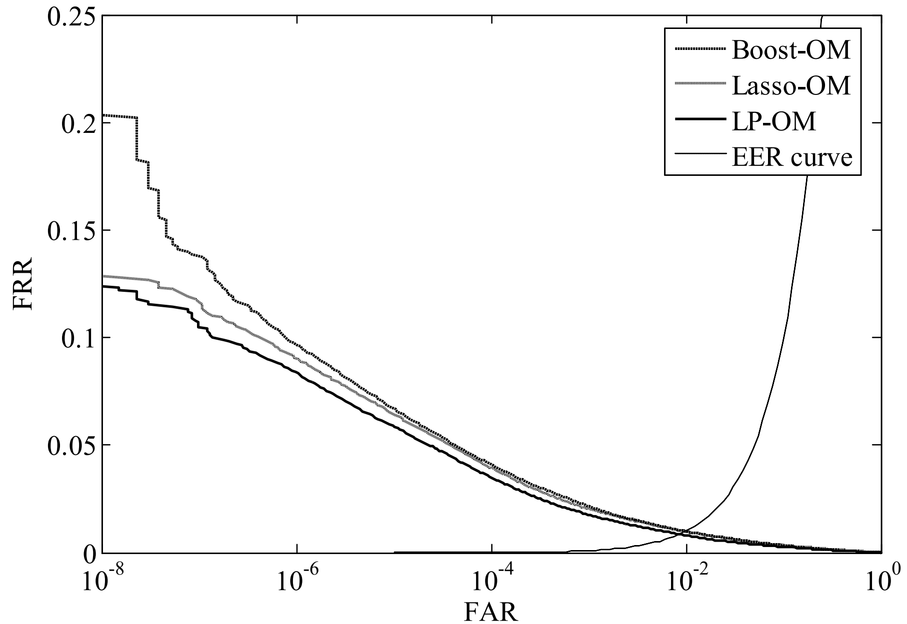


Boost-OM

Performance comparison for iris recognition

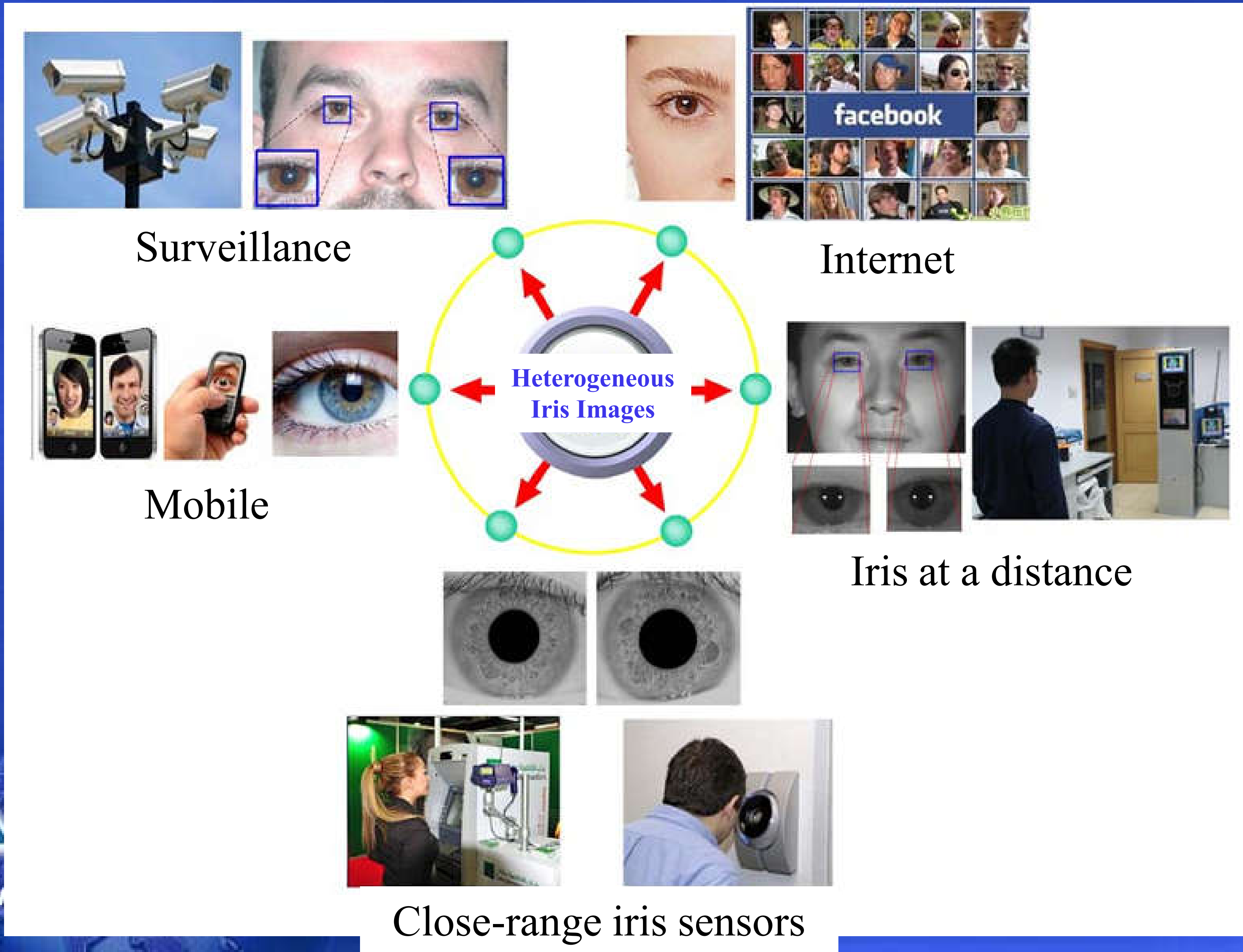


CASIA-Iris-Thousand



CASIA-Iris-Lamp

Heterogeneous Iris Images



Recognition of Heterogeneous Iris Images

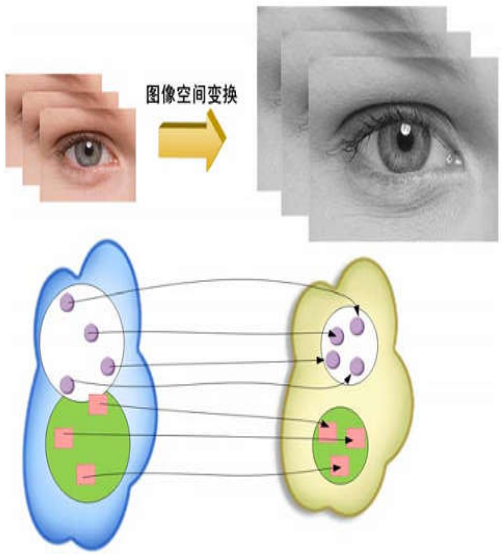
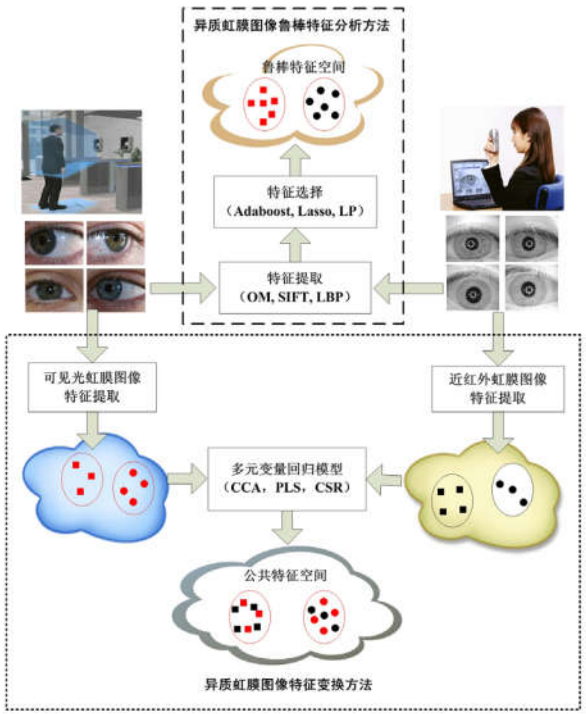
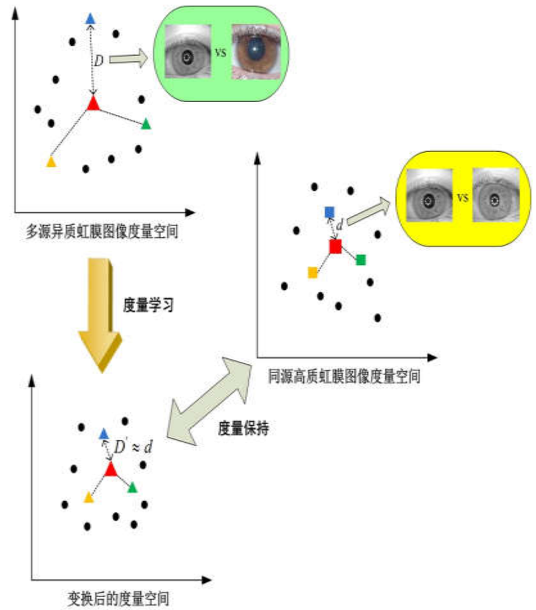


Image level

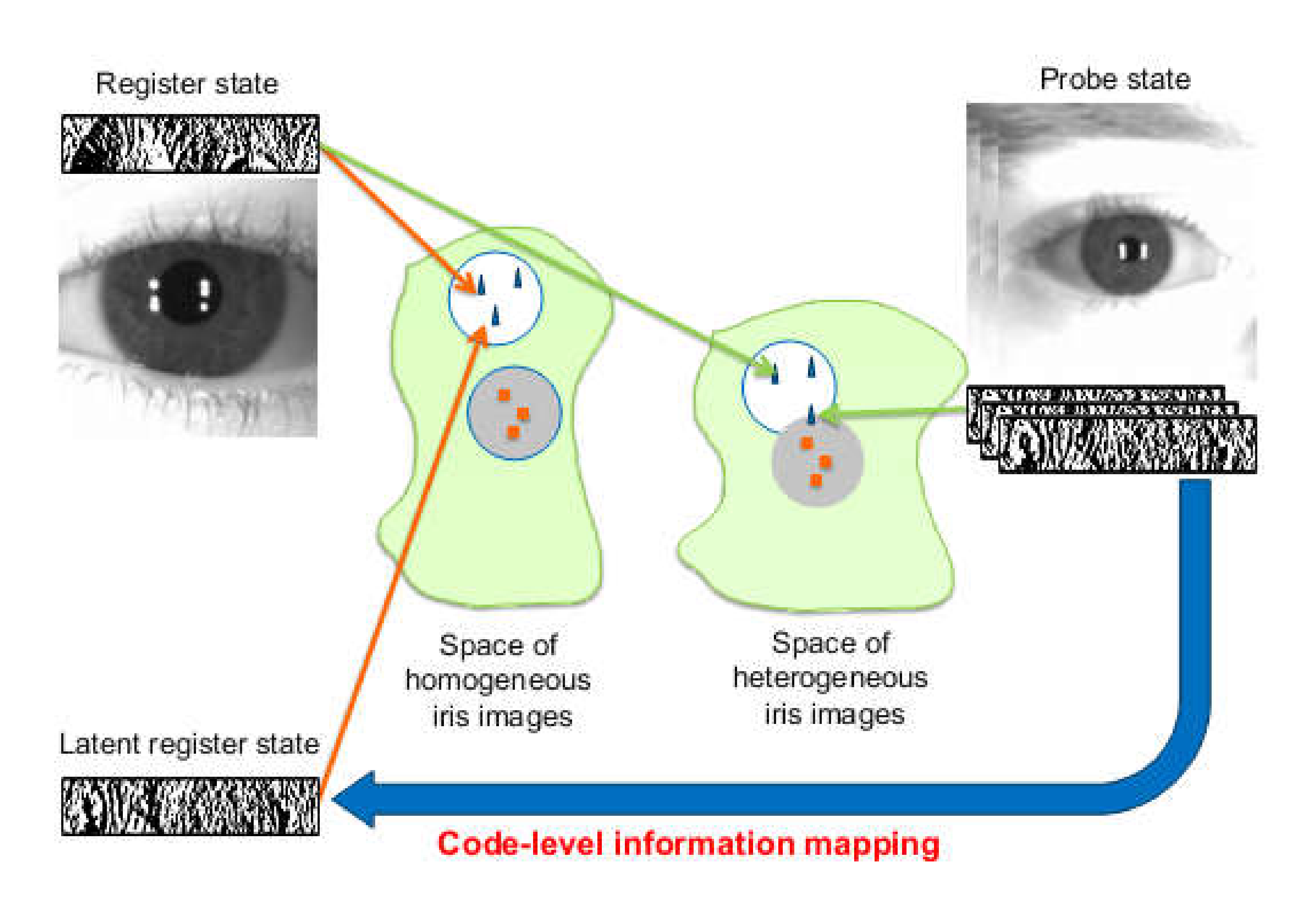


Feature level

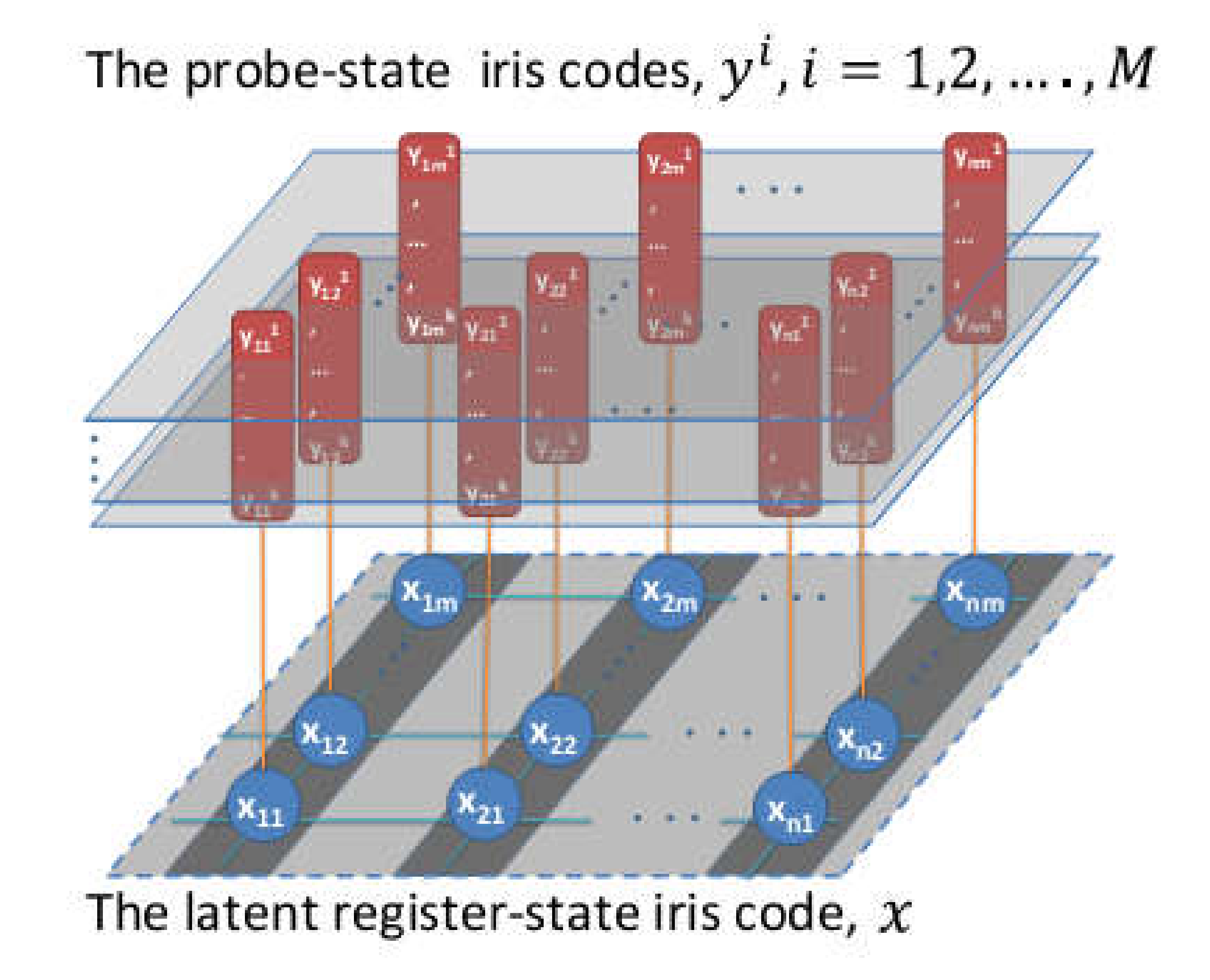


Metric level

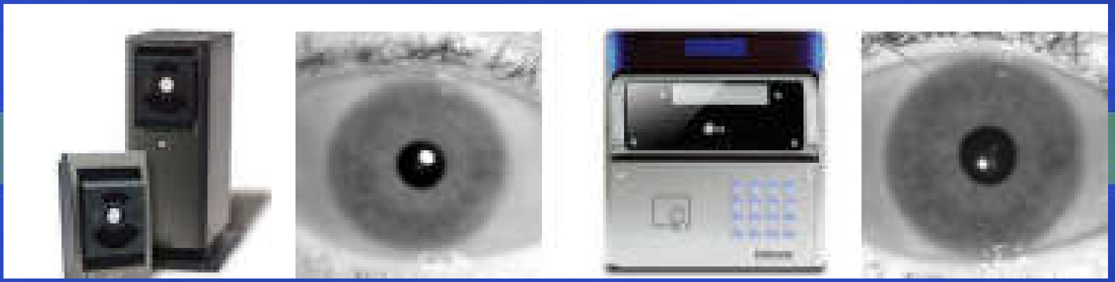
Code-level Information Mapping for Heterogeneous Iris Recognition

