# Iris Recognition: Sensors, Algorithms and Applications

**Zhenan Sun**

Email: ZNSUN@NLPR.IA.AC.CN

Center for Research on Intelligent Perception and Computing
National Laboratory of Pattern Recognition
Chinese Academy of Sciences' Institute of Automation

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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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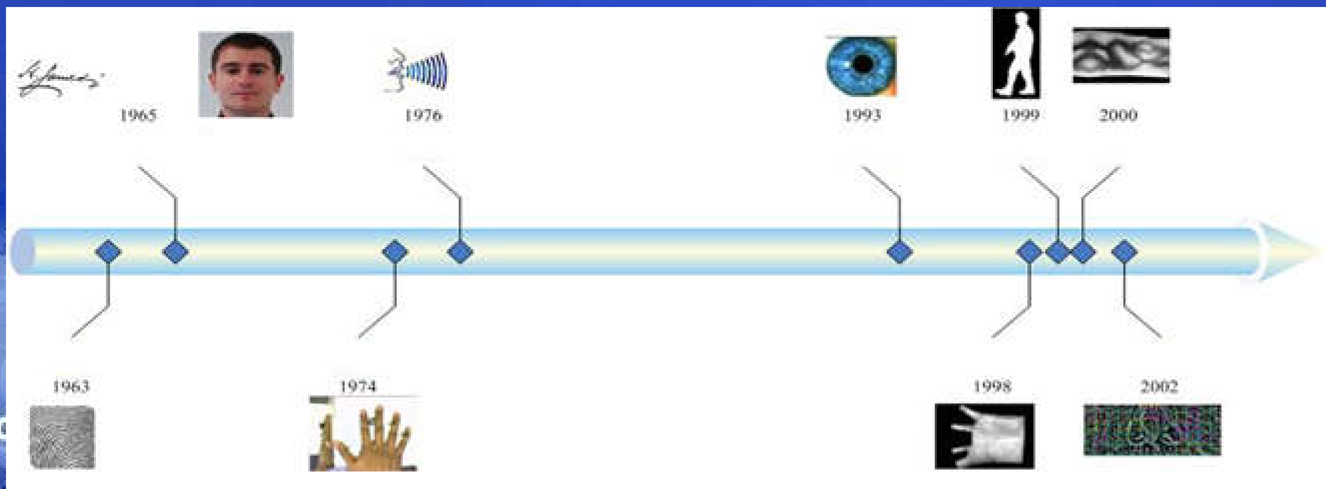
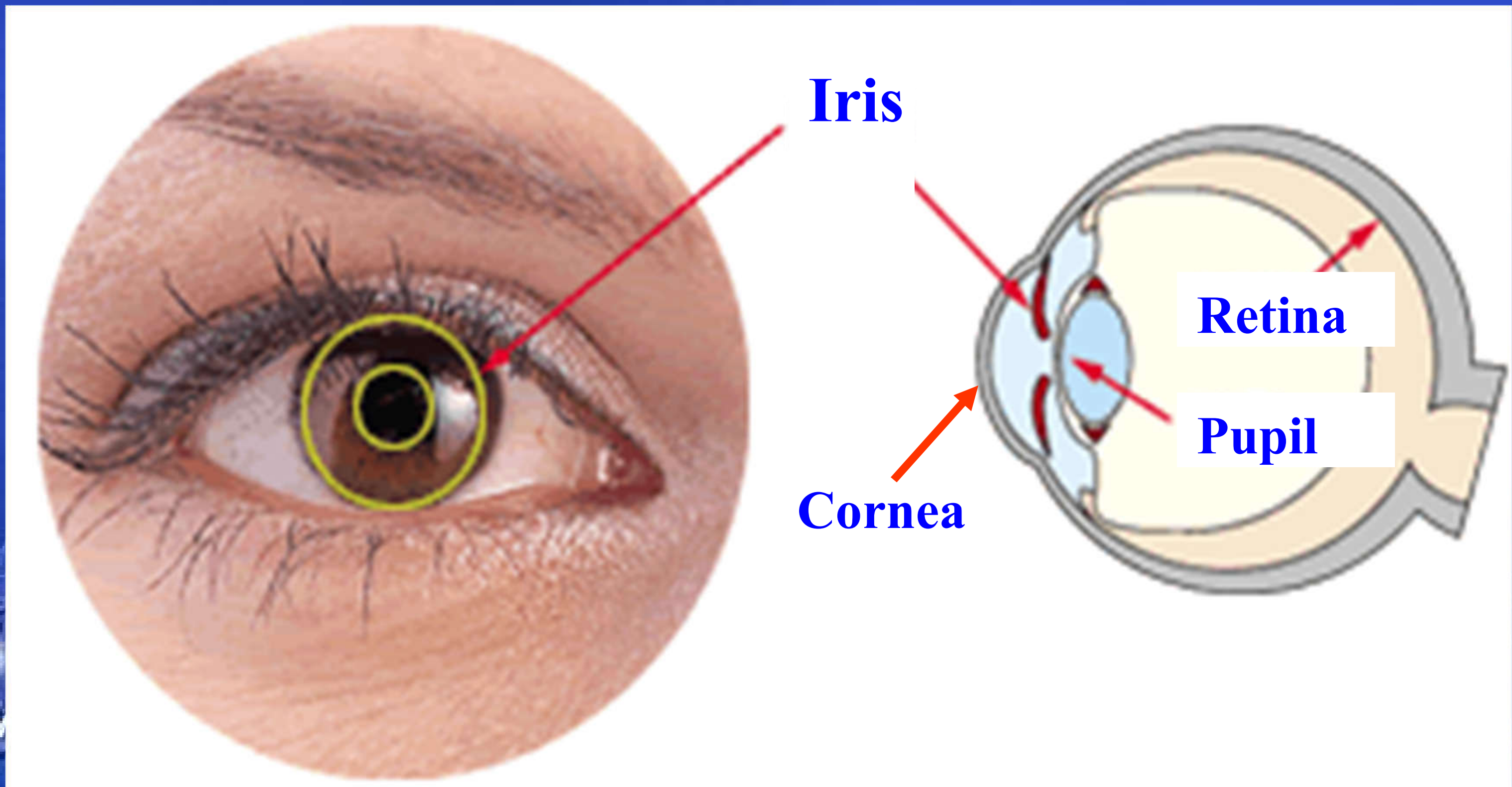
# Iris in the context of biometrics

# What is iris?

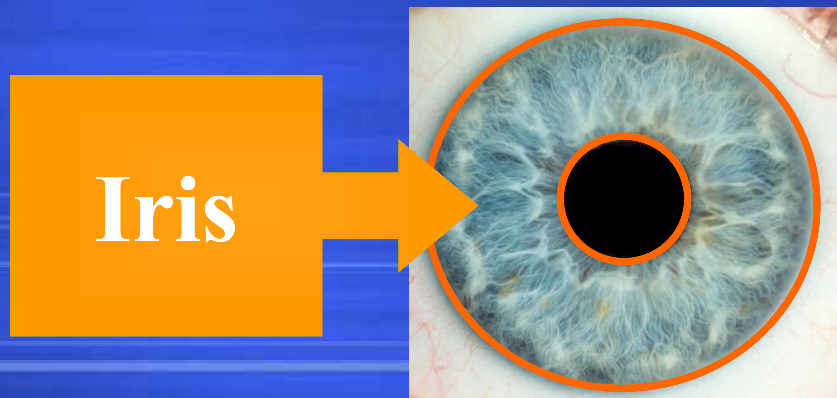
- The iris of your eye is the circular, colored membrane that surrounds the pupil.
- It controls light levels inside the eye similar to the aperture on a camera.
- Highly protected by cornea but externally visible at a distance



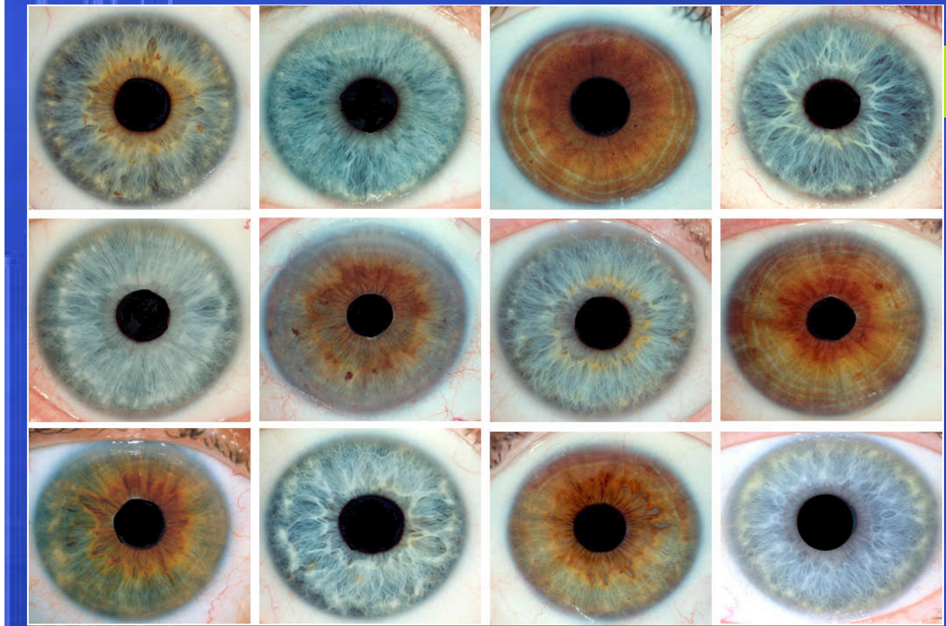
# Iris Recognition

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

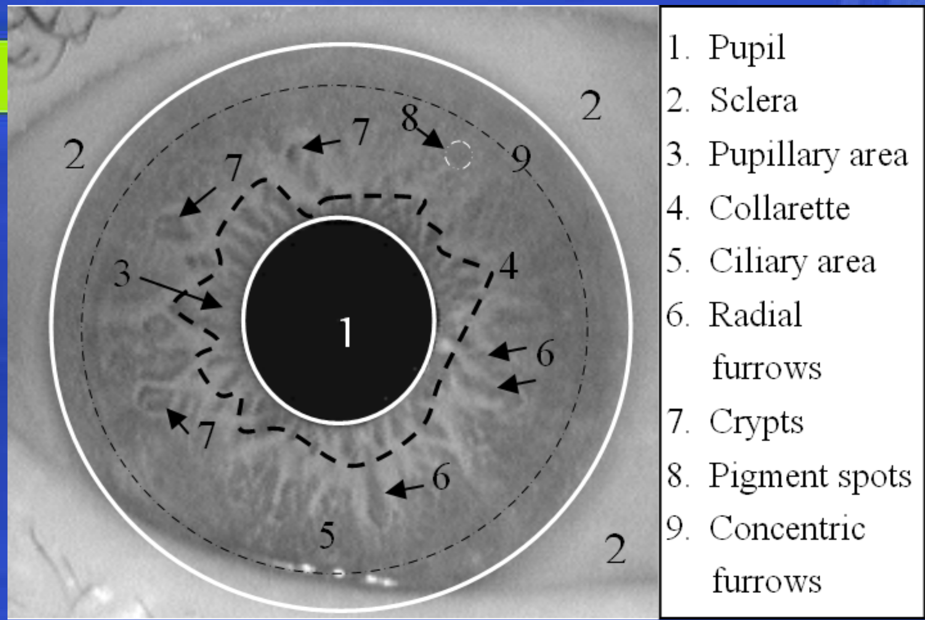
Who are you?



# 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

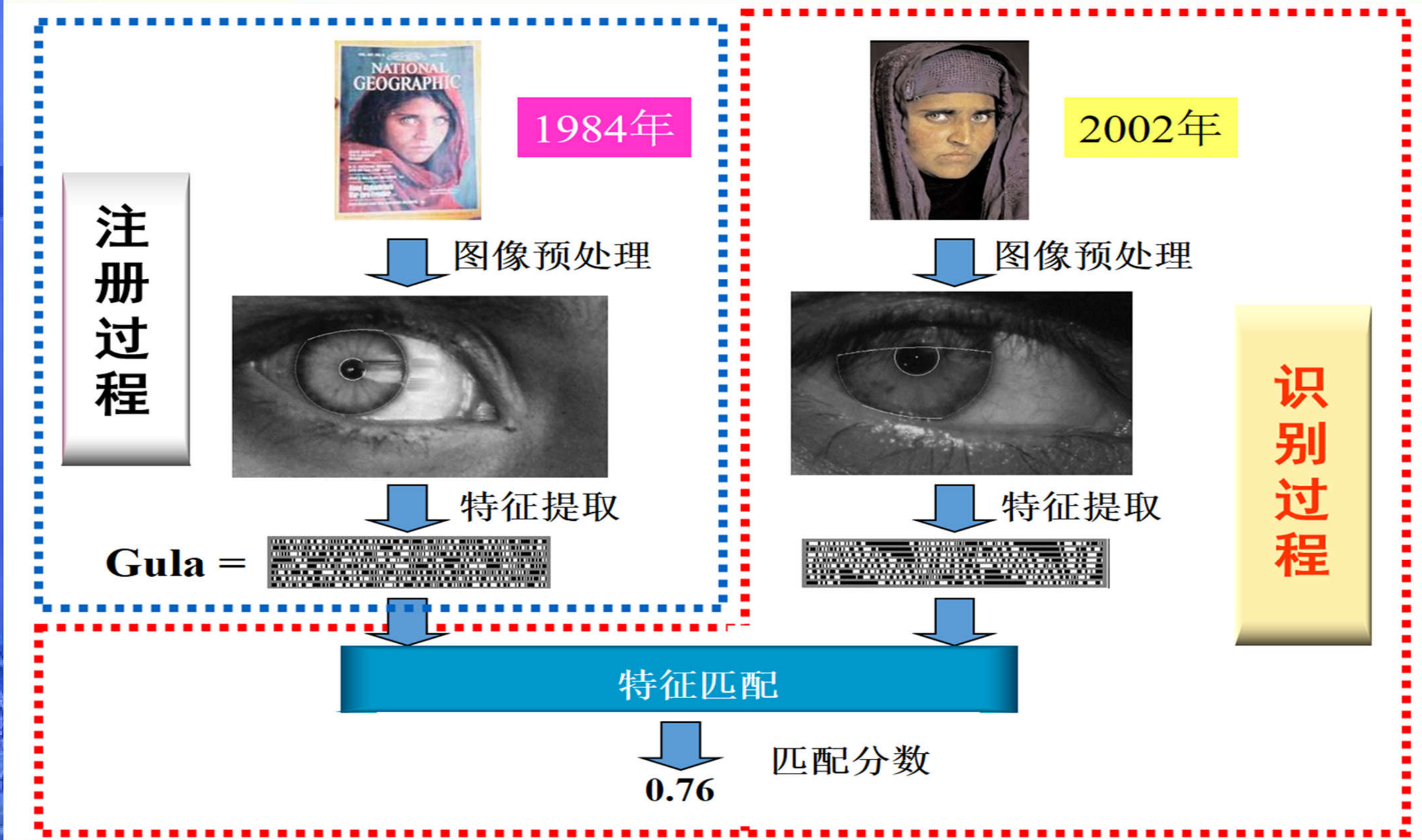
  phenotypic randomness, minute image features, rich information
- Stability

  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 |

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.

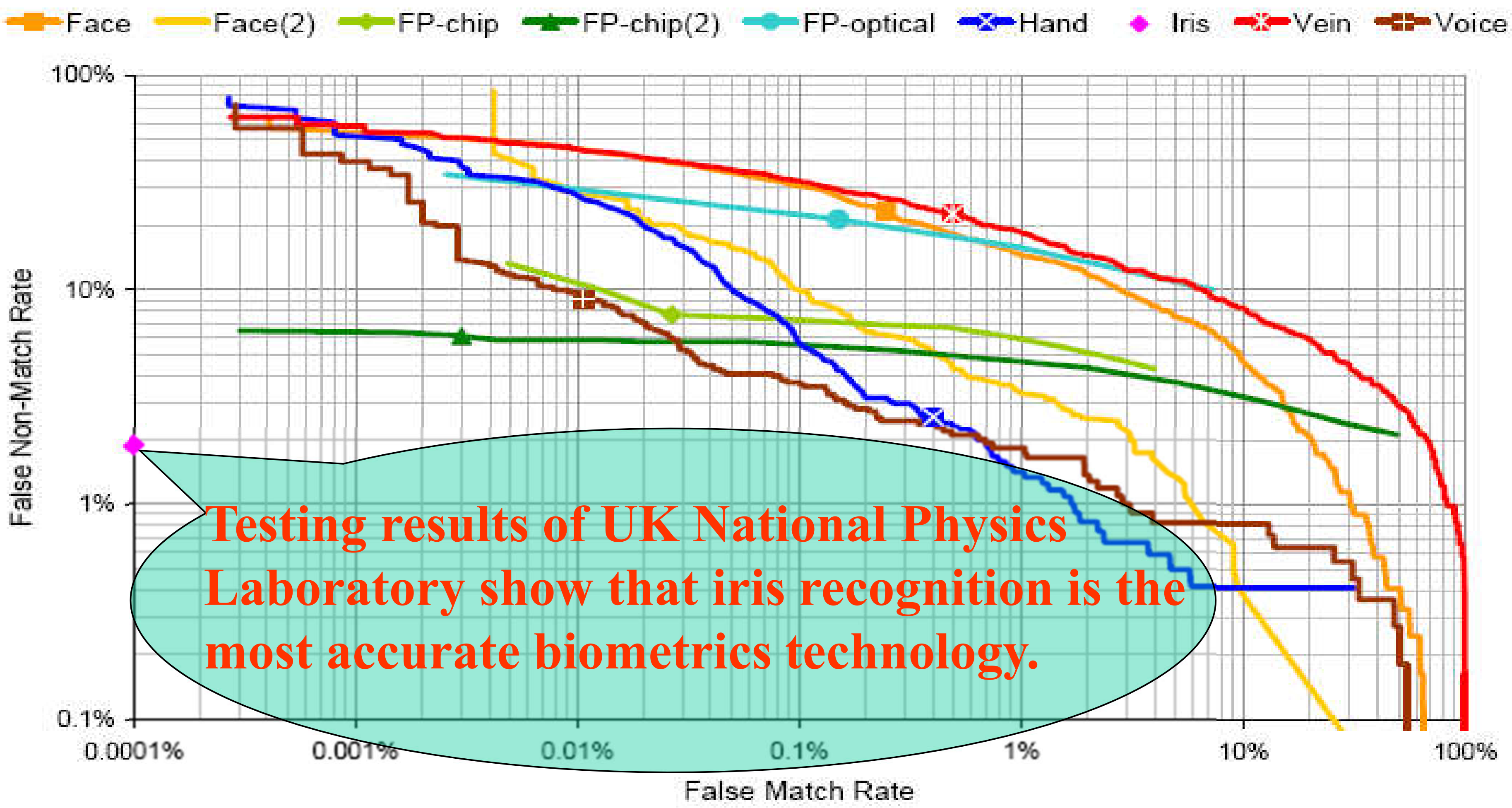



**Figure 4. Detection error trade-off: FMR vs FNMR**

# 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

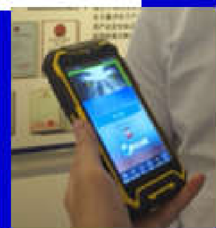
**2006**
**Sarnoff**
Iris on the Move

**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



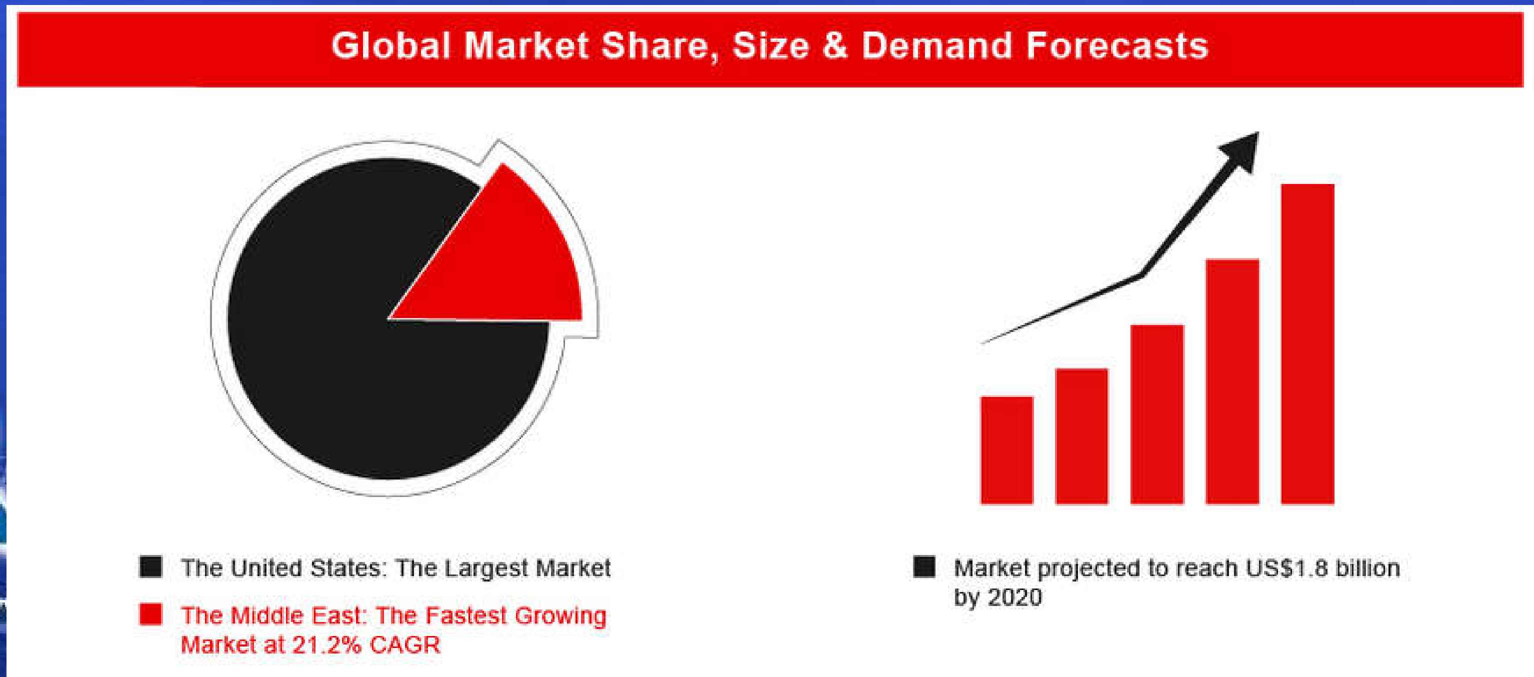
**2015**
**IrisKing**
Binocular Iris recognition on smartphones

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

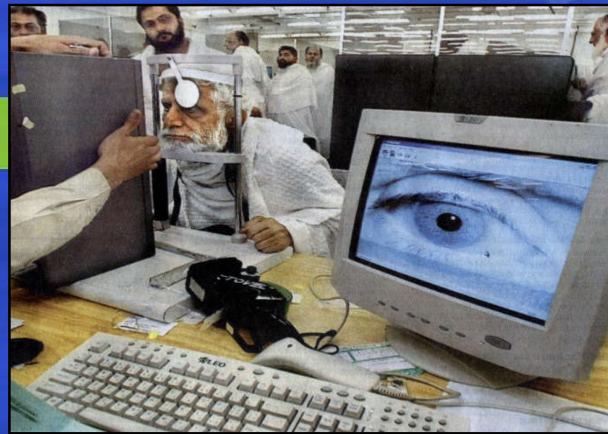
**The global market for Iris Biometrics is projected to reach US$1.8 billion by 2020, driven by effervescent technology advancements and growing use in access, surveillance and identity applications.**



# 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.

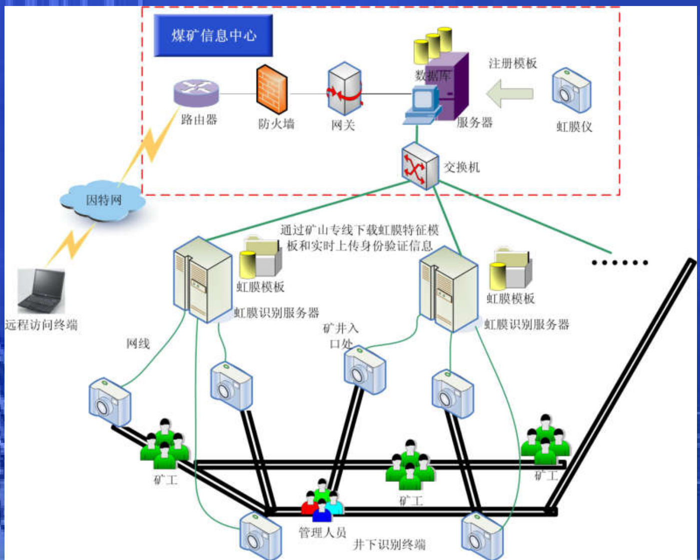
NIST reports FPIR rate of ten-finger identification to be between 1.5 to 3.5% on a gallery size of approximately one million. UIDAI reports FPIR rate of 0.057% over a gallery size of 100 million. This is a 50 times accuracy improvement despite a 100-times larger database.

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


# 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

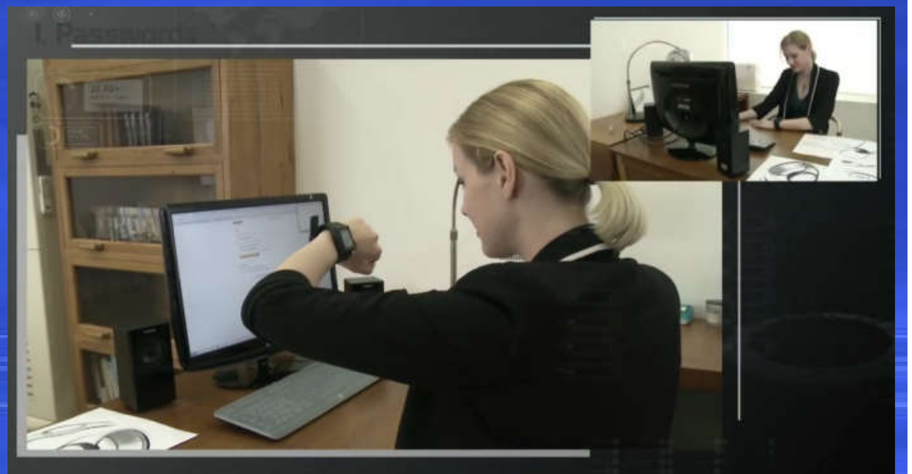
# Iris Recognition for  Prison Management

//www.ia.ac.cn

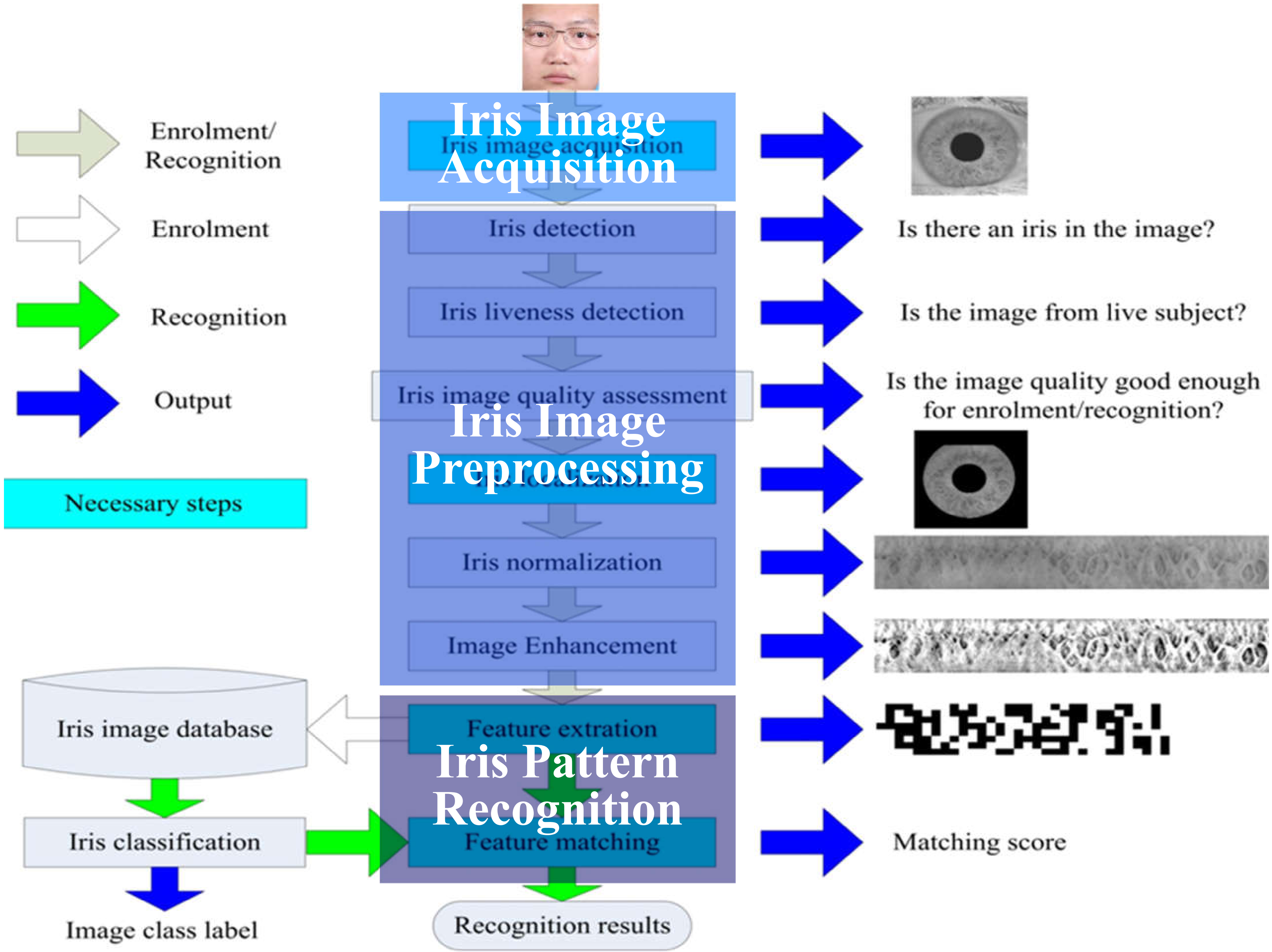
# Iris Recognition on Mobile Devices

# Iris Recognition in Smart Watch





# Basic Modules of IR System



Enrolment/ Recognition
Enrolment
Recognition
Output
Necessary steps
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
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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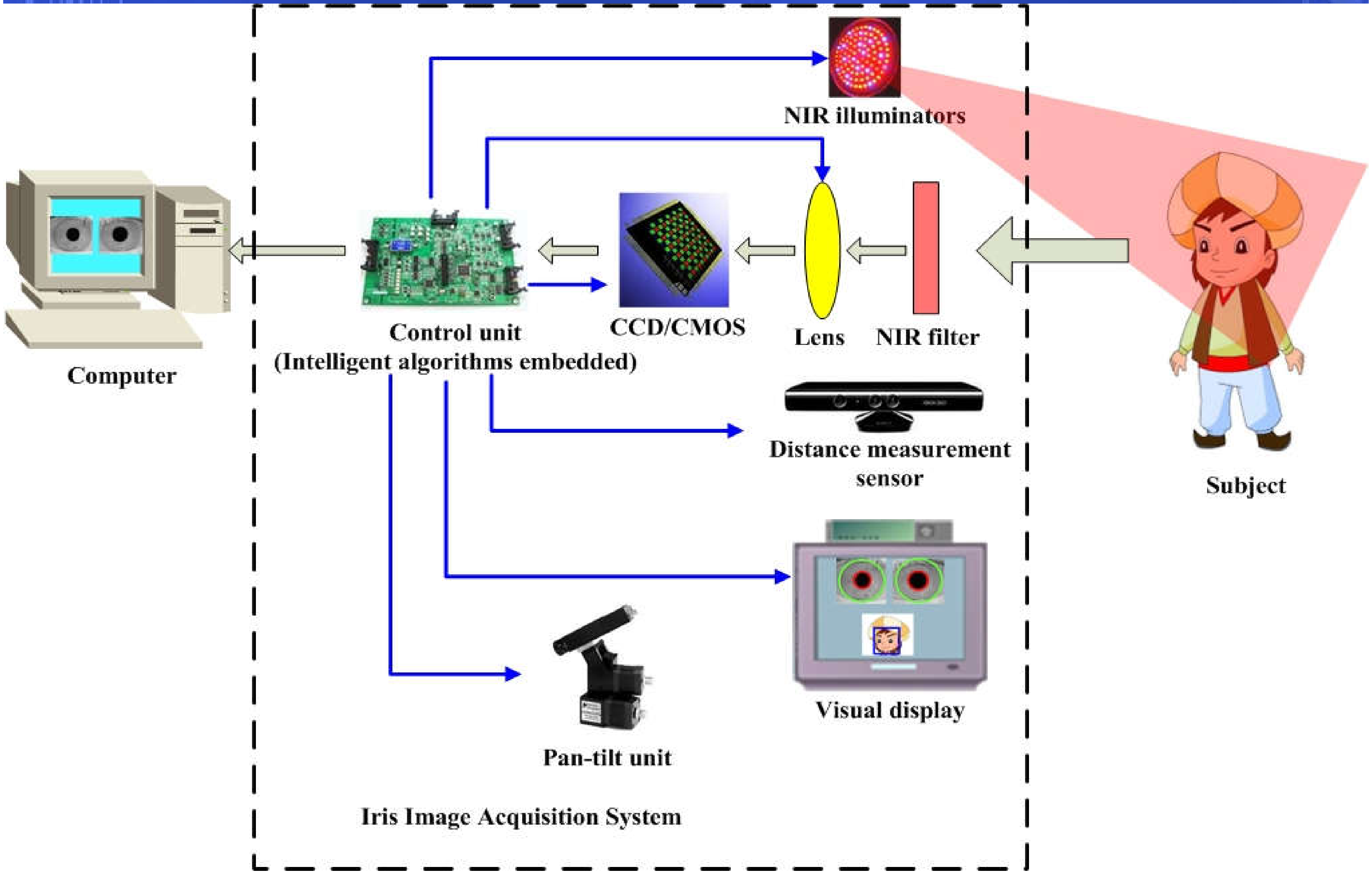
# Difficulties of iris image acquisition

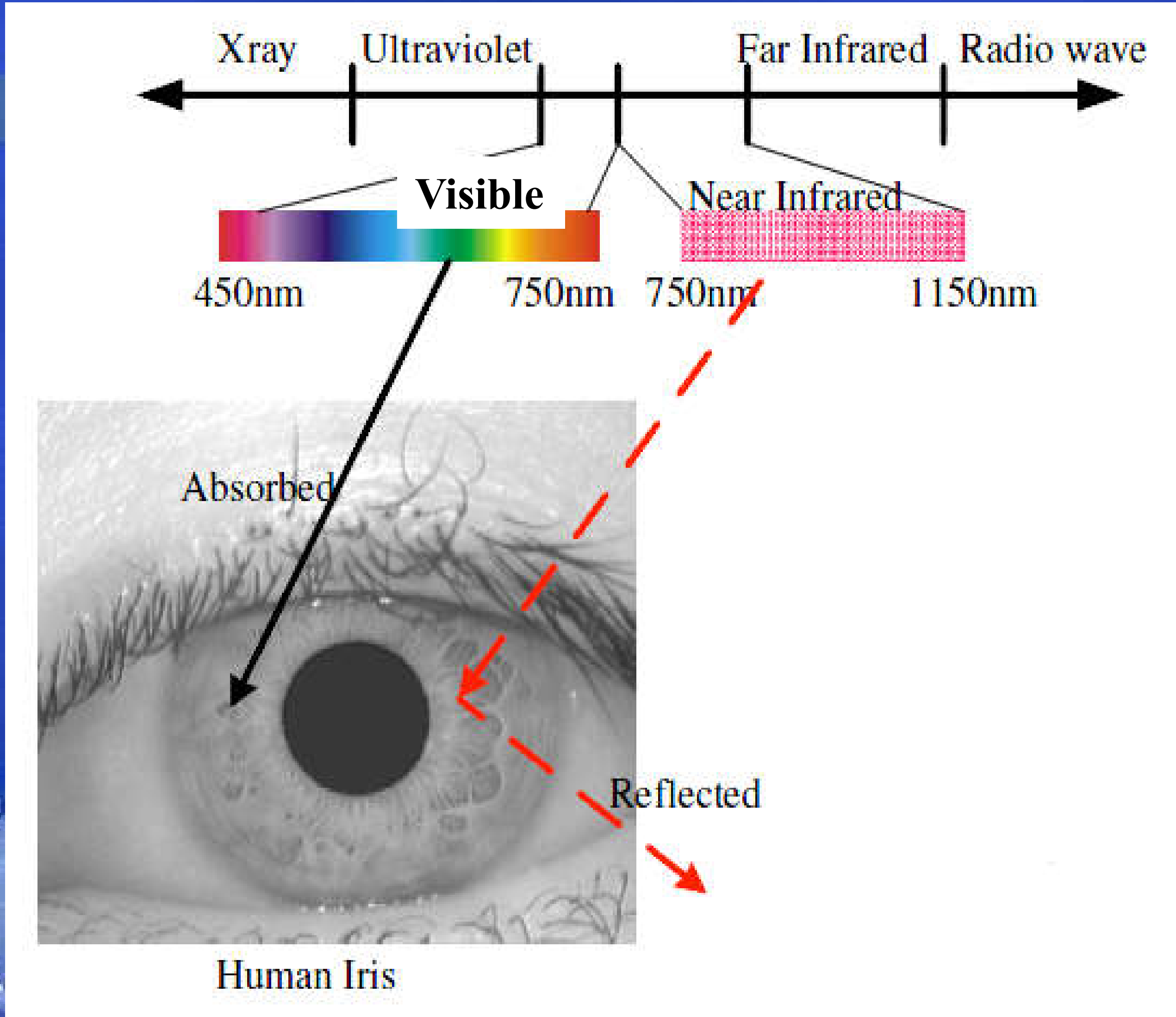

- Small size (11mm)
- Sufficient resolution (200 pixels)
- Narrow depth of field
- Must be optically on-axis
- Stop and stare
- Near infrared illumination
- Specular reflections
- Eyeglasses

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

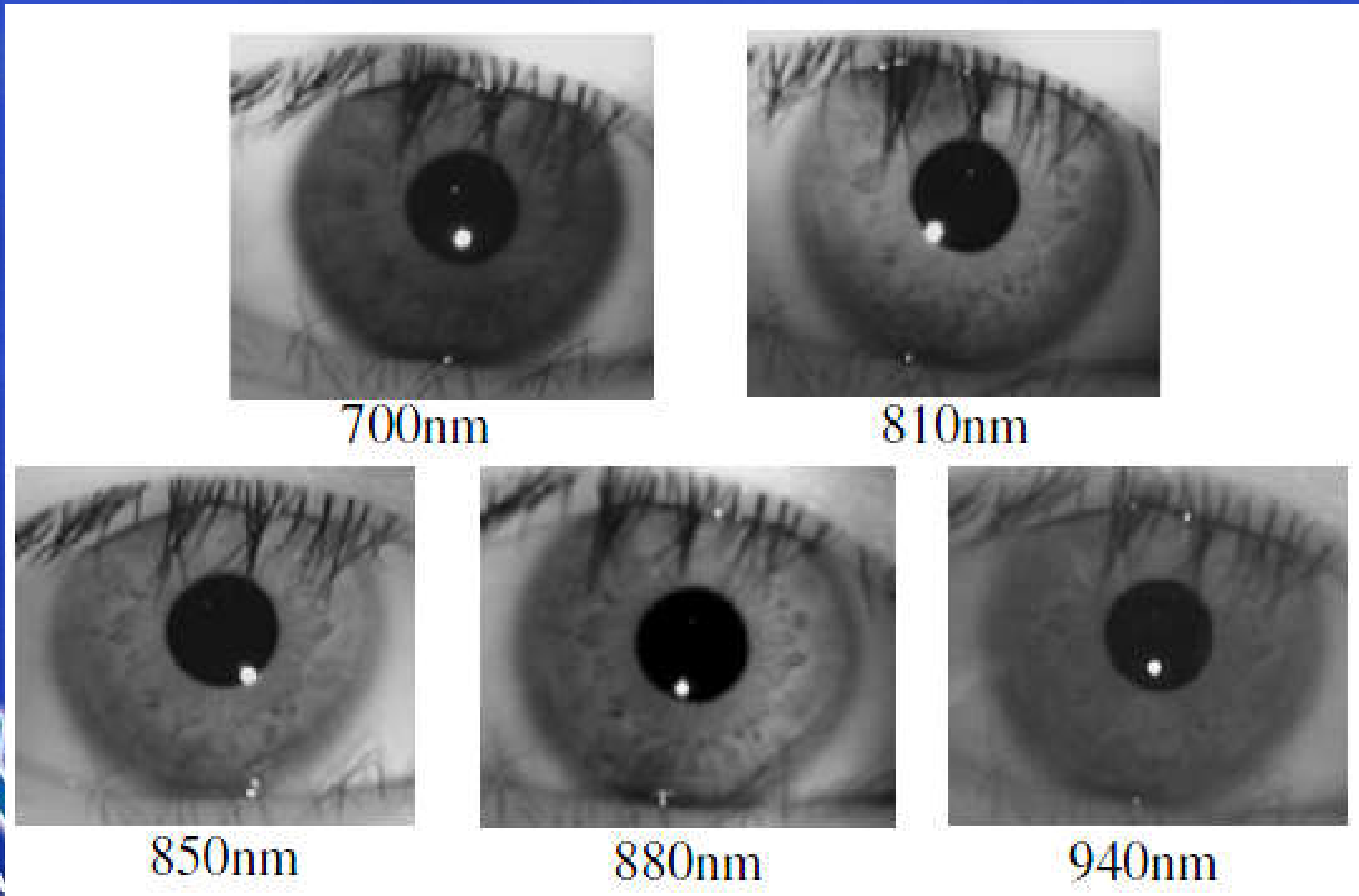
# Basic Components of Iris Sensor



# 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

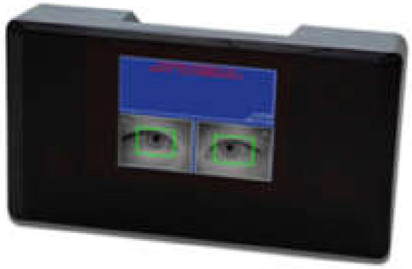
Panasonic BM-ET500

IrisGuard IG-H100

IrisGuard IG-AD100

SecuriMetrics PIER 2.3

Crossmatch I SCAN2

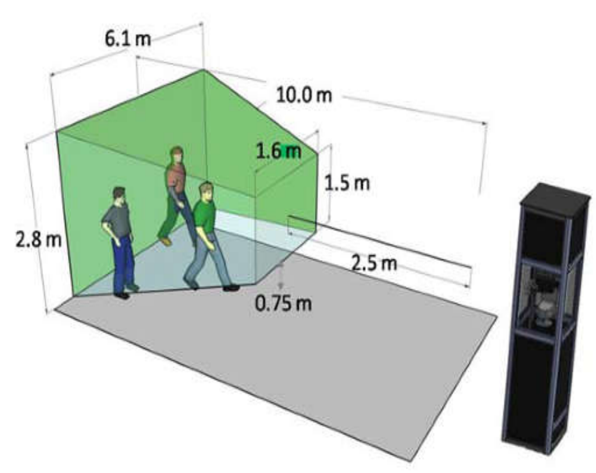


IrisKing IKEMB-110

# Long-range iris devices

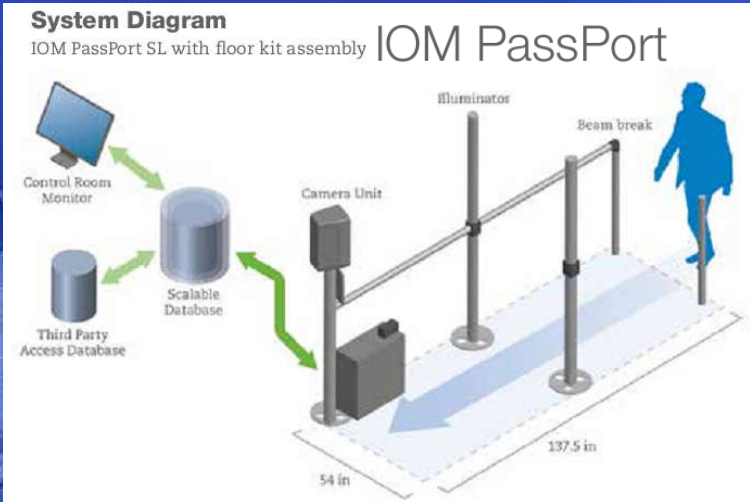
Aoptix InSight

EyeLock HBOX




Eagle-eyes

IOM PassThru




IOM PassPort

IrisID iCAM D1000

CASIA

# Iris image acquisition devices of CASIA

1999

2000

2001

2004

2005

2007

2008

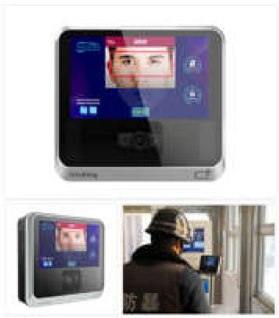
2009

2014

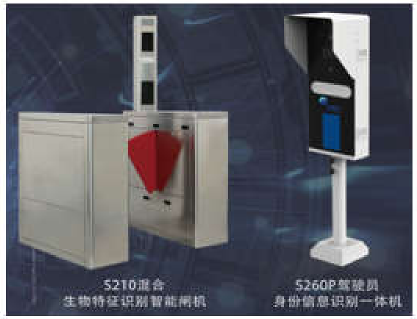

2015

2016

智能虹膜人脸一体机 IKAI1000

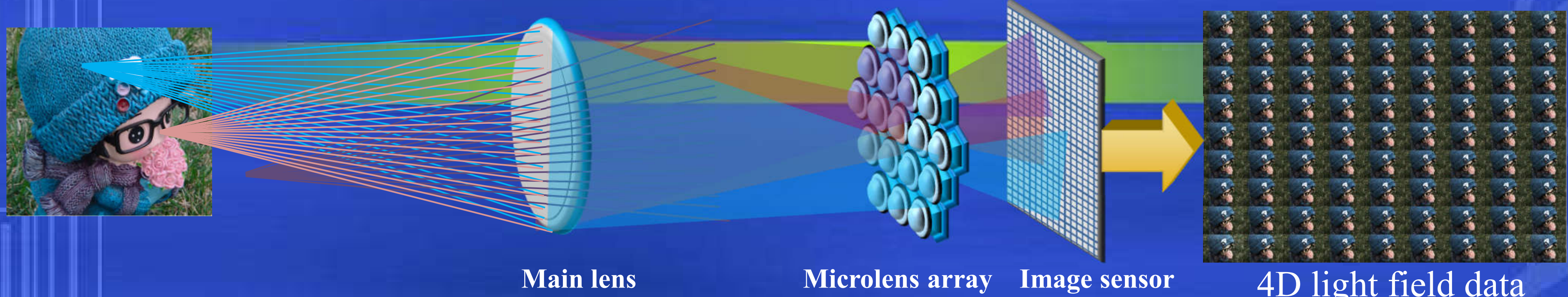


2018




2019

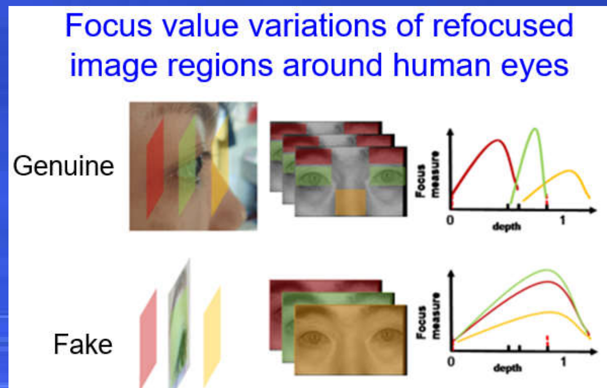
# Recent Progress of Iris Image Acquisition




**Light-field Camera (Plenoptic Camera)**

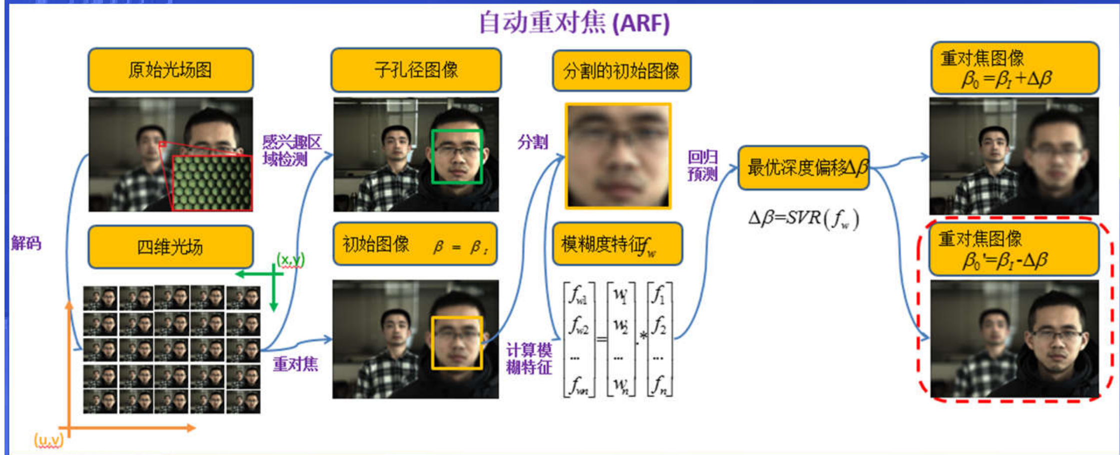
Extending depth of field

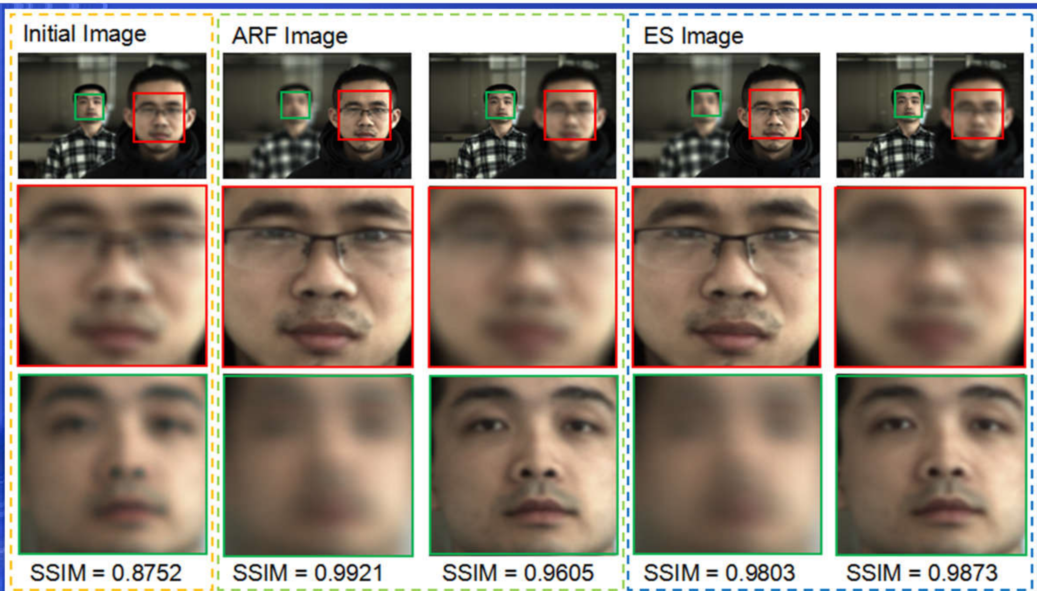
Depth perception




Liveness detection

# Auto-refocusing to improve depth-of-field of iris cameras



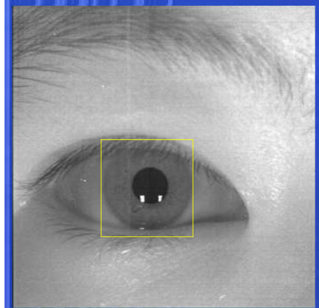



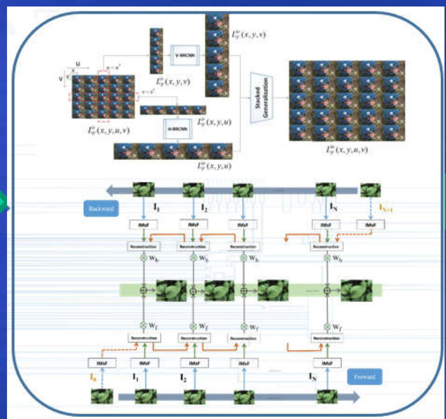


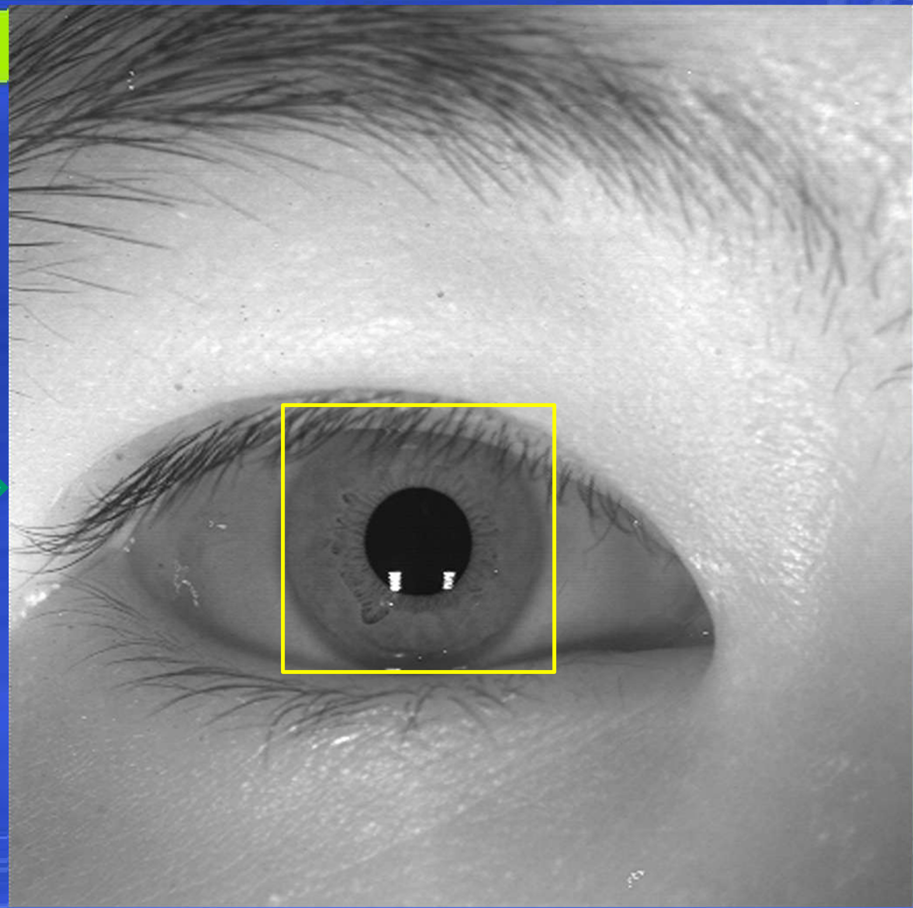
Chi Zhang, Guangqi Hou, Zhaoxiang Zhang, Zhenan Sun, Tieniu Tan, Efficient auto-refocusing for light field camera, Pattern Recognition, Volume 81, 2018, pp.176-189.

# LFNet for light field image super-resolution

**Modeling spatial correspondence between sub-aperture images using 4D recurrent convolutional neural networks**

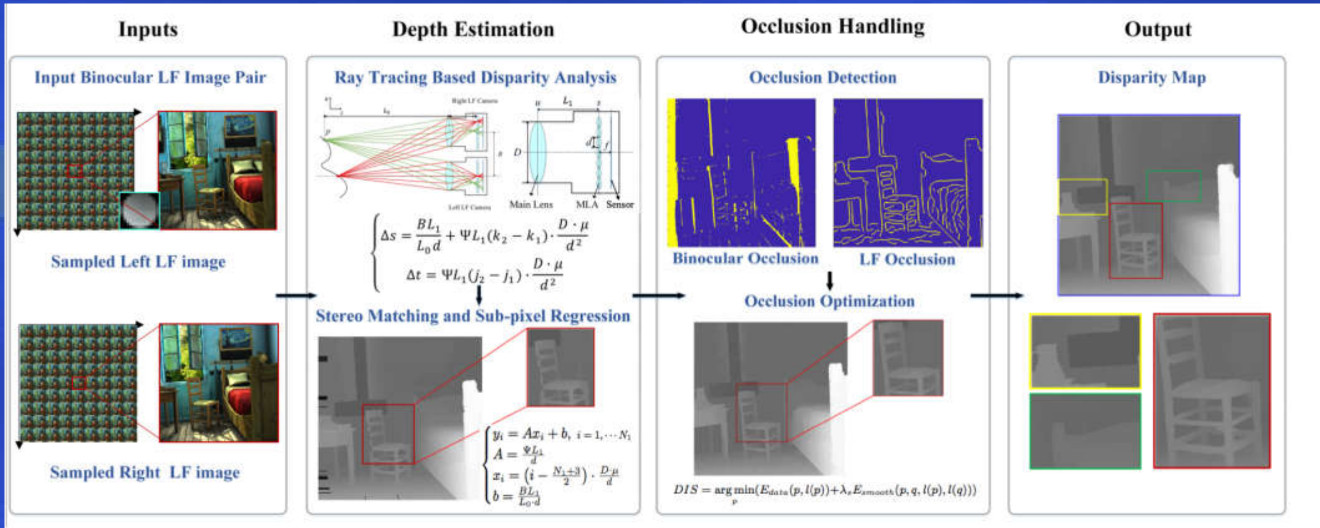


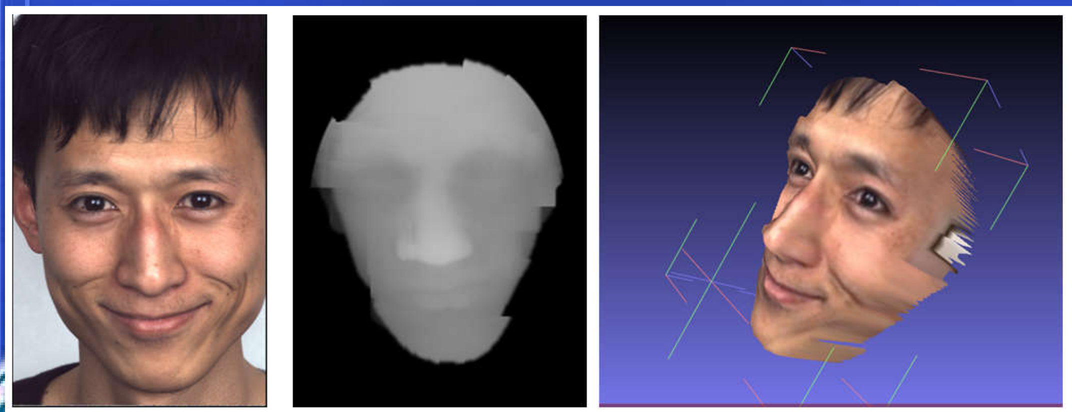




Yunlong Wang, Fei Liu, Kunbo Zhang, Guangqi Hou, Zhenan Sun, Tieniu Tan, LFNet: A Novel Bidirectional Recurrent Convolutional Neural Network for Light-Field Image Super-Resolution, IEEE Transactions on Image Processing, Vol. 27, No. 9, 2018, pp.4274-4286.

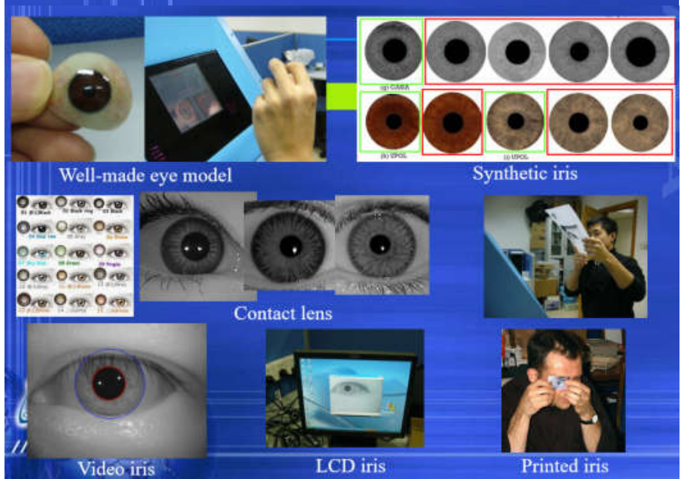
# Depth Perception from Light Field Images



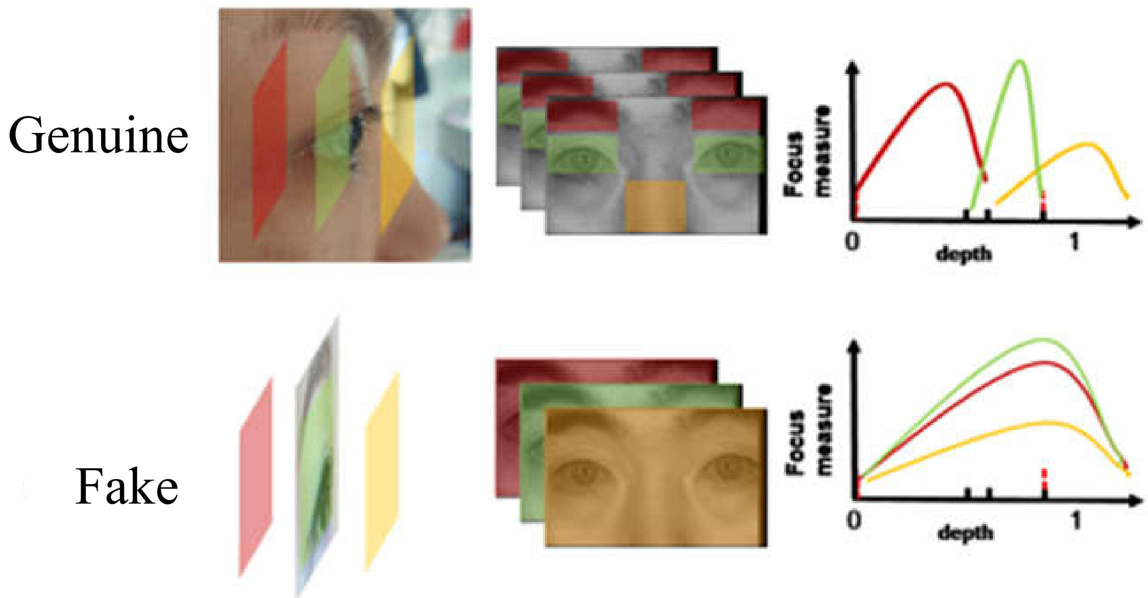



1. Fei Liu, Shubo Zhou, Yunlong Wang, Guangqi Hou, Zhenan Sun, Tieniu Tan, Binocular Light-Field: Imaging Theory and Occlusion-Robust Depth Perception Application, IEEE Transactions on Image Processing, 2020.
2. Fei Liu, Guangqi Hou, Zhenan Sun, Tieniu Tan, High quality depth map estimation of object surface from light-field images, Neurocomputing, Vol.252, 2017, pp.3-16.

# Iris Liveness Detection Based on Light Field Imaging




Focus value variations of refocused image regions around human eyes




Ping Song, Ling Huang, Yunlong Wang, Fei Liu, Zhenan Sun, Iris Liveness Detection Based on Light Field Imaging, Acta Automatica Sinica, vol.45, no.9, pp.1701-1712, 2019.

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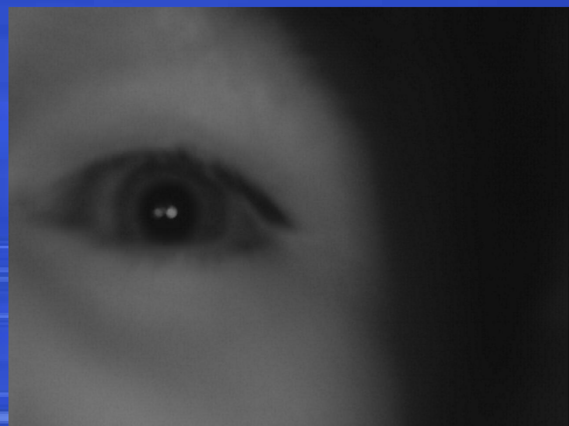
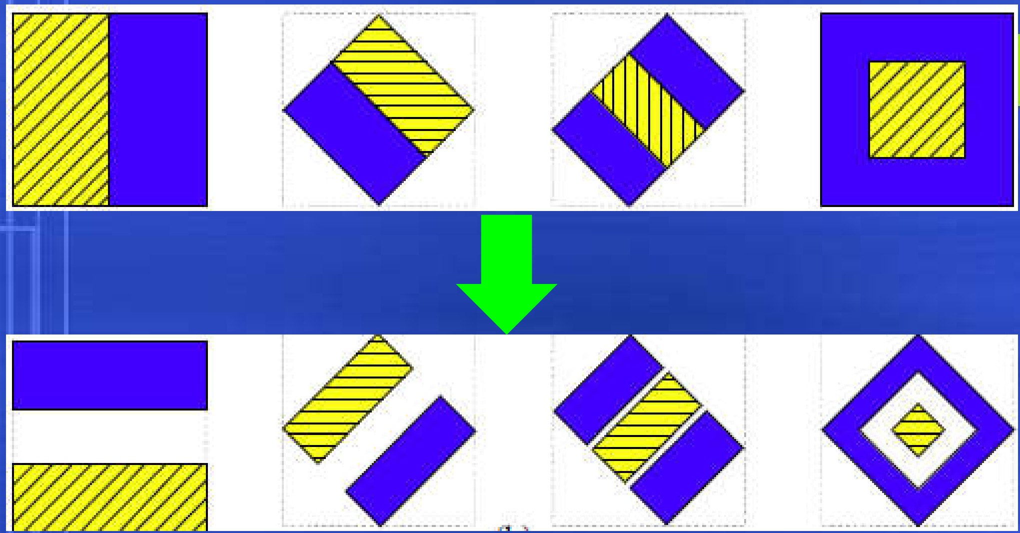
# Iris detection

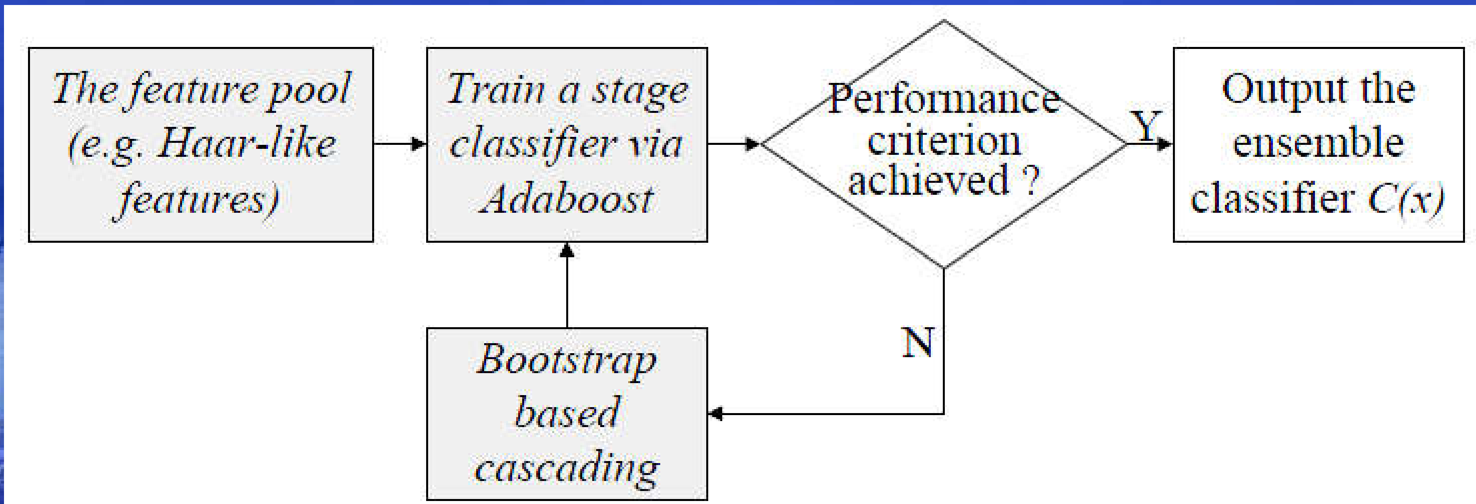
# Is there an iris in the input image?



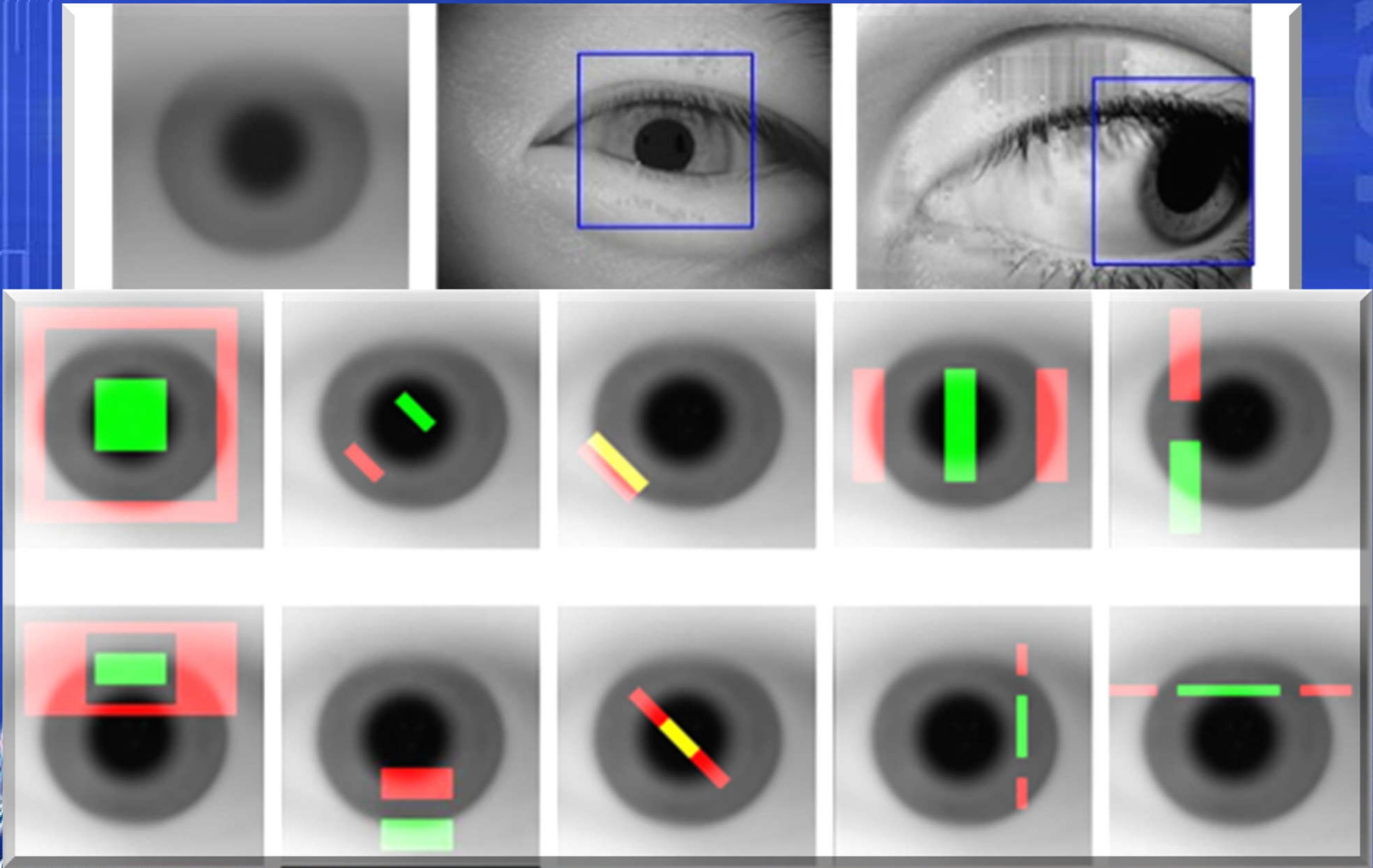



# Solution to iris detection: Extended Haar features + Boosting learning





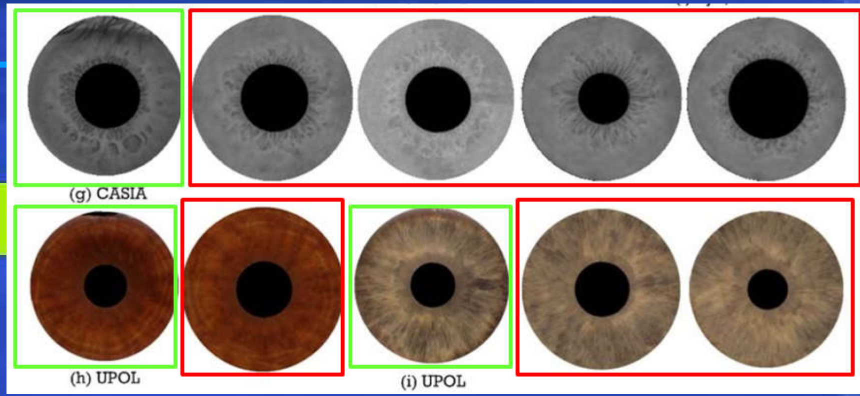
# Iris detection results



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

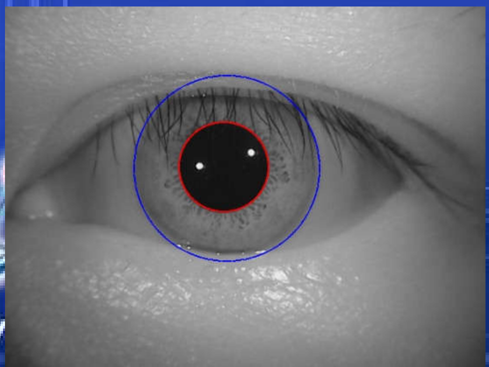
# Risk of Fake Iris Attacks

Well-made eye model

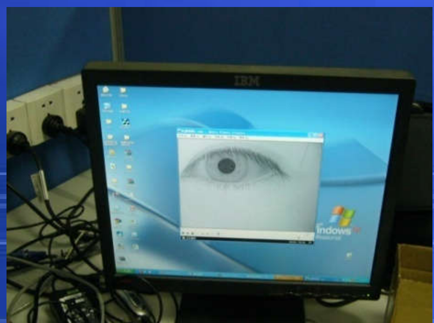



Synthetic iris


Contact lens



Video iris



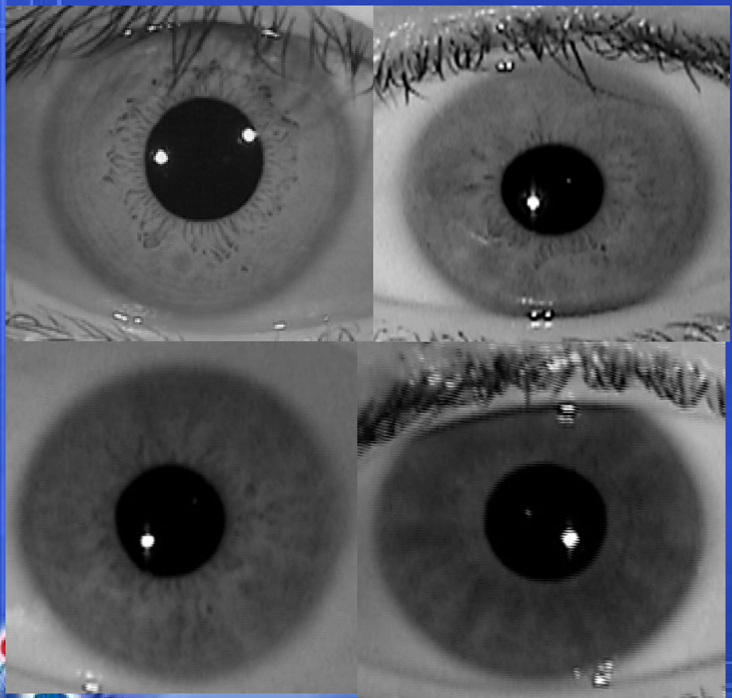
LCD iris

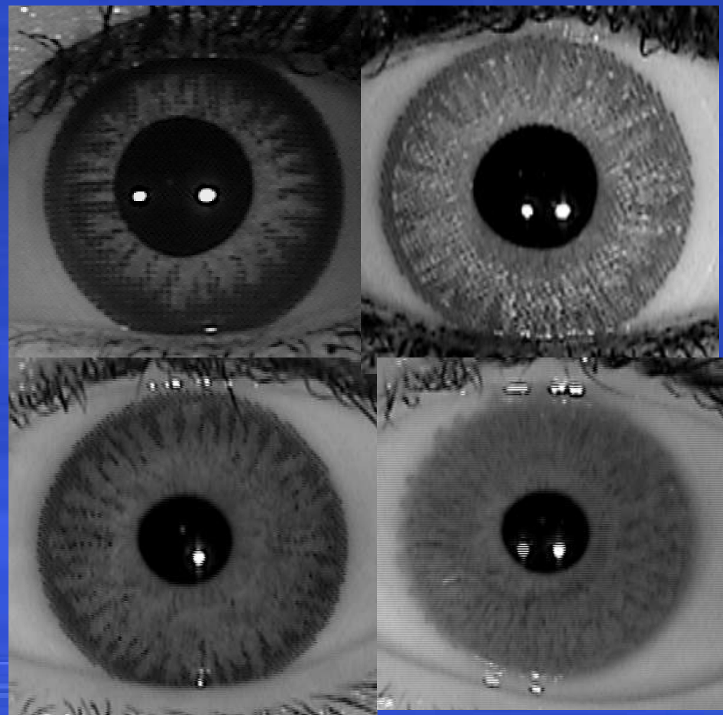
Printed iris

# Iris liveness detection: a texture solution

Smooth texture

Coarse texture





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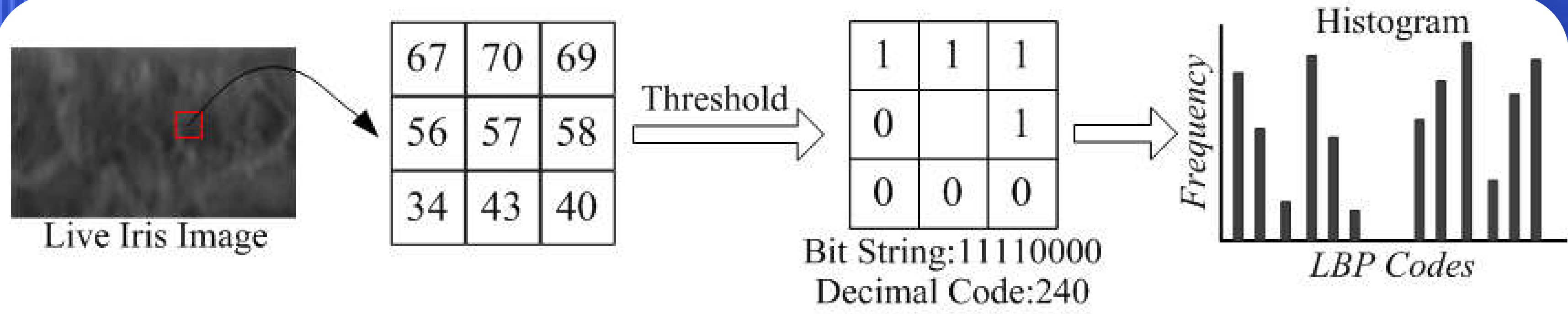
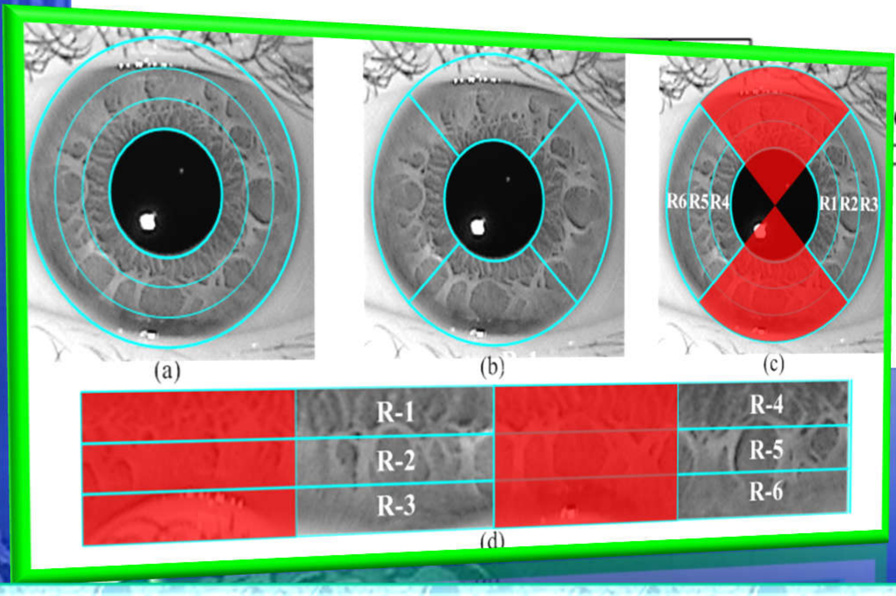
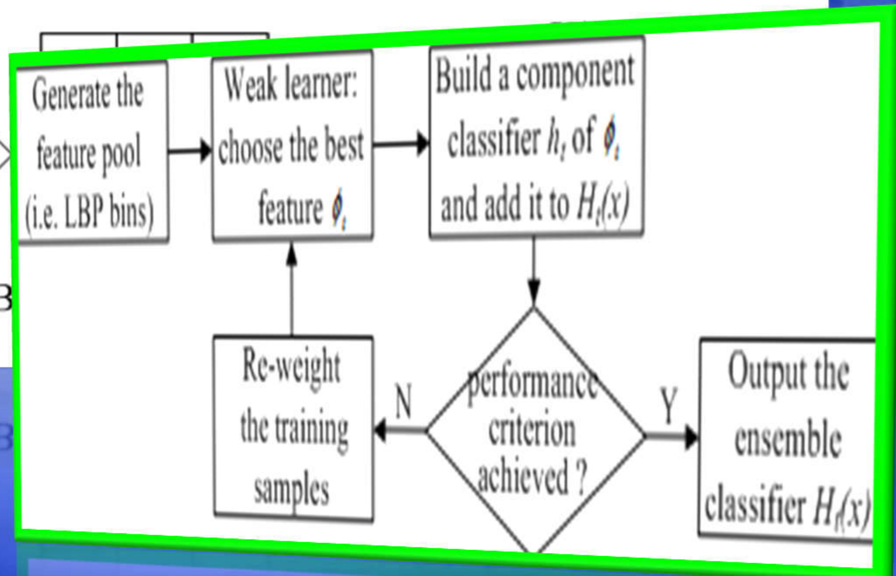
# LBP+Boosting