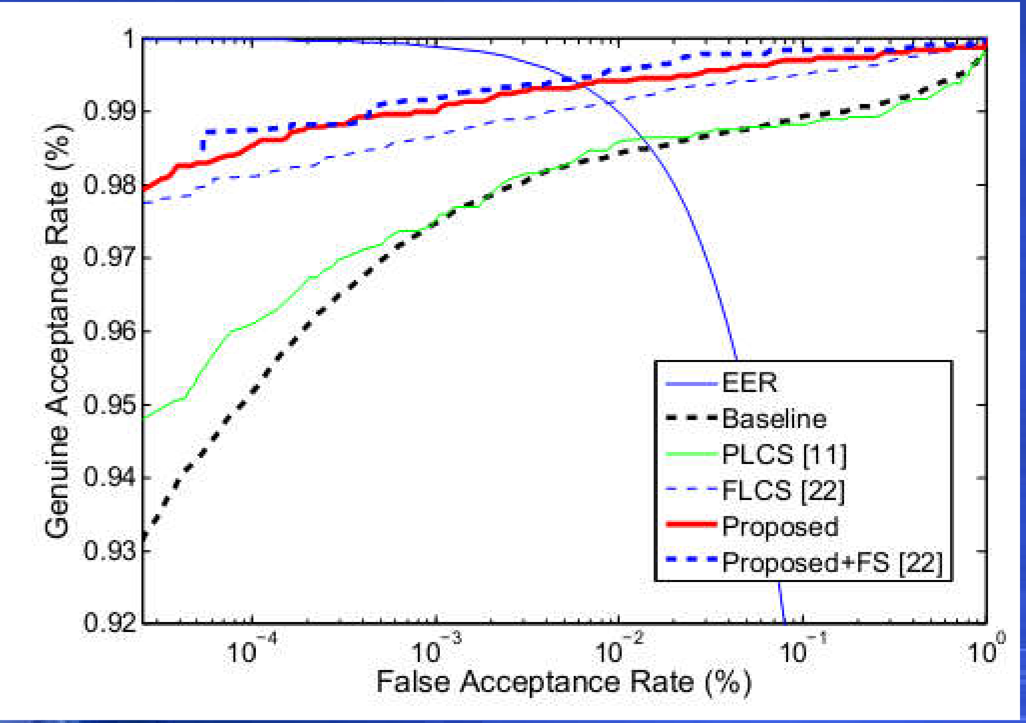


Markov network



Cross-sensor Iris Recognition

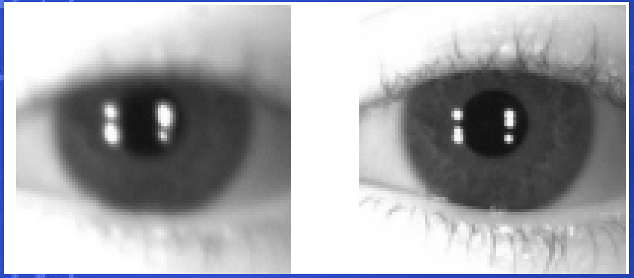




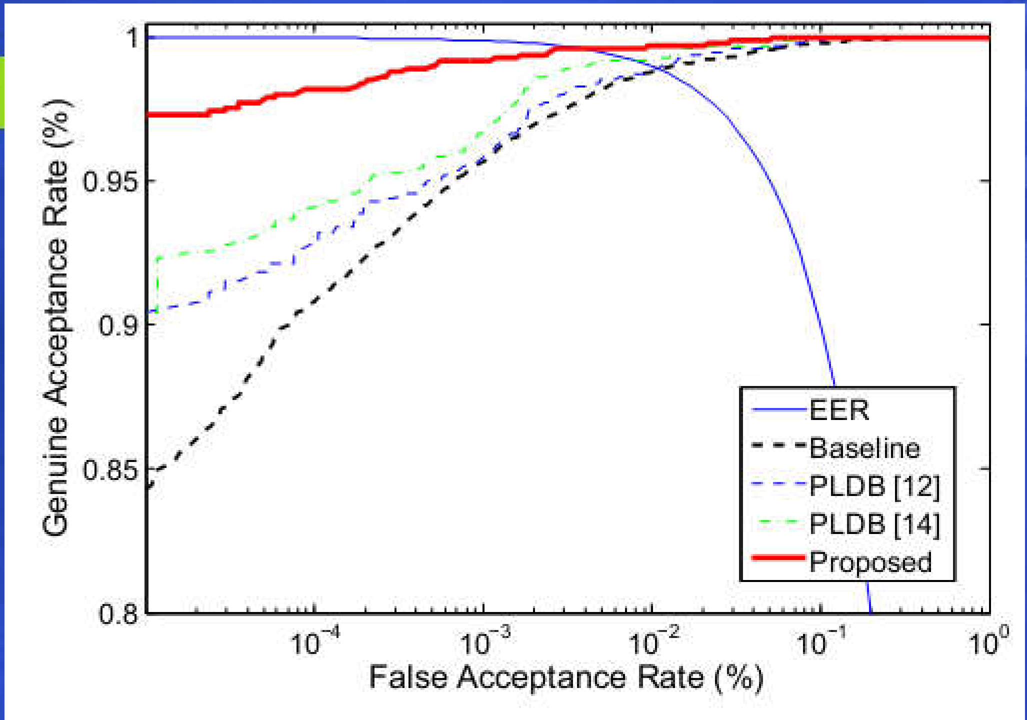
[11] S. S. Arora, M. Vatsa, R. Singh, and A. Jain, "On iris camera interoperability," in *Int'l Conf. on Biometrics: Theory, Applications and Systems. (BTAS)*. IEEE, 2012, pp. 346–352.

[22] L. Xiao, Z. Sun, and T. Tan, "Coupled feature selection for cross-sensor iris recognition," in *IEEE Int'l Conf. on Biometrics: Theory Applications and Systems. (BTAS)*. IEEE, 2013.

Cross-quality Iris Recognition



Defocused   Clear



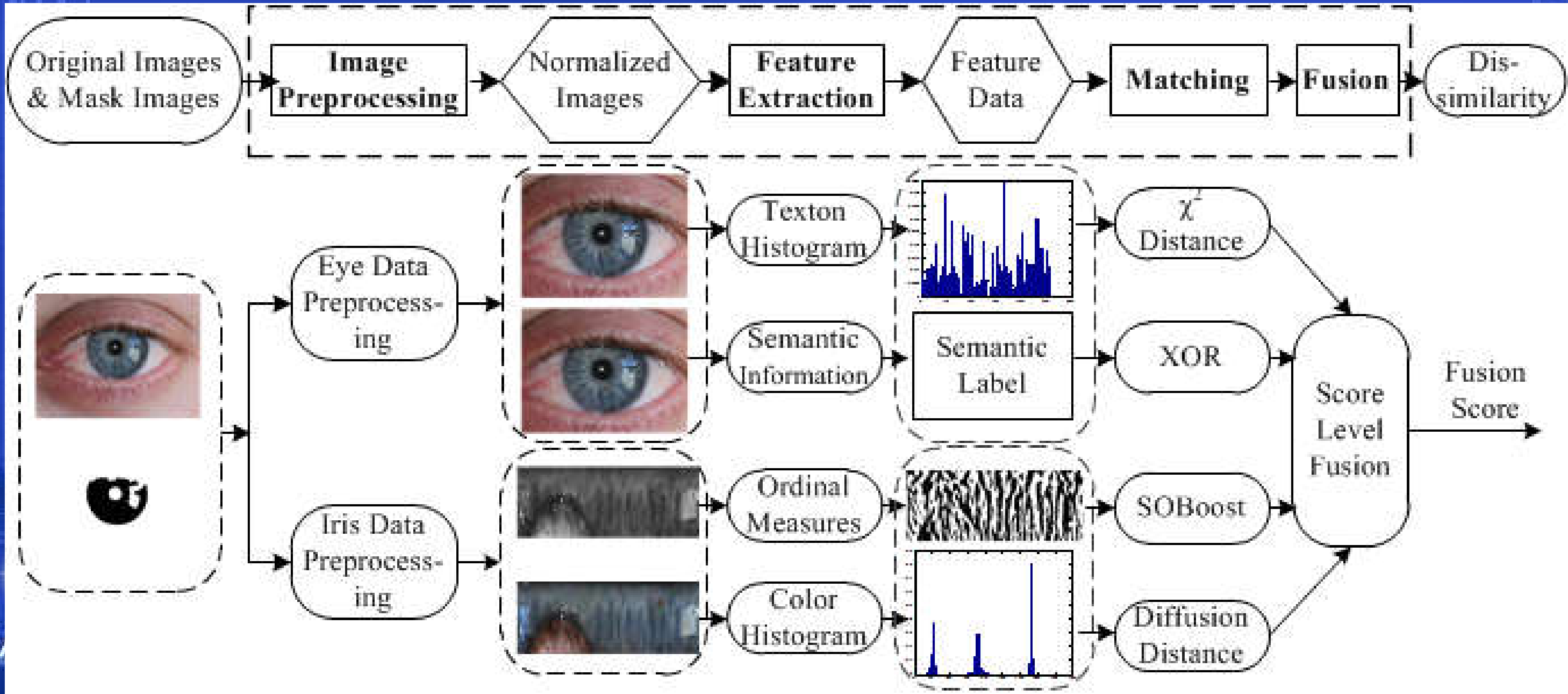
[12] B. Kang and K. Park. Real-time image restoration for iris recognition systems. *IEEE Trans. on Systems, Man, and Cybernetics, Part B: Cybernetics*, , 37(6):1555–1566, 2007.

[14] J. Liu, Z. Sun, and T. Tan, "Iris image deblurring based on refinement of point spread function," in *Biometric Recognition*. Springer, 2012, pp. 184–192.

Noisy Iris Image Matching by Using Multiple Cues

Motivations:

- Long-range personal identification
- Visible light iris images
- Personal identification on the move



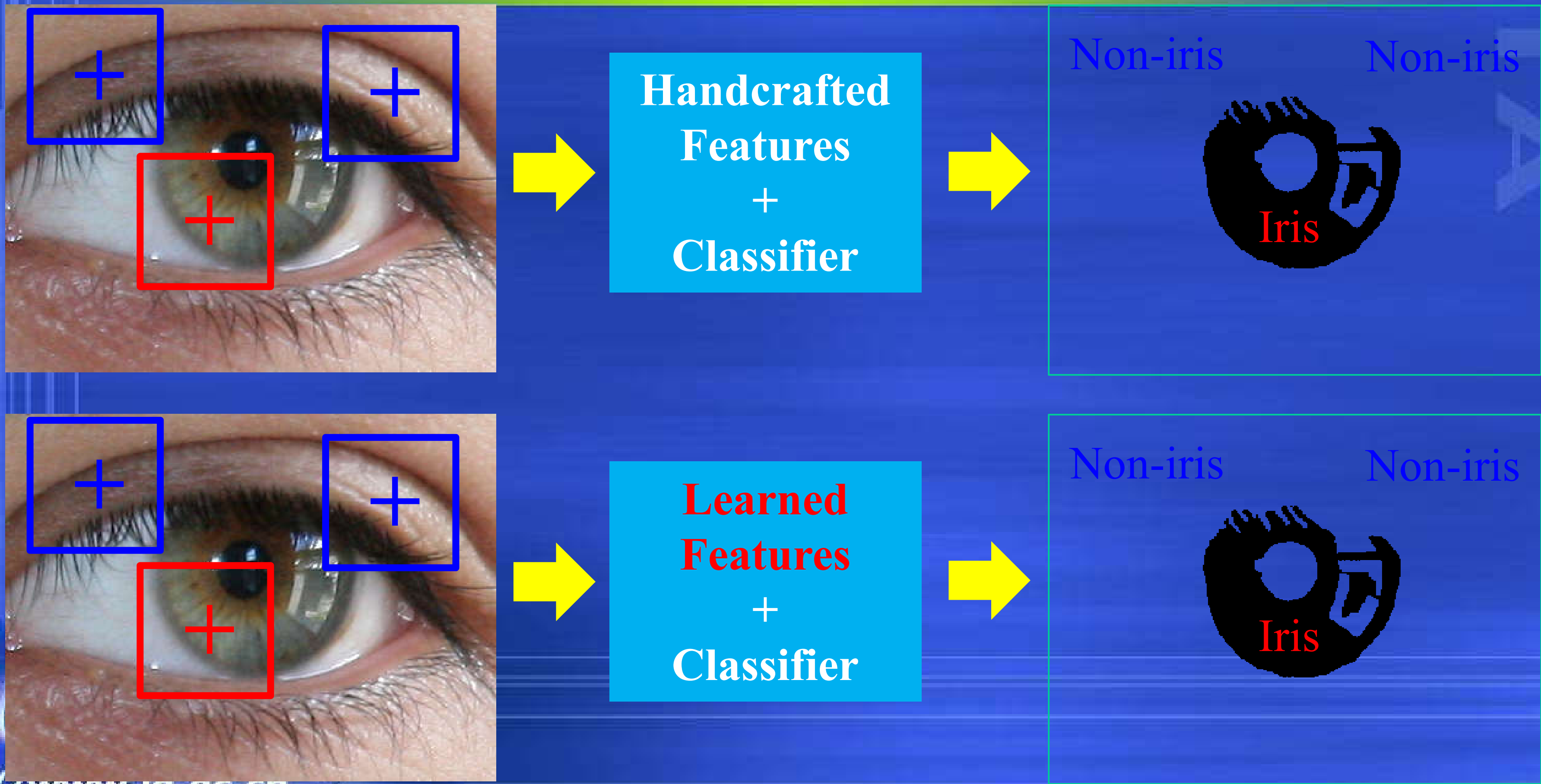
Deep Learning for Iris Recognition

- Deep Learning for Iris Image Segmentation
- Deep Learning for Iris Verification
- Deep Learning for Iris Liveness Detection
- Deep Learning for Gender/Race Classification