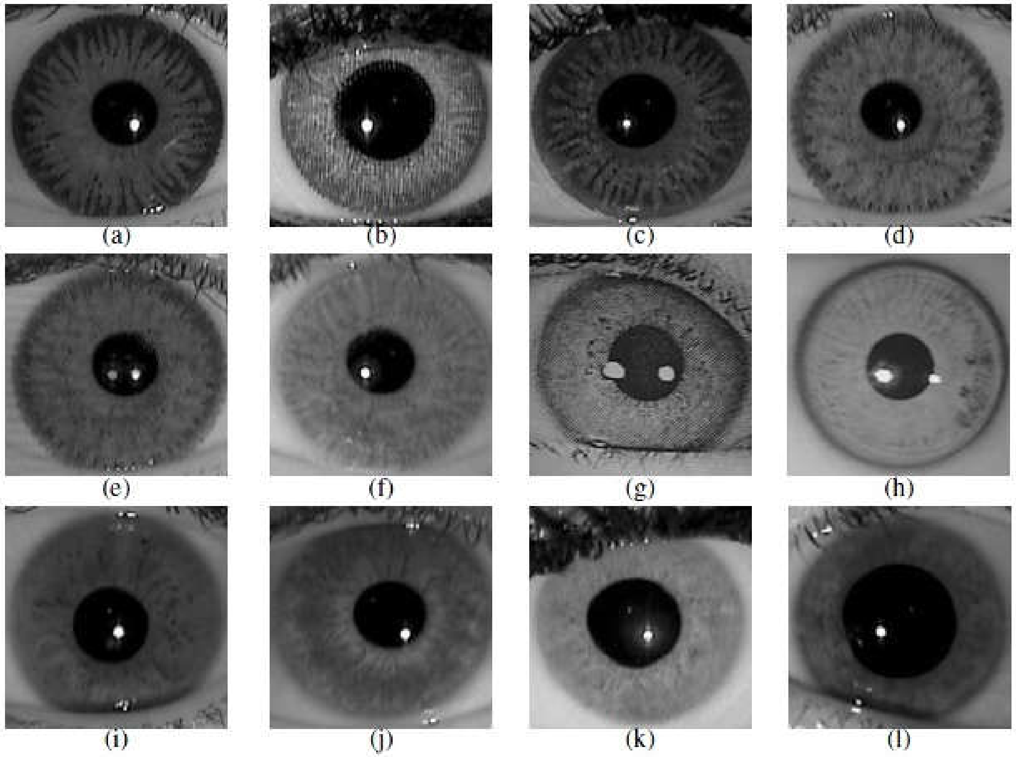



Iris Liveness Detection via Boosted Local Binary Patterns

# 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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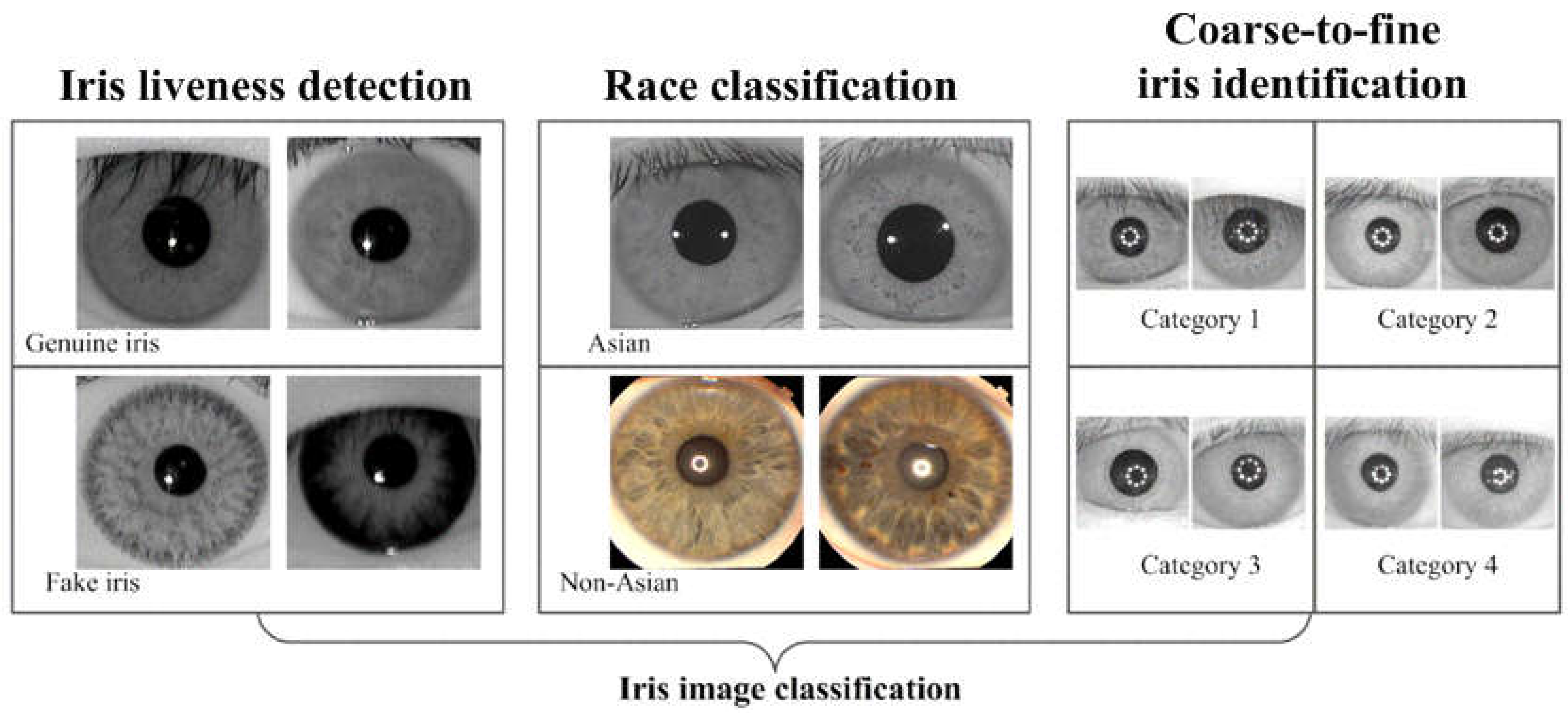
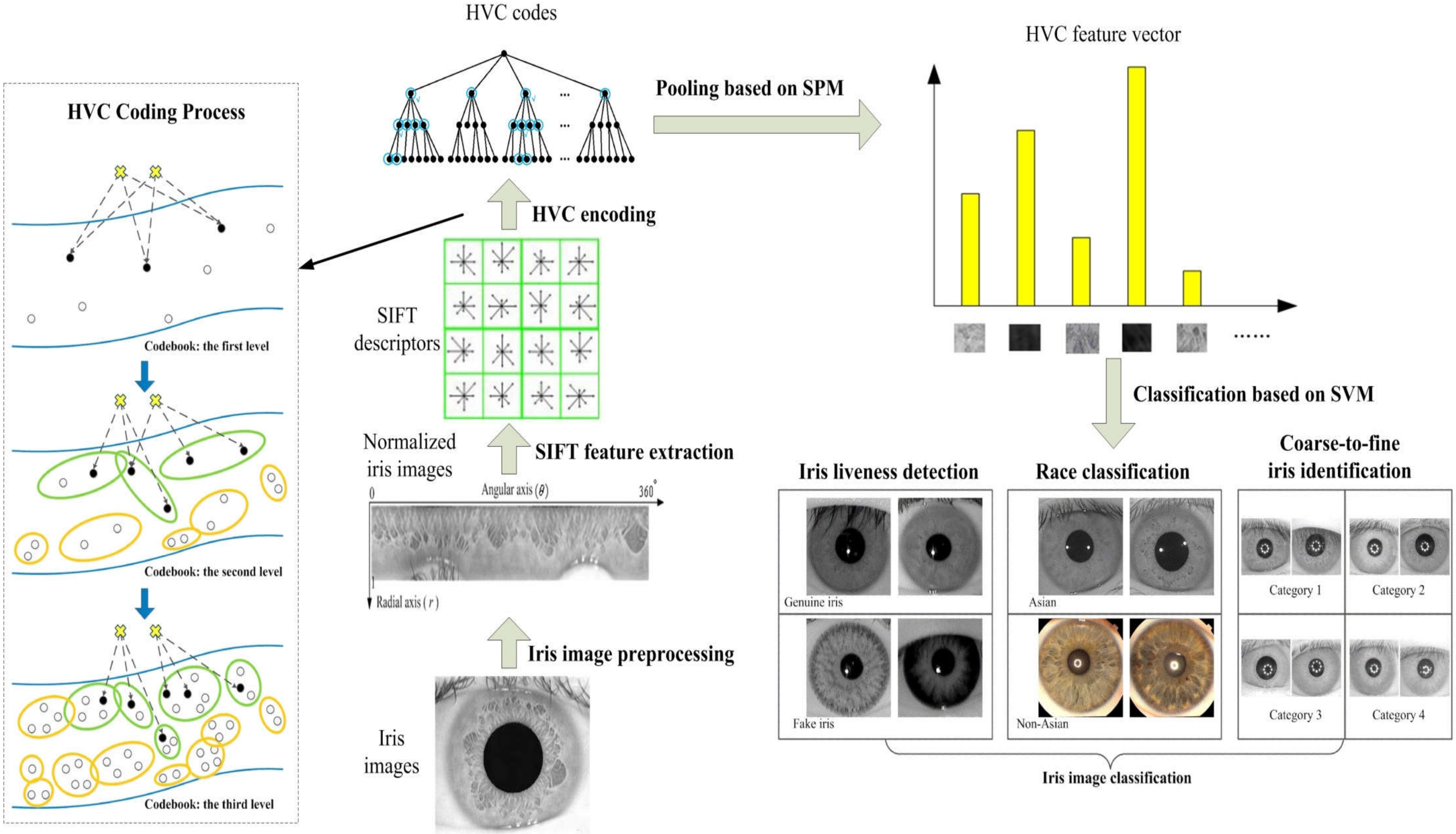
# Iris image classification：one solution to multiple problems



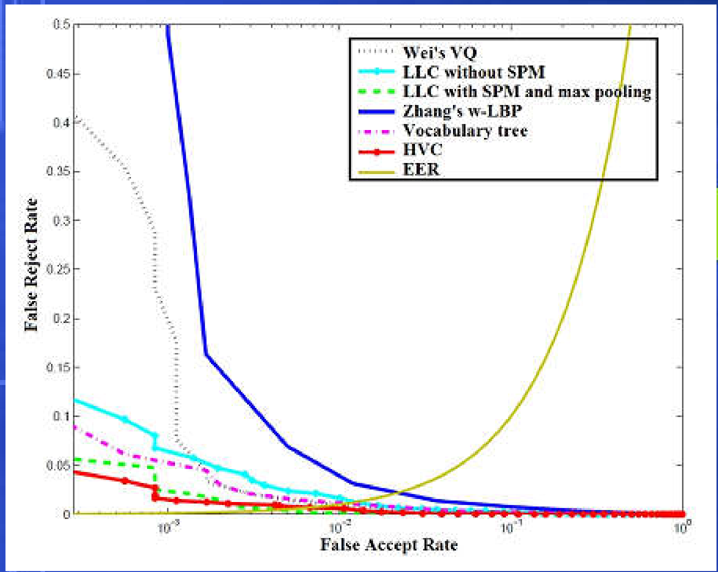

**Iris image classification:**

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

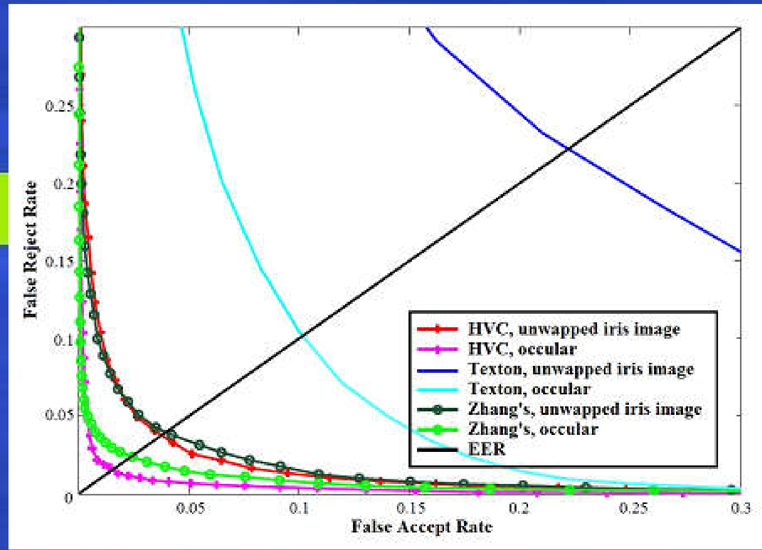
# Iris Image Classification Based on Hierarchical Visual Codebook (HVC)



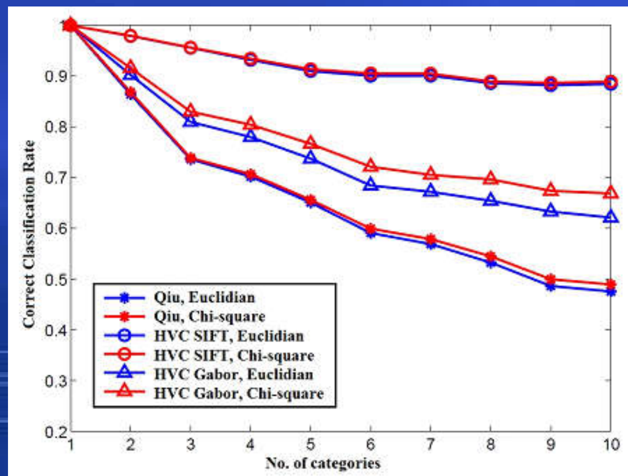
# Experimental results




Iris liveness detection




Race classification

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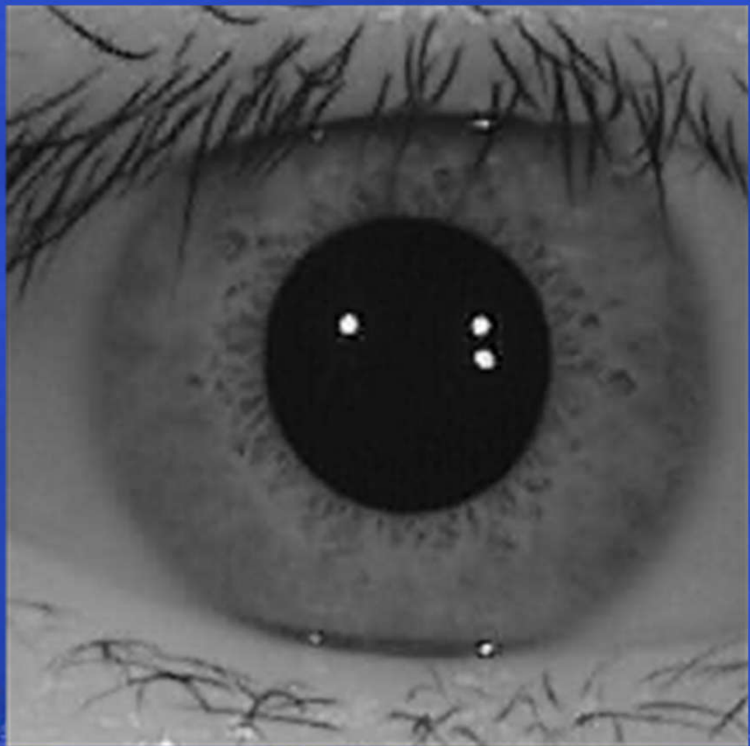
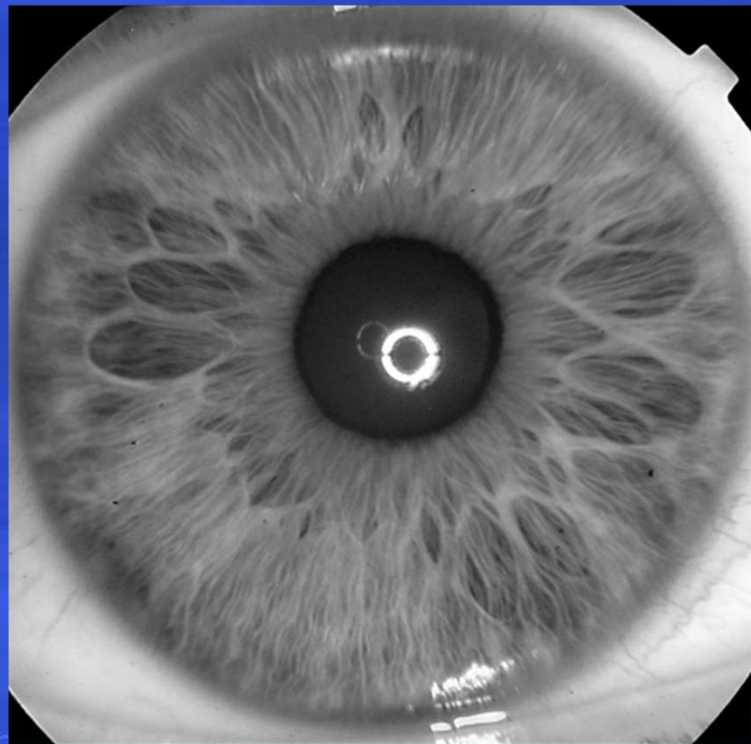
Classification of iris images in large database

**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.**

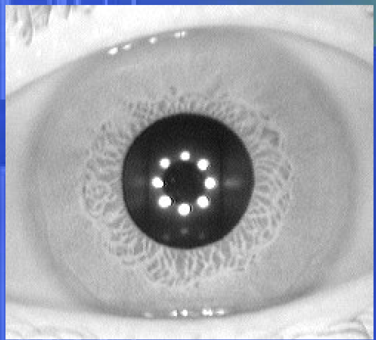


Asian

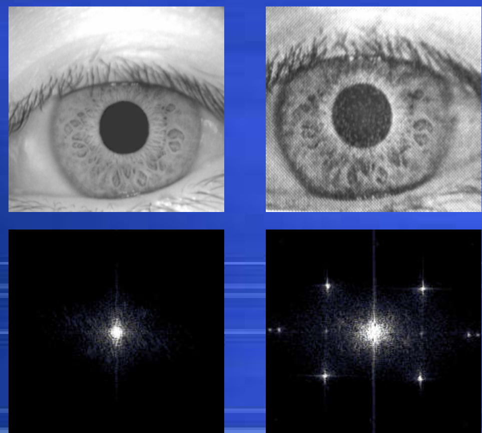


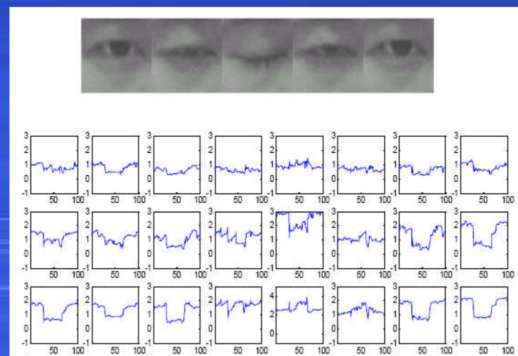
Non-Asian

# 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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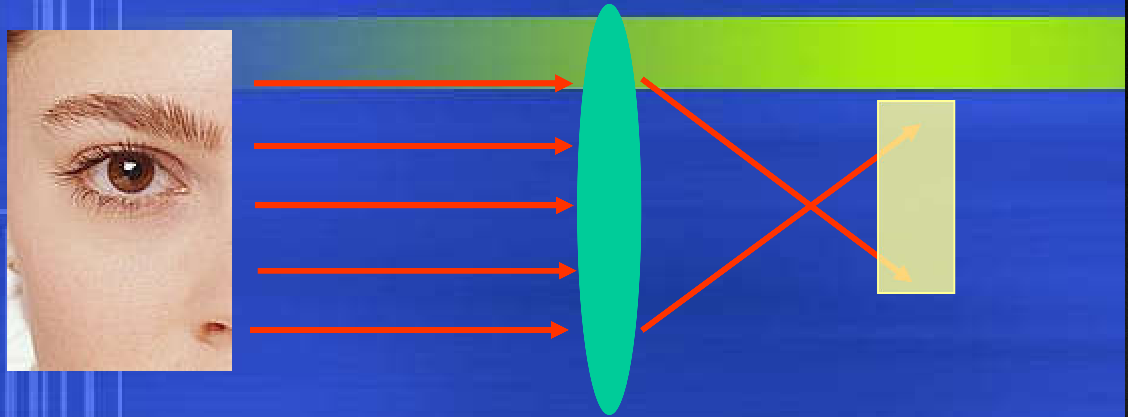
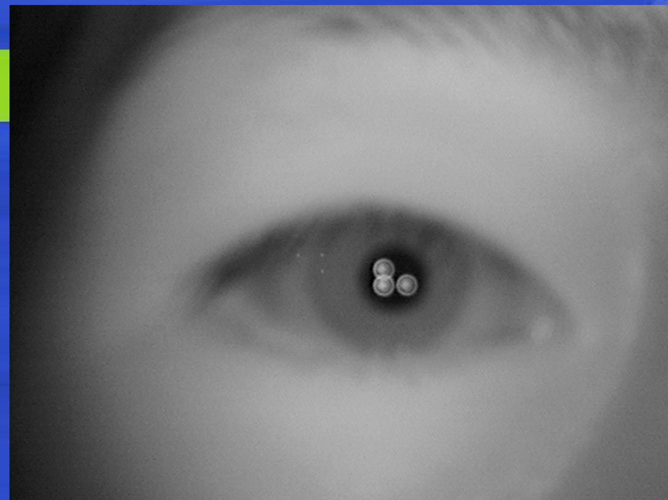
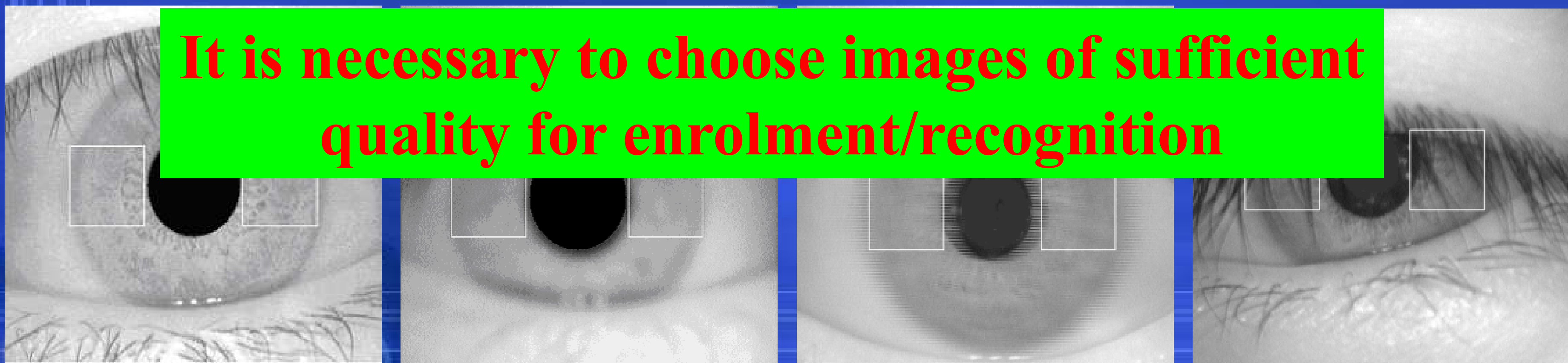
# Iris image quality assessment



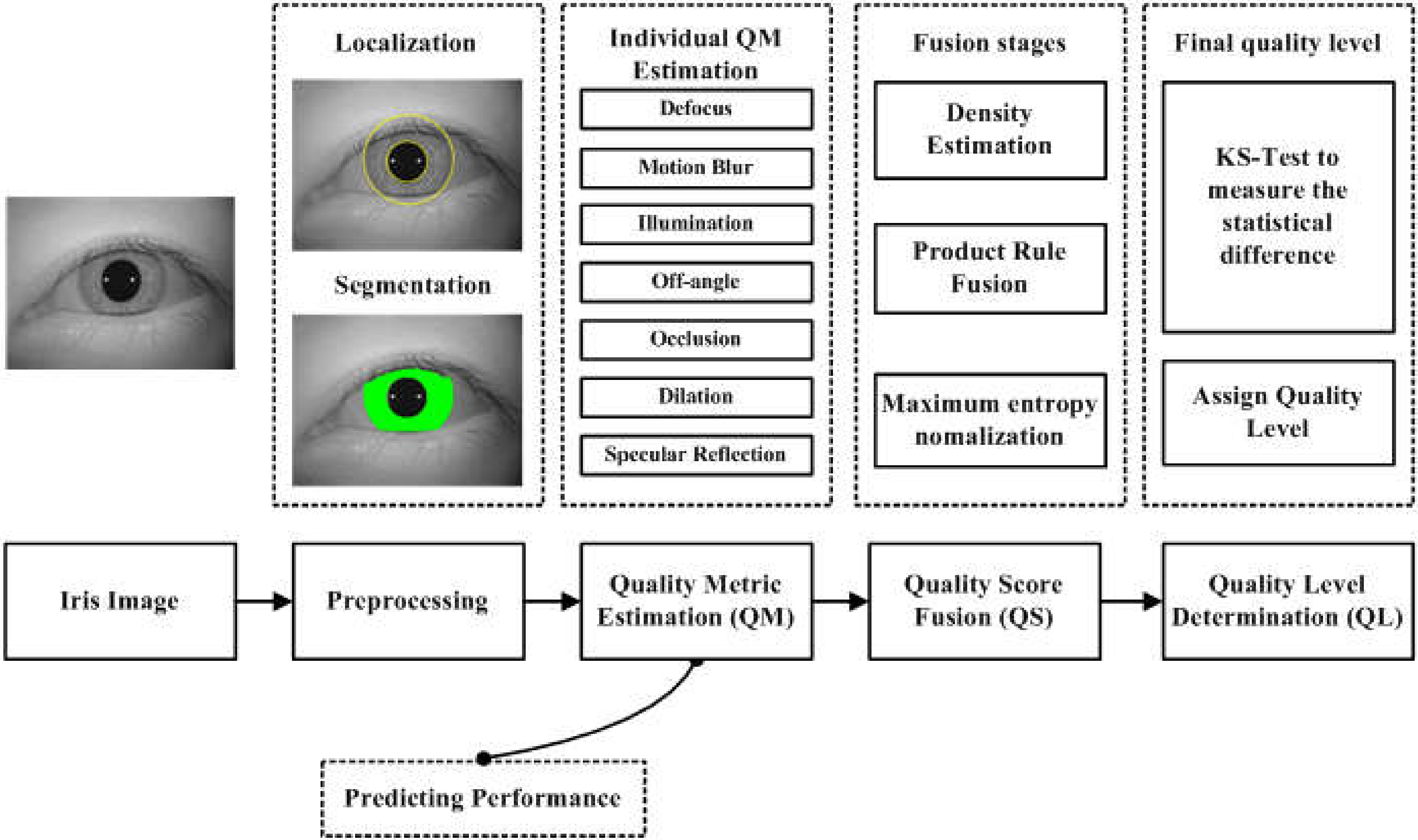


It is necessary to choose images of sufficient quality for enrolment/recognition



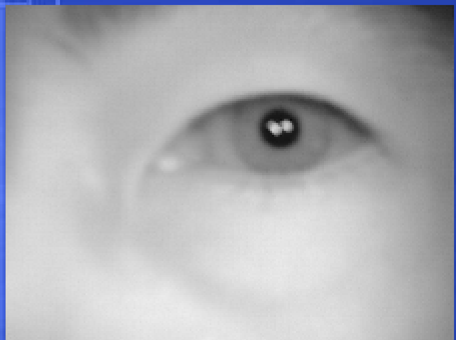
Clear Defocused Motion blurred Occluded

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

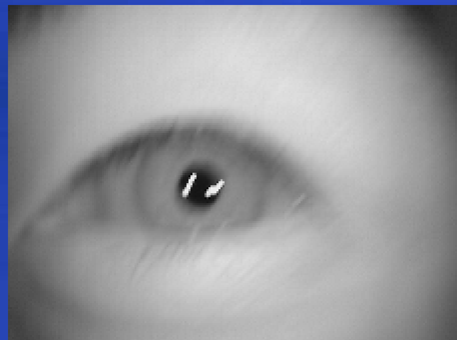


# The first Q: quality metric estimation

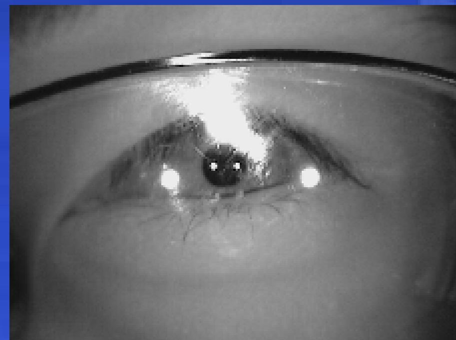
**Defocus**



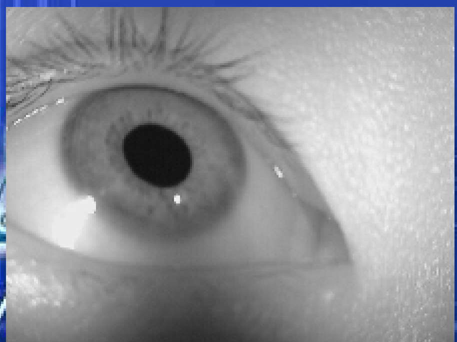
**Motion blur**



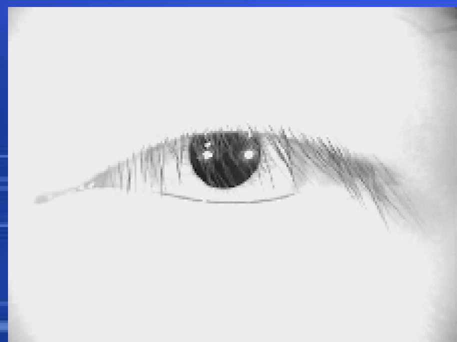
**Valid area**



**Off-angle**



**Illumination**

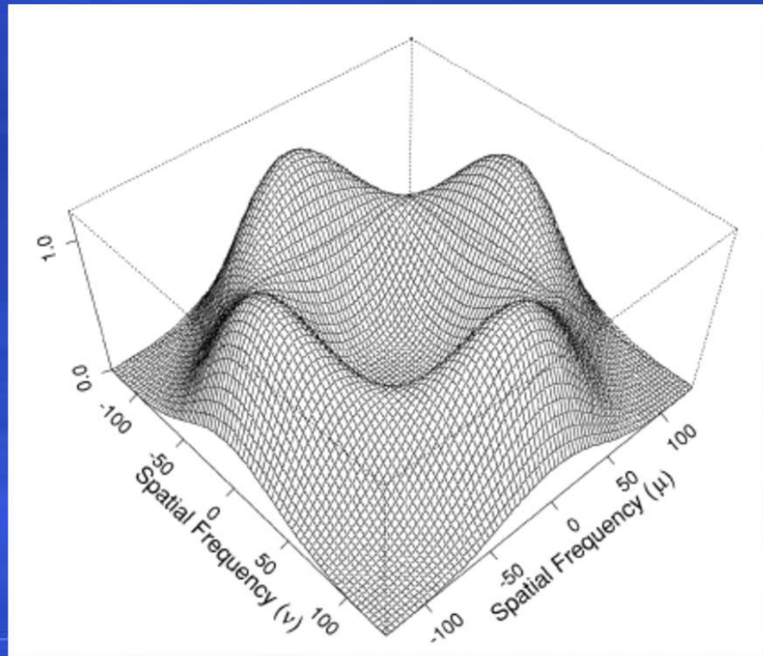


**Dilation**

# Defocused blur assessment

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

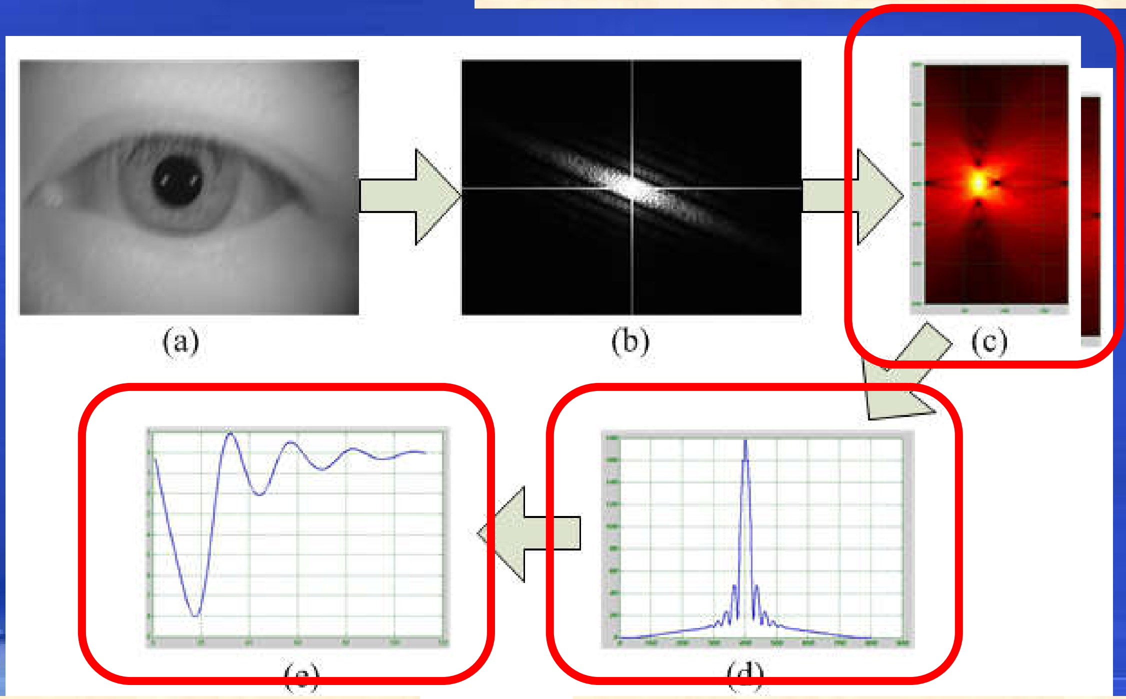
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | +3 | +3 | +3 | +3 | -1 | -1 |
| -1 | -1 | +3 | +3 | +3 | +3 | -1 | -1 |
| -1 | -1 | +3 | +3 | +3 | +3 | -1 | -1 |
| -1 | -1 | +3 | +3 | +3 | +3 | -1 | -1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

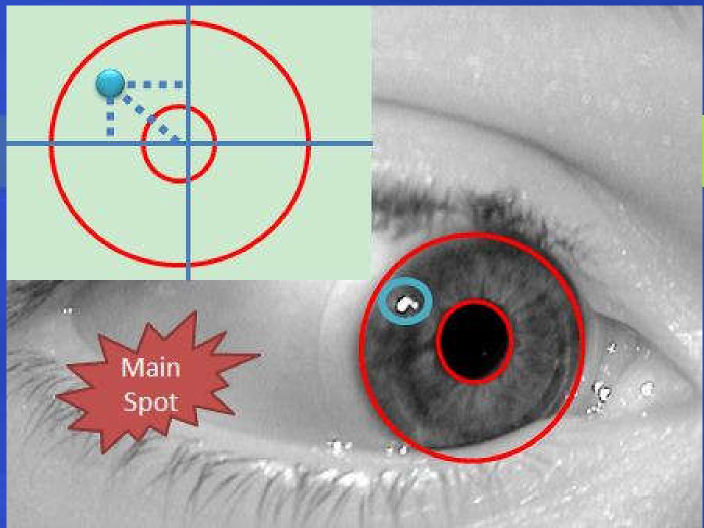
$$R_{p,\theta} = \iint_D f(x,y)\delta(P - x\cos\theta - y\sin\theta)\,dx\,dy$$




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

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

# Off-angle iris image identification

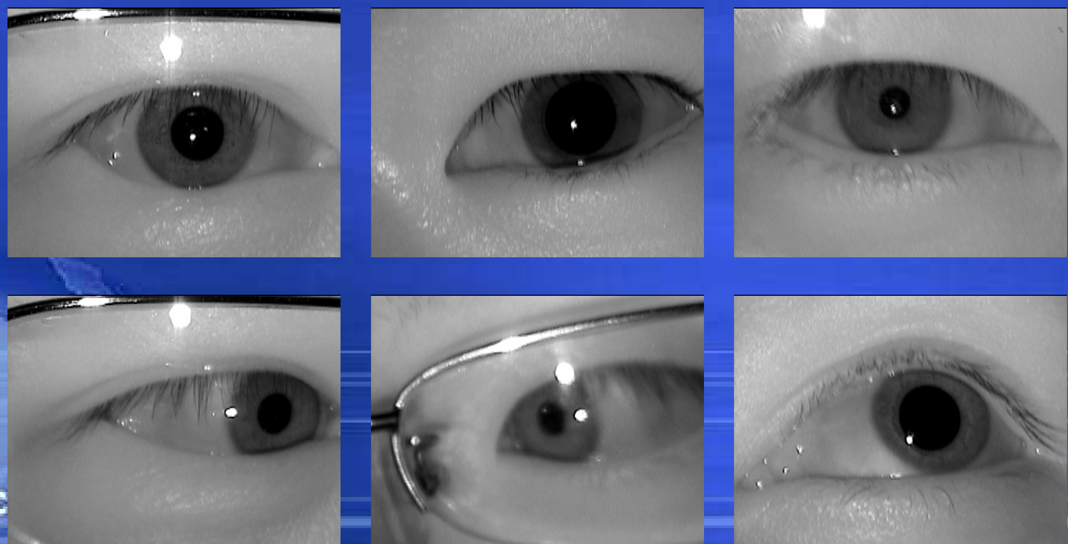



Geometric Information

Classifier

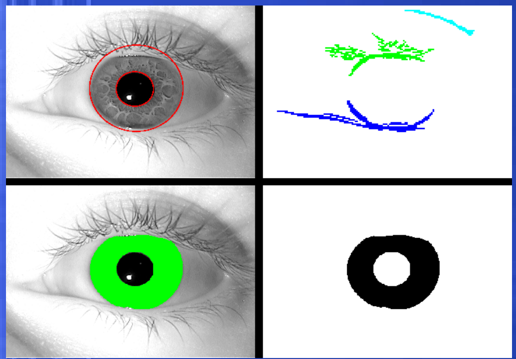
Frontal iris images

Off-angle iris images

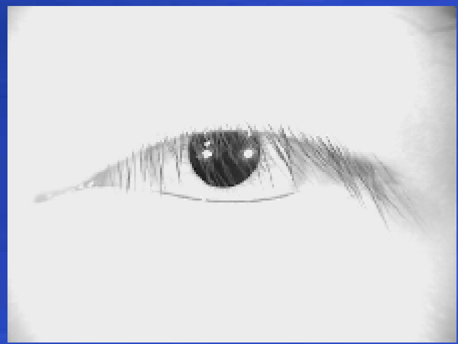


# Other quality metrics

**Valid area**



**Illumination**

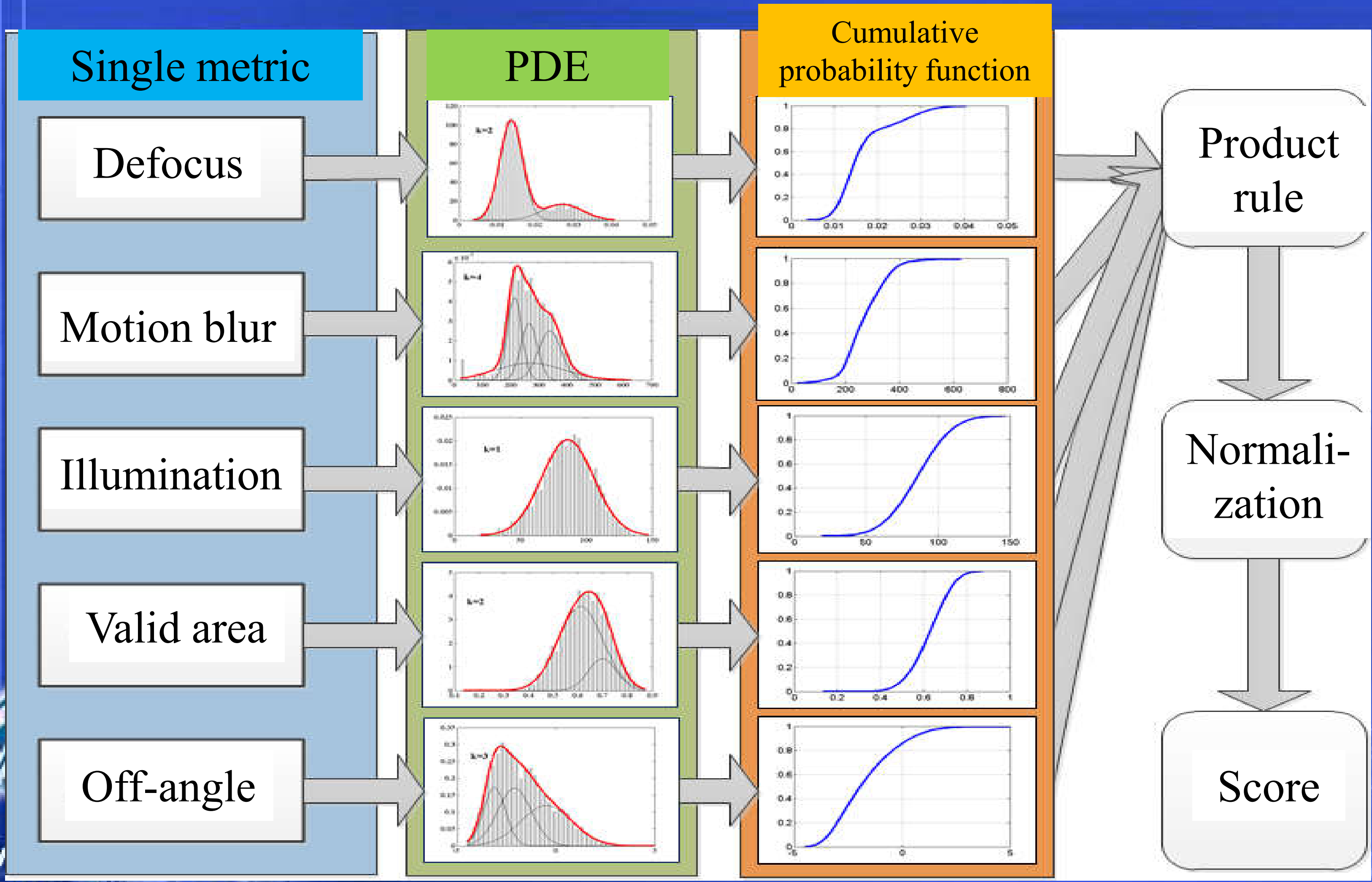


Mean gray value in the valid iris region

**Dilation**

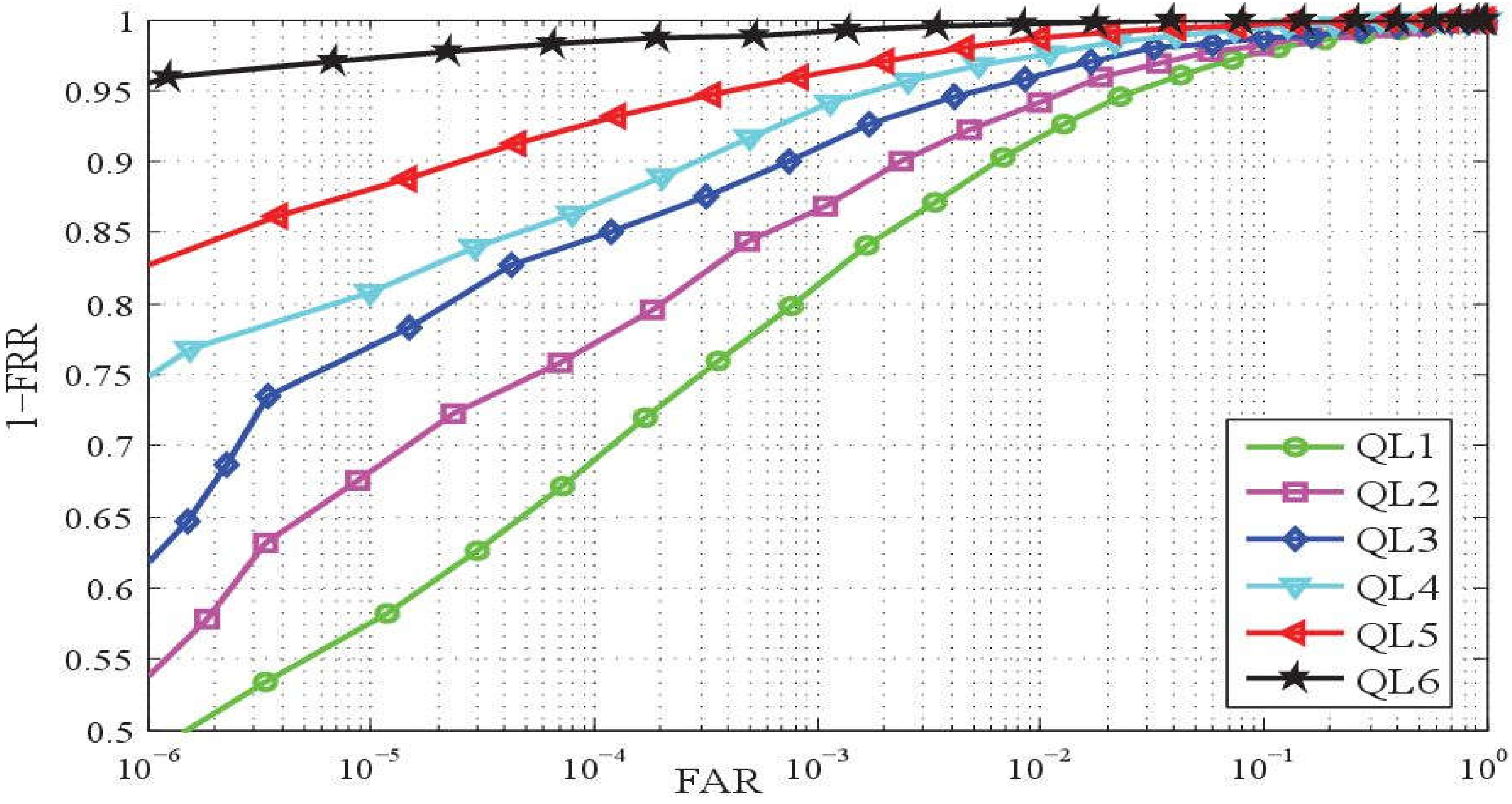
$$Q_{dilation} = \frac{IrisArea}{IrisArea + PupilArea}$$