//www.ia.ac.cn

Iris Segmentation Based on Deep CNNs

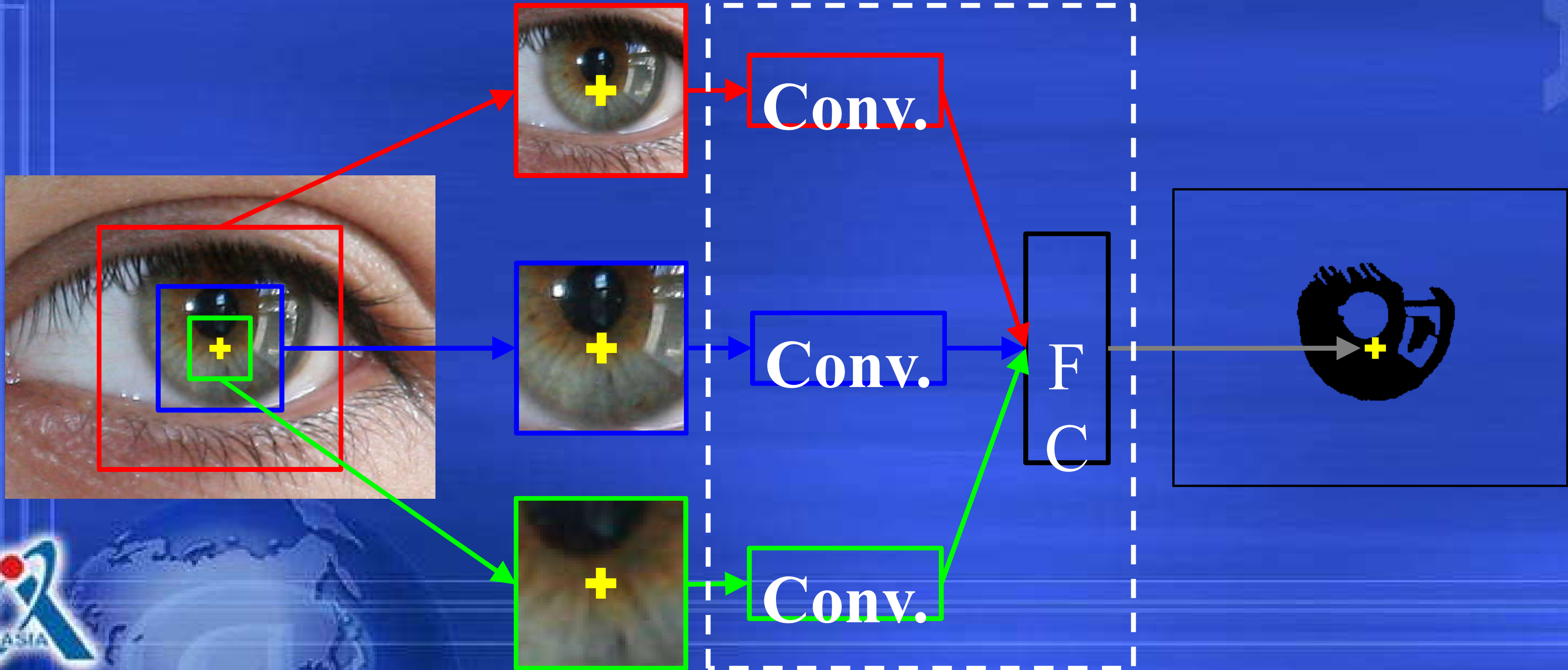
CNNs: Convolutional Neural Networks



Iris Segmentation Based on Deep CNNs

CNNs: Convolutional Neural Networks

Hierarchical Deep CNNs



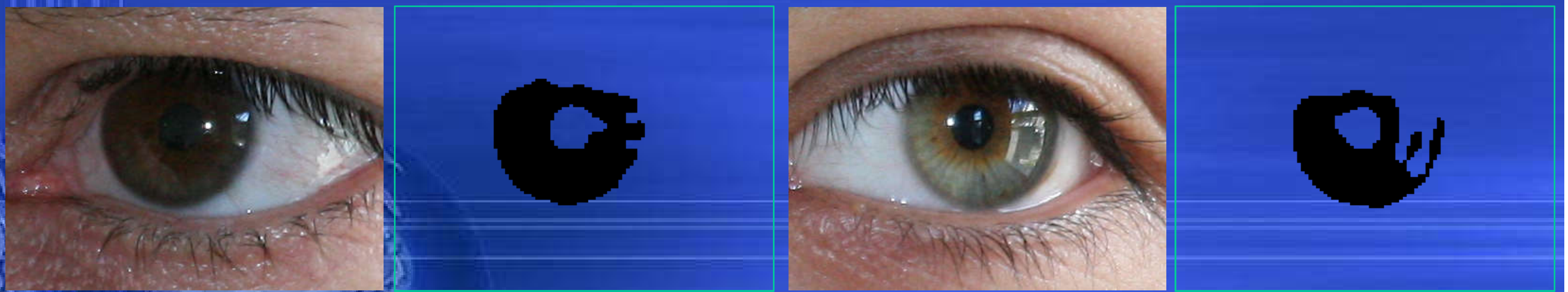
Iris Segmentation Based on Deep CNNs

Results on the NICE I dataset

Classification error: 0.0106, 19% improvement

NICE.I classification.

Rank	Authors	Affiliation	Error
1	Tan et al.	Chinese Academy of Sciences	0,0131
2	Sankowski et al.	Technical University of Lodz	0,0162
3	Pedro Almeida	University of Beira Interior	0,0180

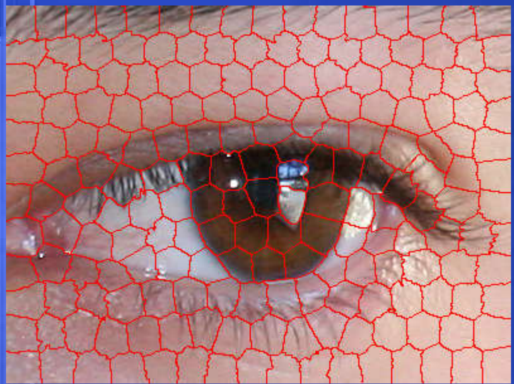


Iris Segmentation Based on Deep CNNs

Hardware： one NVIDIA TITAN GPU and one Intel i7 CPU

Elapsed time： about 30s per image

Reduce the number of pixels that need to be classified.



Superpixels

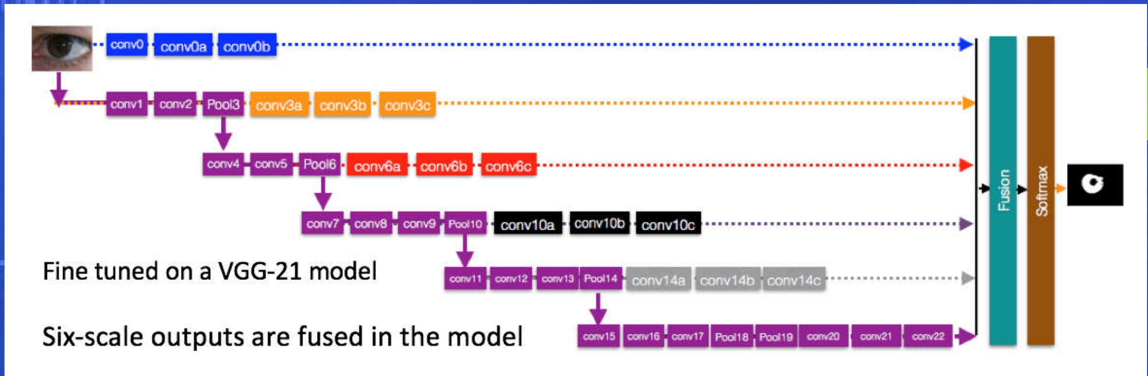
Coarse Loc.

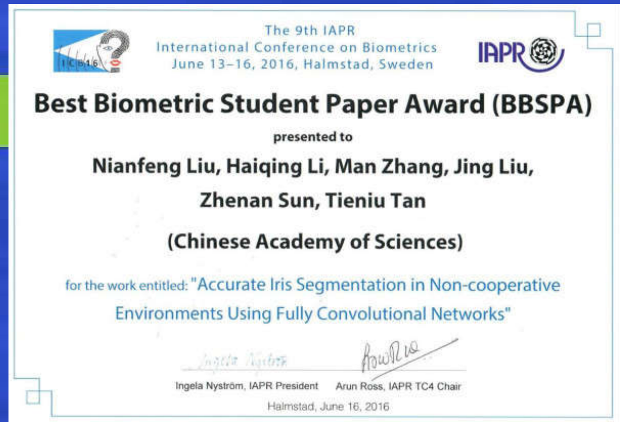
Fine Seg.

The elapsed time is reduced to 8s with nearly the same segmentation accuracy.

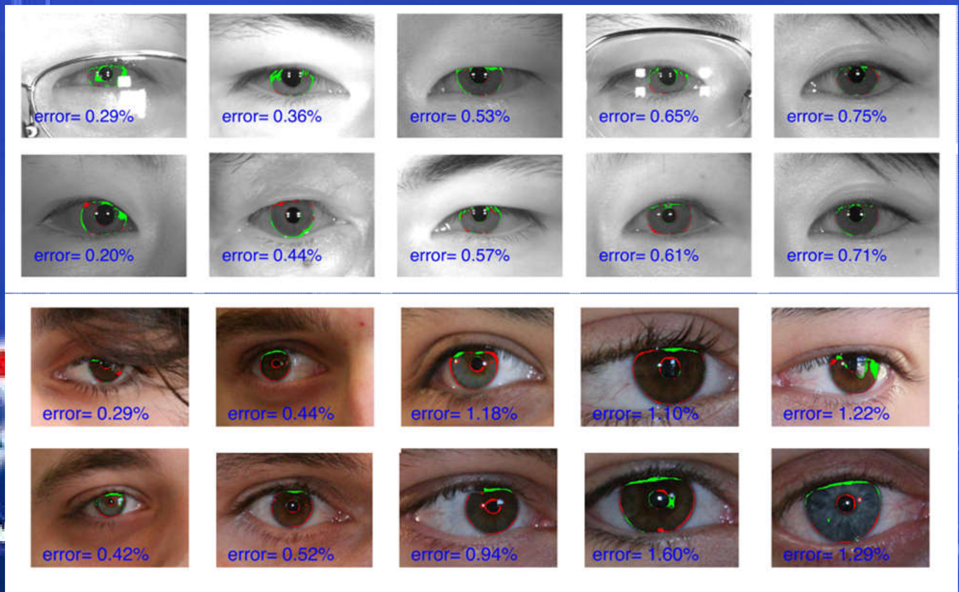
基于深度神经网络的噪声虹膜图像分割

Multi-scale fully convolutional networks (MFCNs), more accurate and 1800 times faster than HCNNs

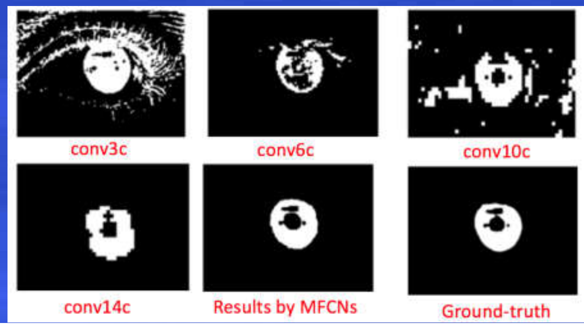




Segmentation results
(The red and green points are false-accept and false–reject points)



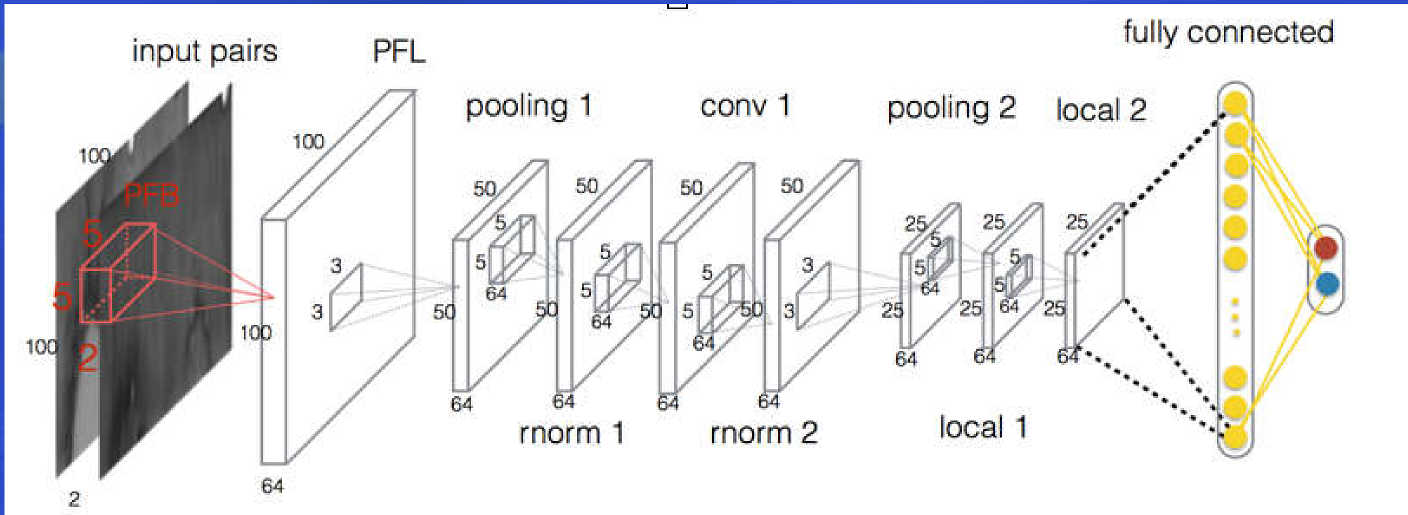
Feature maps from shallow to deep



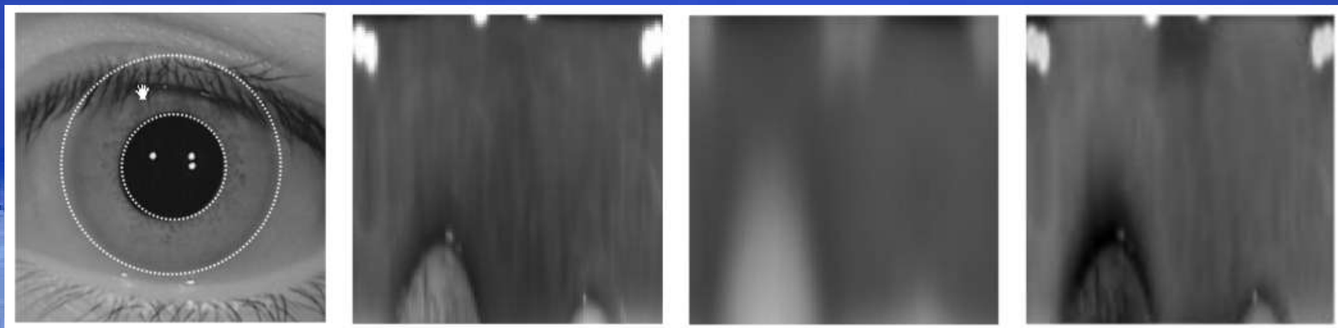
Method	UBIRIS.v2 error(%)	CASIA.v4 error(%)
Ours MFCNs	**0.90**	**0.59**
Ours HCNNs	1.11	1.08
Z. Zhao and A. Kumar, ICCV, 2015 [33]	1.21	0.68
T. Tan *et al.*, IVC, 2009 [28]	1.31	-
C. Tan and A. Kumar, T-IP, 2013 [27]	1.72	0.81
H. Proença, T-PAMI, 2010 [19]	1.87	-
C. Tan and A. Kumar, T-IP, 2012 [26]	1.90	1.13

Iris Verification Based on Deep CNNs

Architecture



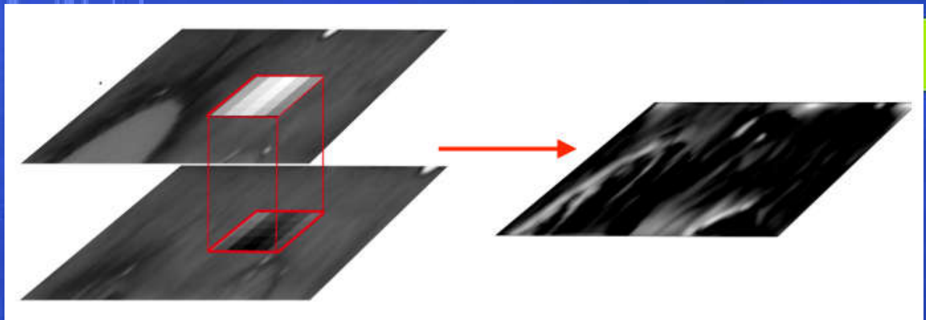
Iris images preprocessing:



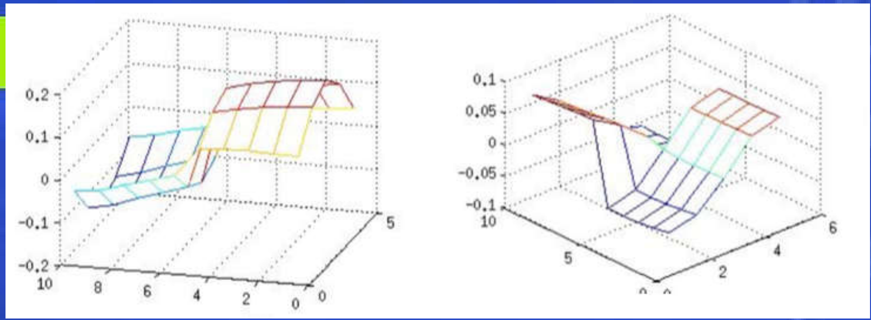
Localization   Normalization   Mean image   Subtract the mean image

Iris Verification Based on Deep CNNs

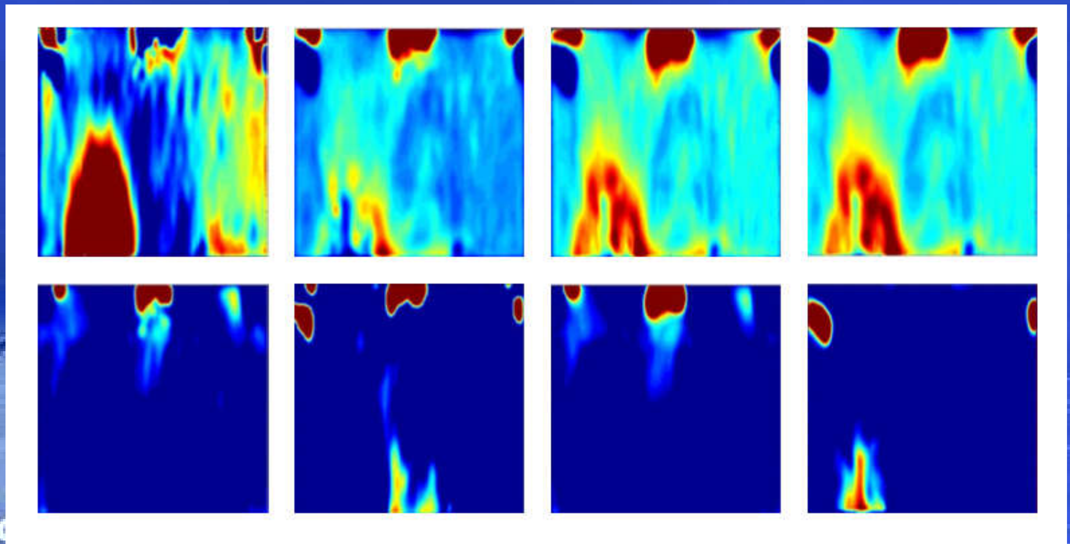
The first convolutional layer



Learned differential filters



The feature maps after the first layer filtering



Inter-class

Intra-class

Iris Verification Based on Deep CNNs

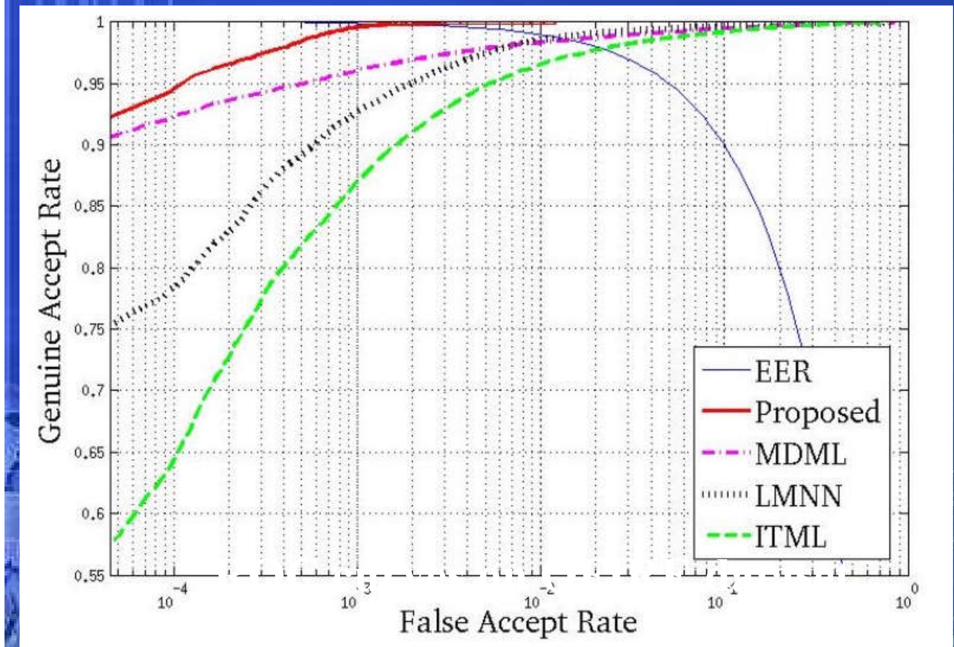
Test on the QFIRE database

images are captured at different distance

	number of classes	number of images
05 feet-train	100	1680
05 feet-test	60	911
11 feet-train	100	1568
11 feet-test	60	966

5 feet

11 feet



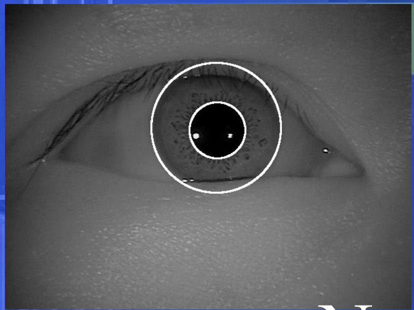
Hardware： one NVIDIA Titan GPU and one Intel i7 CPU

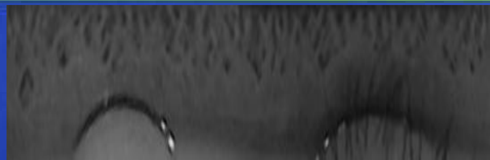
Elapsed time： 0.7ms per pair

Methods	EER
ITML (Davis et al., 2007)	2.35%
LMNN (Weinberger et al., 2005)	1.73%
MDML (Liu et al., 2014)	1.67%
Proposed	0.15%

Iris Liveness Detection Based on CNNs

Traditional iris liveness detection methods



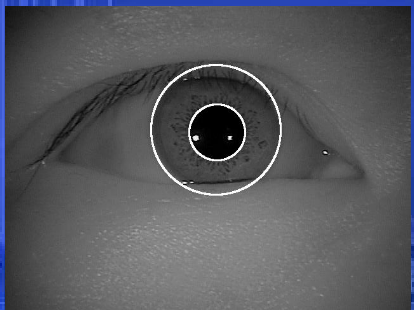


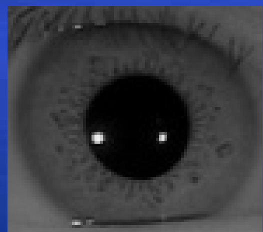
Normalized in polar coordinates

Handcrafted Features + Classifier

Genuine or Fake

Our CNN based iris liveness detection method





Normalized in Cartesian coordinates

Learned Features + Classifier

CNNs

Genuine or Fake

Iris Liveness Detection Based on CNNs

Test on the combined CASIA-Iris-Fake database

Correct Classification Rate (CCR)

Method	Weighted LBP	Learned iris texton	HVC	HVC with SPM	*CNNs*
CCR (%)	95.34	98.93	99.51	99.79	***99.48***

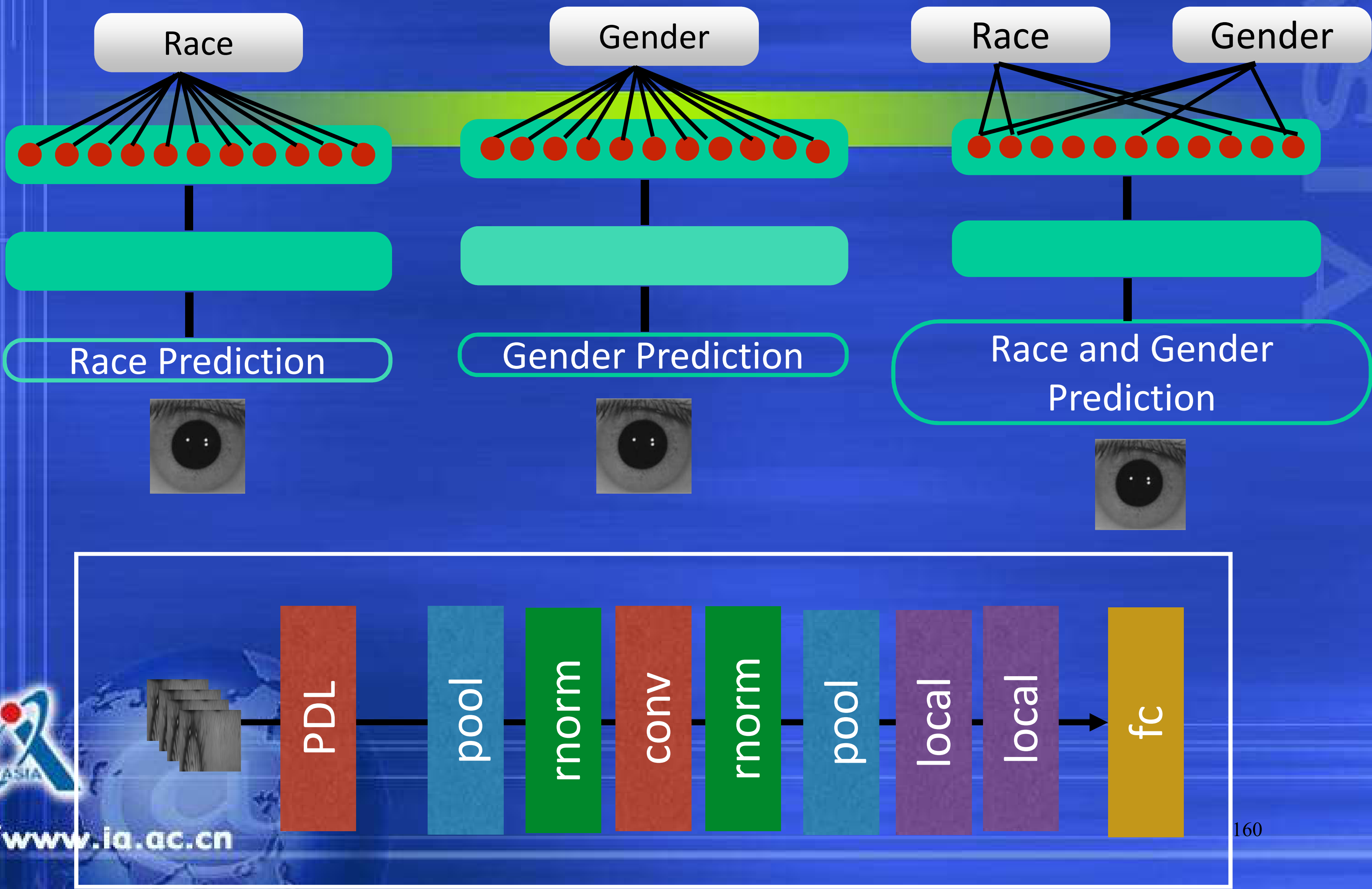
Test on the LIVDET-IRIS-2013 Warsaw database

FAR: Rate of misclassified live iris images

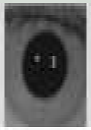
FRR: Rate of misclassified spoof iris images

Method	ATVS	Federico	Porto	*CNNs*
FAR (%)	26.28	21.15	5.23	***3.61***
FRR (%)	7.68	0.65	11.93	***0.88***