# The second Q: quality score fusion from multiple metrics



# The third Q: quality level determination

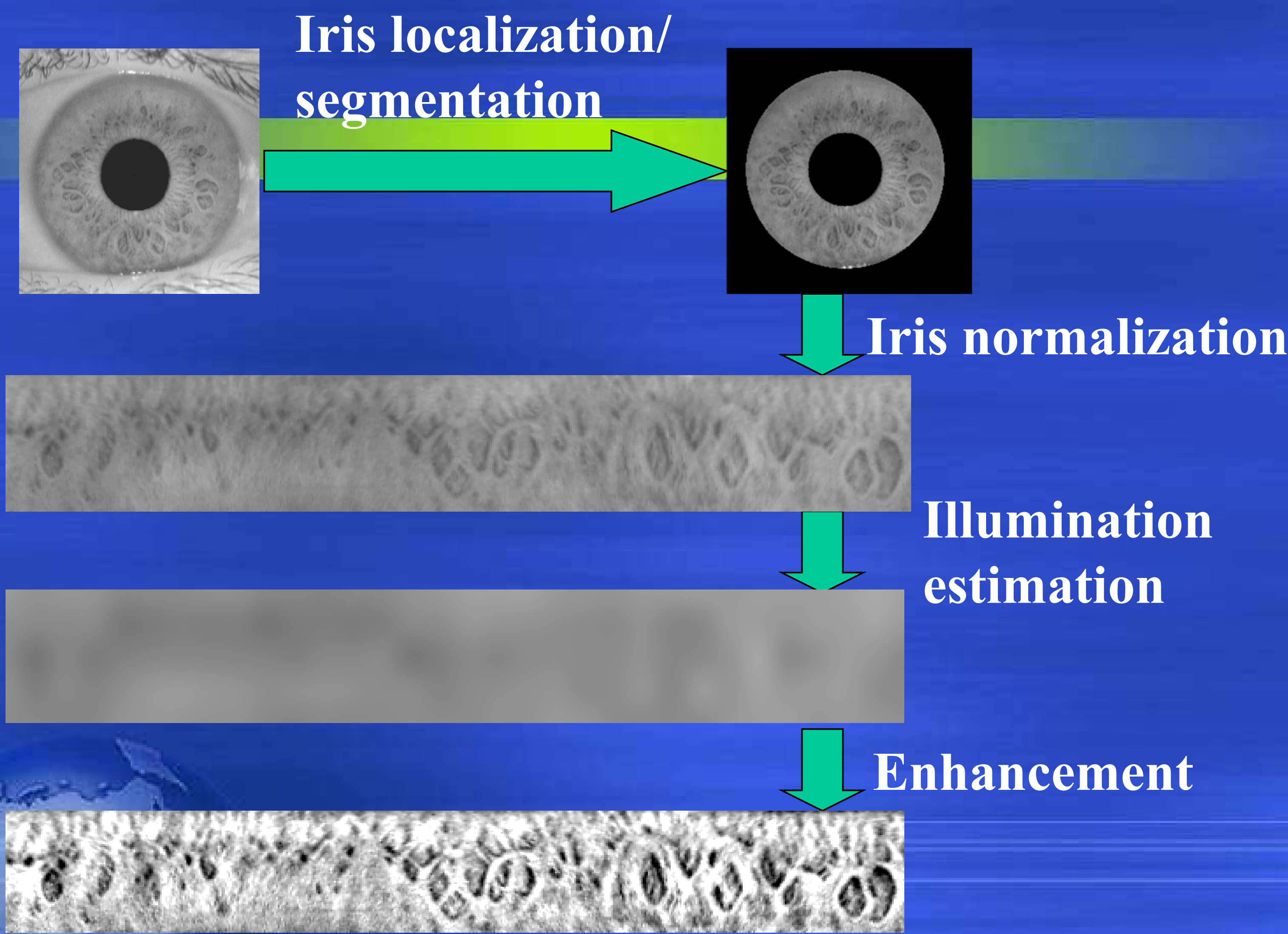
**Iris recognition performance as a function of QL on the CASIA database**



# 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

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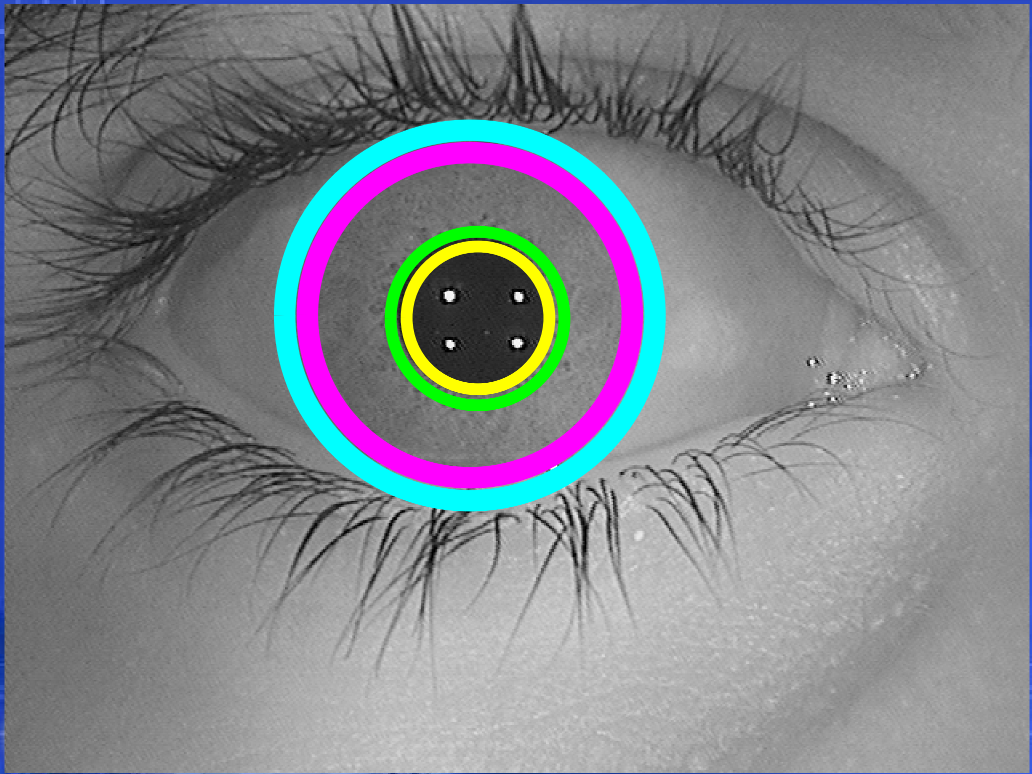
# Iris localization

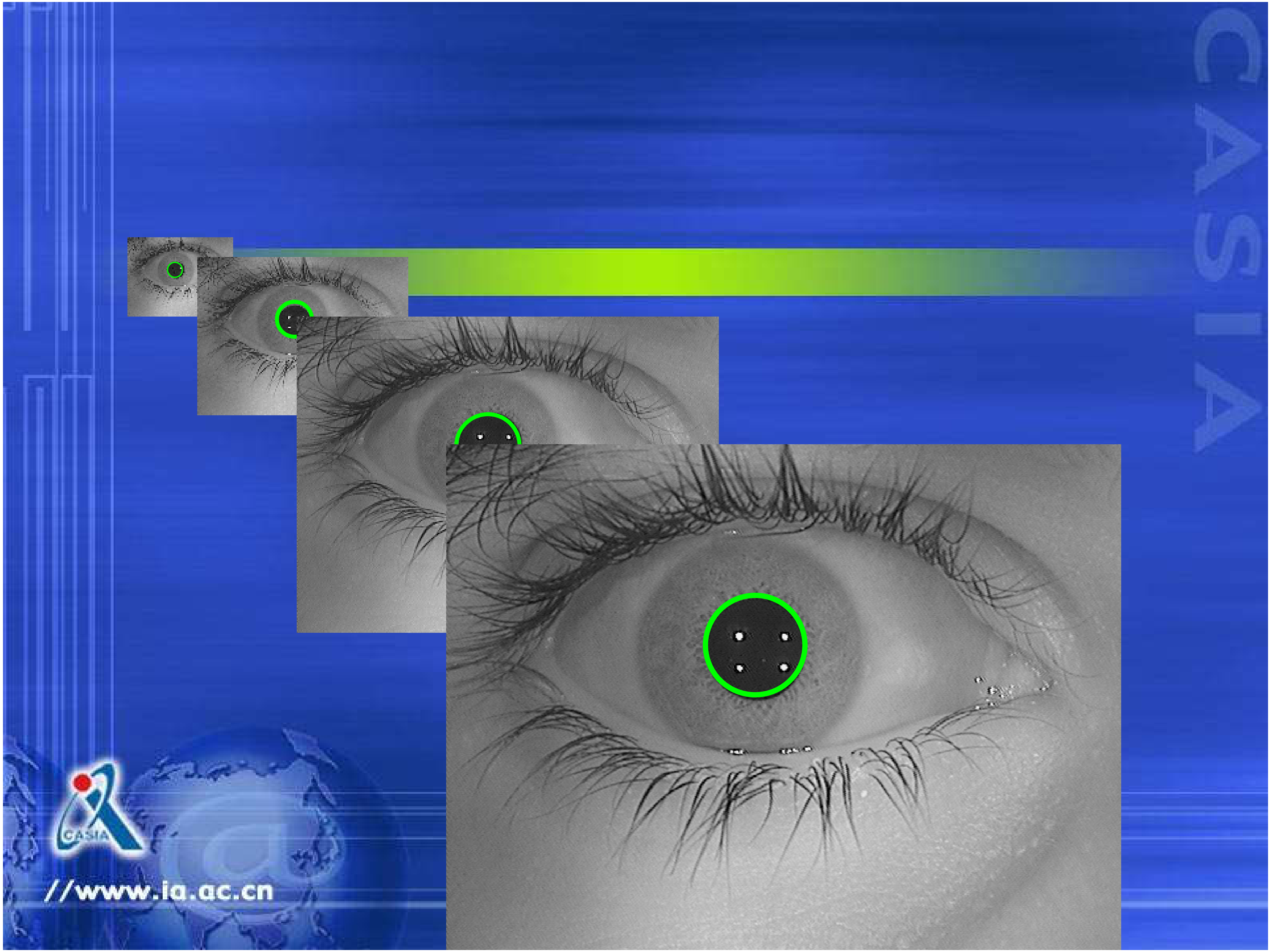
## －Daugman's algorithm－



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
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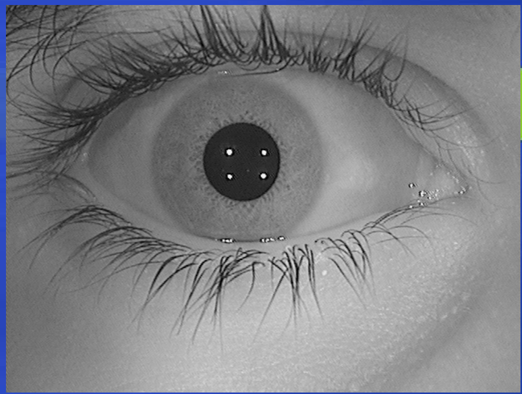
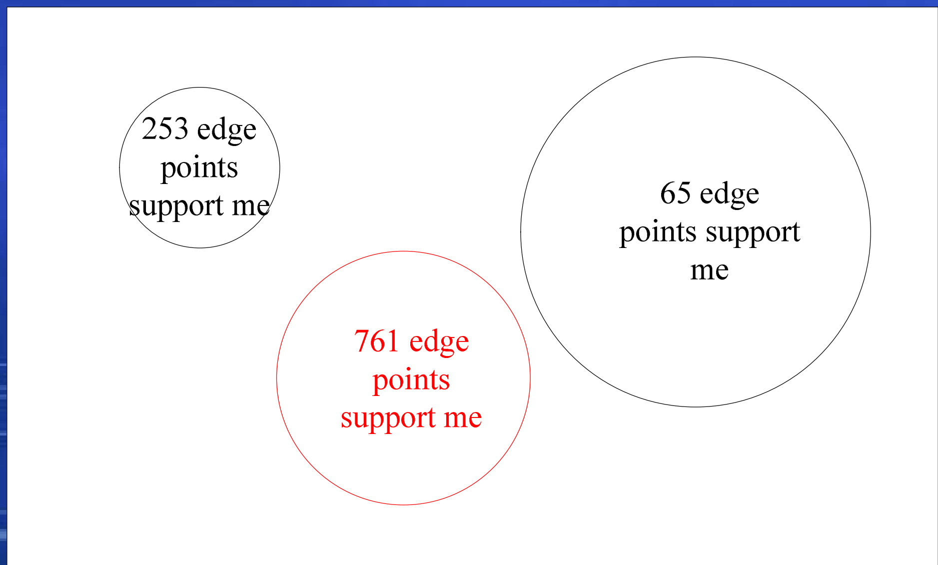
# Iris localization

## —Wildes' algorithm—



Edge detection

Hough transform

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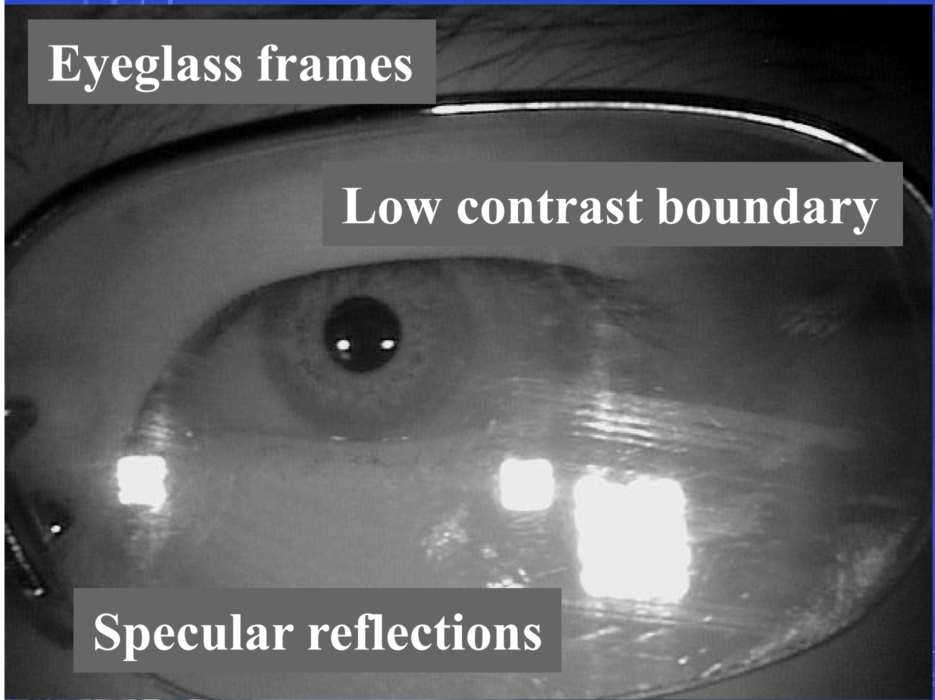
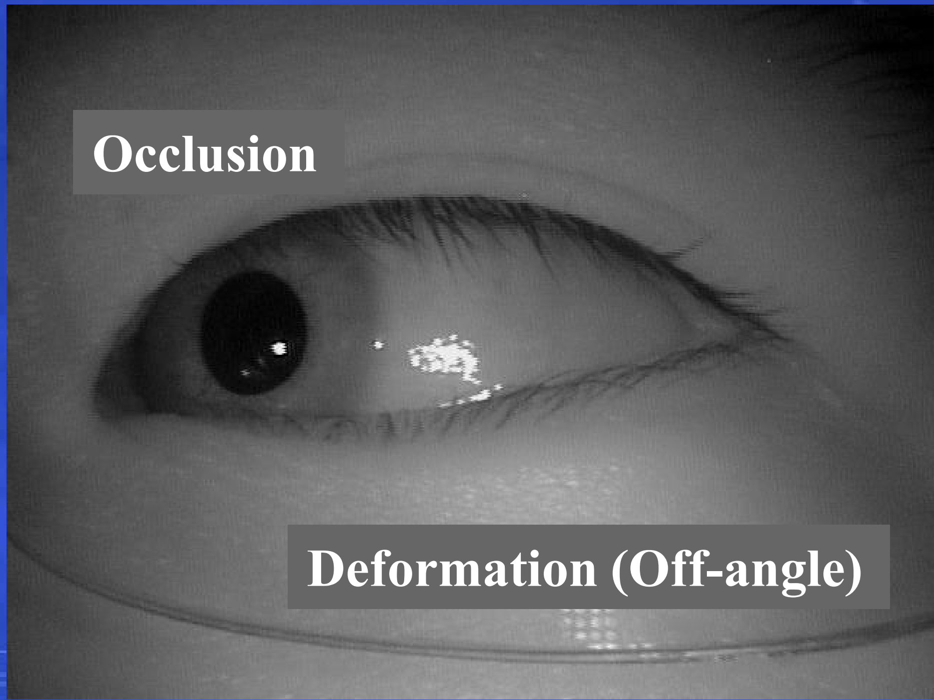
# The main challenges of iris image segmentation



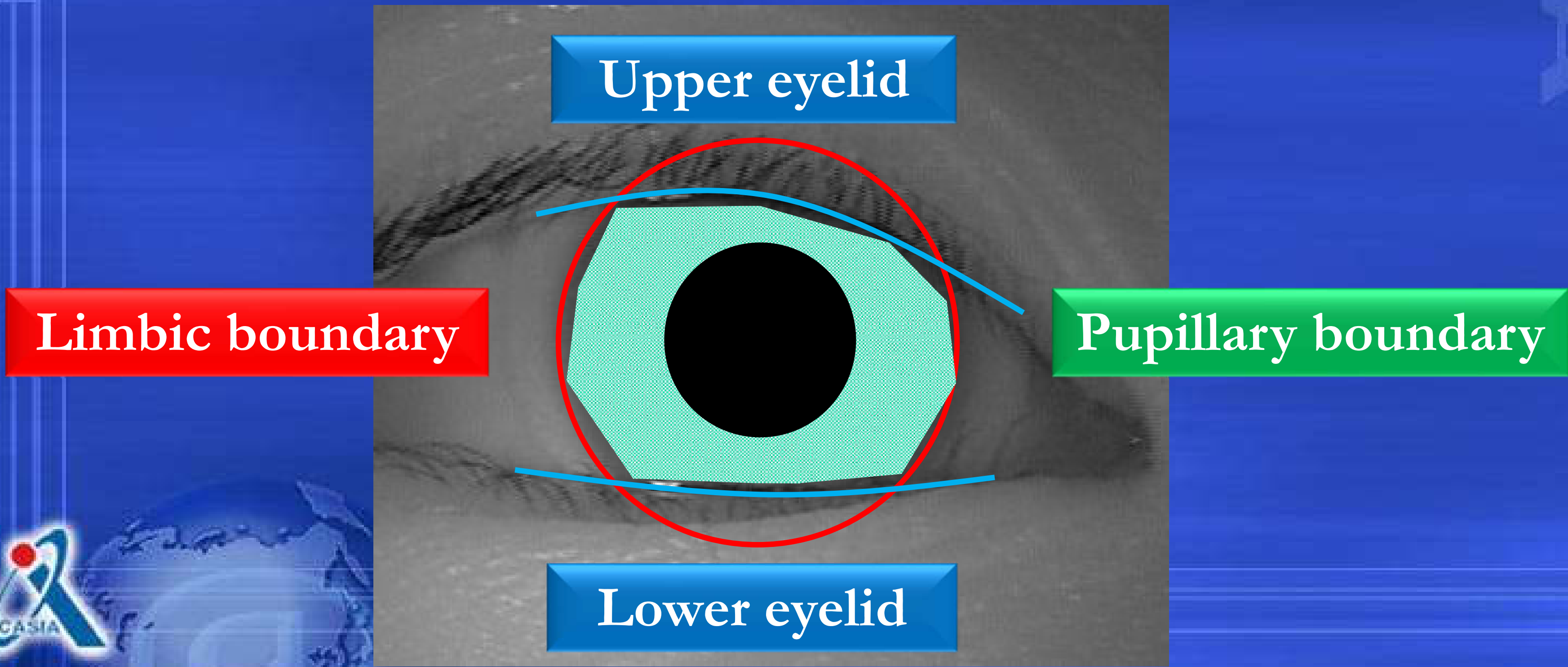
# Related works

## Region Based Methods

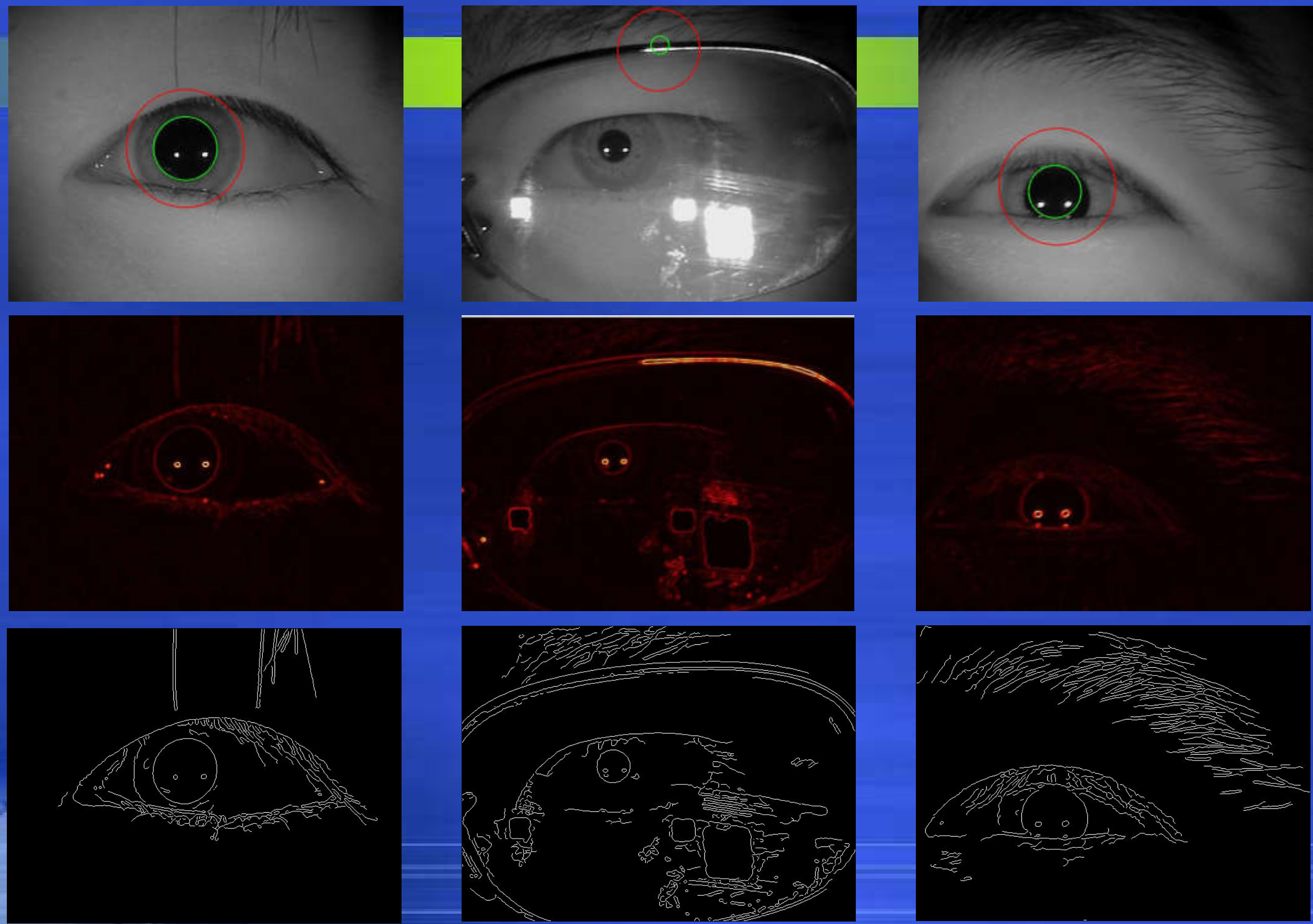
Pixel classification (Proença, TPAMI'10)
Pixel clustering (Tan, IVC'10)

## 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

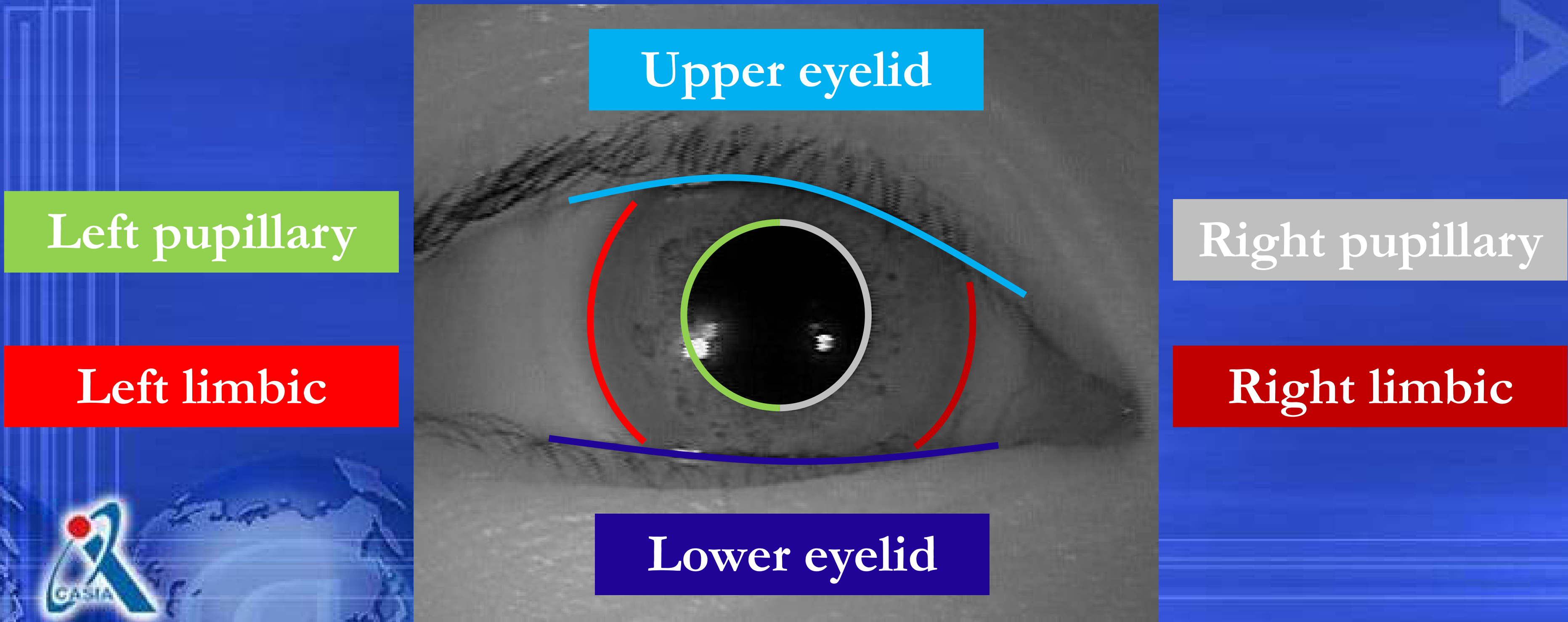



**How to identify the edges on the iris boundaries?**

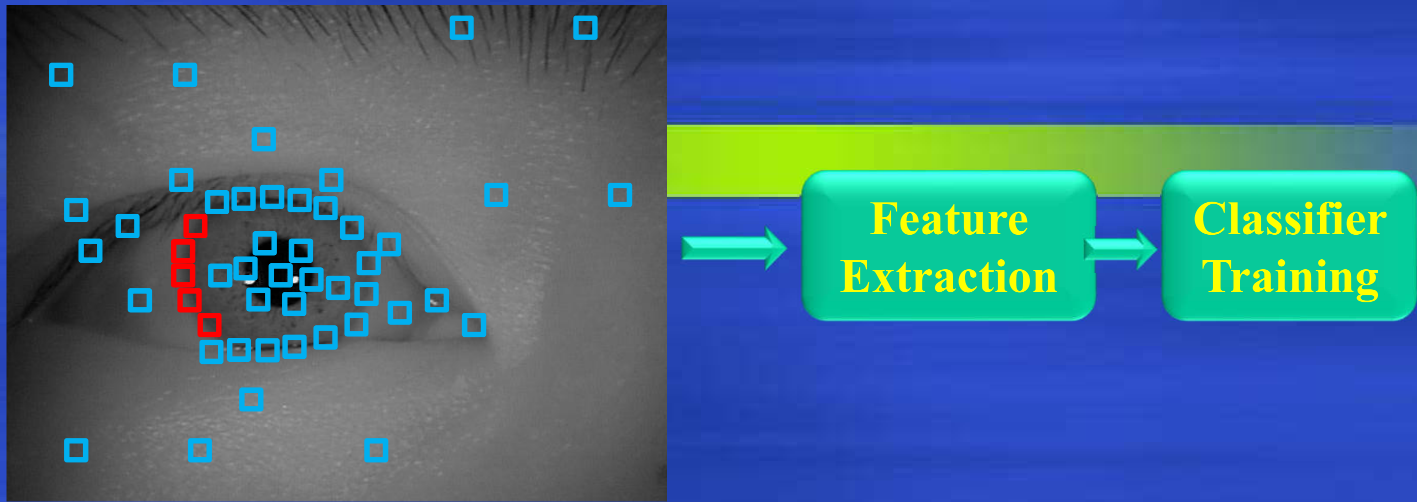
# Our solution: specific edge detectors only sensitive to the edge points on iris boundaries

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

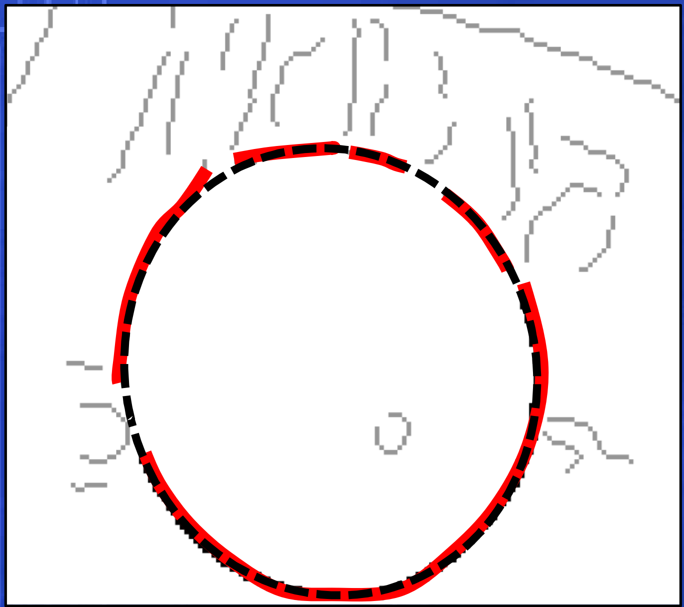
14091 features in total

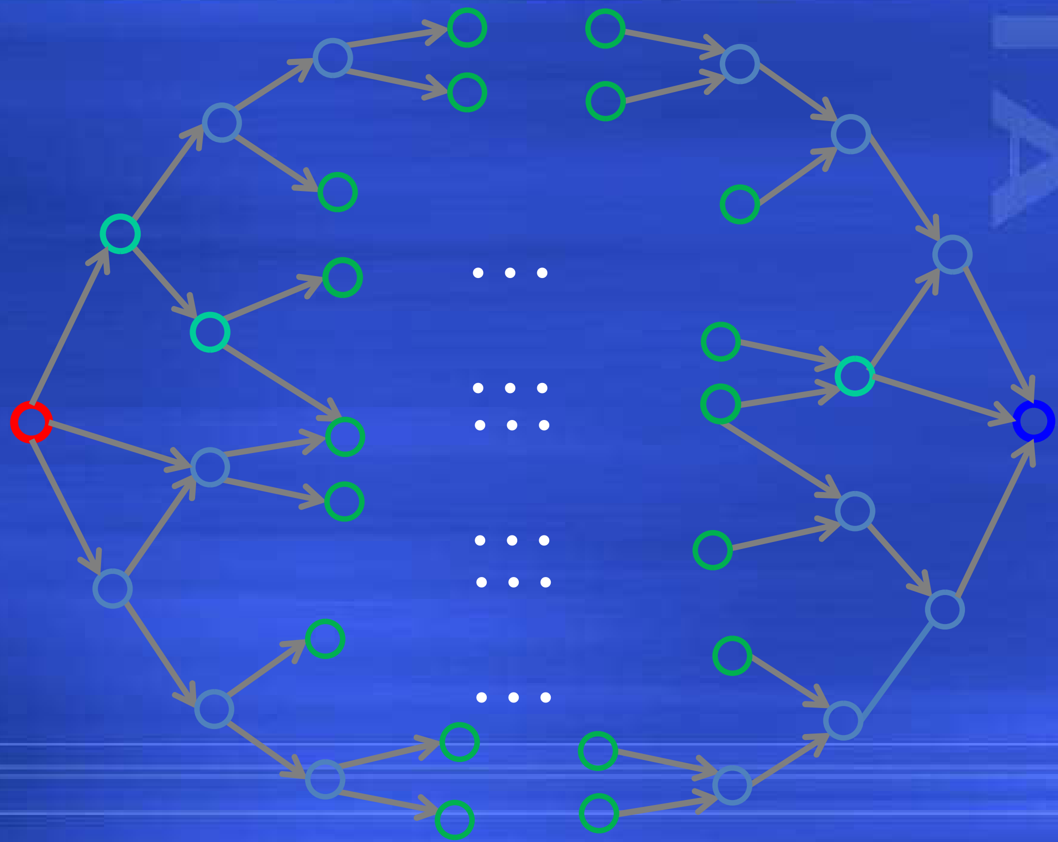
**Integer intensities**

All features can be computed efficiently

# Contour connection based on energy minimization

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





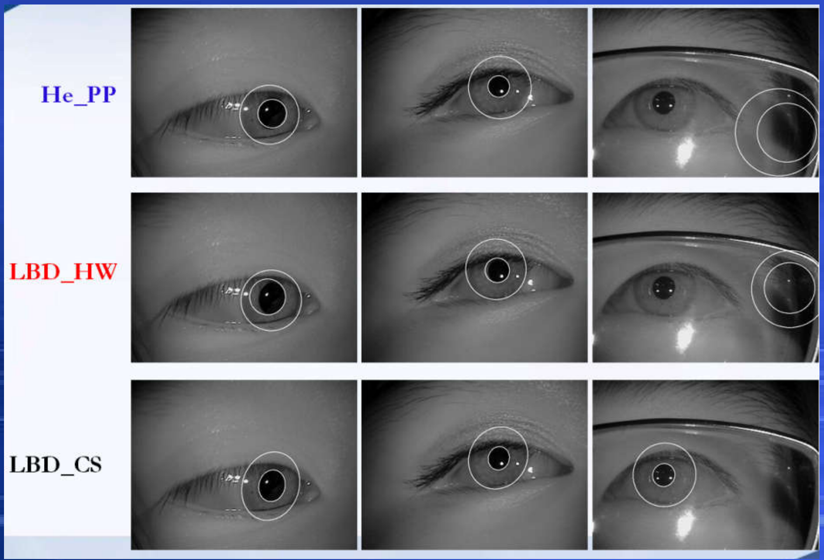
# Performance of iris localization

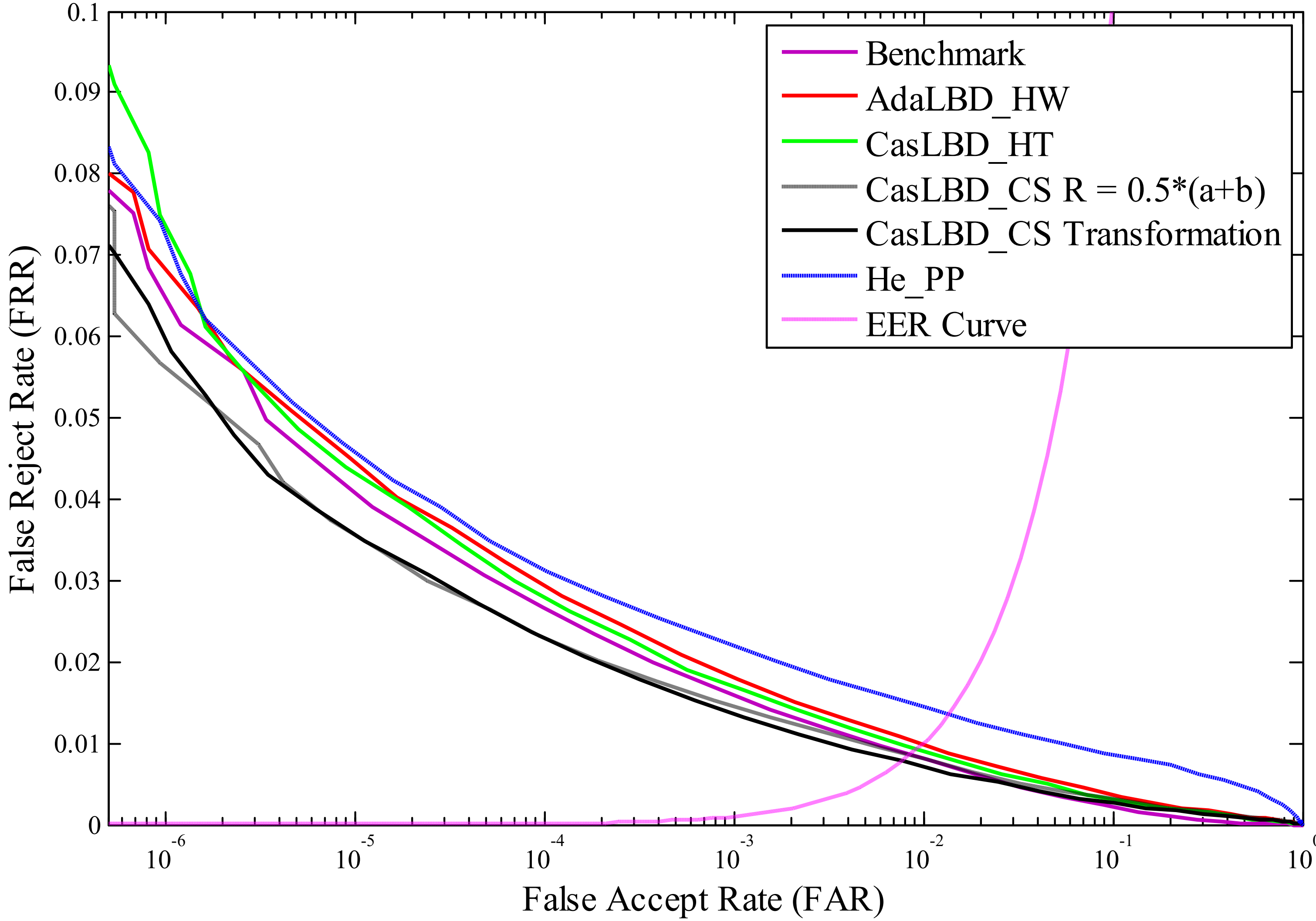
**CASIA-Iris-Thousand**: 20,000 iris images from 2,000 eyes of 1,000 persons.