Iris Attributes Analysis Based on Deep CNNs



Iris Attributes Analysis Based on Deep CNNs

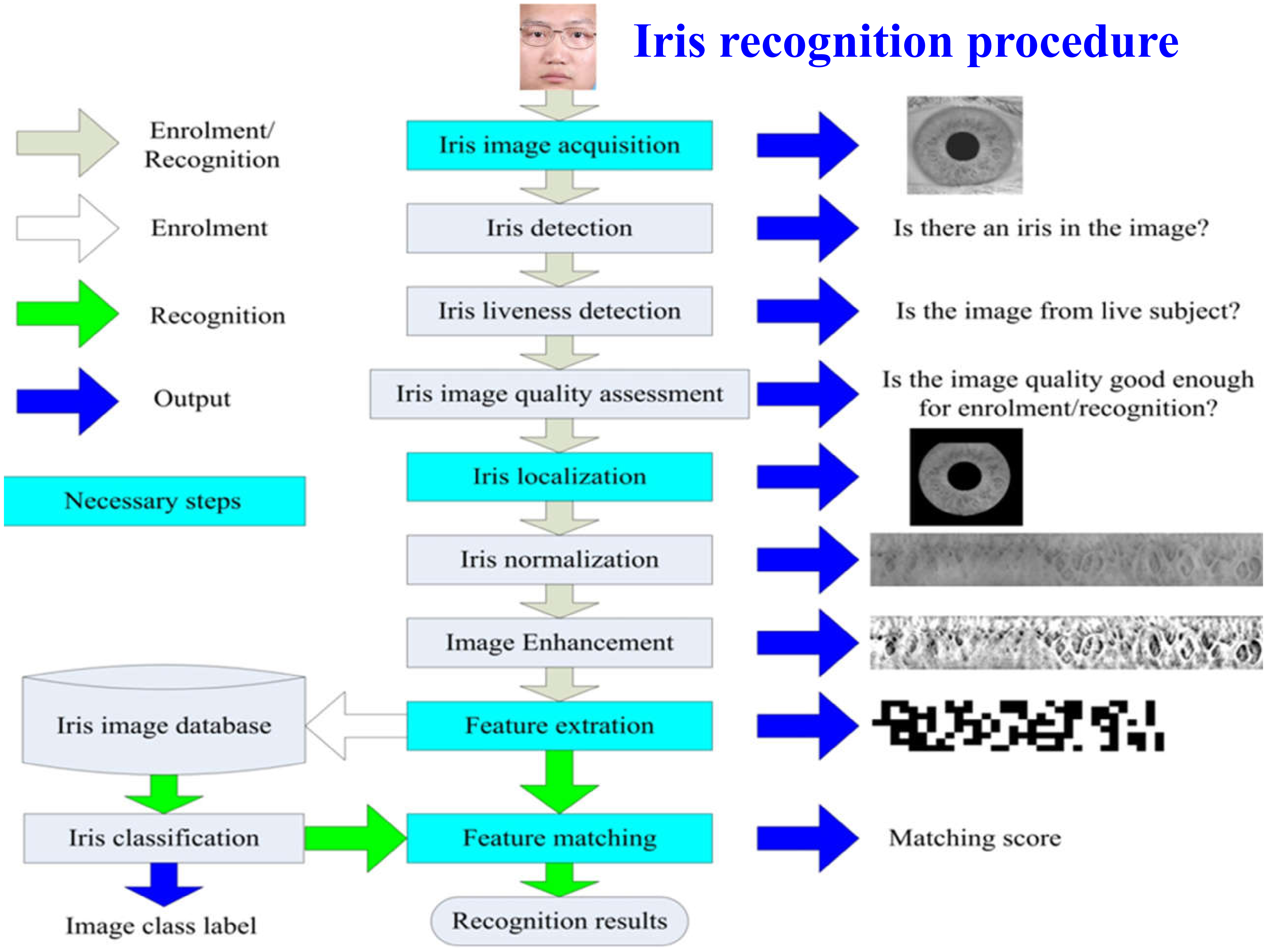
 Iris	Race-Han	Race-Zang	Race-Meng
Male	404 subjects 8068 images	178 subjects 3560 images	58 subjects 1160 images
Female	266 subjects 5318 images	124 subjects 2480 images	72 subjects 1439 images
Total	670 subjects 13386 images	302 subjects 6040 images	130 subjects 2599 images

Iris Attributes Analysis Based on Deep CNNs

Correct classification rate:

Race prediction	98.09%
Gender prediction	98.46%
Race and gender (Multi-task)	Race: 99.05% Gender: 99.23%

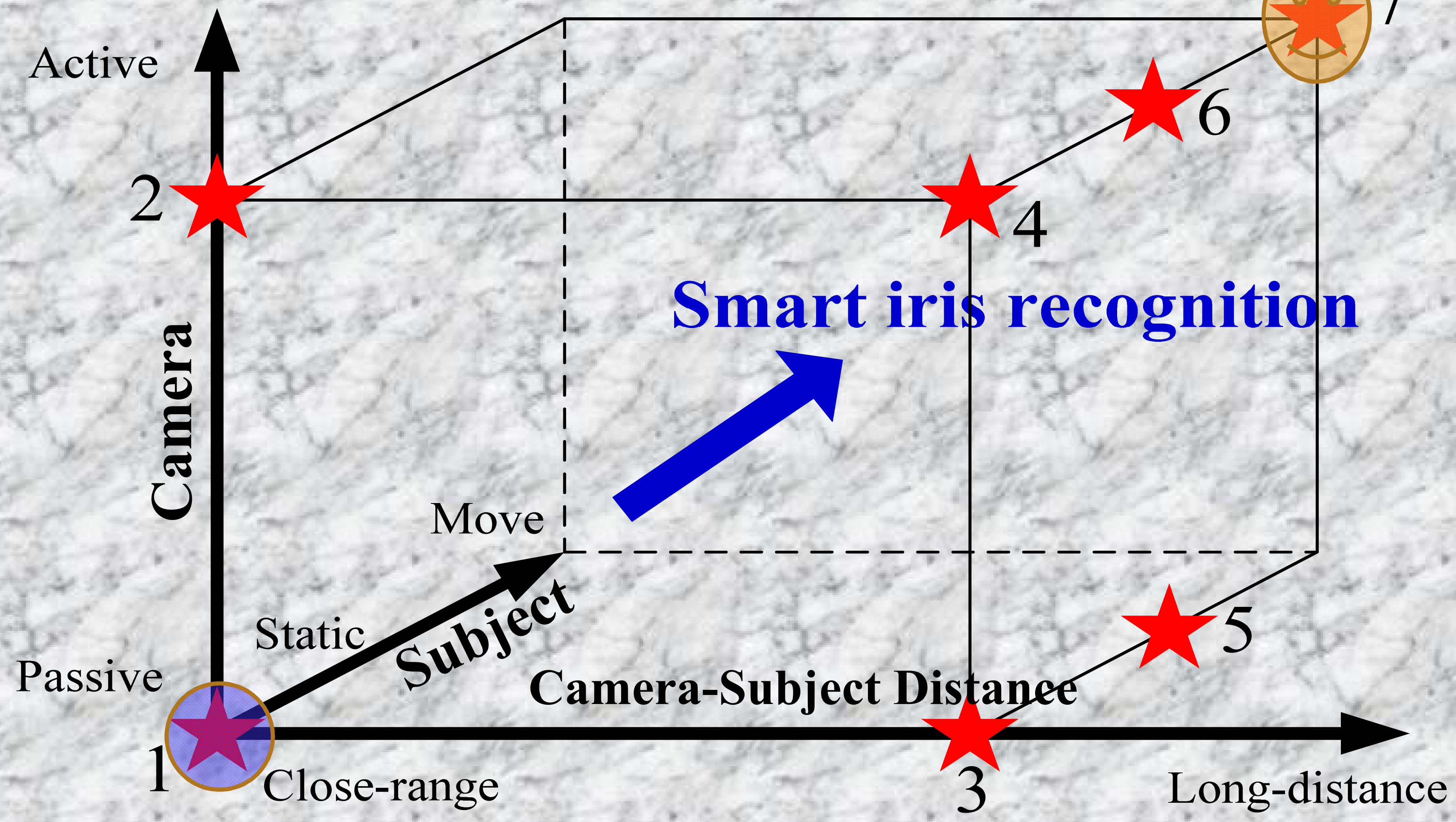
Iris recognition procedure

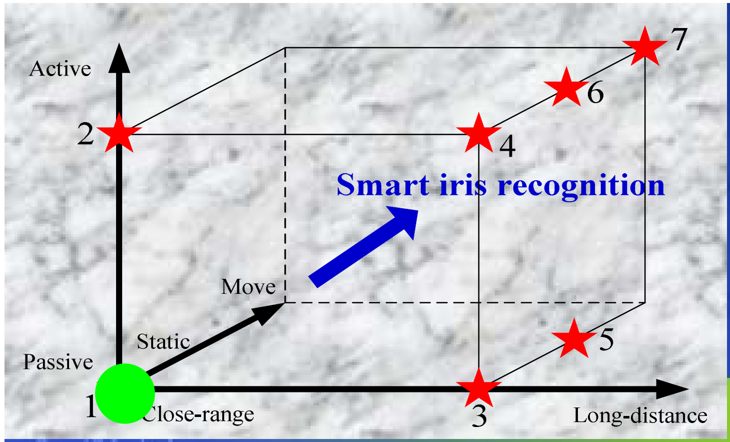


Outline of Talk

- Preamble
- Iris image acquisition
- Iris image preprocessing
- Iris pattern recognition
- **Roadmap of iris recognition**
- Resources and conclusions

Where Now and What Next: IR Roadmap





Stage 1: Close-range iris recognition

Main features

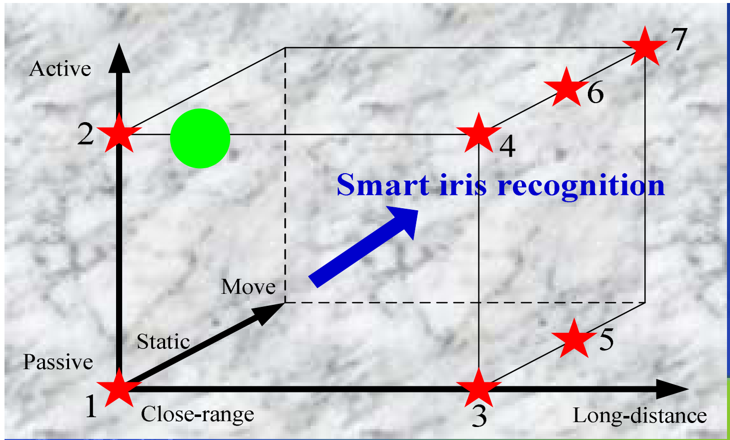
Camera: Passive (Fixed lens/No PTZ)

Distance: Close-range

Depth of field: Small

Motion: Static

Subject: Single



Stage 2: Active iris recognition

Main features

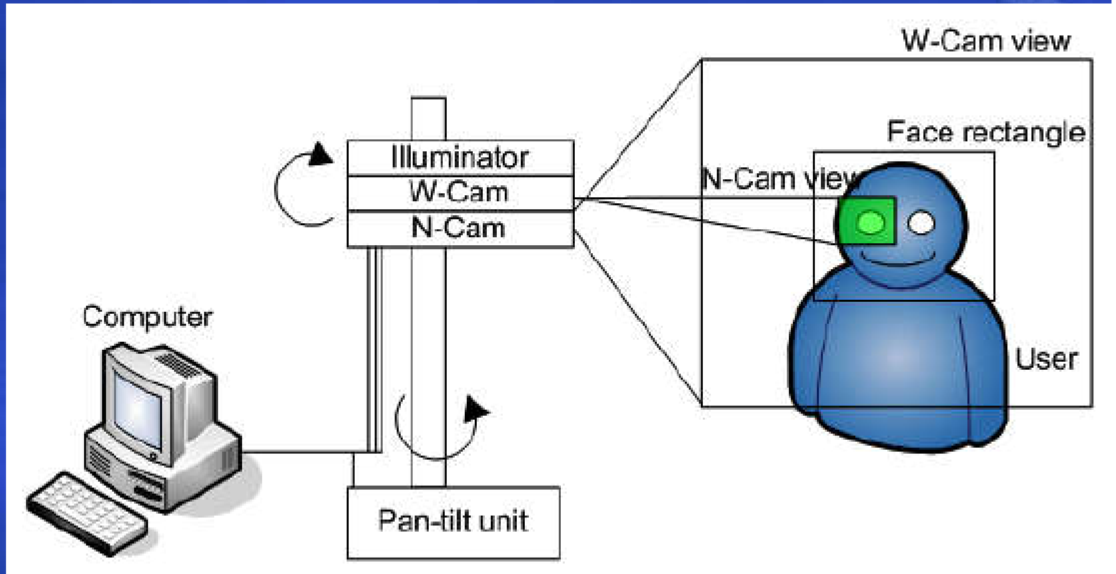
Camera: Active (PTZ, face + iris camera)

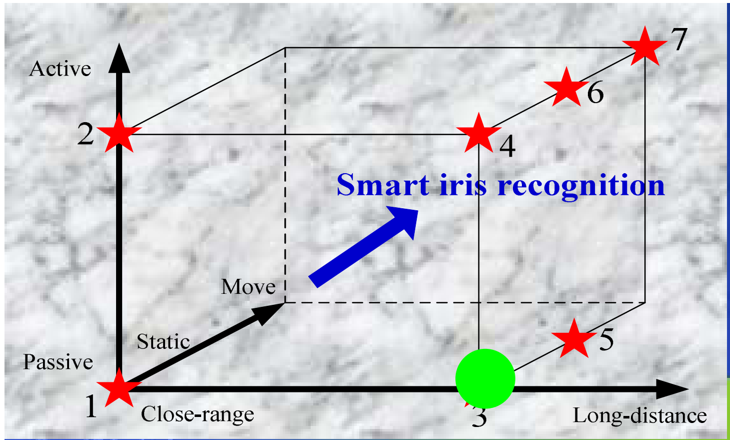
Distance: close to mid-range

Depth of field: Large

Motion: Static

Subject: Single





Stage 3: Iris recognition at a distance

Main features

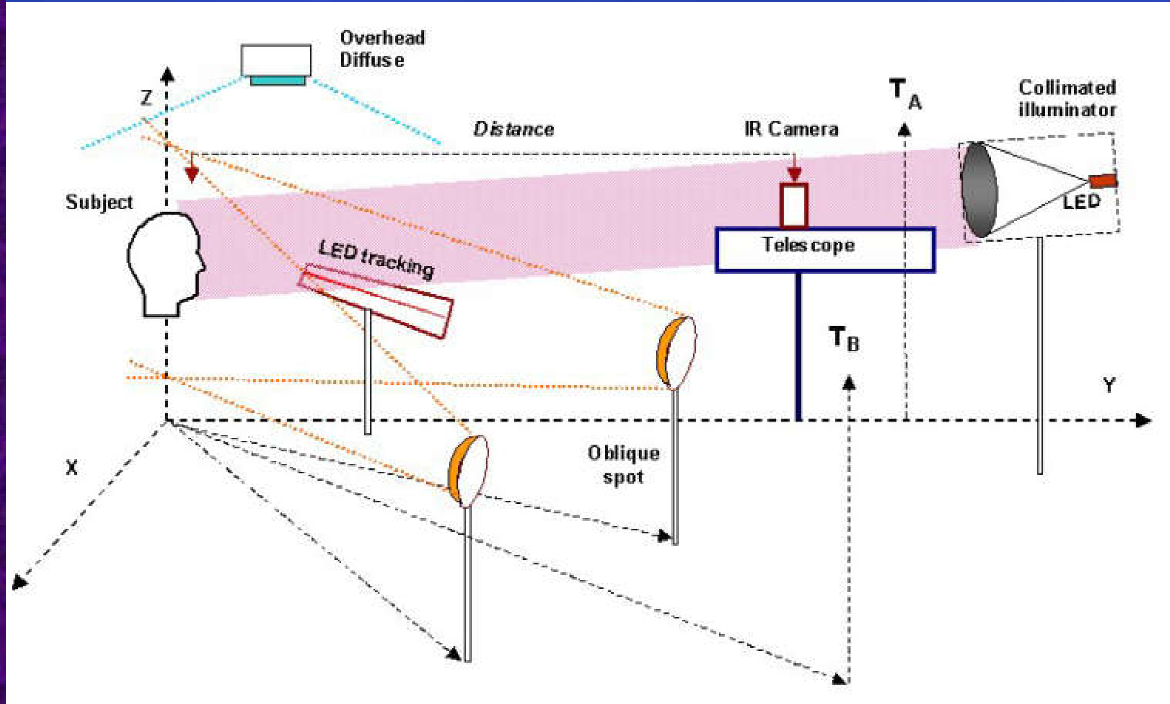
Camera: Passive (one fixed lens cam)

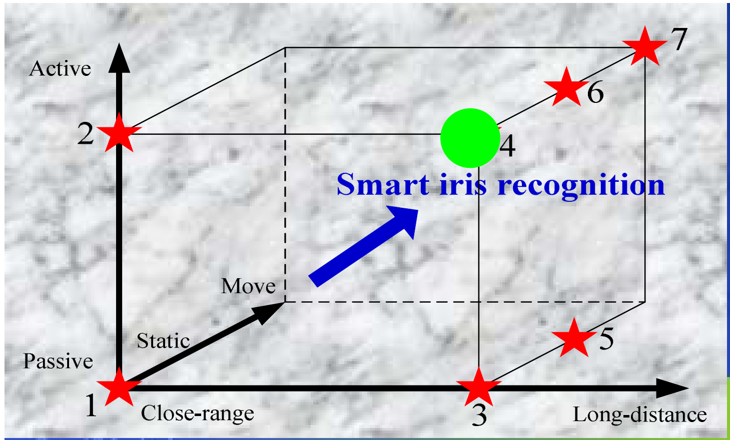
Distance: Long-range

Depth of field: Small

Motion: Static

Subject: Single





Stage 4: Active iris recognition at distance

Main features

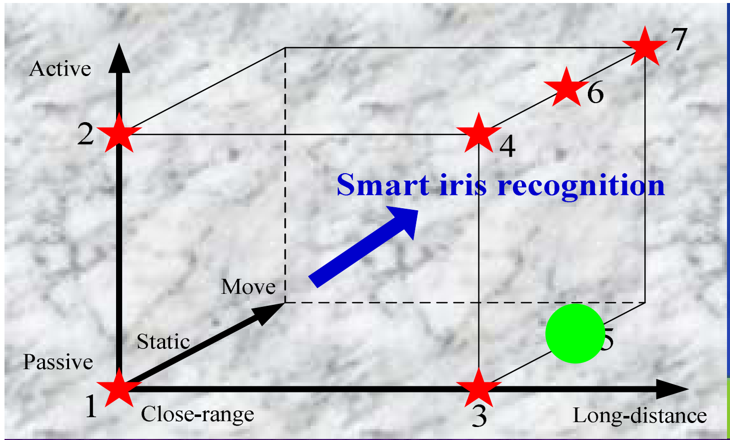
Camera: Active (face cam + High-res iris cam)

Distance: Long-range

Depth of field: Small

Motion: Static

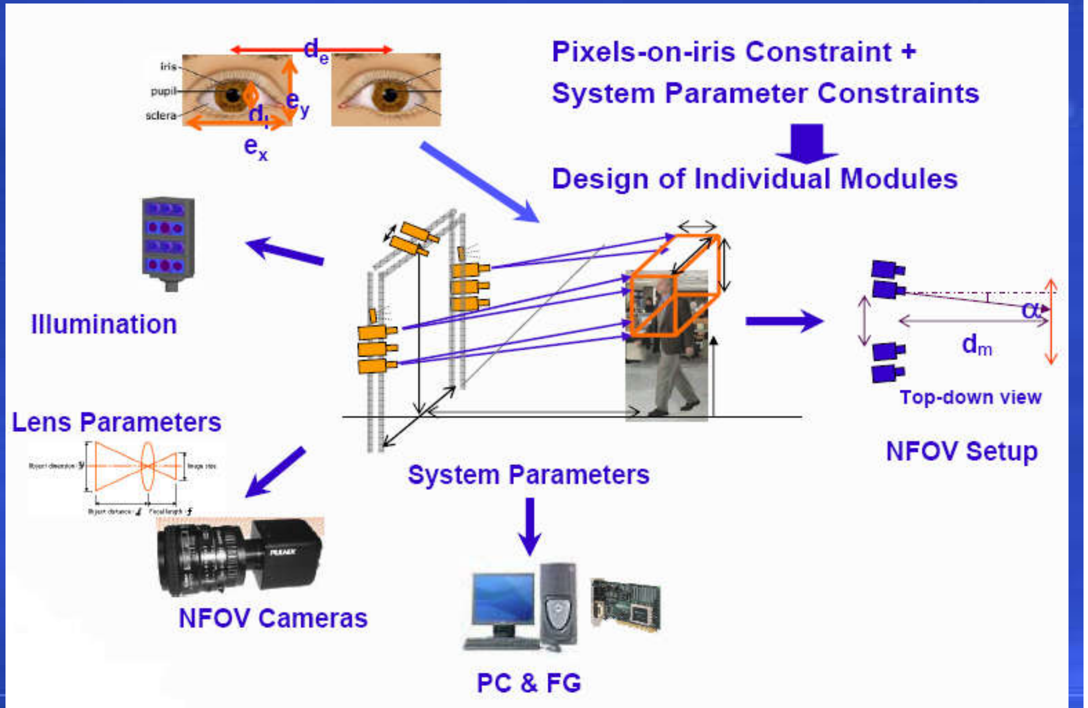
Subject: Single

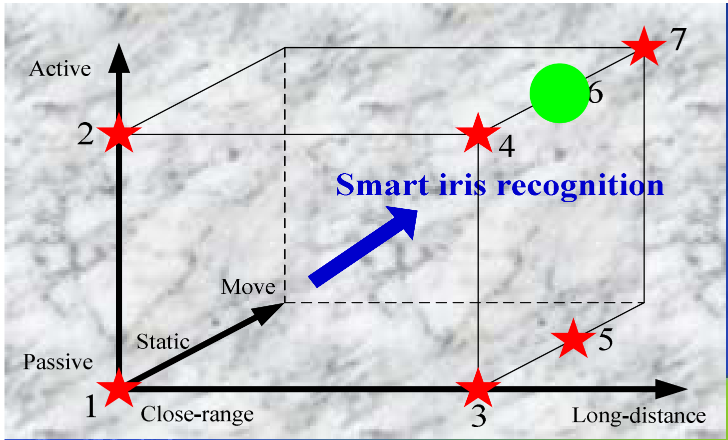


Stage 5: Passive IR on the move

Main features

Camera: Passive
(Multi high-res iris cams)
Distance: Long-range
Depth of field: Small
Motion: Walk on defined path
Subject: Single





Stage 6: Active IR on the move

Main features

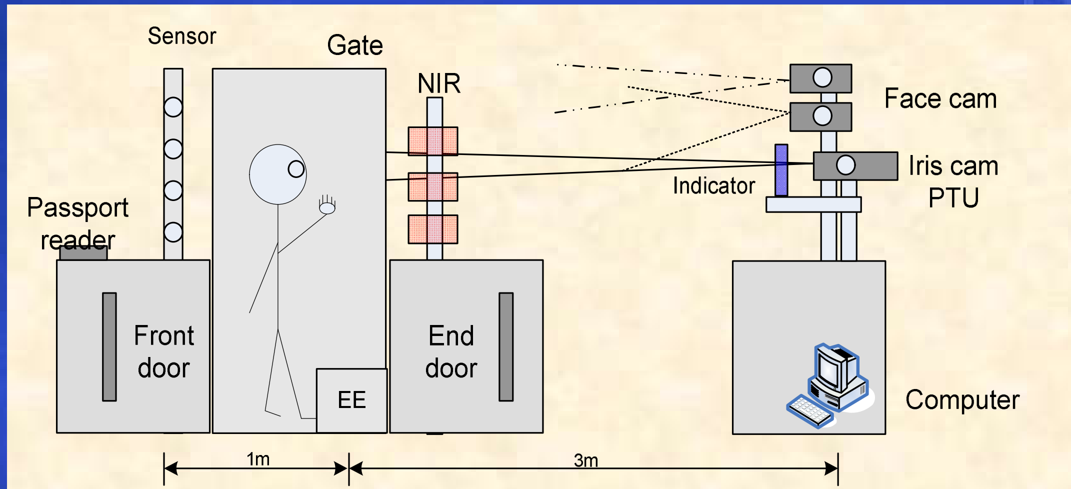
Camera: Active (PTZ, face+iris cam)