**Accuracy Rate:**

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

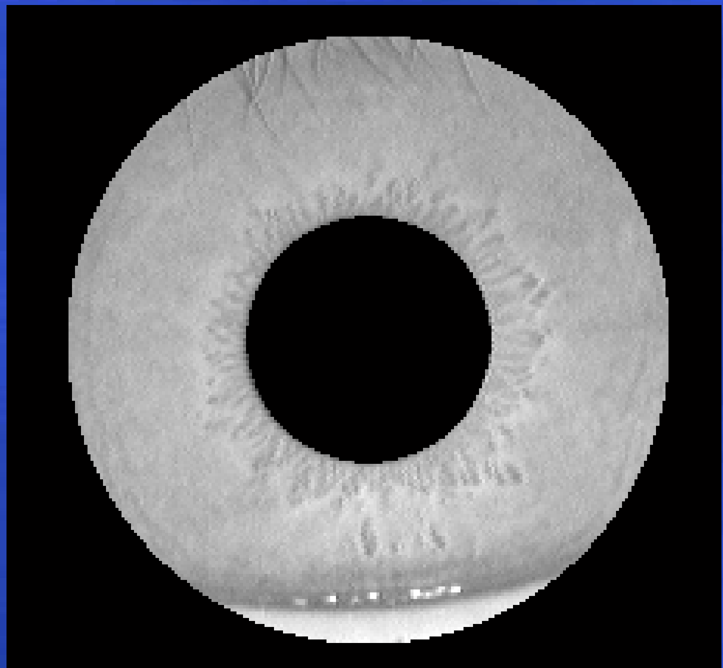
| | |
|---|---|
| **He_PP (He, Tan et al. TPAMI 2009)** | **95.30%** |
| CasLBD_HT (Cascaded LBDs + Hough Transform; ICB 2012 ) | 99.13% |
| CasLBD_CS (Cascaded LBDs + Contour Segments; ICPR 2012) | 99.28% |



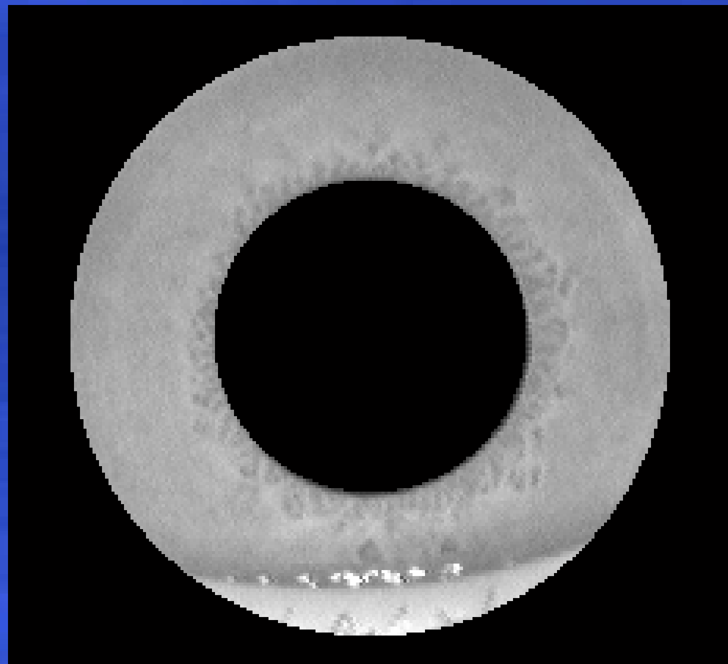


Benchmark
AdaLBD_HW
CasLBD_HT
CasLBD_CS R = 0.5*(a+b)
CasLBD_CS Transformation
He_PP
EER Curve
False Reject Rate (FRR)
False Accept Rate (FAR)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0

# Nonlinear iris deformation

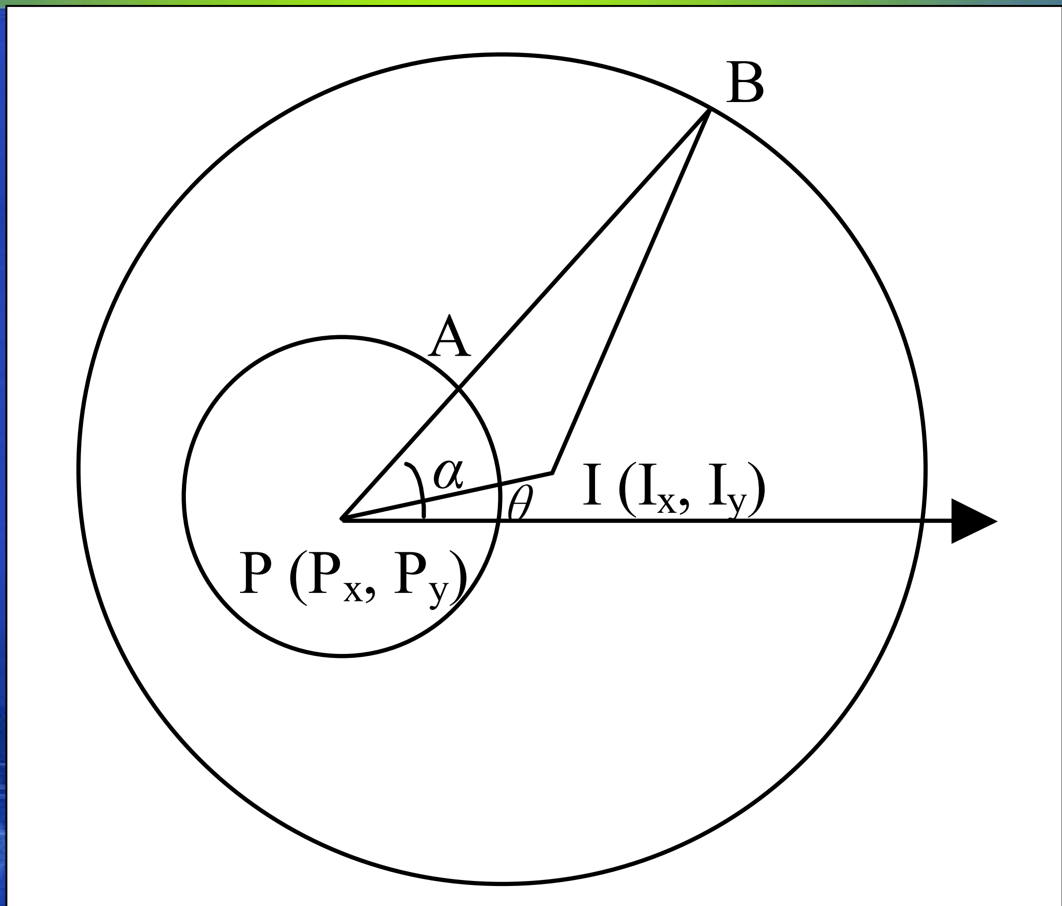


Normal illumination



Weak illumination

# Iris normalization



# Iris normalization model

Linear mapping model：

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

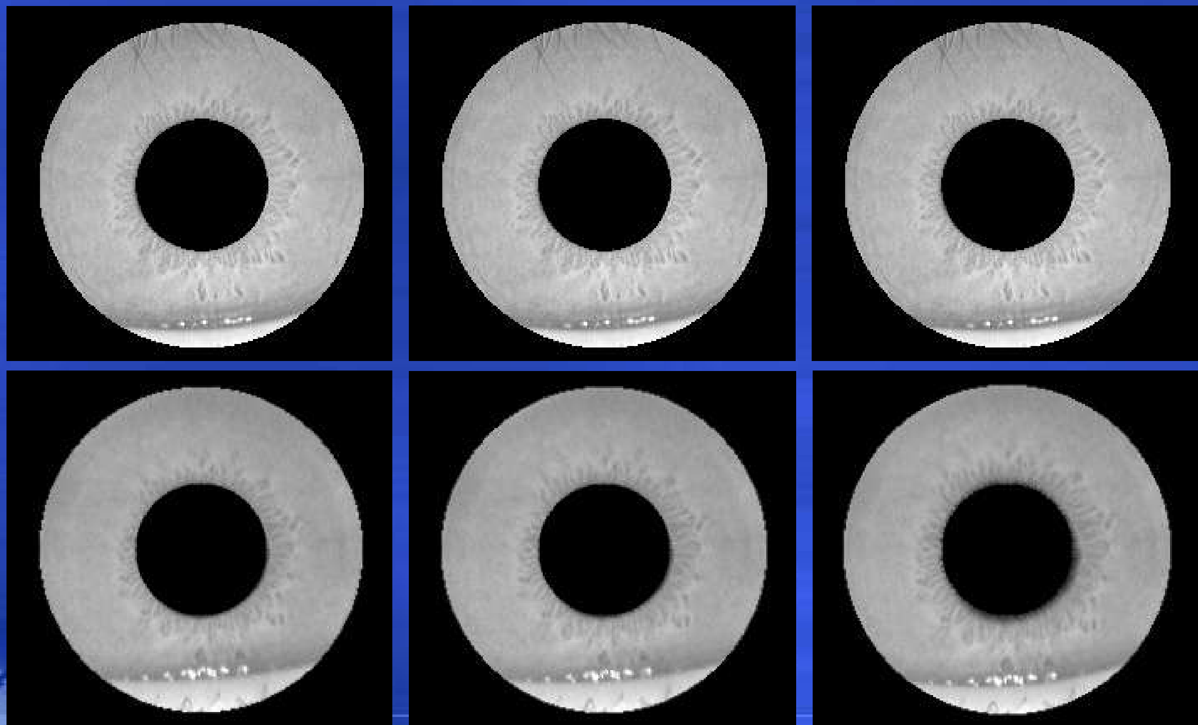
Piecewise-linear mapping model：

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

Nonlinear mapping：

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

# Iris normalization results



Linear Piecewise-linear Nonlinear

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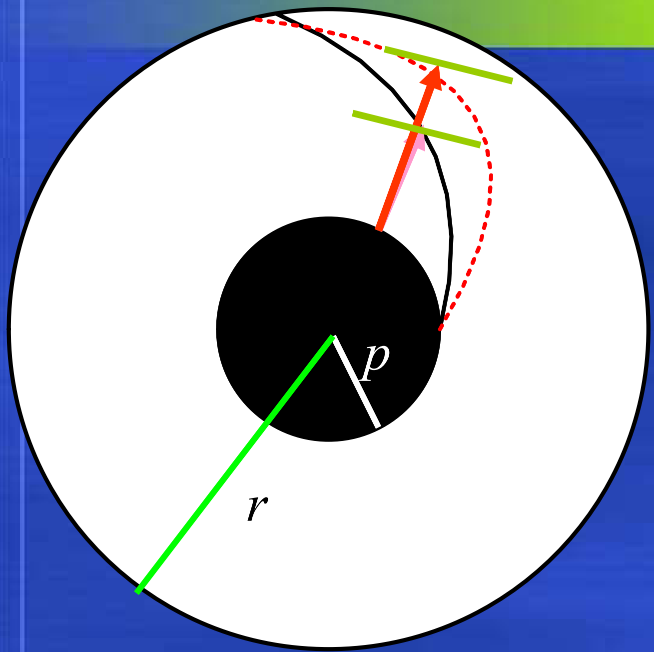
# Nonlinear iris deformation correction

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




Iris linear stretch

Iris nonlinear stretch

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

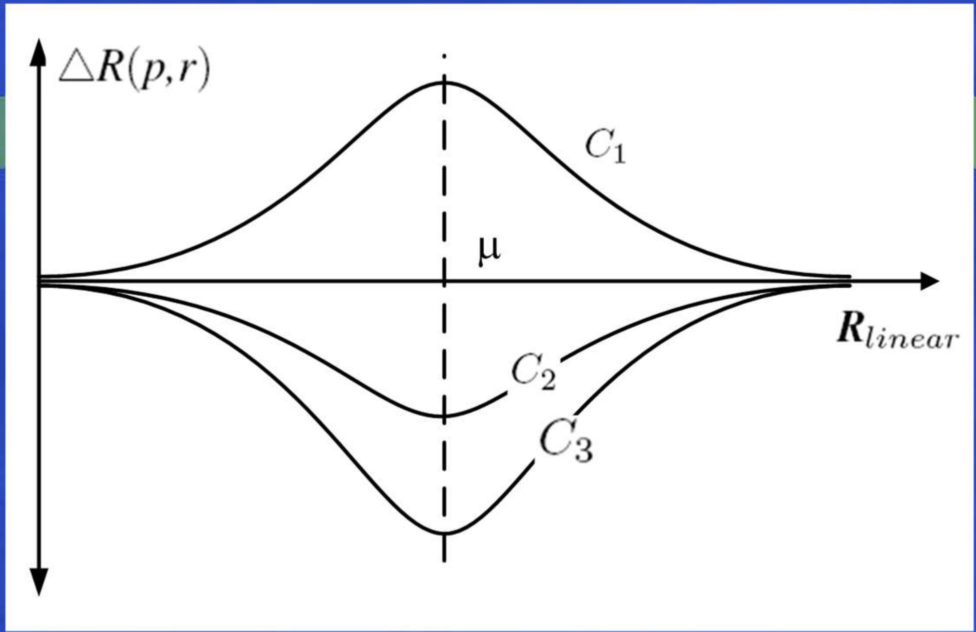
$$R_{nonlinear} = R_{linear} + \Delta R(p,r)$$

$R_{linear}$ Linear stretch position

$R_{nonlinear}$ Nonlinear stretch position

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

# Our solution: Gaussian function to model the additive component

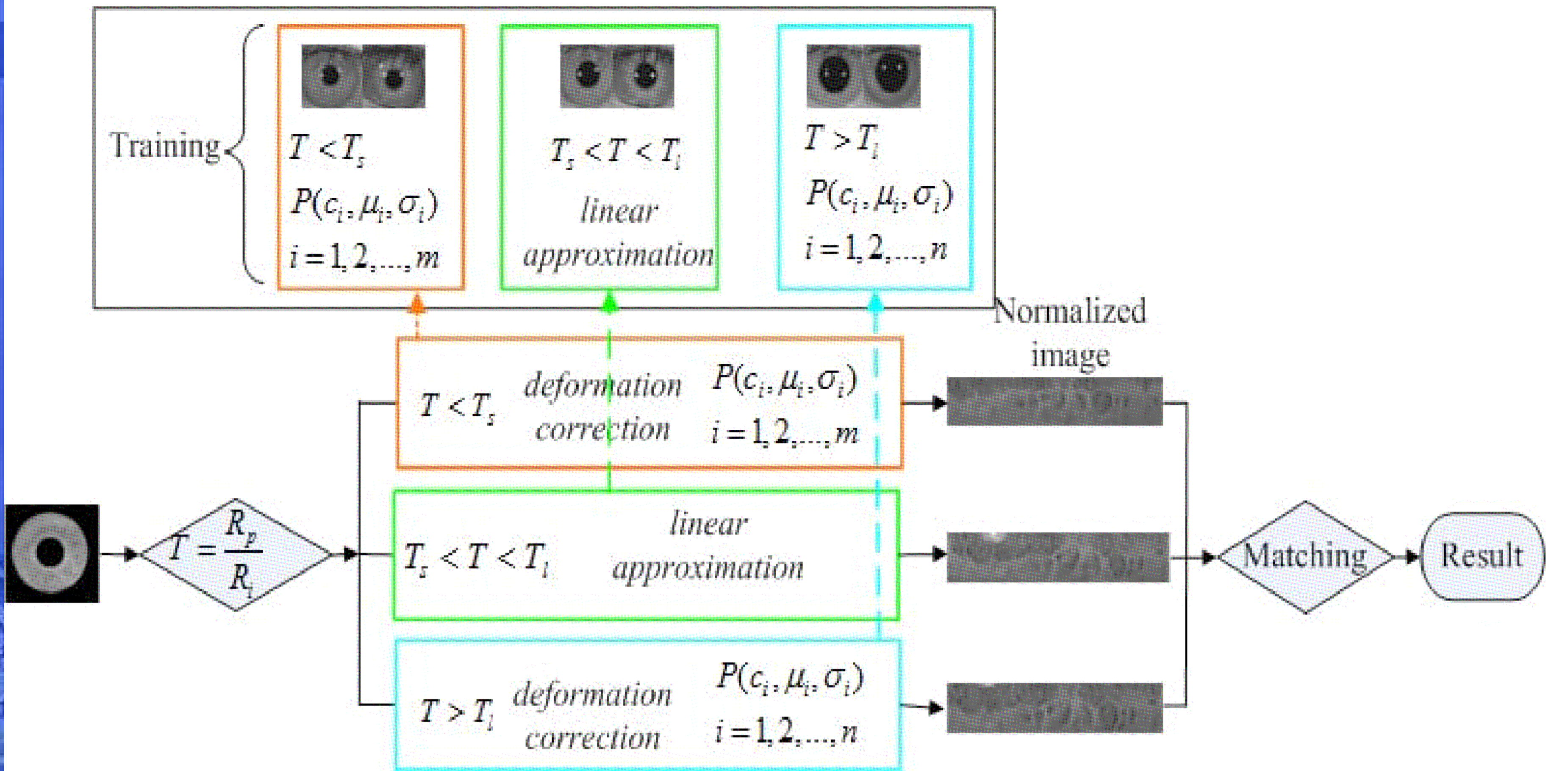



$$\triangle R = C \times \exp[-\frac{1}{2} \times \frac{(R_{linear} - \mu)^2}{\sigma^2}]$$

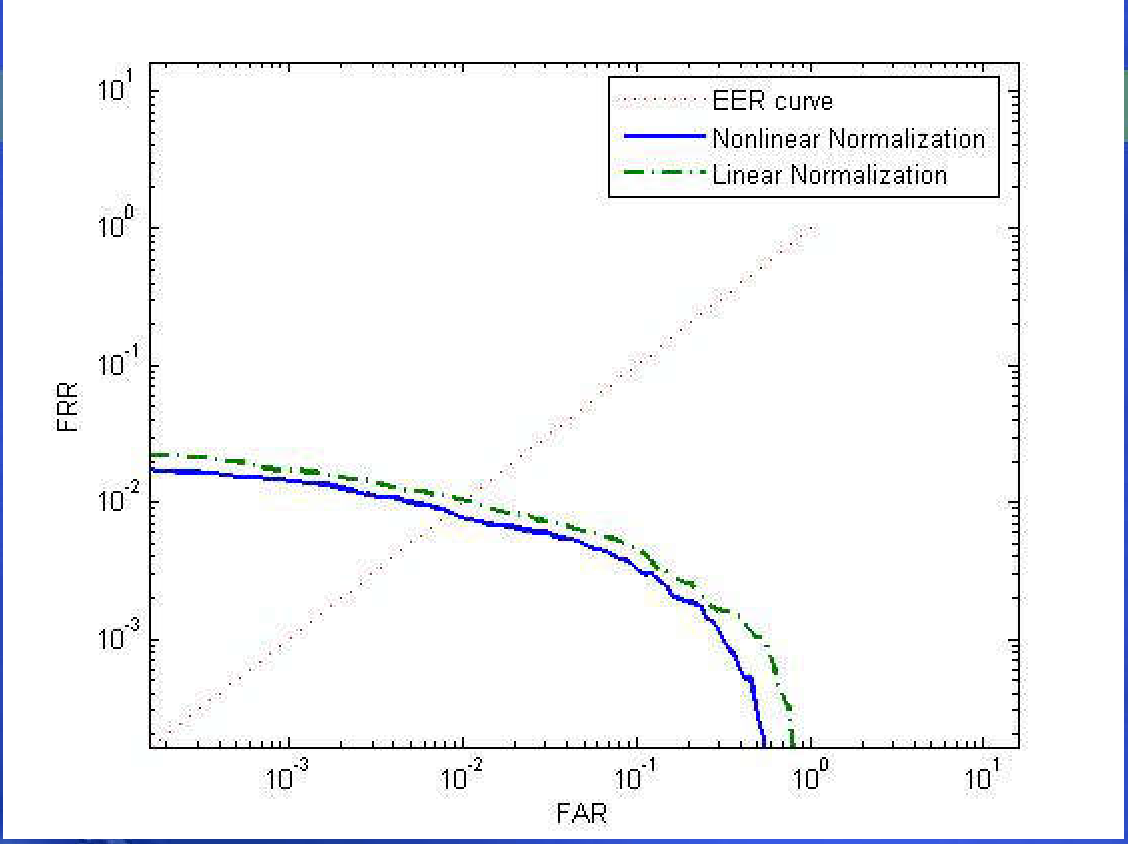
$$C = \lambda - \frac{p}{r}$$

where $\lambda$ is the standard ratio of pupil radius per iris radius

# Flowchart of nonlinear iris deformation correction



# Recognition using different normalization methods



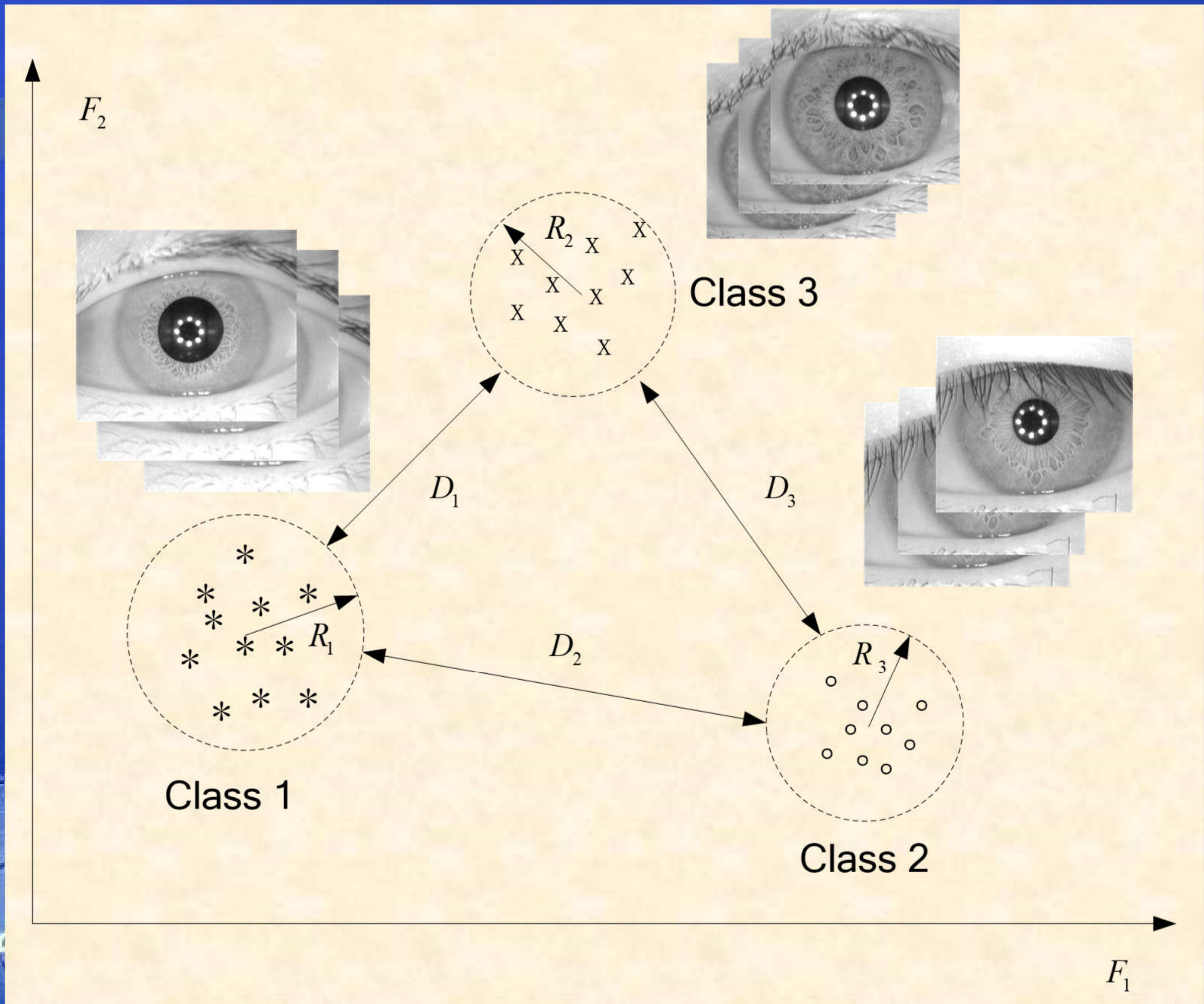

| | EER | Discri Index | Time (s) |
|---|---|---|---|
| Linear | 1.0585% | 4.7094 | 0.0862 |
| Nonlinear | 0.85067% | 4.9913 | 0.0693 |

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)**

# John Daugman

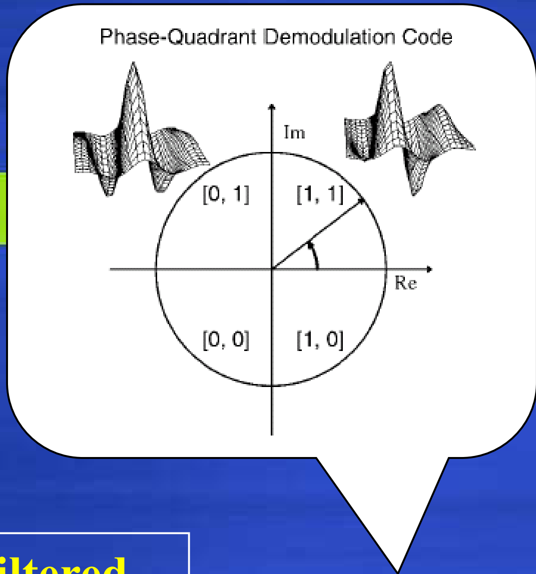
UNIVERSITY OF CAMBRIDGE
Computer Laboratory

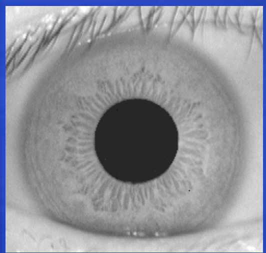
Tel: +44 1223 334501
Fax: +44 1223 334678

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

# Daugman's method: IrisCode

## Feature extraction



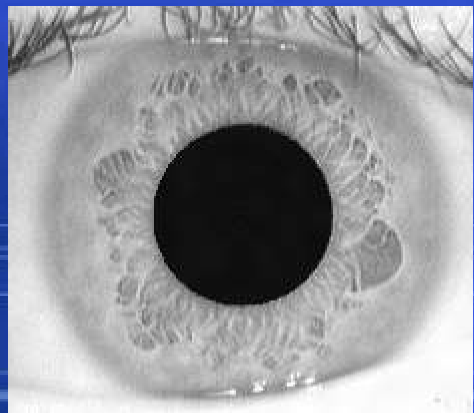



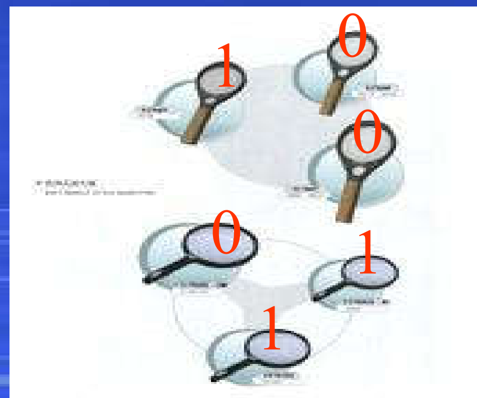
Multiscale Gabor filters

Filtered results

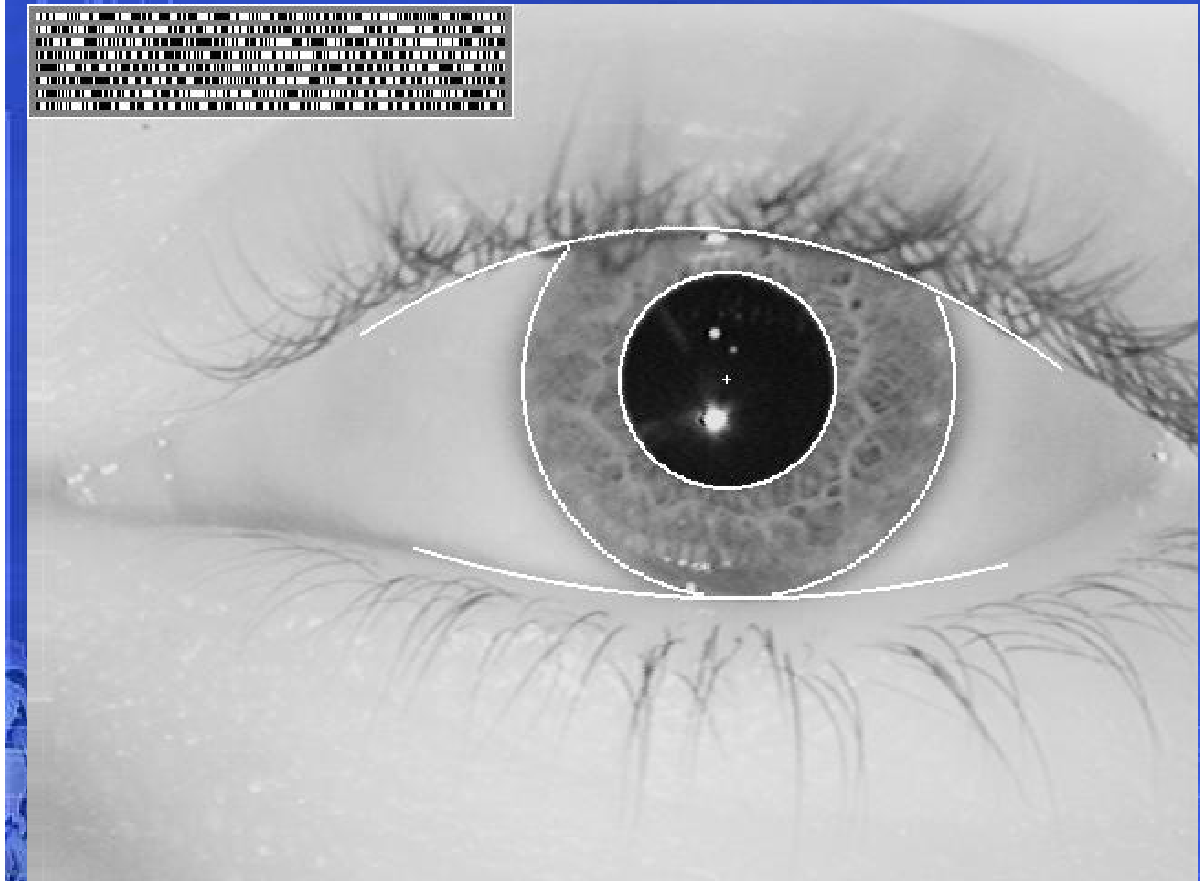
Quantization

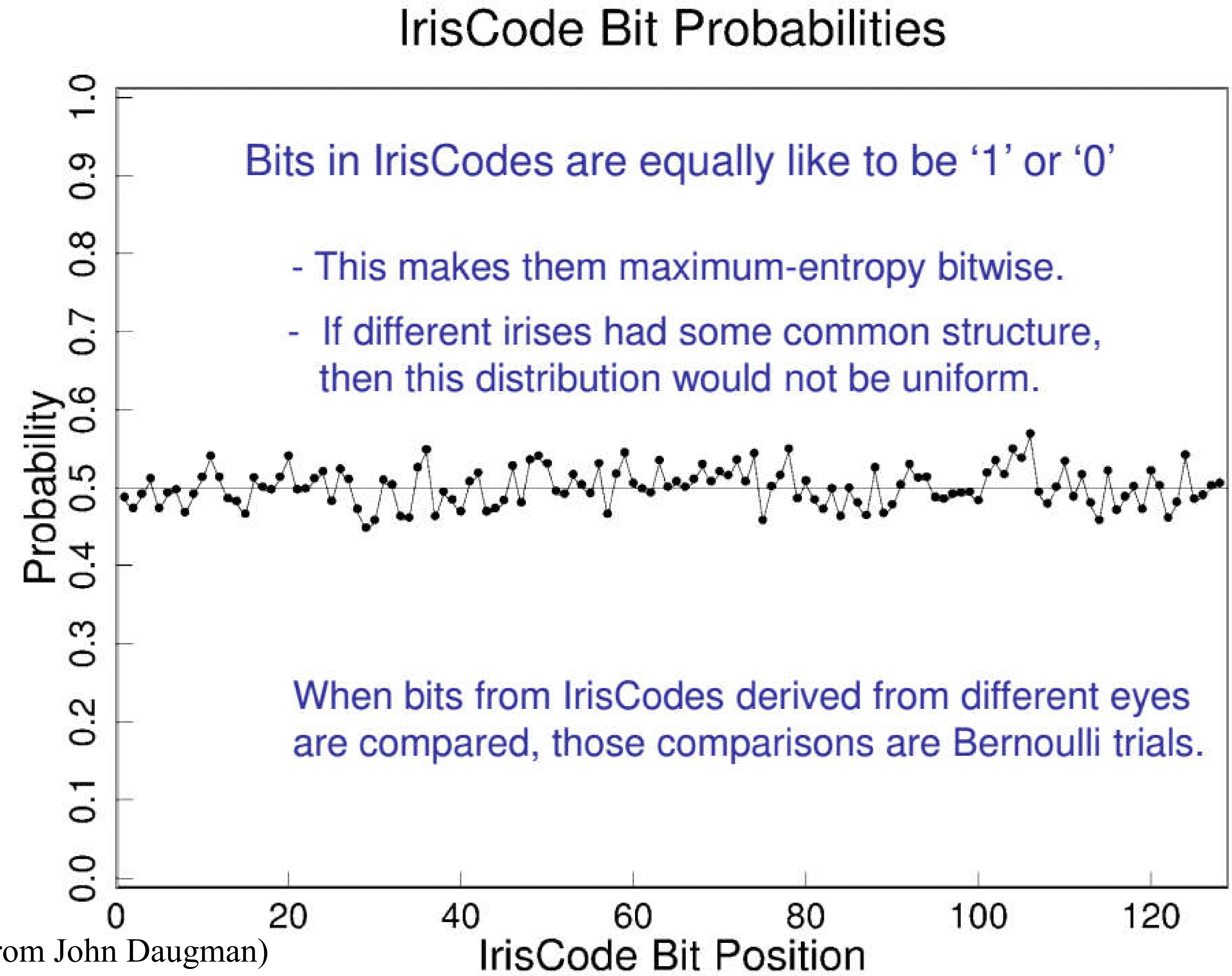
IrisCode



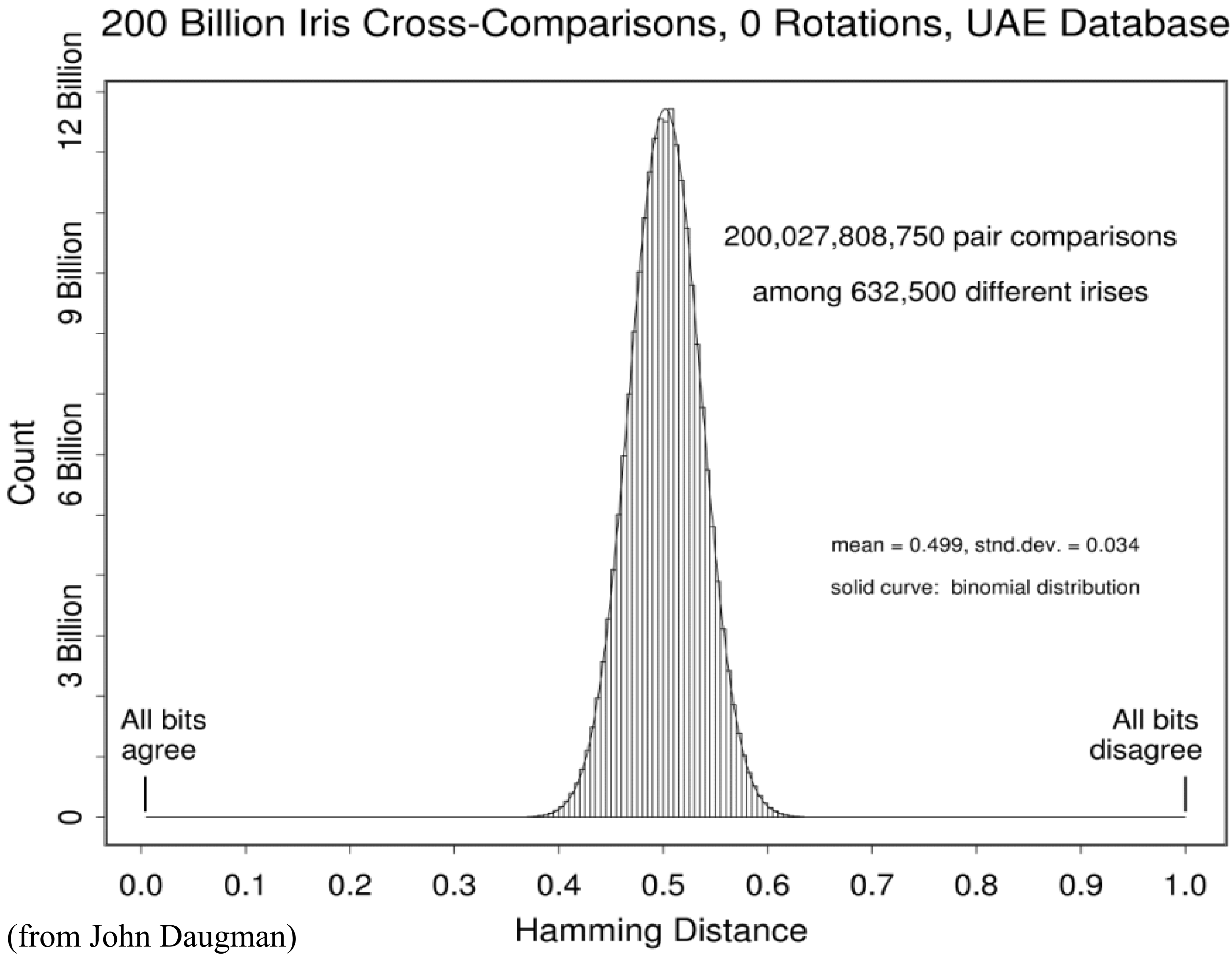


# Examples of IrisCodes






(from John Daugman)



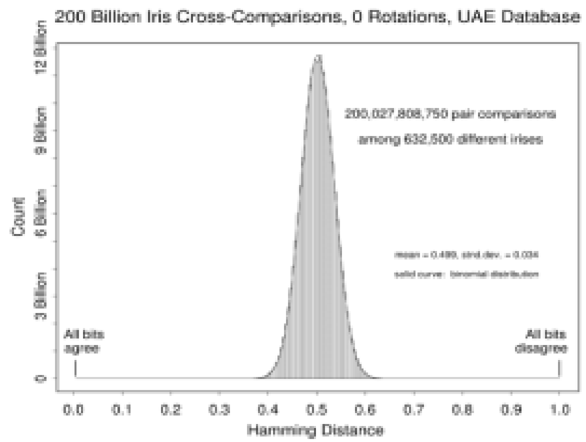

(from John Daugman)

# 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:

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

University of Groningen




(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:

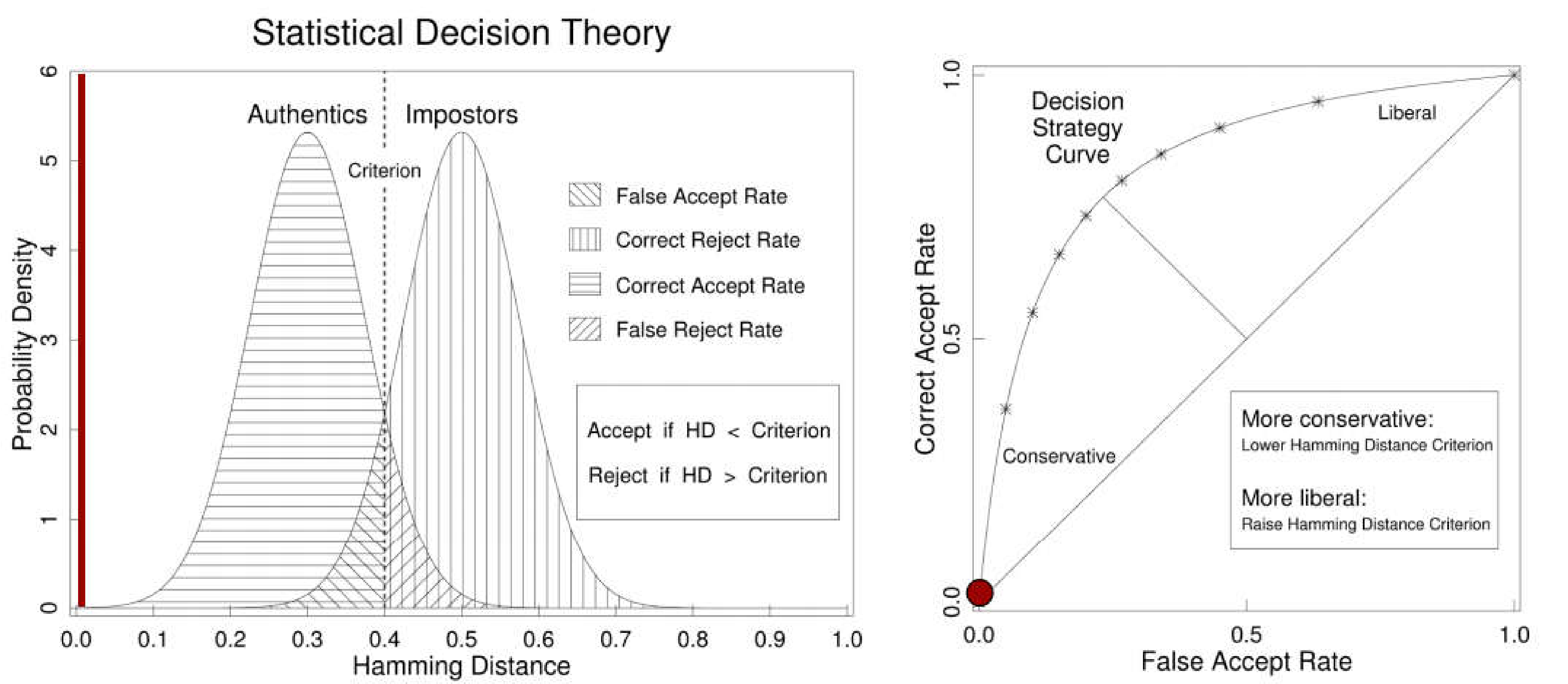
$$HD_{\text{norm}} = 0.5 - (0.5 - HD_{\text{raw}})\sqrt{\frac{n}{911}}$$

Decision Criterion normalisation by database size and query rate:

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

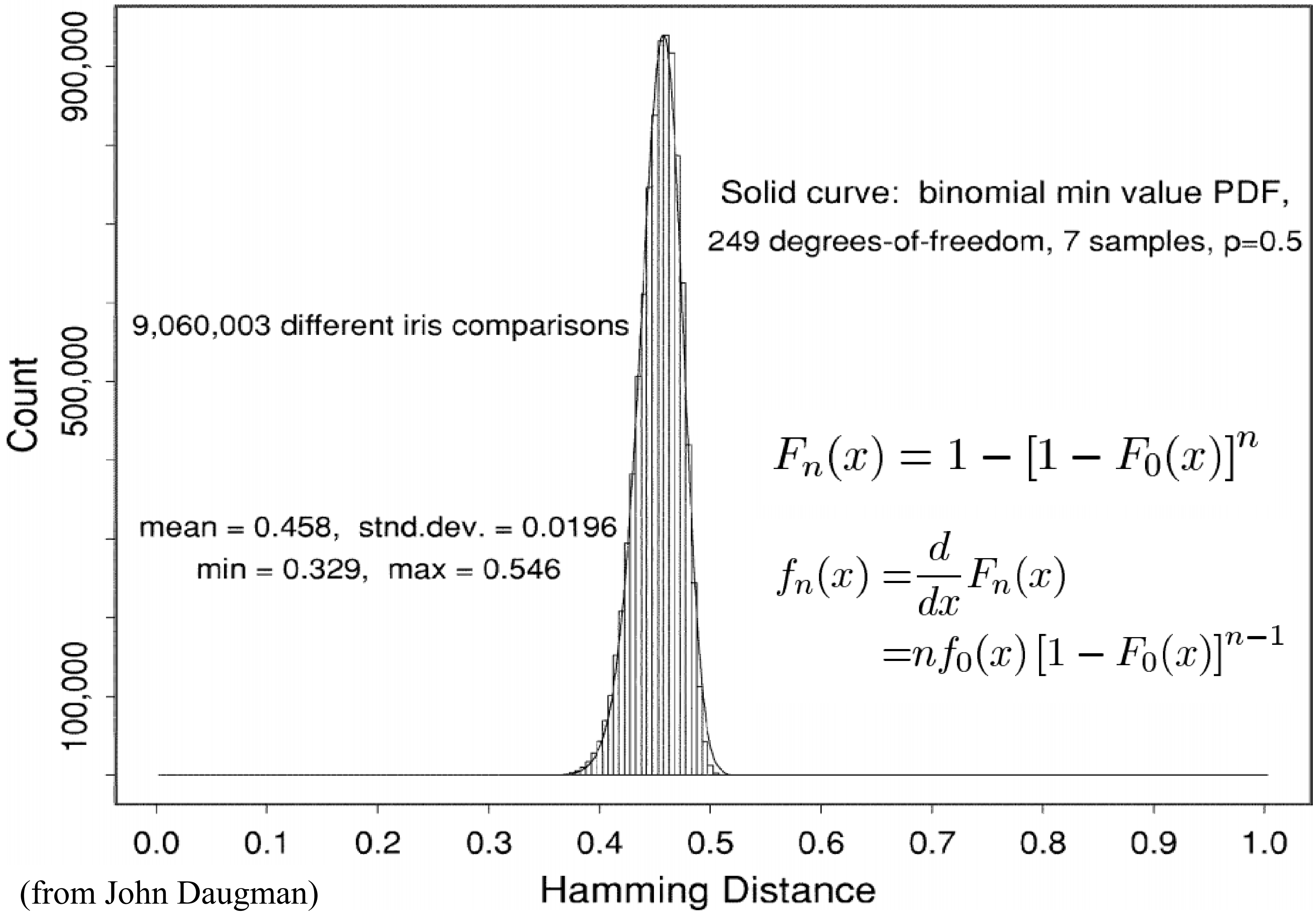
where $N$ is the search database size, $M$ is the number of queries to be compared against the full database, while requiring nil False Matches

# Distribution of HDs and Decision



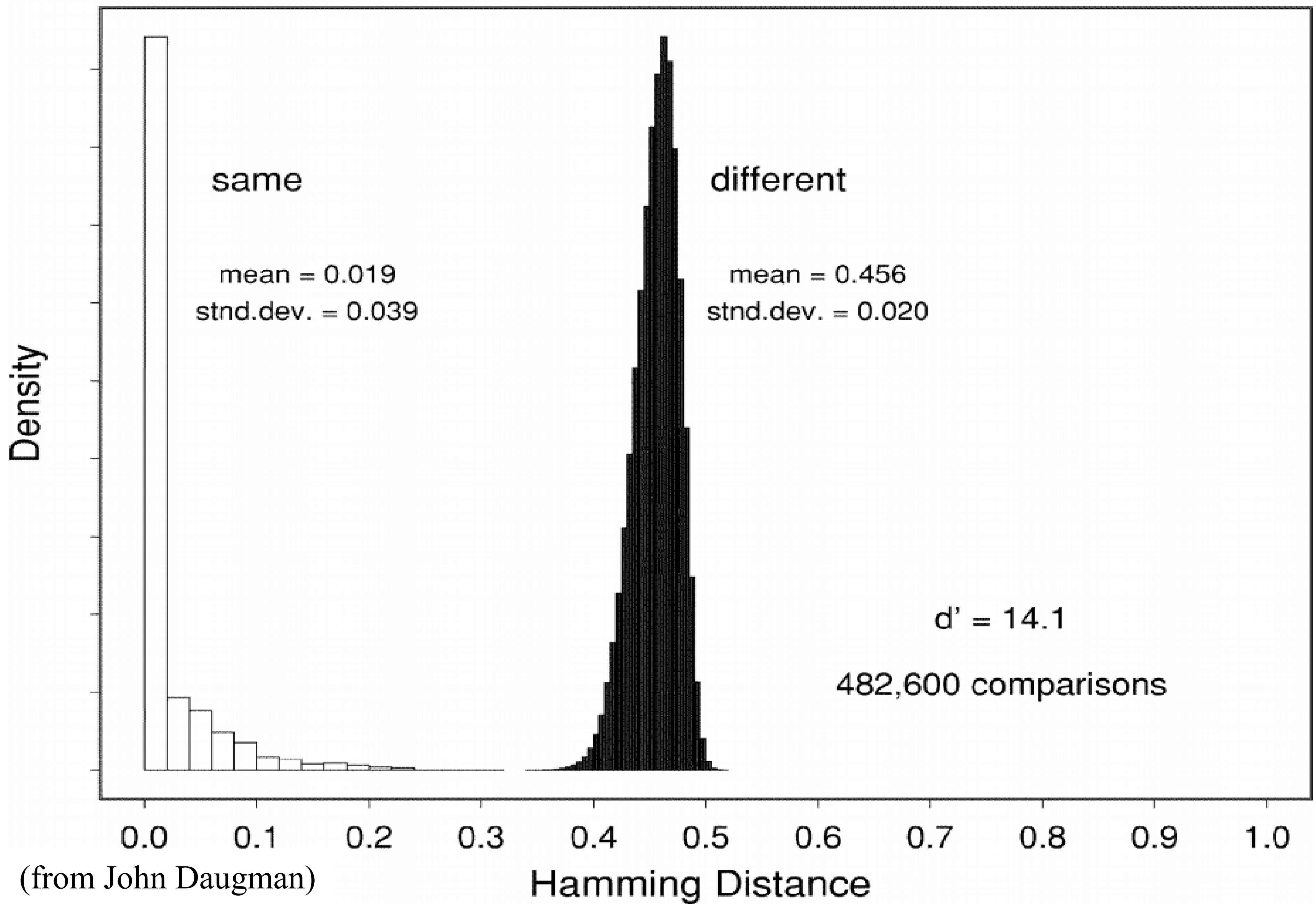

(from John Daugman)

# IrisCode Comparisons after Rotations: Best Matches



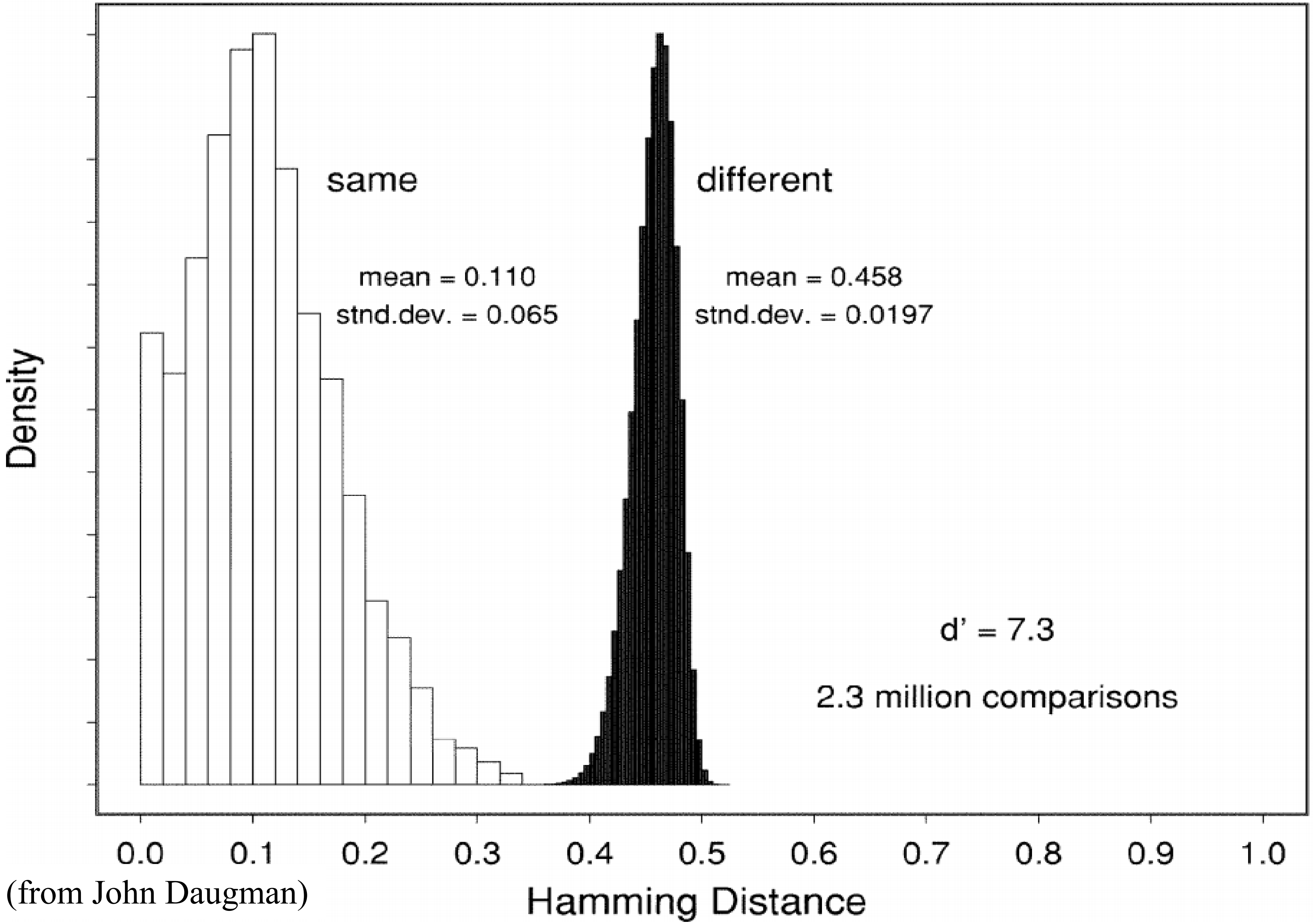

(from John Daugman)

# Decision Environment for Iris Recognition: Ideal Imaging



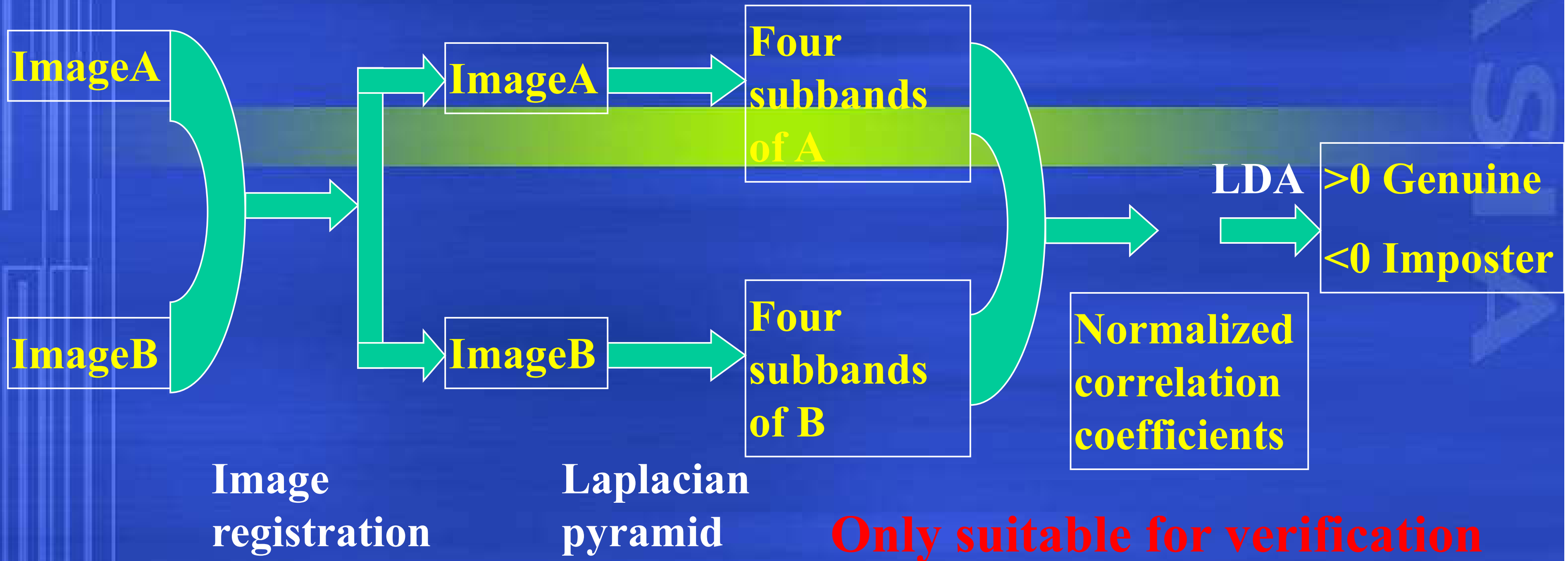

(from John Daugman)

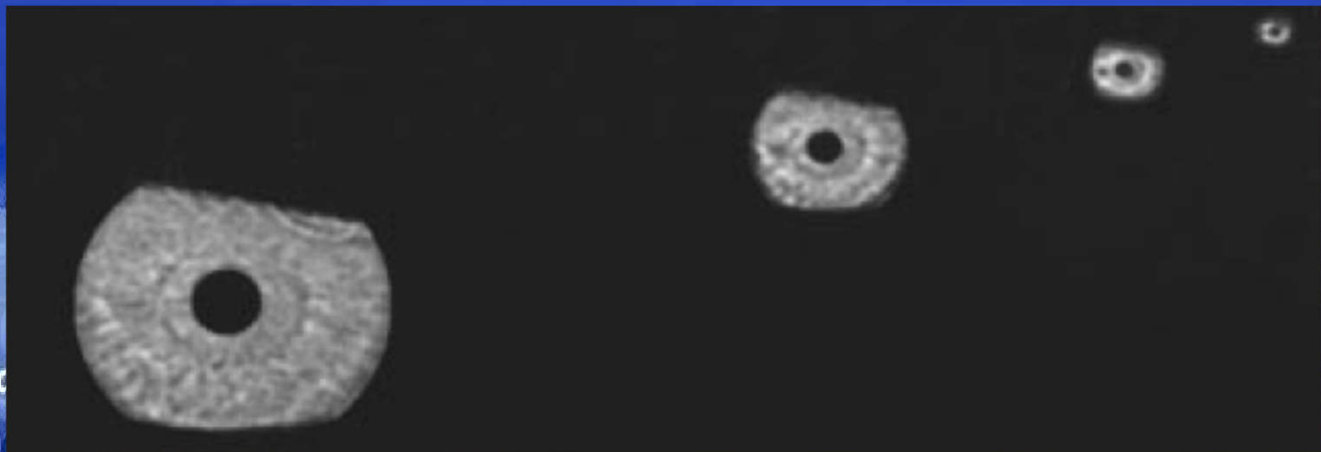
# Decision Environment for Iris Recognition: Non-Ideal Imaging




(from John Daugman)

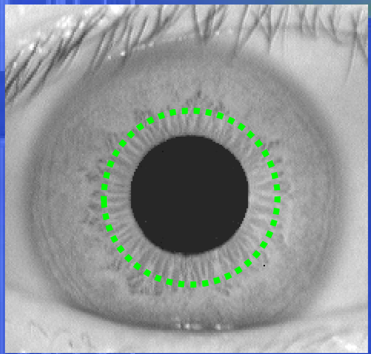
# Wildes' method

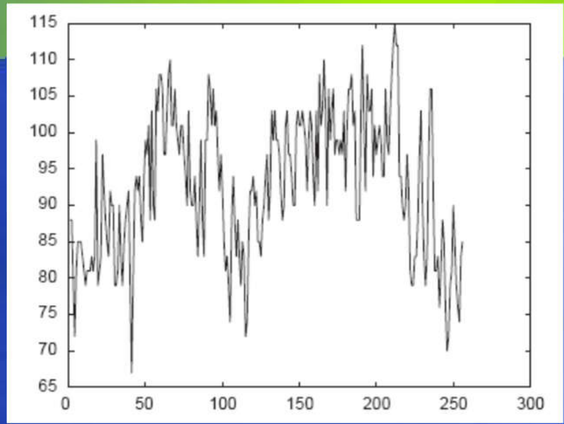


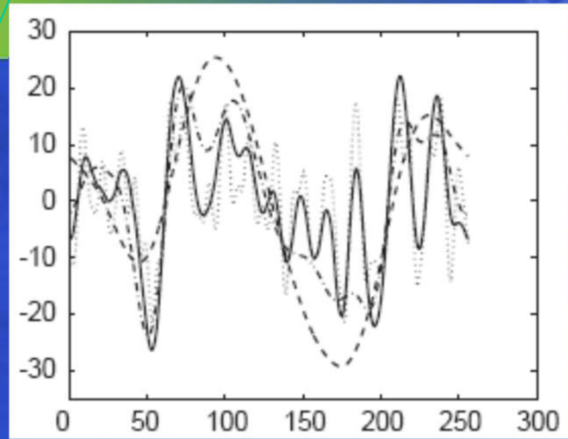
# Boles' method

1D Signal Sampling

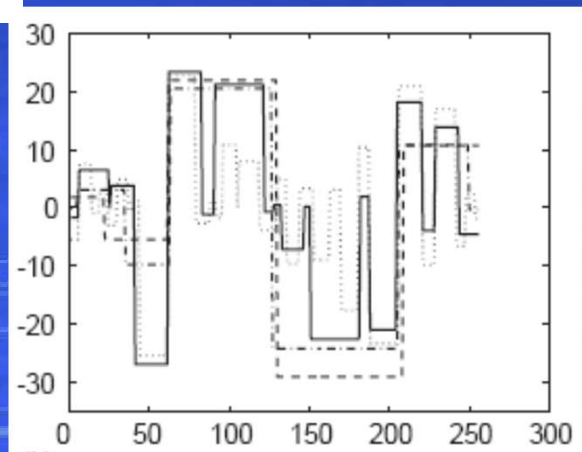





Wavelet transform




Zero-crossing representation




Feature matching

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

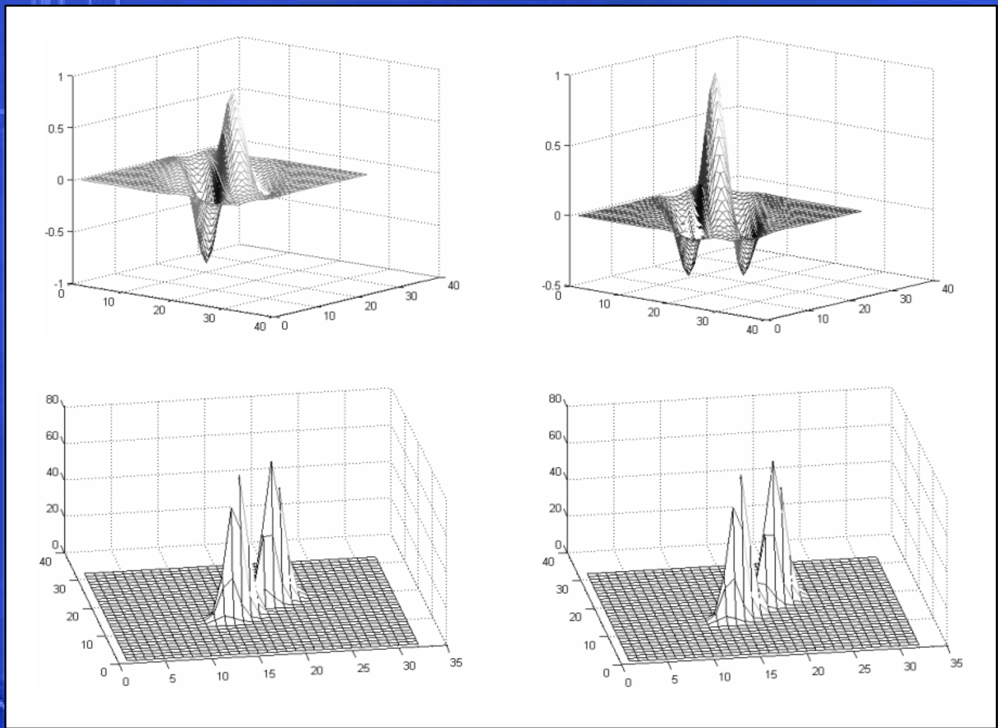
$$m \in [0, N-1]$$

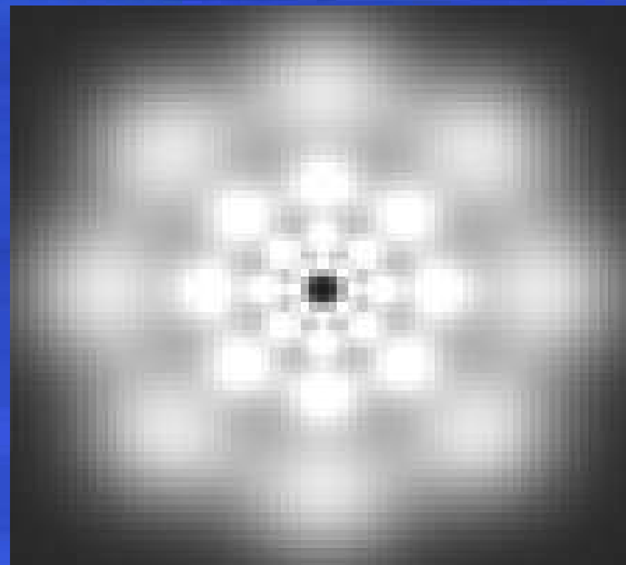
$$d_j^{(2)}(f, g) = \min_m \frac{\sum_{r=1}^{R_j} \{[\mu_j(r)]_f[\rho_j(r)]_f - \Gamma[\mu_j(r+m)]_g[\rho_j(r+m)]_g\}^2}{\Gamma \sum_{r=1}^{R_j} |[\mu_j(r)]_f[\rho_j(r)]_f| \, |[\mu_j(r)]_g[\rho_j(r)]_g|}$$

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

# 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.

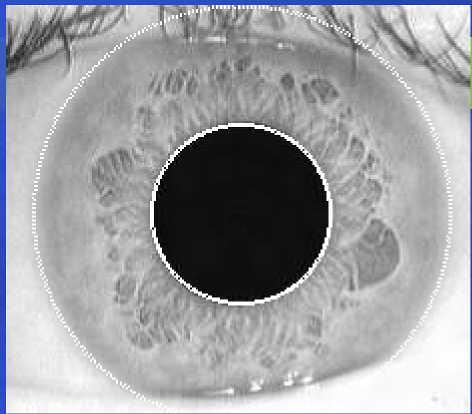
Recognition results as a function of Gabor frequency

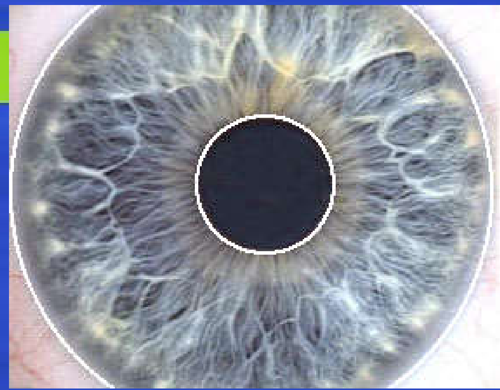
| Frequency | $2\sqrt{2}$ | $4\sqrt{2}$ | $8\sqrt{2}$ | $16\sqrt{2}$ | All frequencies |
|---|---|---|---|---|---|
| CCR | 90.14% | 91.92% | 79.71% | 53.68% | 94.91% |
| DI | 3.35 | 3.28 | 2.46 | 1.91 | 3.50 |

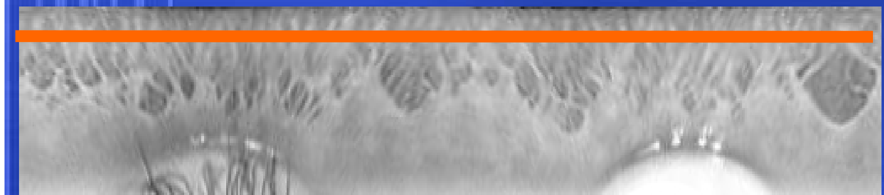
2. Most of the distinctive features of iris texture are in low- and medium- frequencies.

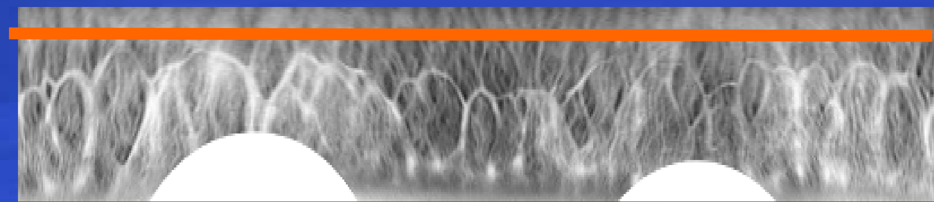
# Gaussian-Hermite moments based method

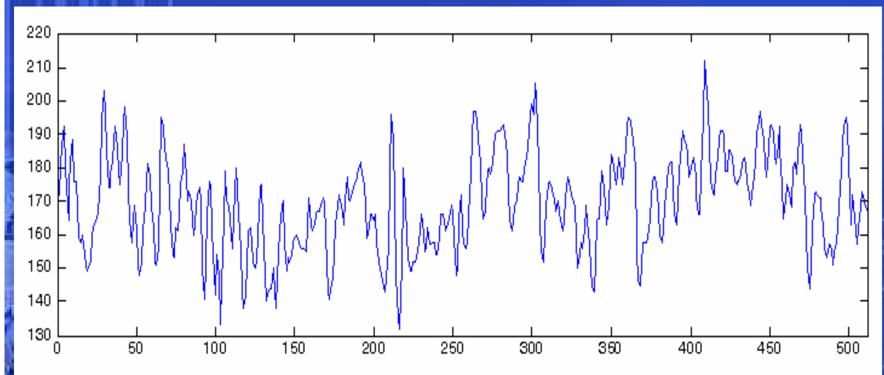
## －1D signal representation－

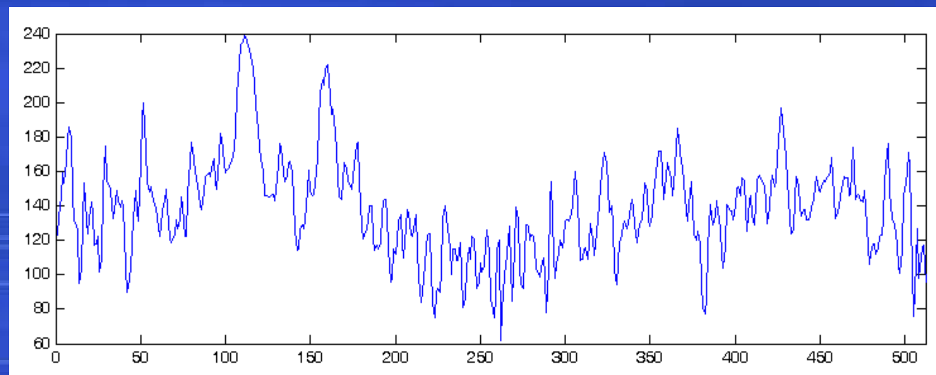






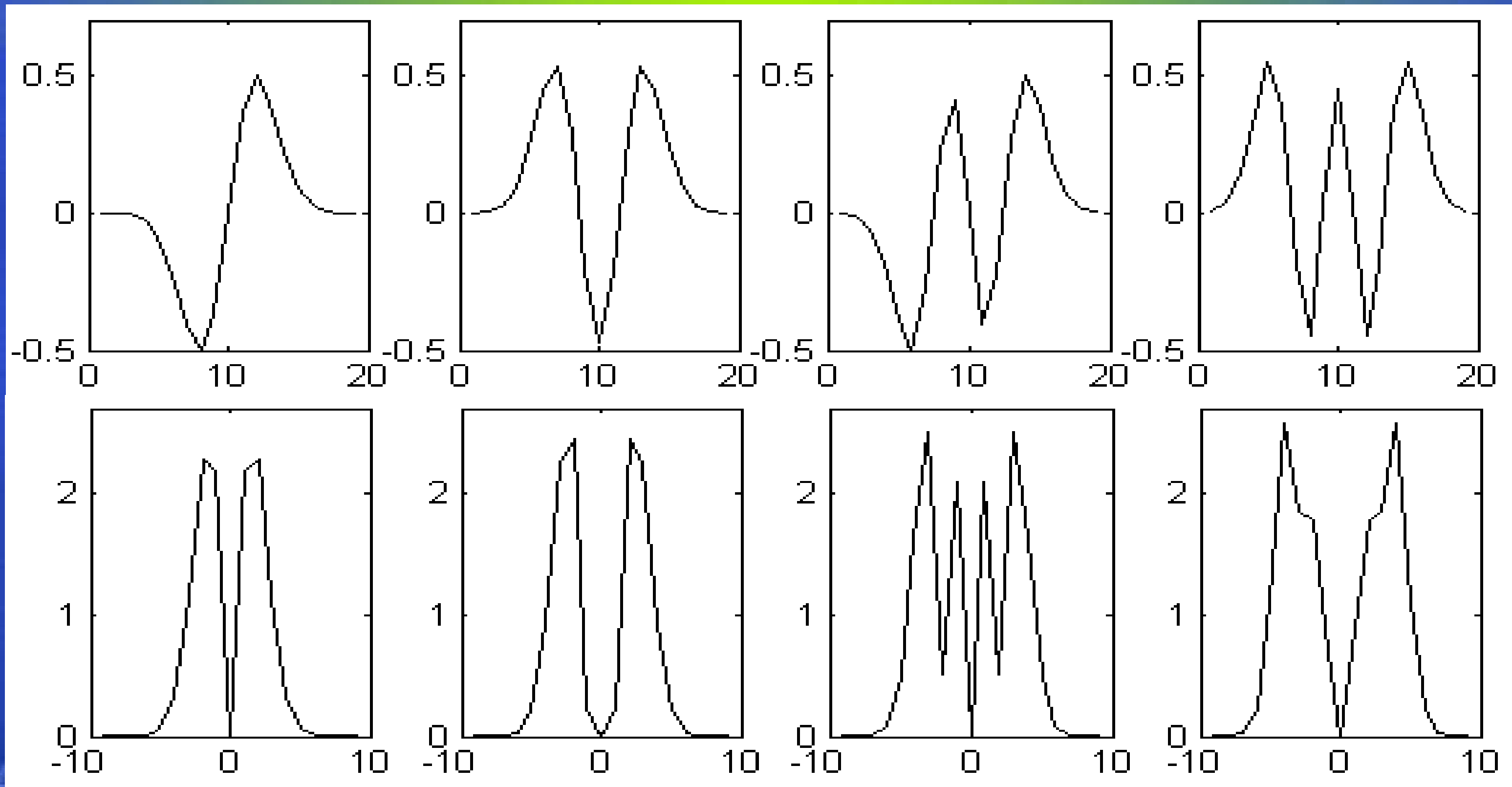




# Gaussian-Hermite moments based method

## —GH moments used for shape analysis—



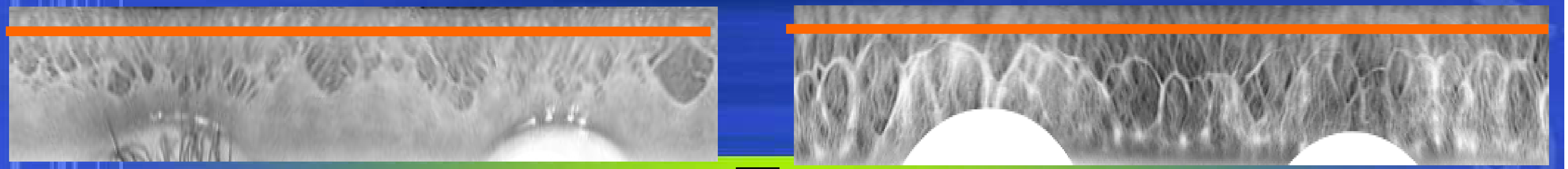

L. Ma, T. Tan, D. Zhang and Y. Wang, "Local Intensity Variation Analysis for Iris Recognition", Pattern Recognition, Vol.37, No.6, pp. 1287-1298, 2004.

# Gaussian-Hermite moments based method

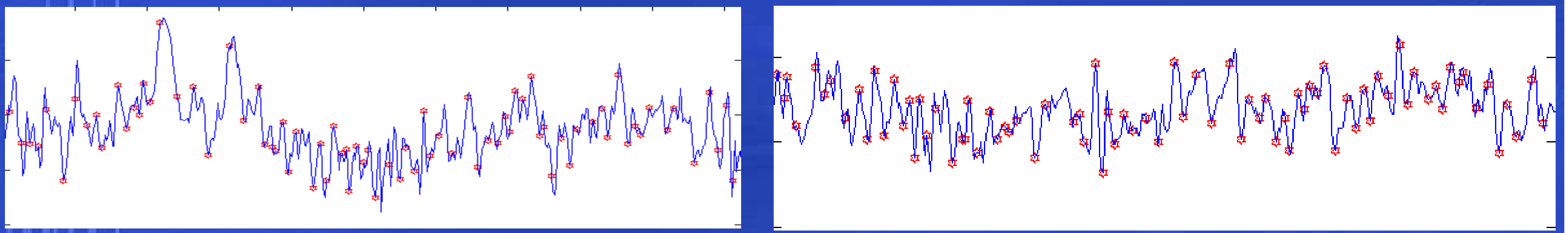
## —Conclusions—

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.

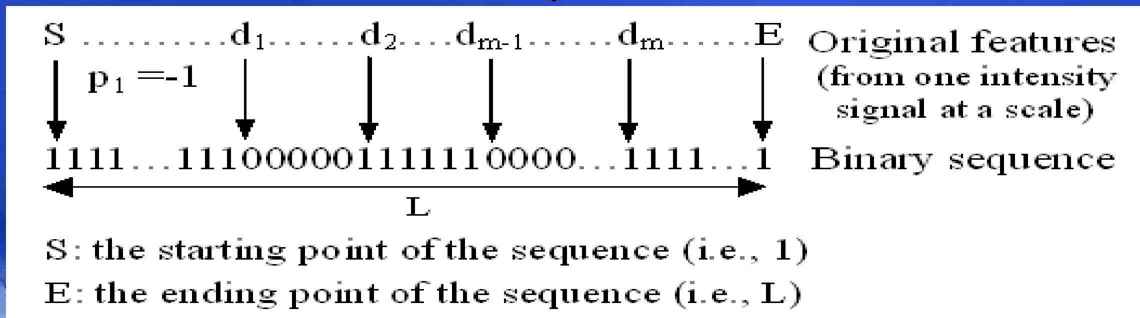
# Local sharp variation based method



Sharp variation point detection



Feature transform



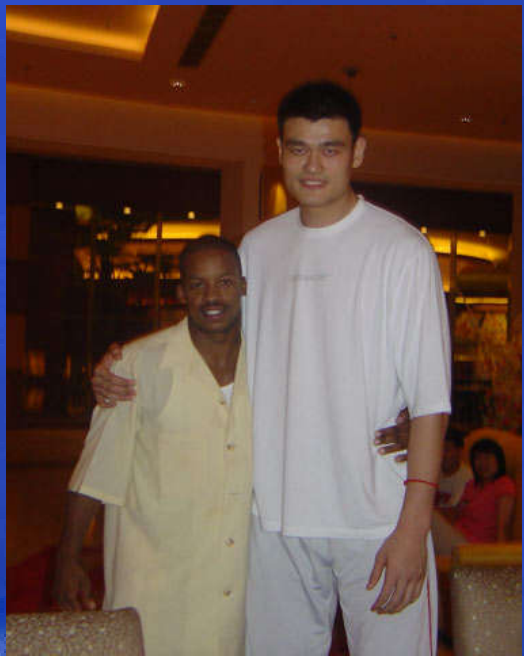

Li Ma, Tieniu Tan, Yunhong Wang and Dexin Zhang, "Efficient Iris Recognition by Characterizing Key Local Variations", IEEE Trans. on Image Processing, Vol. 13, No.6, pp. 739- 750, 2004.

# 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

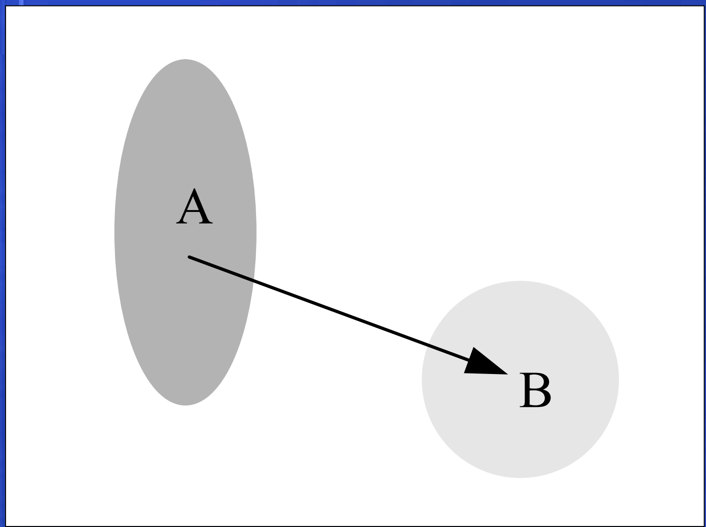
2C>B+D

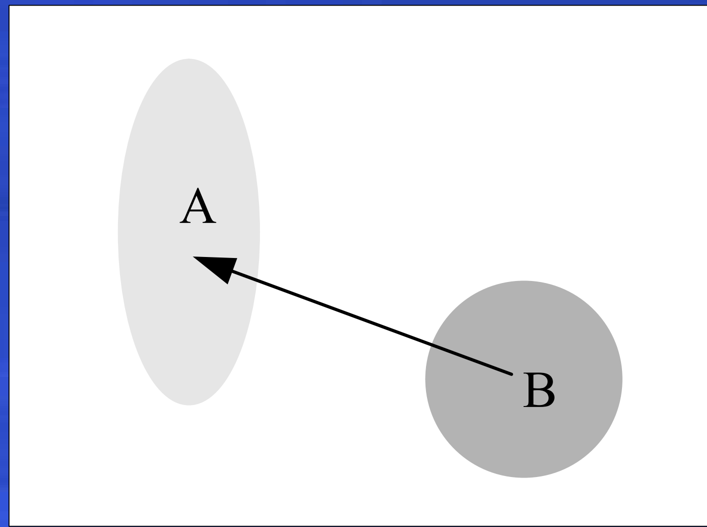
C+D+F>

A+B+E

……

# Ordinal measures in visual images

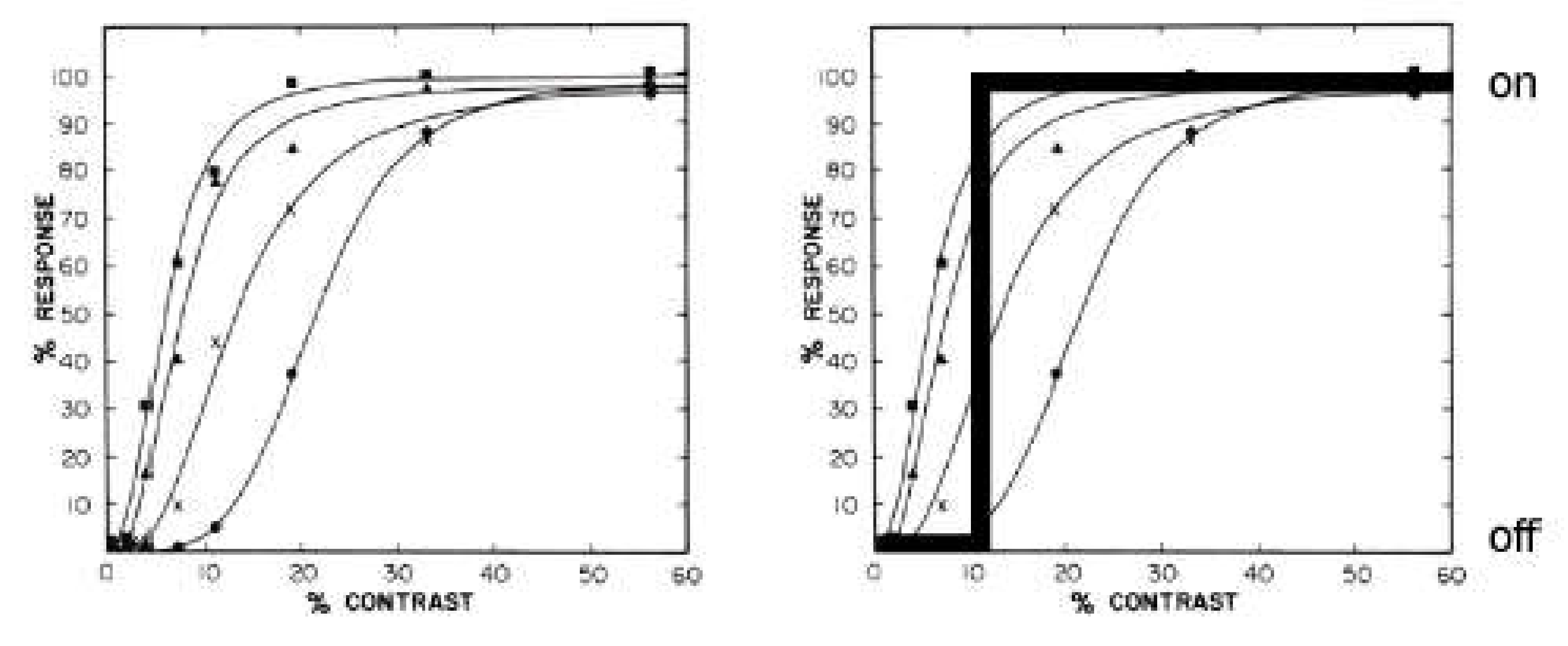



$A \prec B$ $A \succ B$

**1 one bit code 0**

# OM in the biological vision system

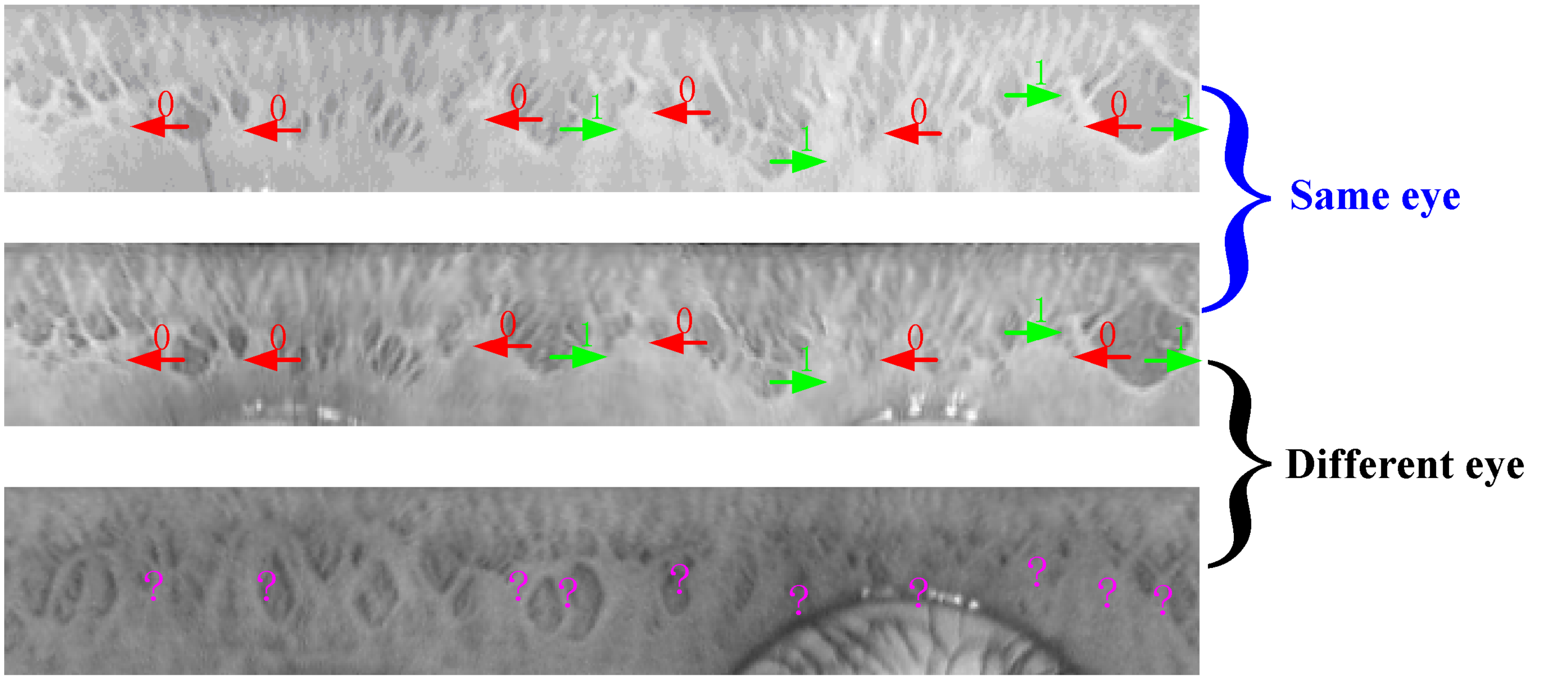



Duane G. Albrecht and David B. Hamilton. Striate cortex of the monkey and cat: Contrast response function. *Journal of Neuroscience*, 48(1):217–237, July 1982.