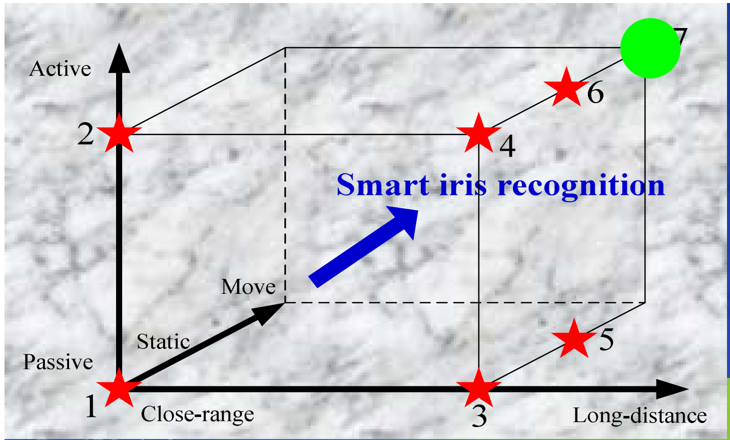
Distance: Long-range

Depth of field: Large

Motion: Walk on defined path

Subject: Single





Stage 7: Iris recognition for surveillance

Main features

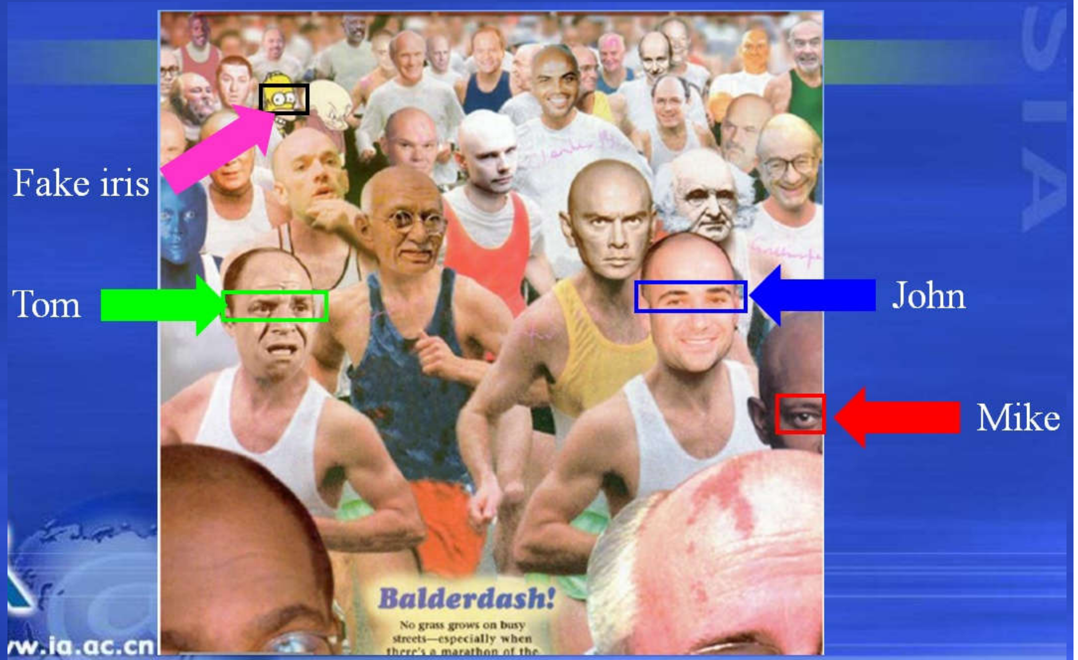
Camera: Active

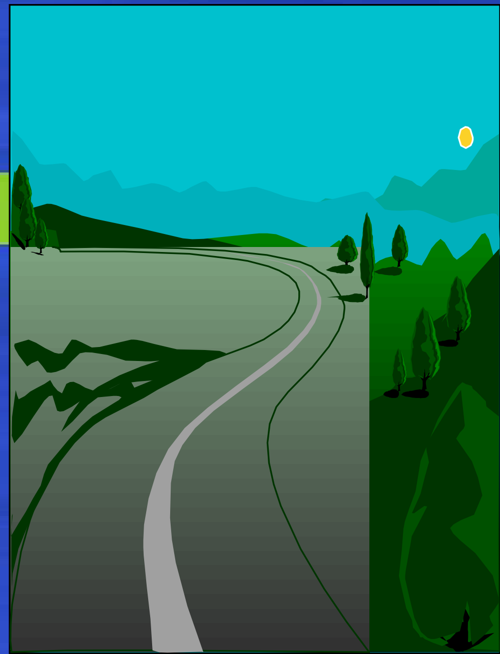
Distance: Long-range

Depth of field: Large

Motion: Free movement

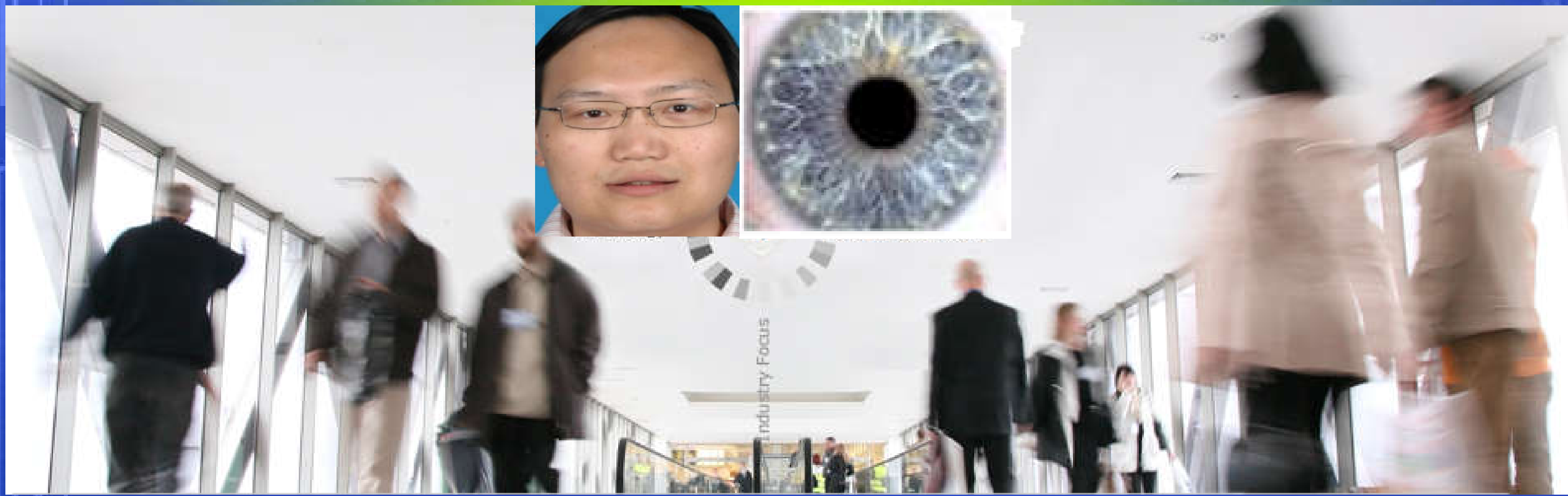
Subject: Multiple



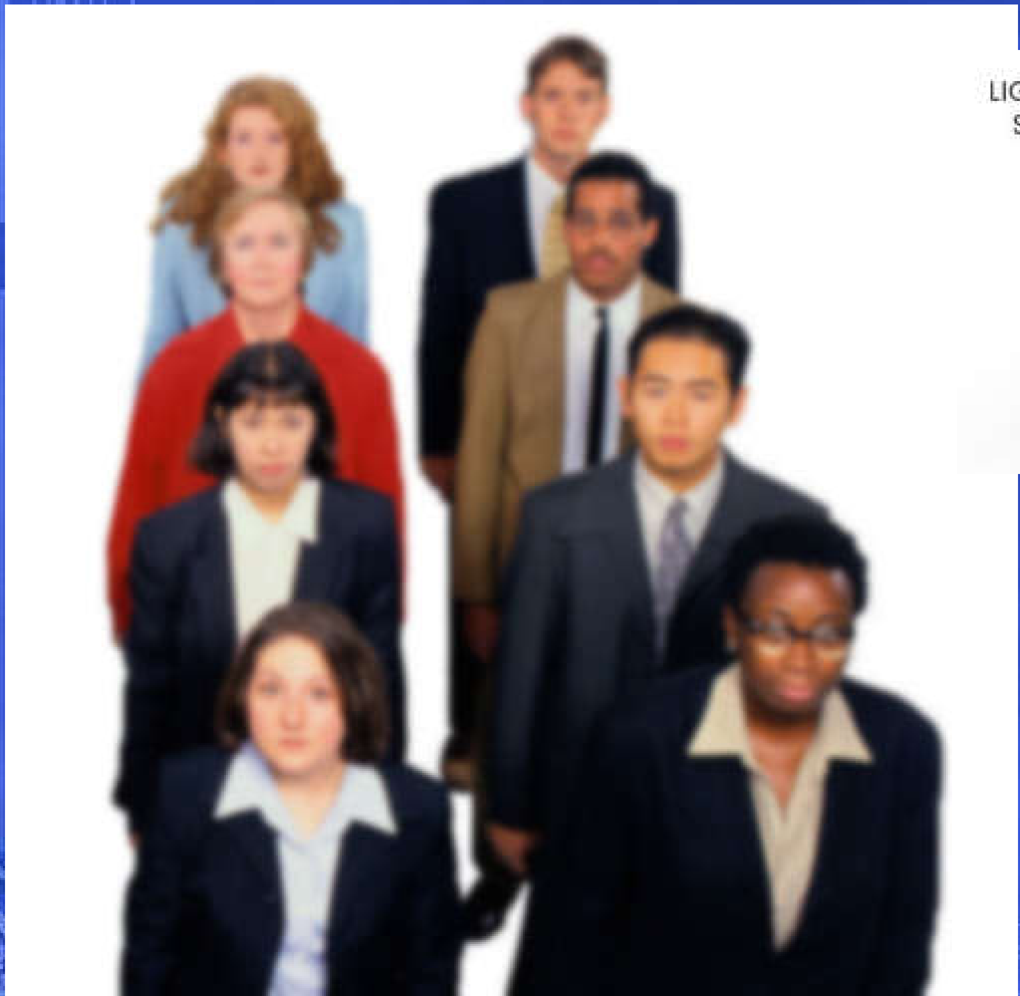


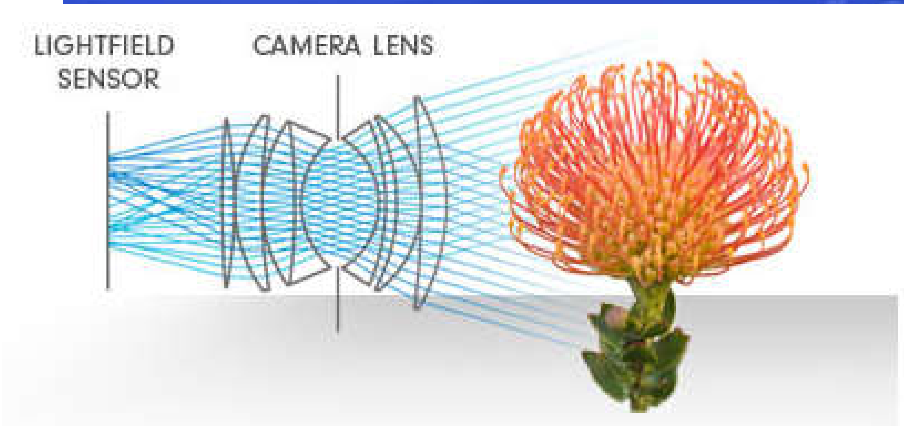
Open problems and future directions in IR

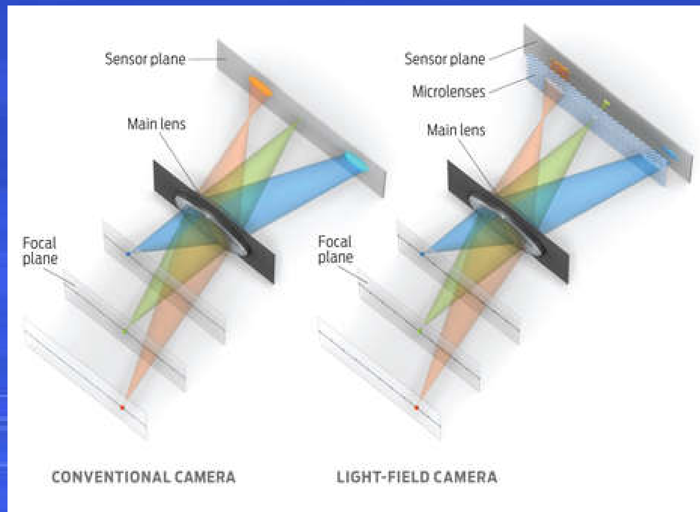
Less or unconstrained iris image acquisition



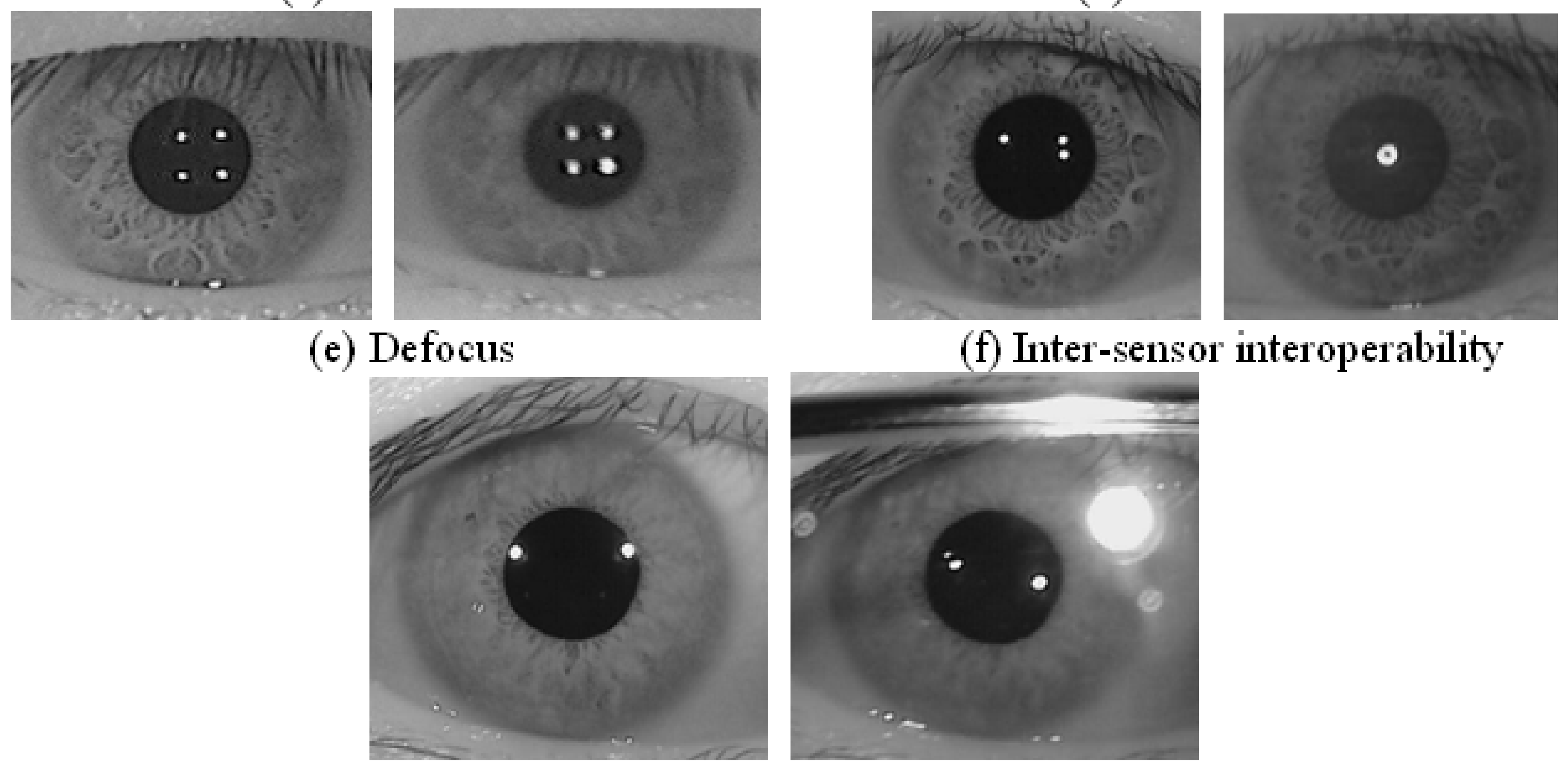
Light field photography for iris image acquisition







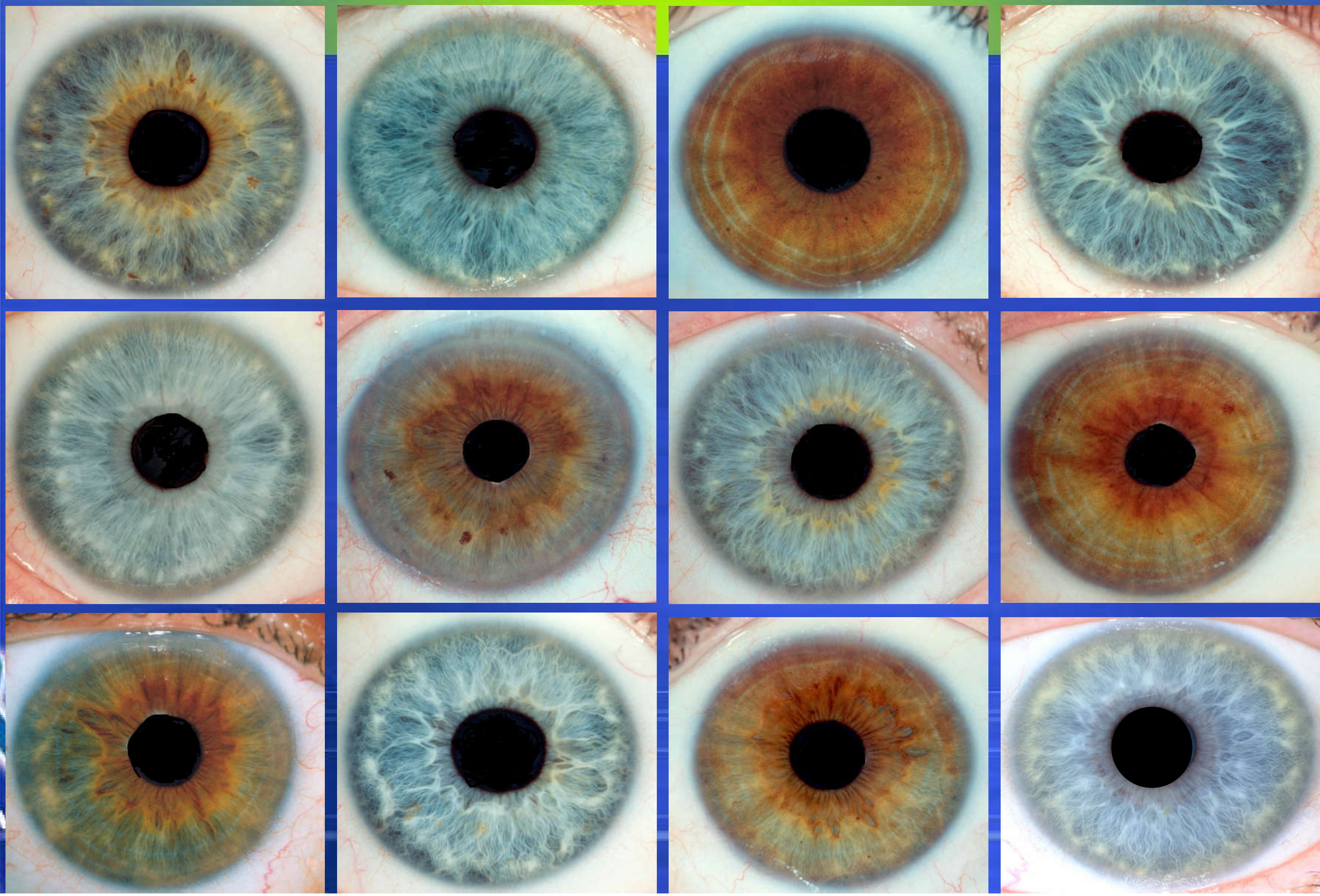
●Robust iris recognition of poor quality iris images



(e) Defocus (f) Inter-sensor interoperability

(g) Eyeglasses

- Iris classification and large scale iris image database retrieval

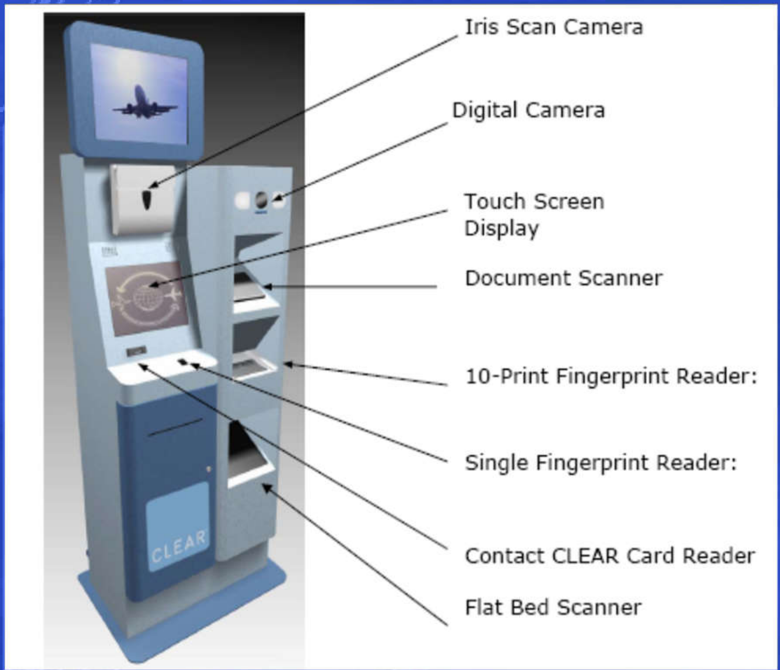


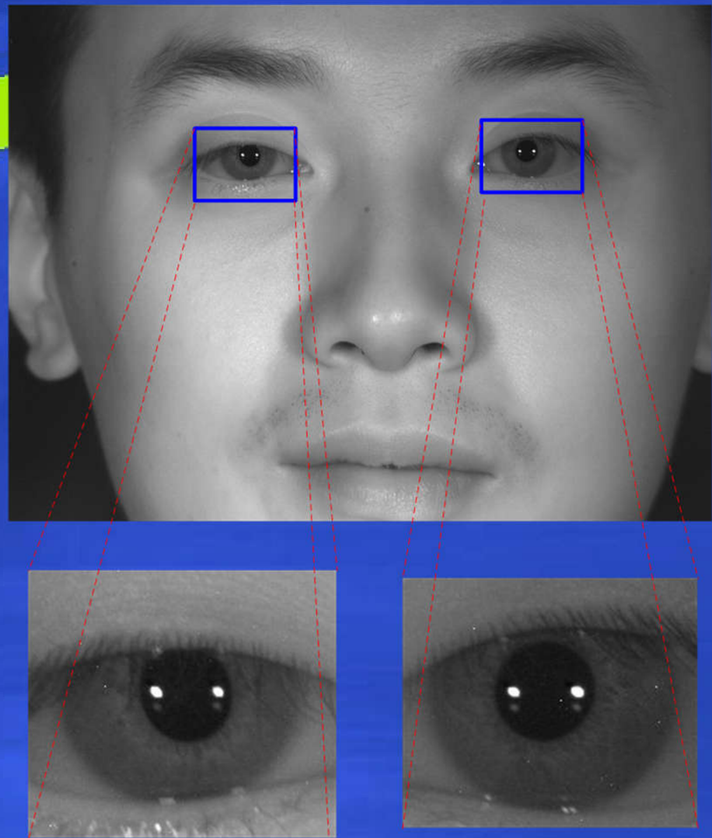
Iris recognition on mobile devices

●Iris recognition for forensic applications

Iris recognition

Multi-modal biometrics

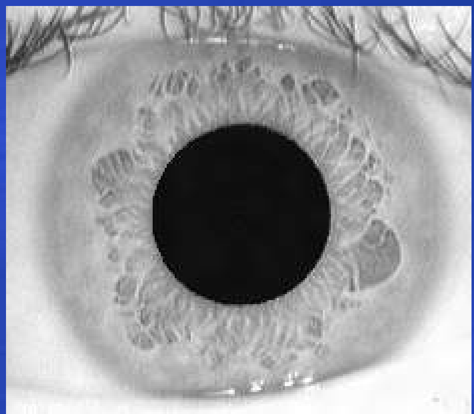




Iris/face/fingerprint

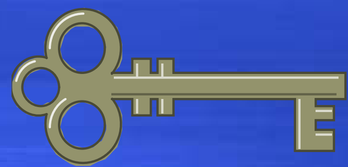
Iris/face/skinprint from one single image