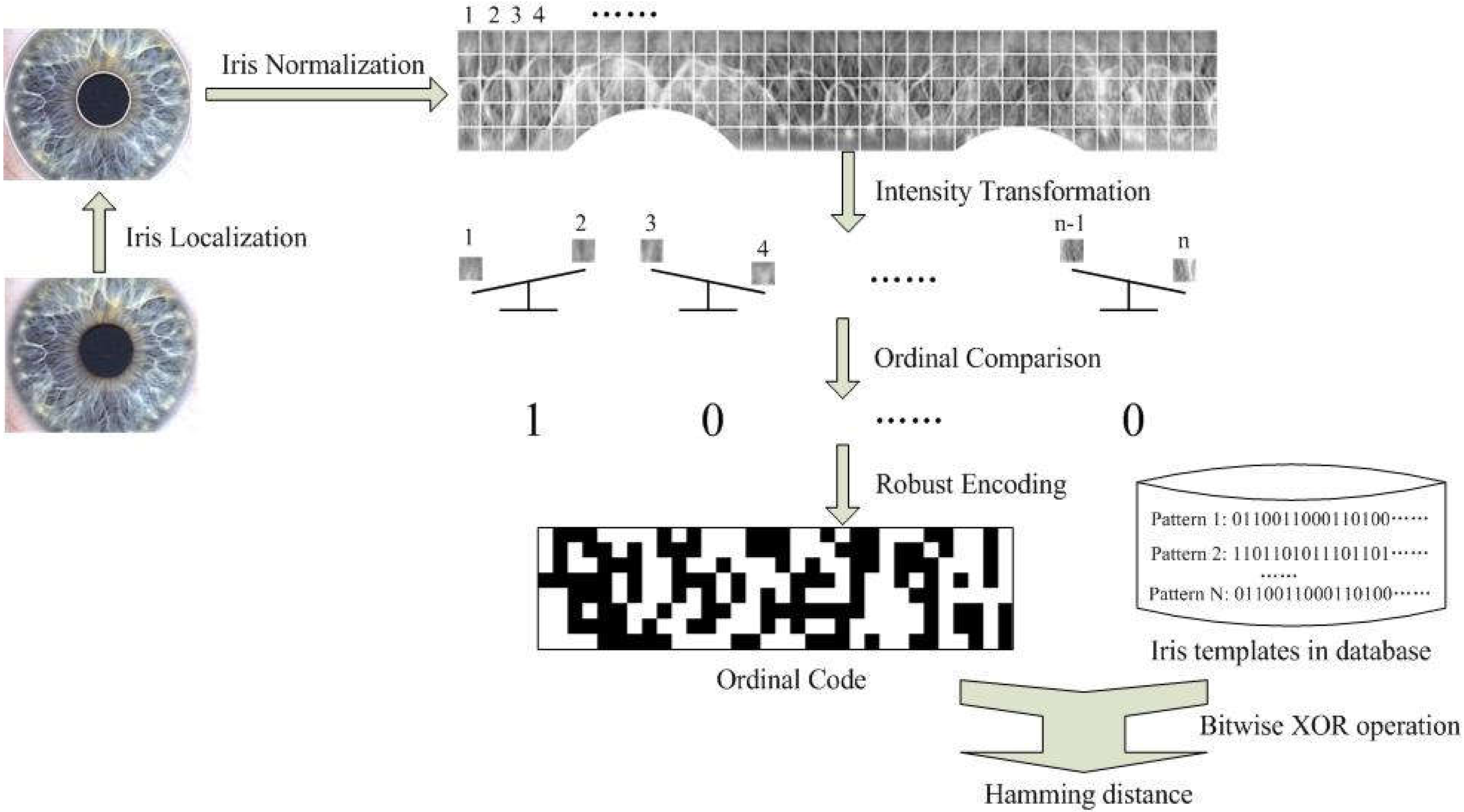
# Desirable properties of ordinal representation

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

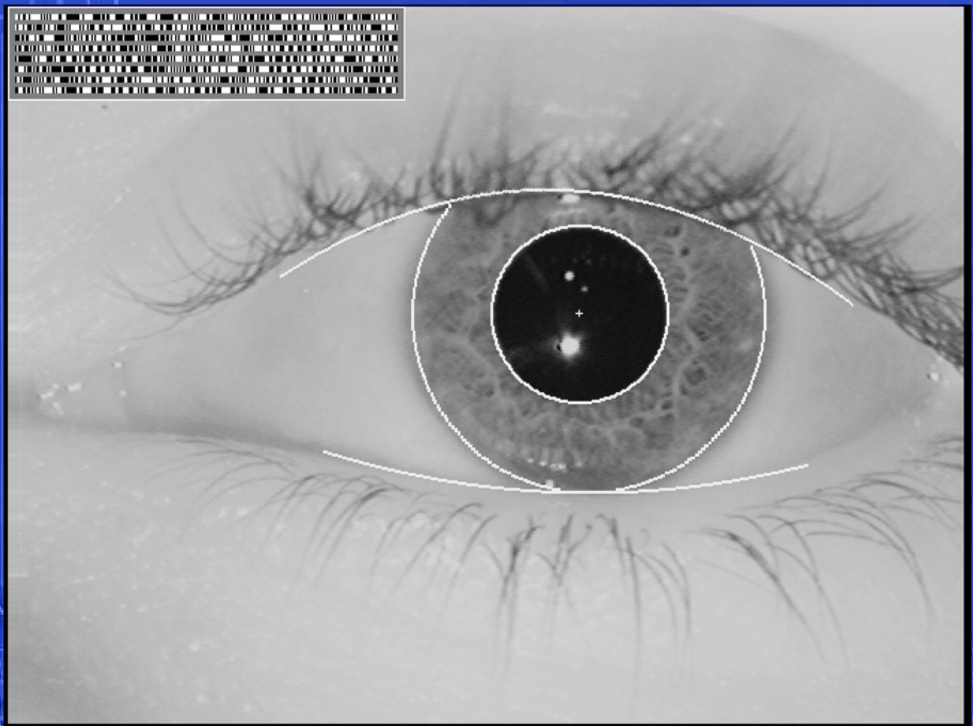
# Ordinal measures in iris images

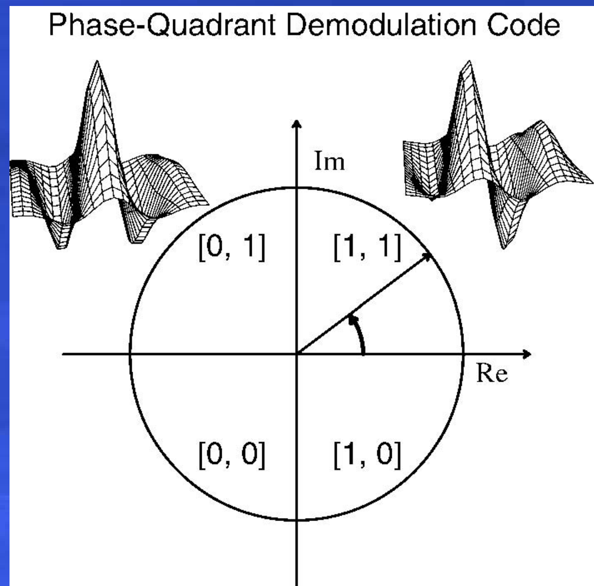


# A General Framework for Iris Recognition Based on OM



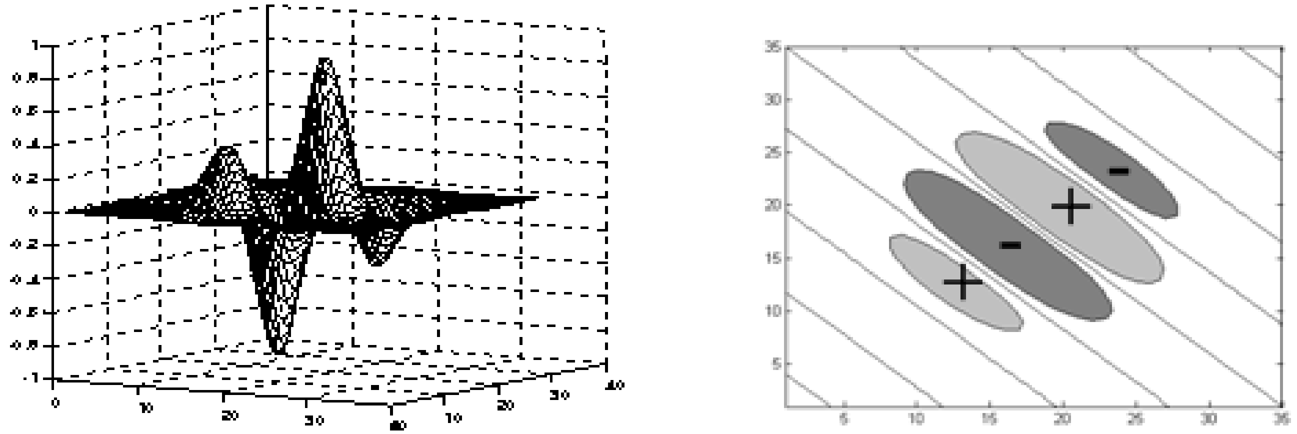
# Phase demodulation based on Gabor filters ( Daugman )

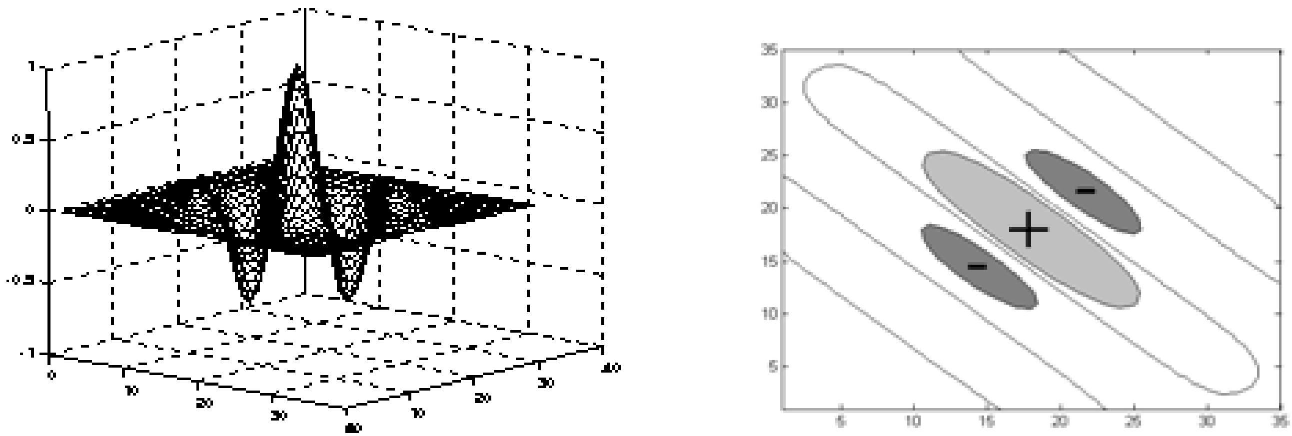



$$\mathrm{HD} = \frac{\|(codeA \otimes codeB) \bigcap maskA \bigcap maskB\|}{\|maskA \bigcap maskB\|}$$

# Gabor filter + phase demodulation is an ordinal operator



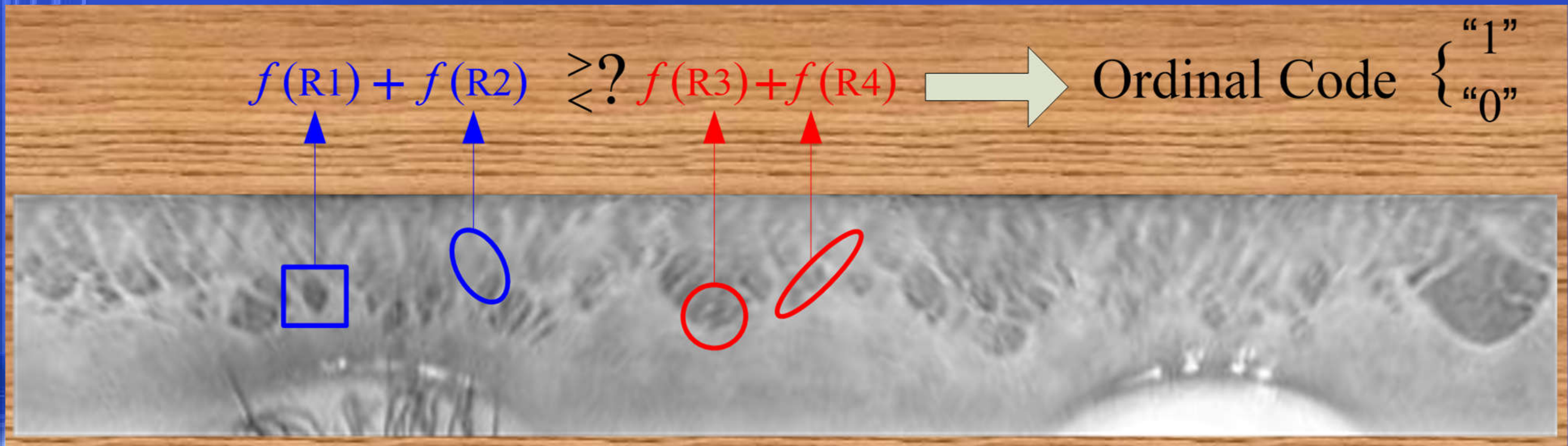
Odd Gabor filter



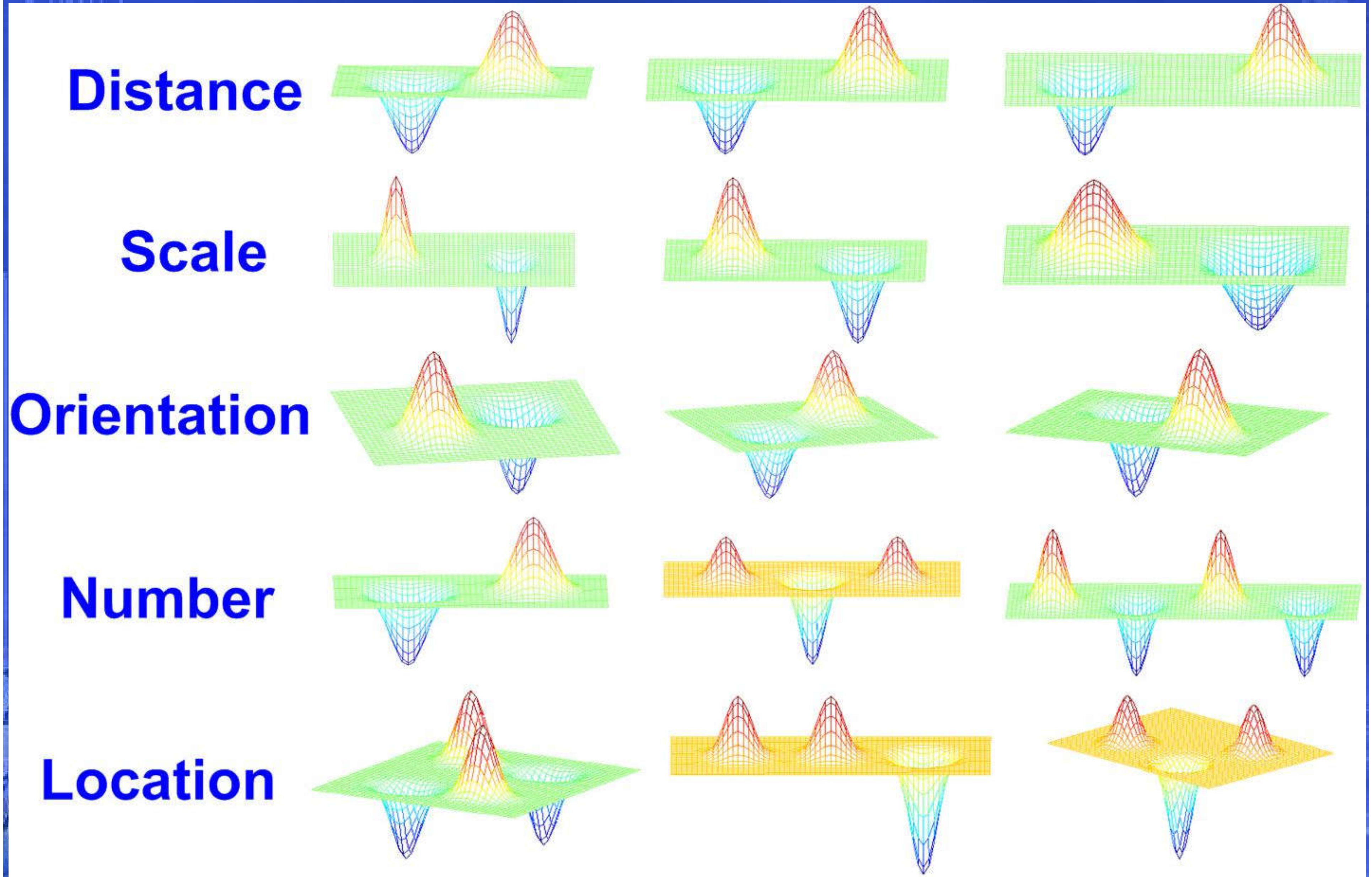
Even Gabor filter

# Variables in ordinal feature extraction

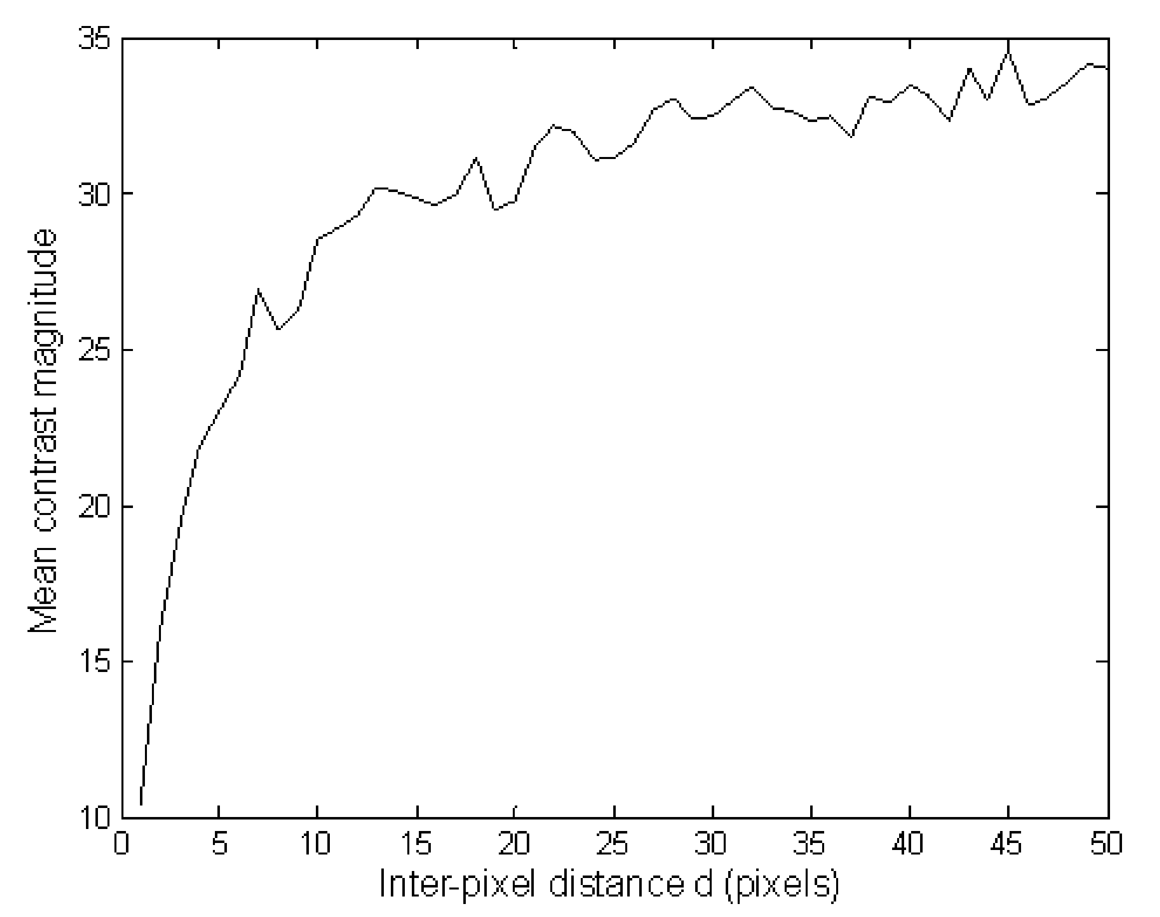
- Location of image regions
- Shape of image regions
- Features of image regions



# Dissociated Multi-Poles



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




Larger distance

↓

Less correlation

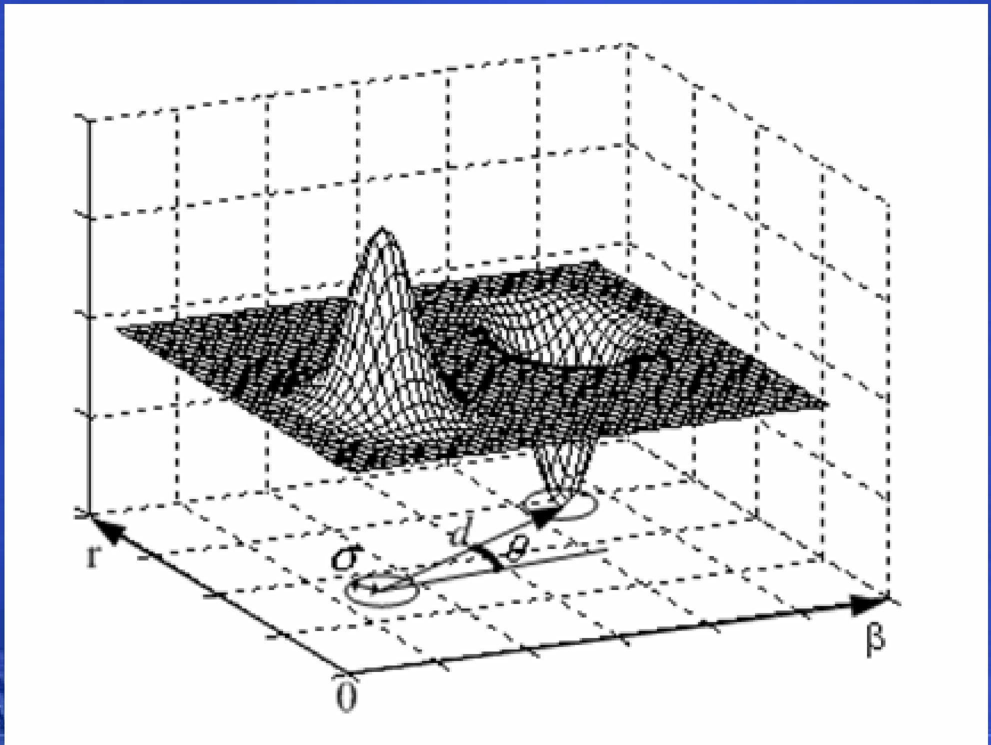
↓

Higher contrast

↓

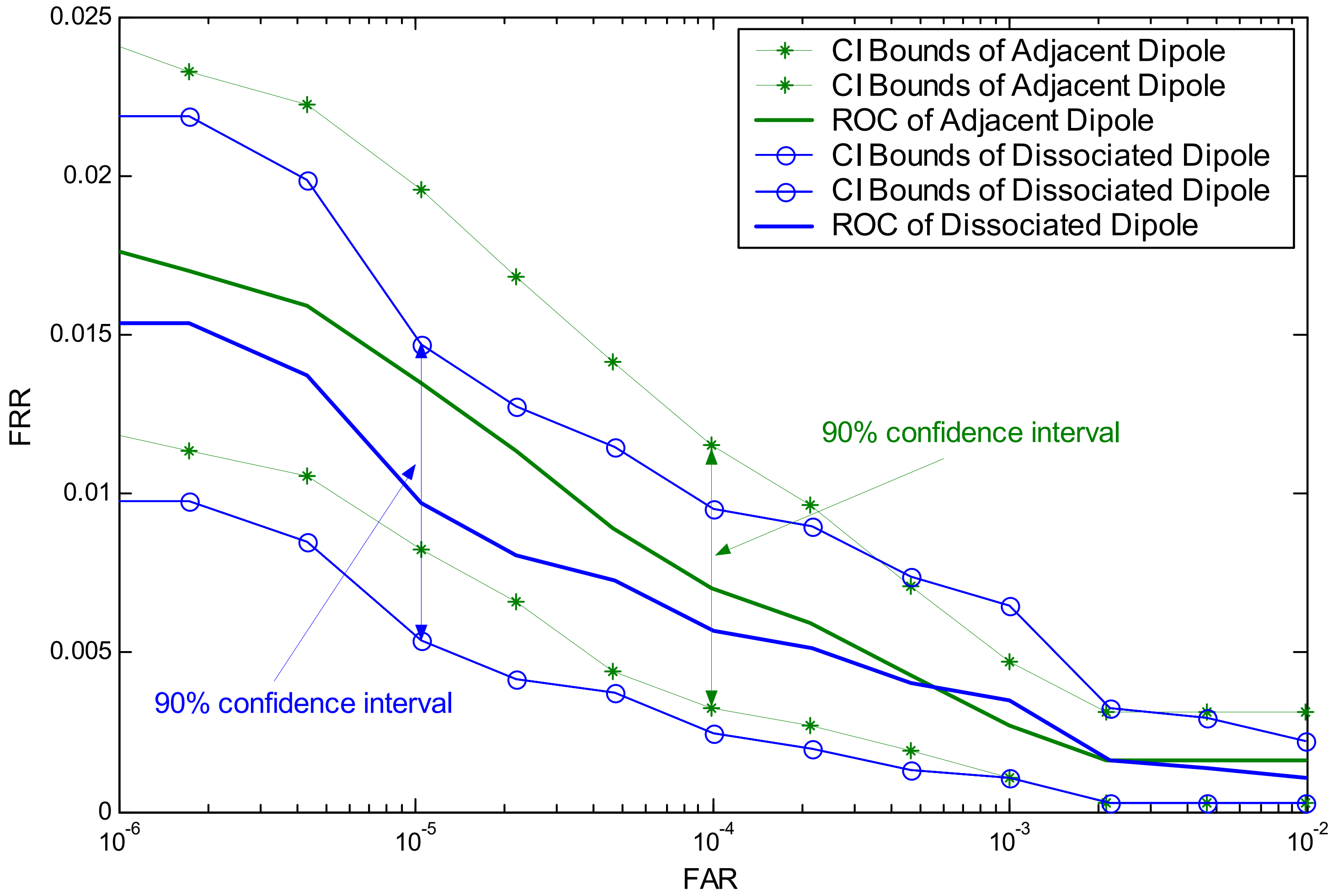
More robust OM

# Local ordinal measures vs. Non-local ordinal measures

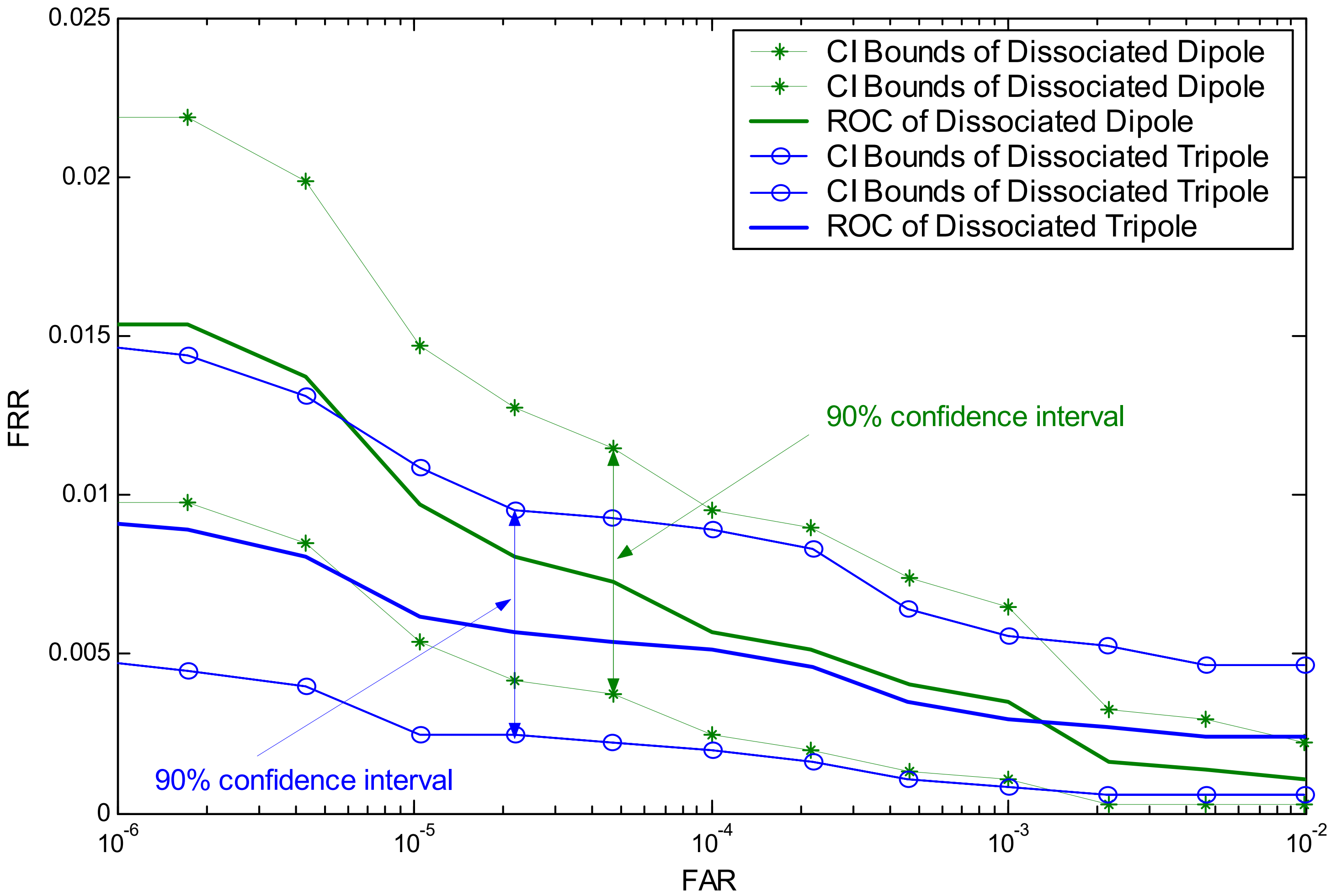



Dissociated Dipoles (from P. Sinha)

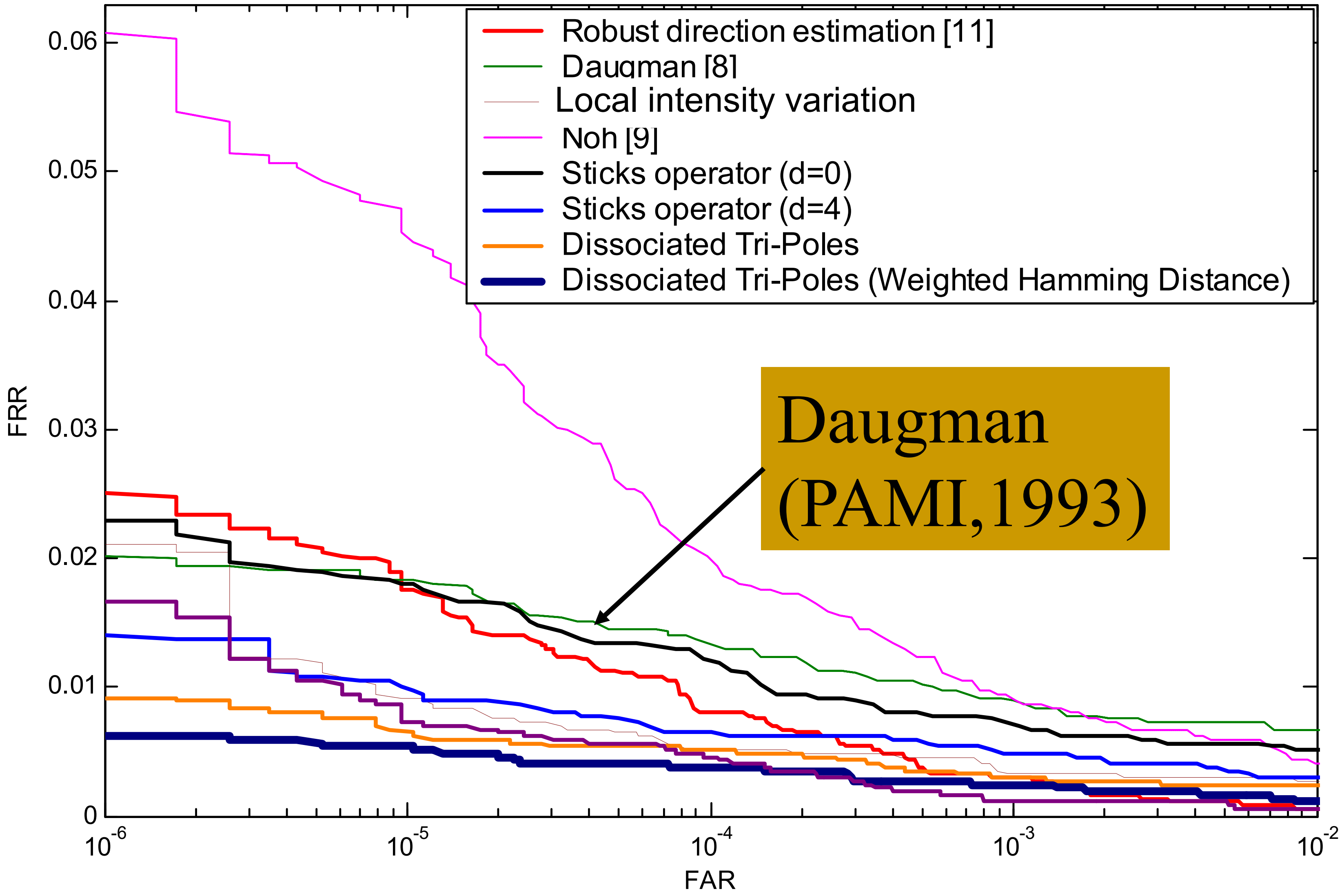
# Local ordinal measures vs. Non-local ordinal measures

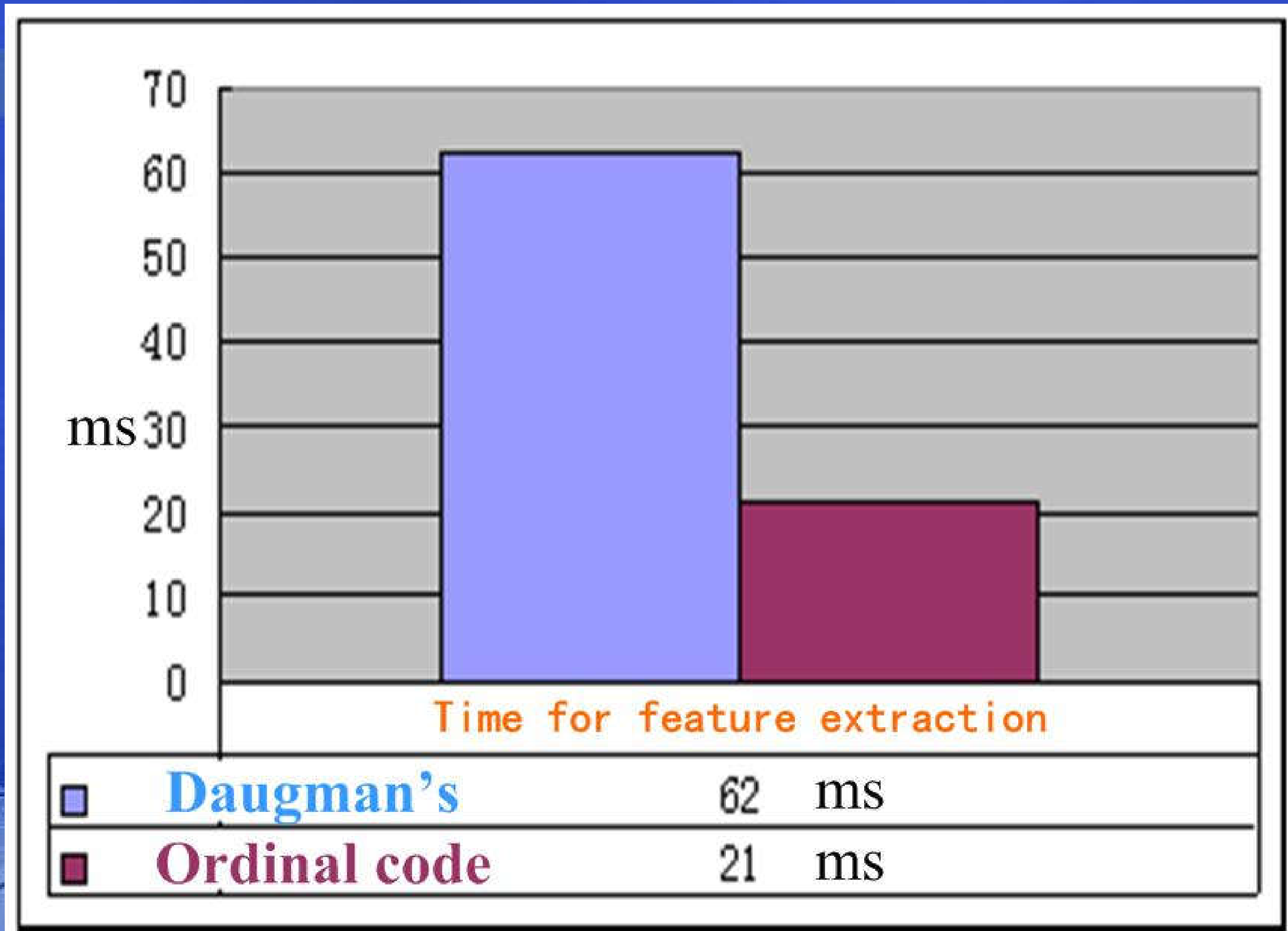


# Dissociated Dipoles vs. Dissociated Tri-poles



# State-of-the-art iris recognition performance



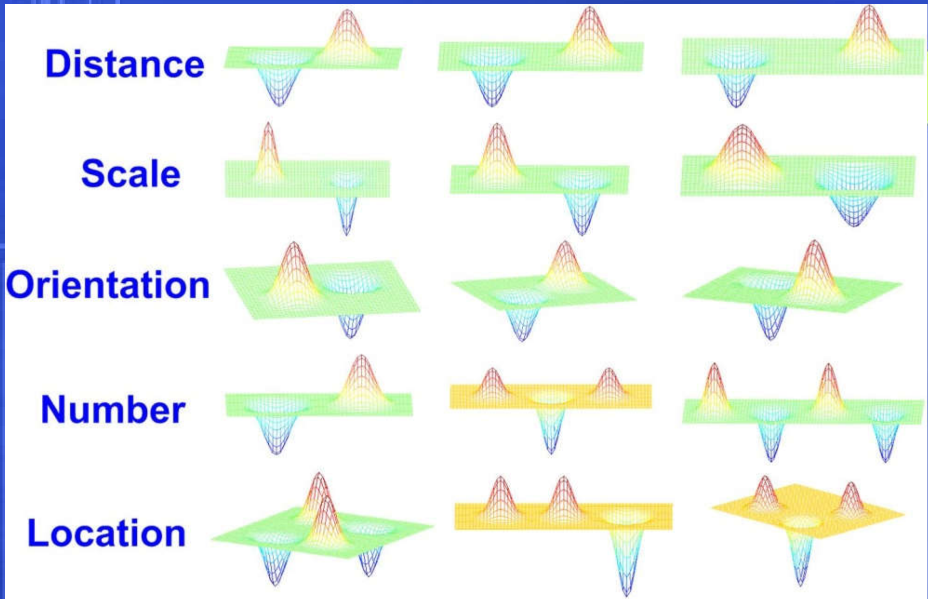

70
60
50
40
ms 30
20
10
0
Time for feature extraction
Daugman's 62 ms
Ordinal code 21 ms