Iris biometrics for information security



101110010110010101 0111

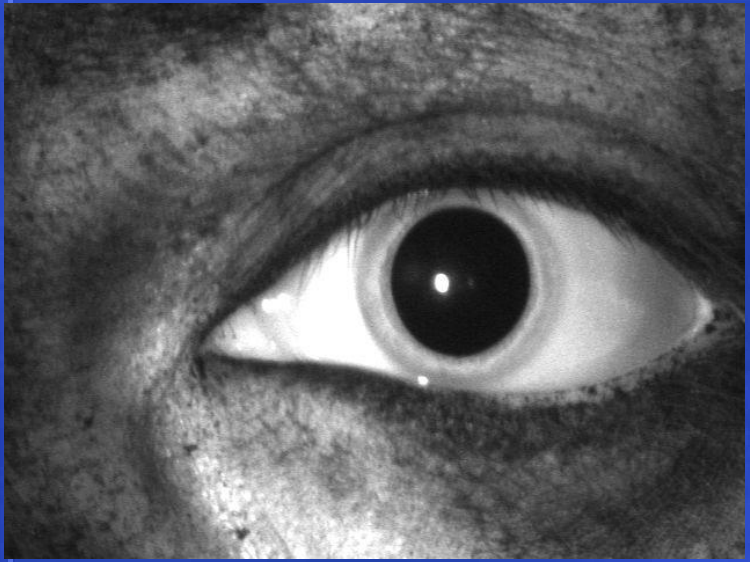
……………



Biometric key

Watermarking, Information hiding, IP protection, …

●Application specific problems

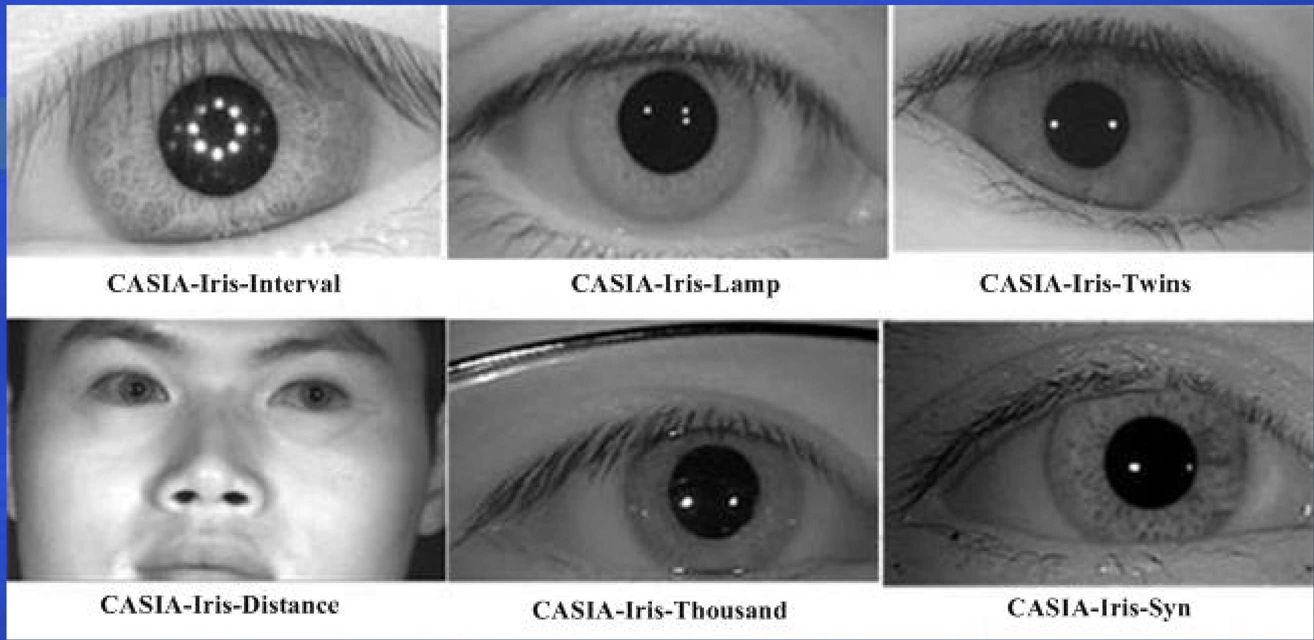


Iris images of coal miners

Outline of Talk

- Preamble
- Iris image acquisition
- Iris image preprocessing
- Iris pattern recognition
- Roadmap of iris recognition
- Resources and conclusions

CASIA Iris Image Database V4.0



Highlights:

- Interval: cross-session, clear texture iris images
- Lamp: deformed iris images
- Twins: iris image dataset of twins
- Distance: long-range and high-quality iris/face images
- Thousand: large scale iris image dataset of one thousand subjects
- Synthesis: large scale synthesized iris image dataset

The CASIA Iris Database has been requested by and released to more than 17000 researchers from 120 countries or regions. It is the most widely used iris database.

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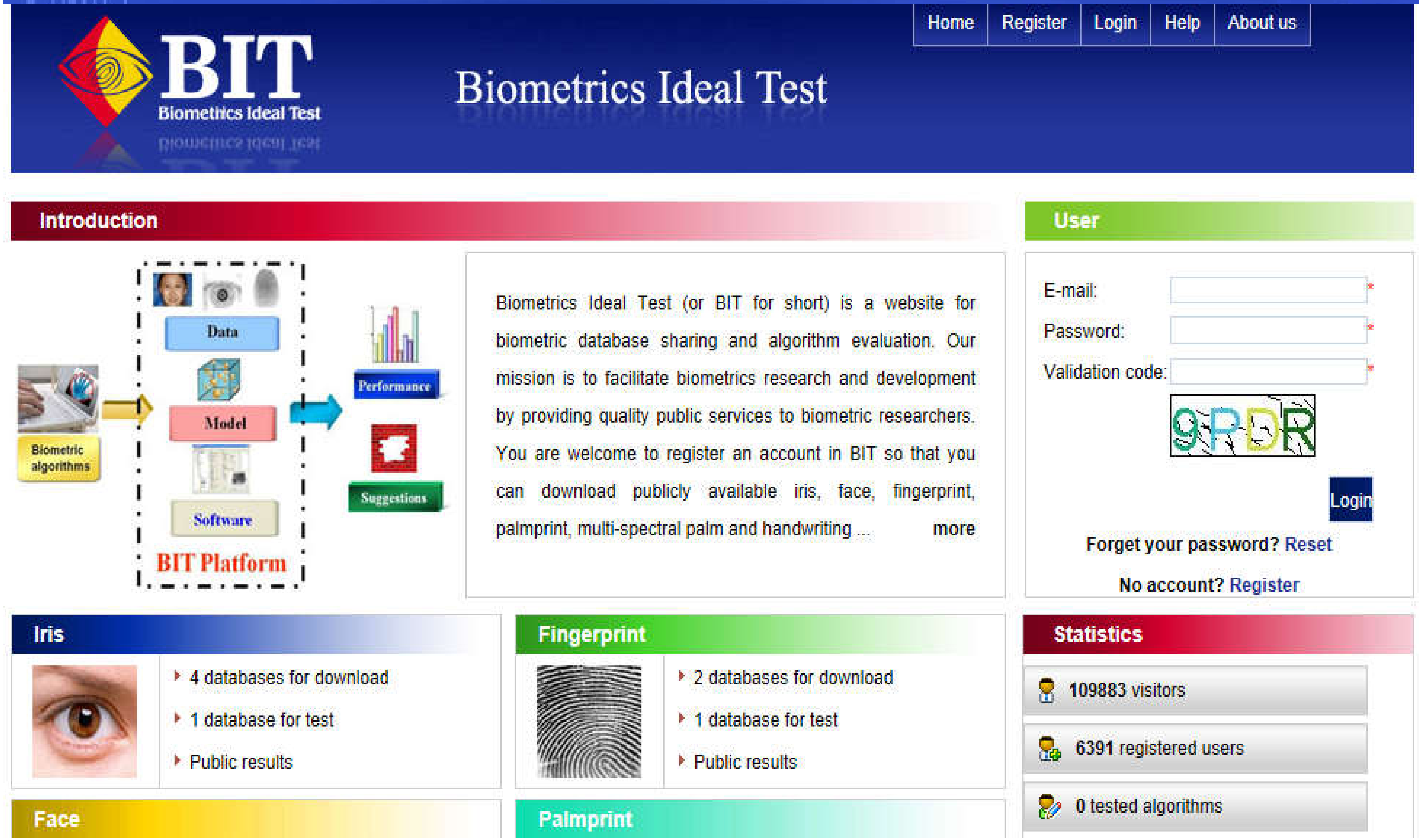
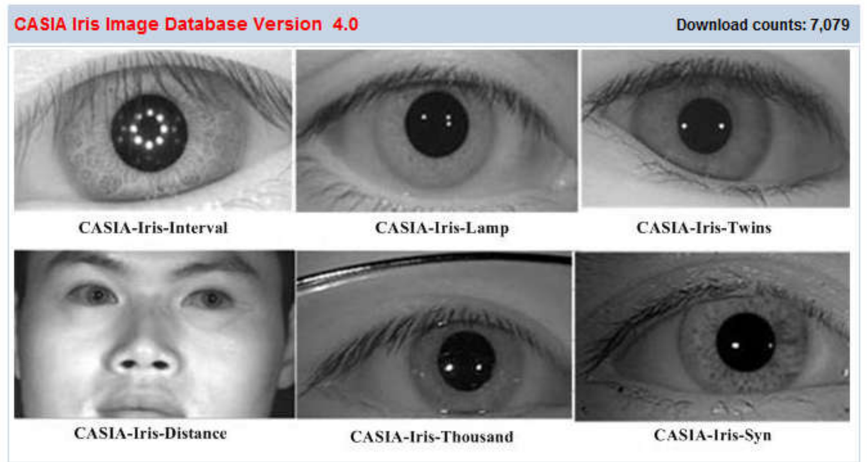
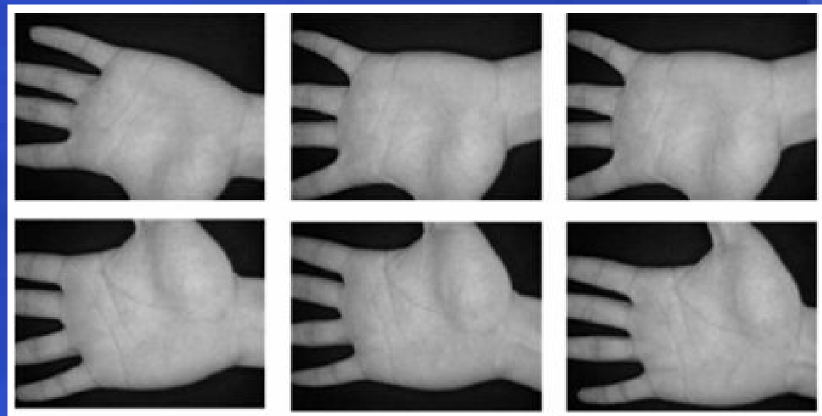
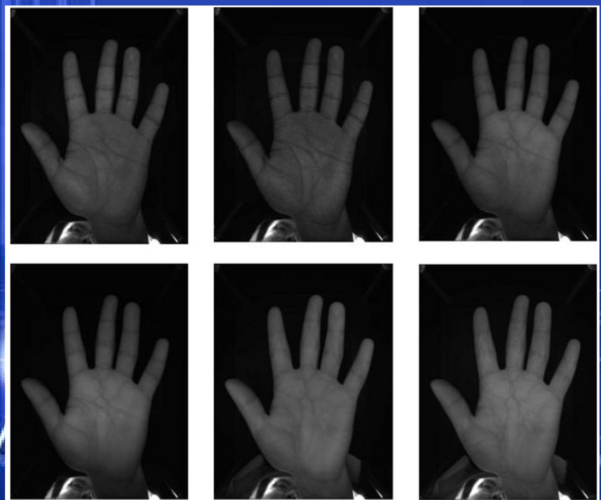
BIT: A website for biometric database sharing and algorithm evaluation (Http://biometrics.idealtest.org)

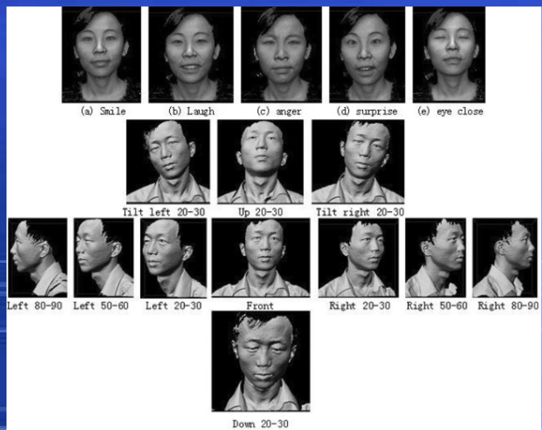


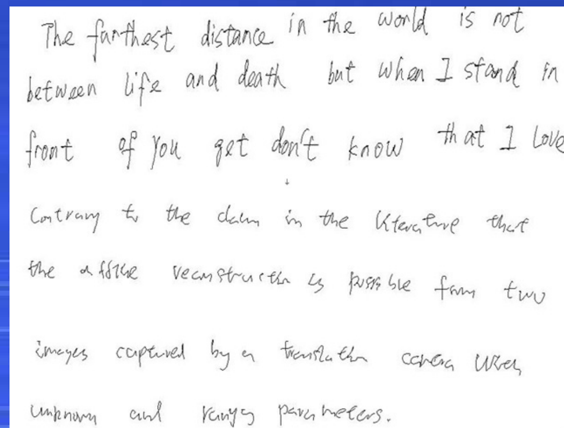
Downloadable biometrics databases











Conclusions

- Great progress on iris recognition has been made in the past two decades.
- State-of-the-art iris recognition methods are accurate and fast enough for many practical applications.
- Many open problems remain to be resolved to make iris recognition more user-friendly and robust.

Small Iris, Big Topic, Great Future!

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Thank you！

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