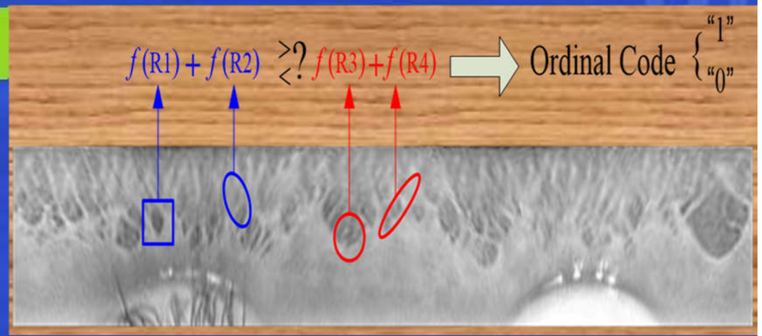
//www.ia.ac.cn

# 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

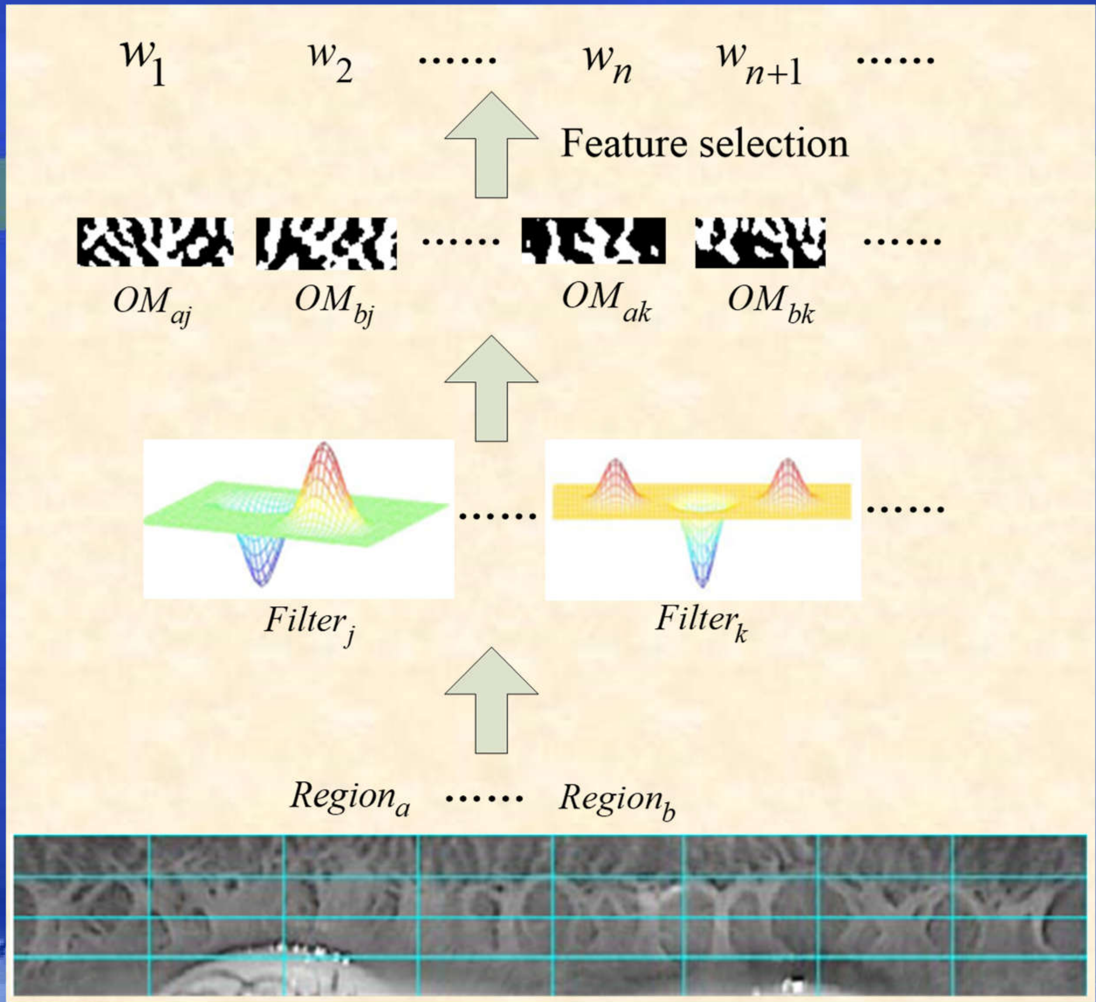



A huge feature set

- 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:

$$\sum_{i=1}^{D} w_i x_{ij}^+ \le \alpha + \xi_j^+, \quad j = 1,2,\cdots,N^+$$

$$\sum_{i=1}^{D} w_i x_{ik}^- \ge \beta - \xi_k^-, \quad k = 1,2,\cdots,N^-$$

$$\xi_j^+ \ge 0, \quad j = 1,2,\cdots,N^+$$

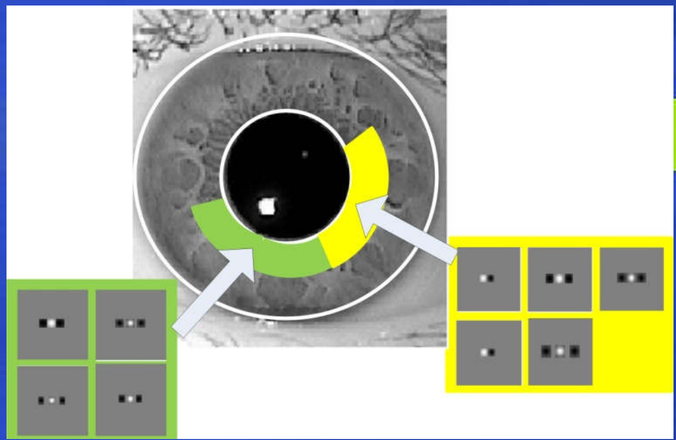
$$\xi_k^- \ge 0, \quad k = 1,2,\cdots,N^-$$

$$w_i \ge 0, \quad i = 1,2,\cdots,D$$

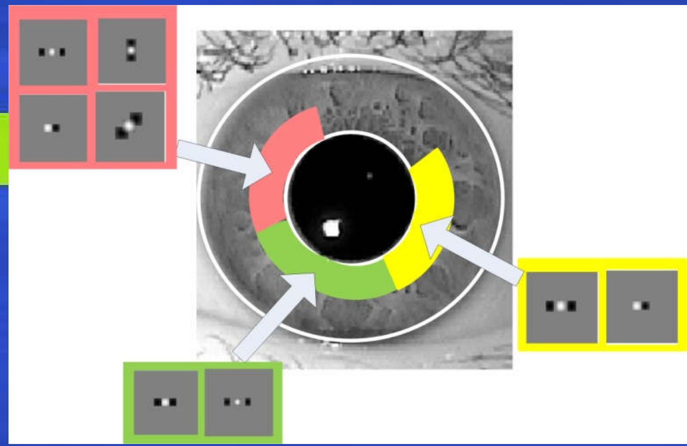
All intra- and inter-class matching samples should be well separated based on a large margin principle

Slack variables

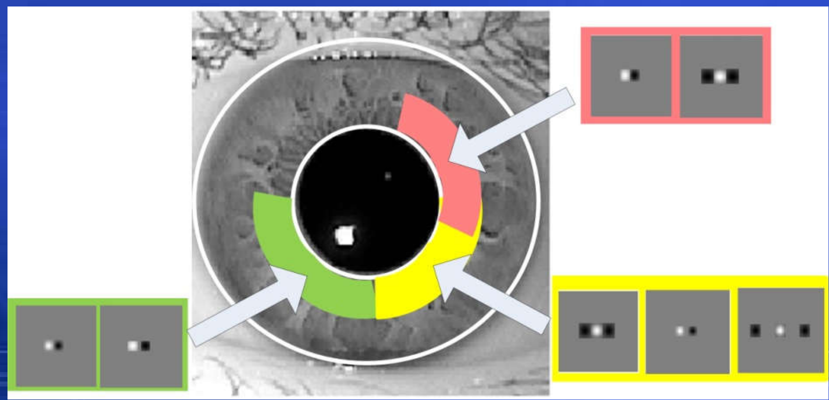
# Feature selection results for iris biometrics



LP-OM

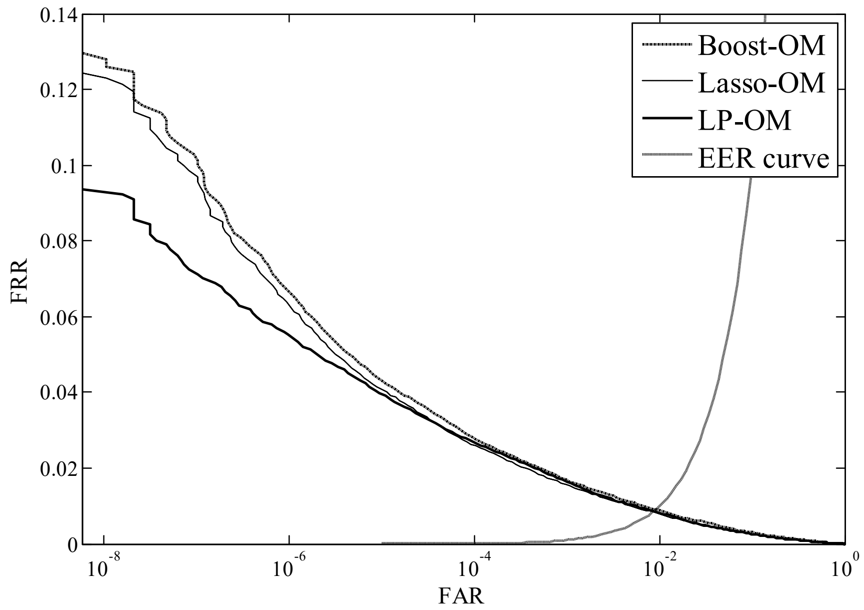


Lasso-OM

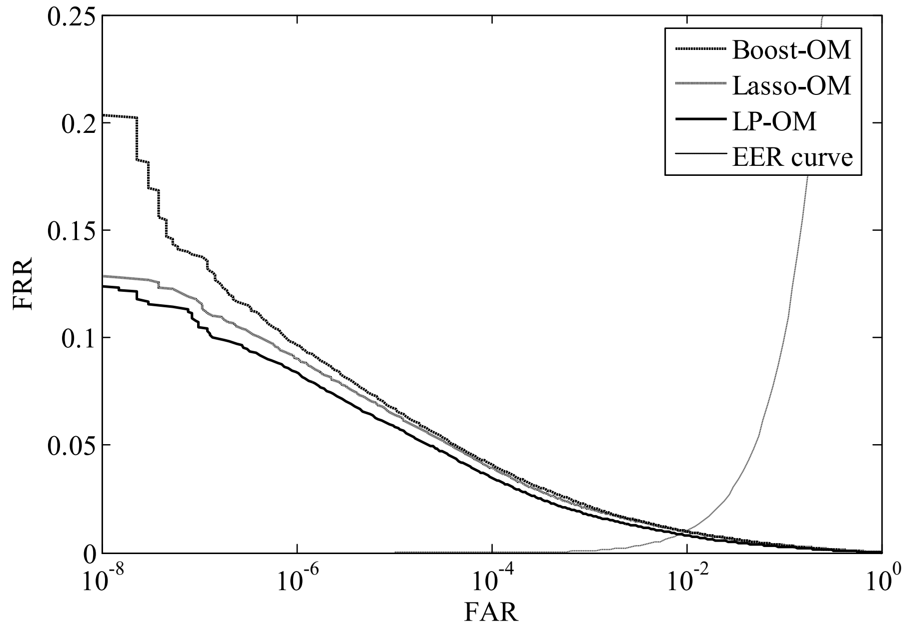


Boost-OM

# Performance comparison for iris recognition

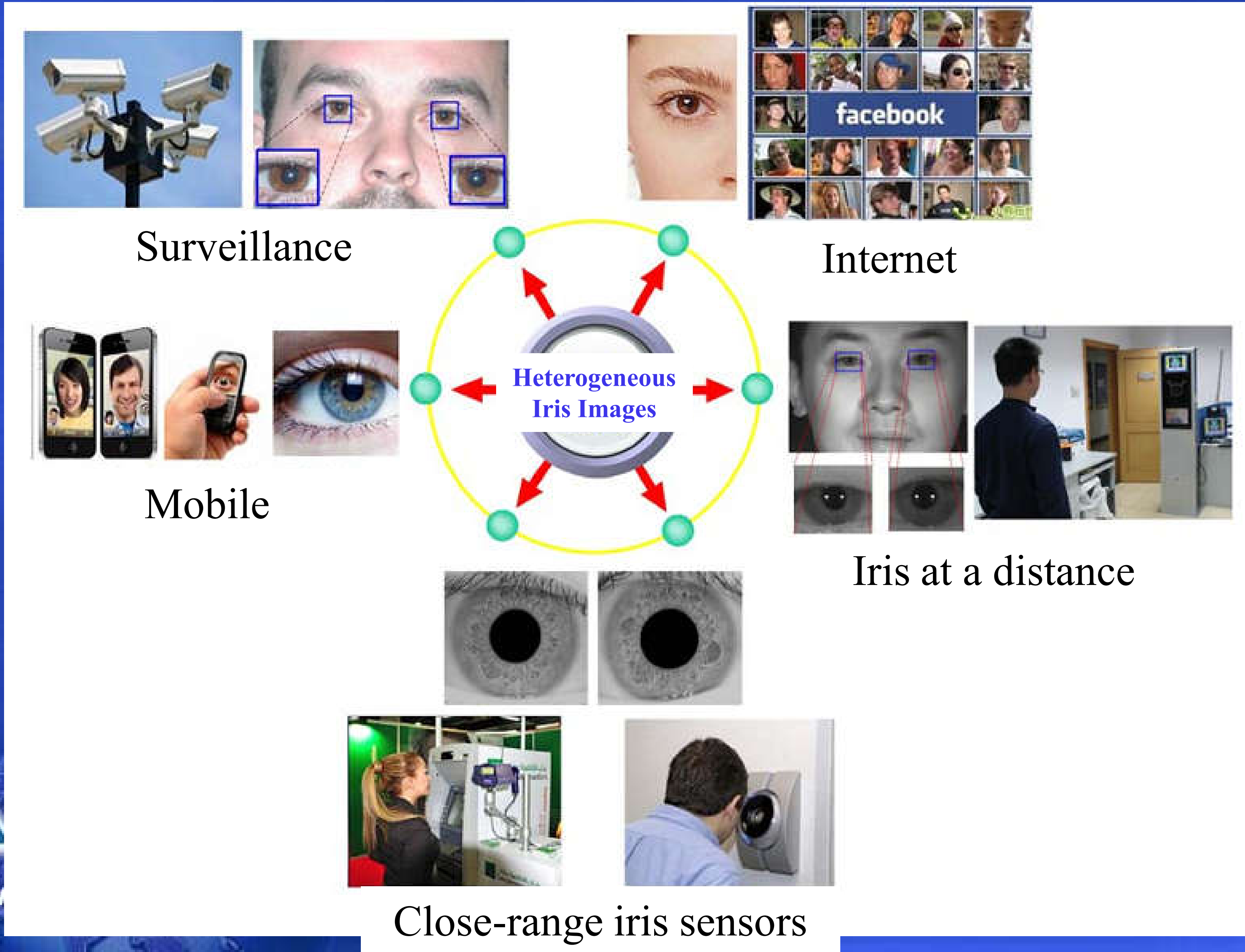



CASIA-Iris-Thousand

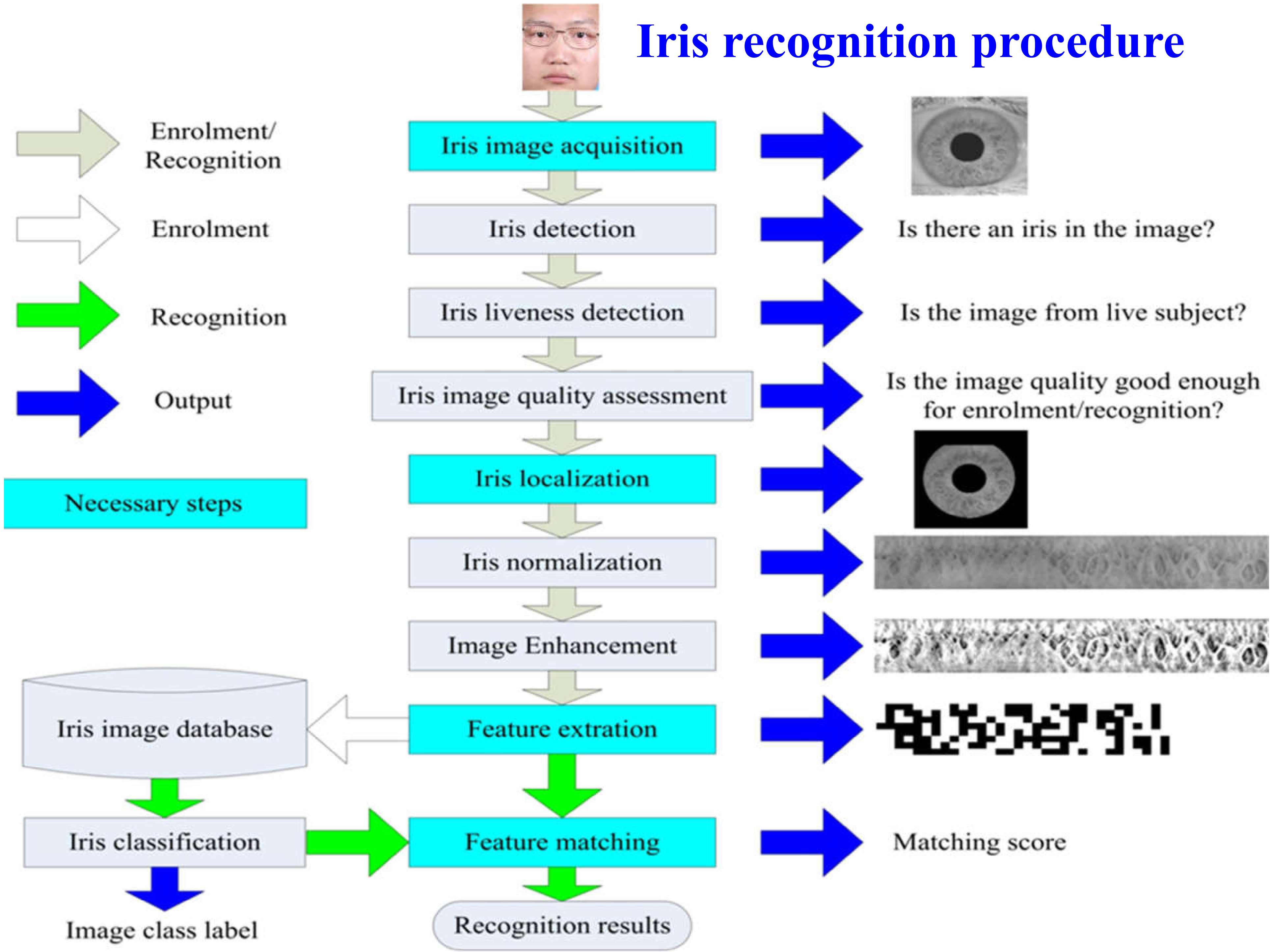



CASIA-Iris-Lamp

# Heterogeneous Iris Images



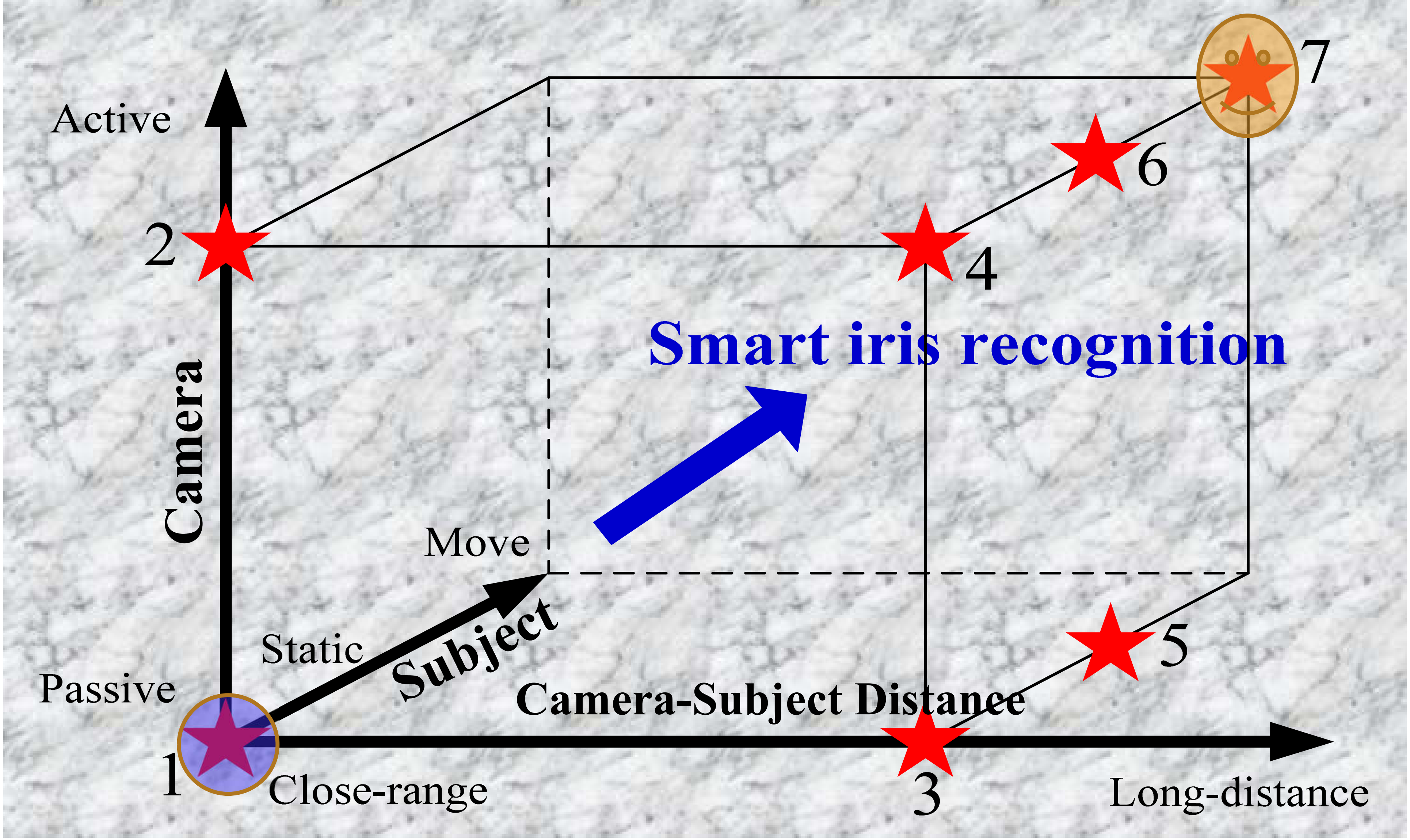
# Iris recognition procedure

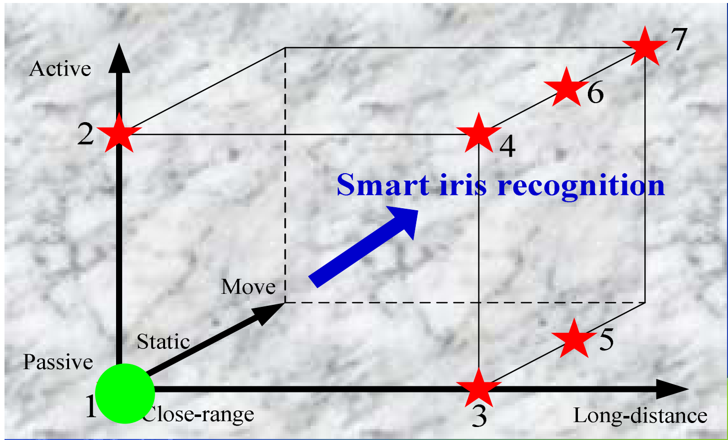


# Outline of Talk

- 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

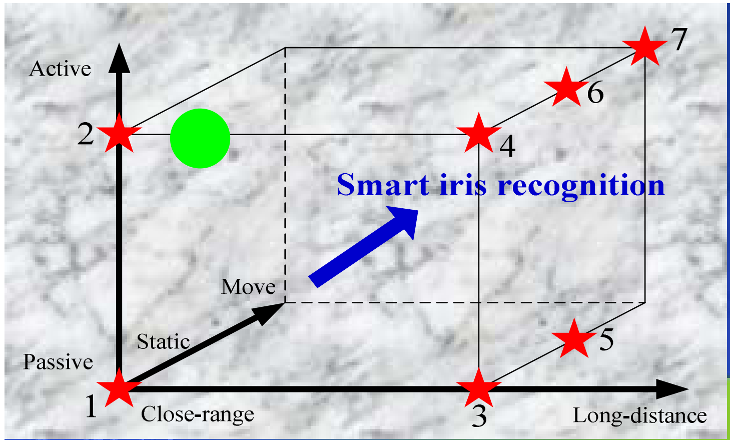
Camera: Passive (Fixed lens/No PTZ)

Distance: Close-range

Depth of field: Small

Motion: Static

Subject: Single




# Stage 2: Active iris recognition

## Main features

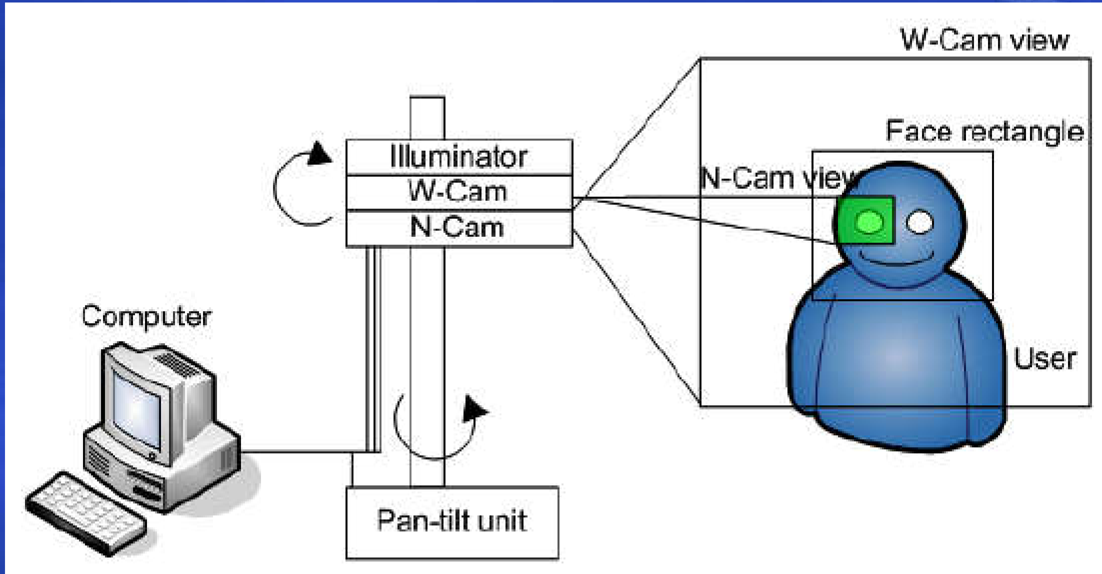
Camera: Active (PTZ, face + iris camera)

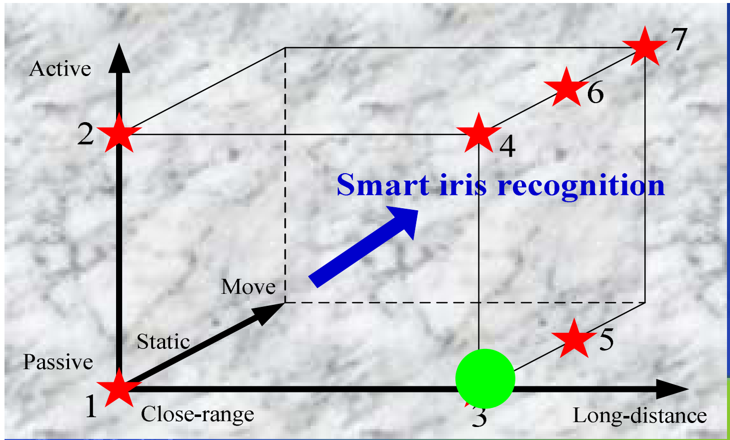
Distance: close to mid-range

Depth of field: Large

Motion: Static

Subject: Single

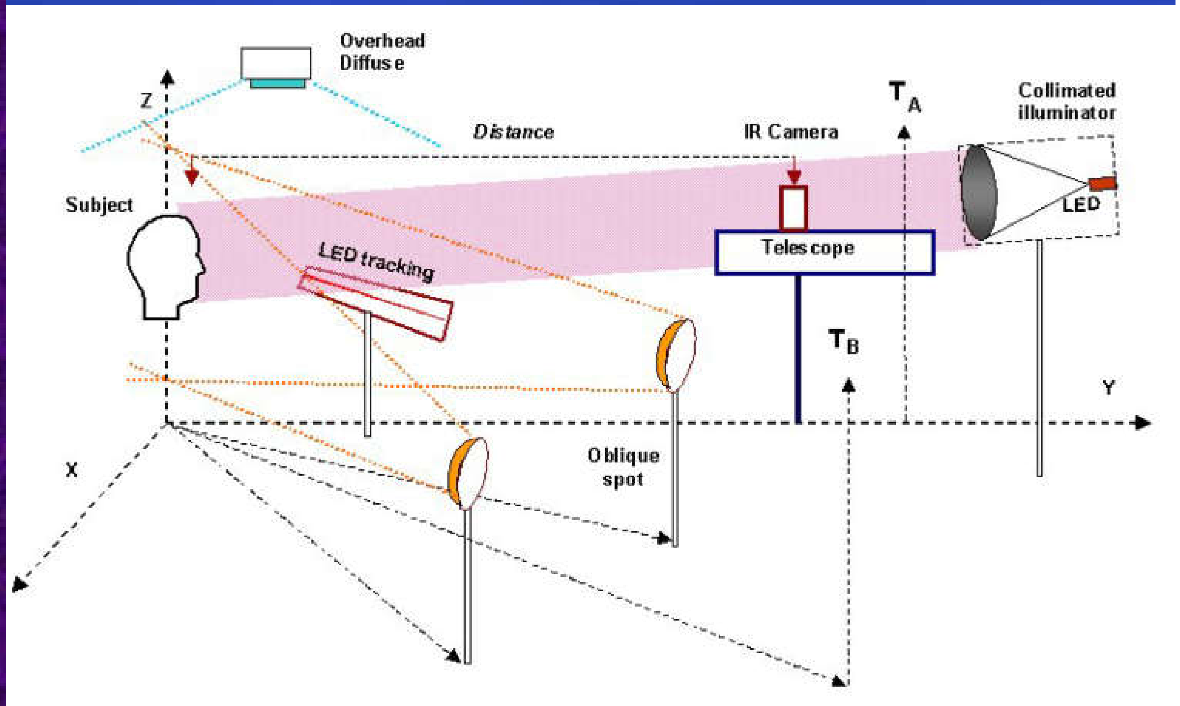





# Stage 3: Iris recognition at a distance

## Main features

Camera: Passive
(one fixed lens cam)
Distance: Long-range
Depth of field: Small
Motion: Static
Subject: Single

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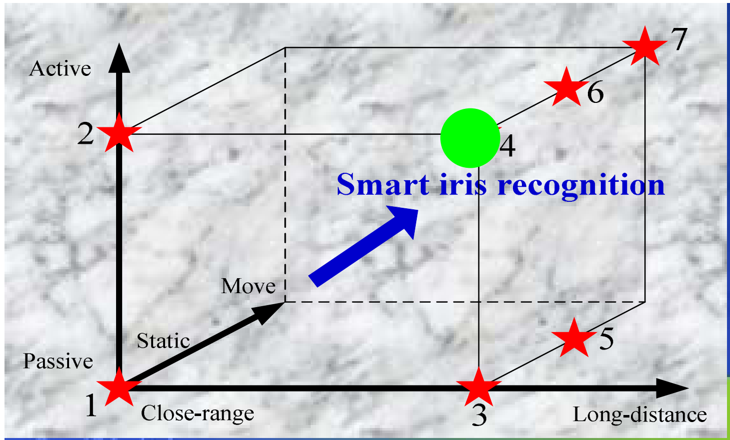



# Stage 4: Active iris recognition at distance

## Main features

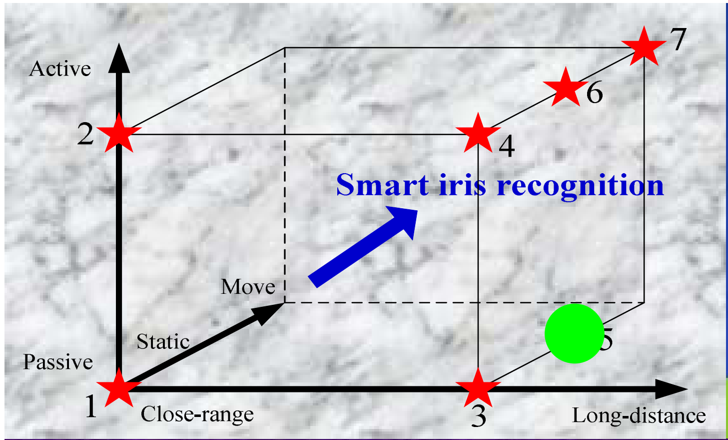
Camera: Active
(face cam + High-res iris cam)

Distance: Long-range

Depth of field: Small

Motion: Static

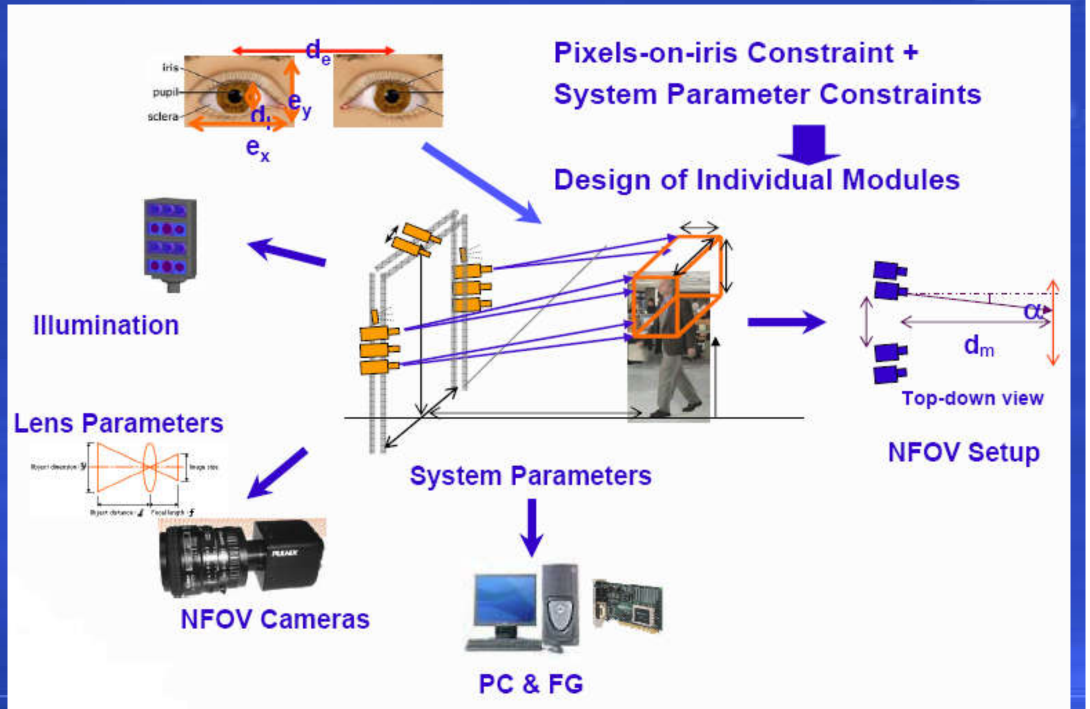
Subject: Single

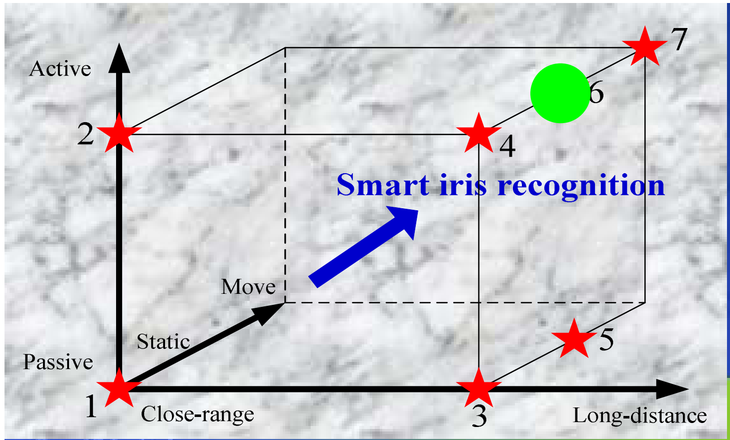



# Stage 5: Passive IR on the move

## 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

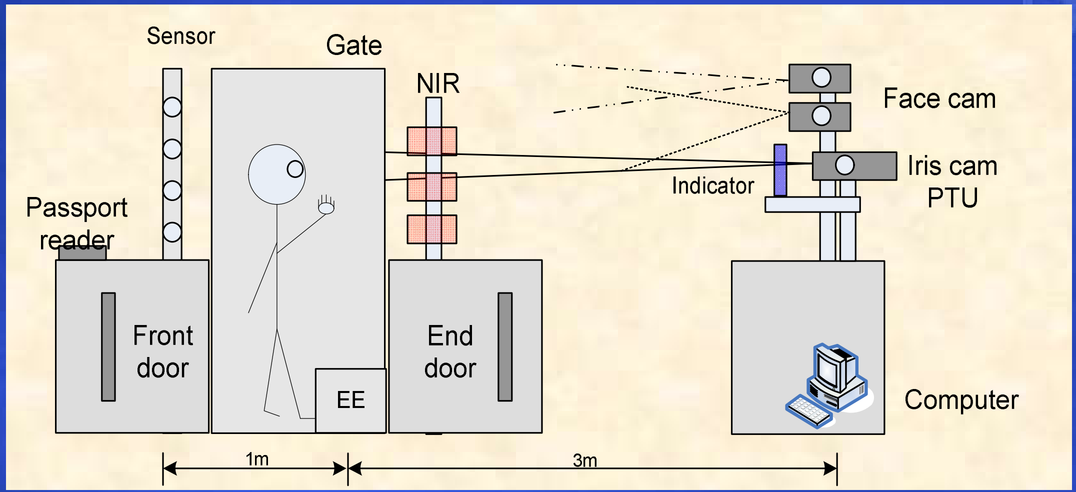
Camera: Active (PTZ, face+iris cam)

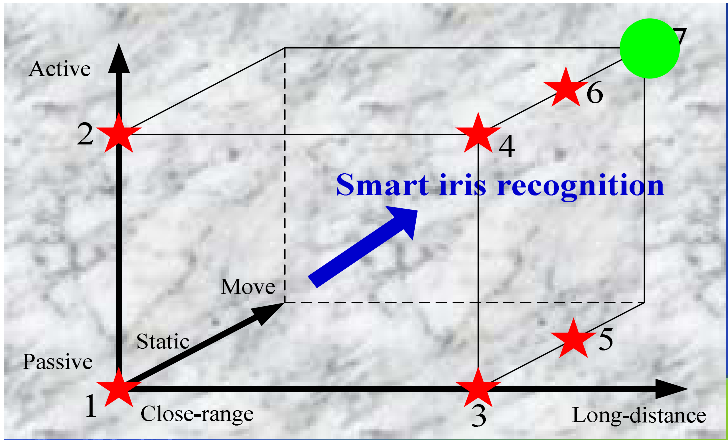
Distance: Long-range

Depth of field: Large

Motion: Walk on defined path

Subject: Single






# Stage 7: Iris recognition for surveillance

## Main features

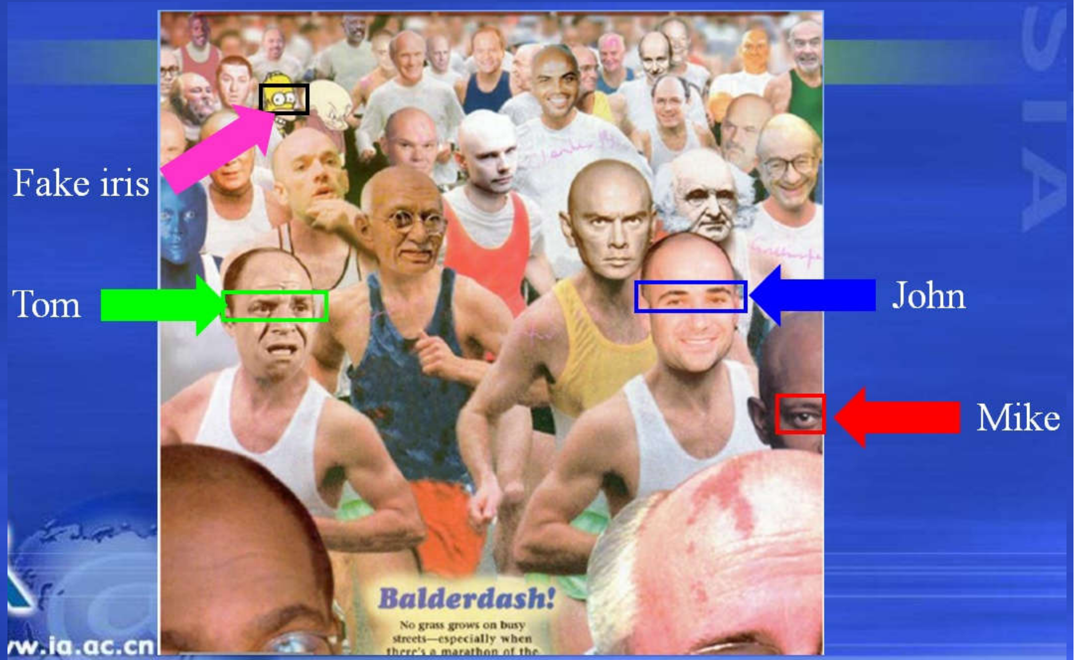
Camera: Active

Distance: Long-range

Depth of field: Large

Motion: Free movement

Subject: Multiple

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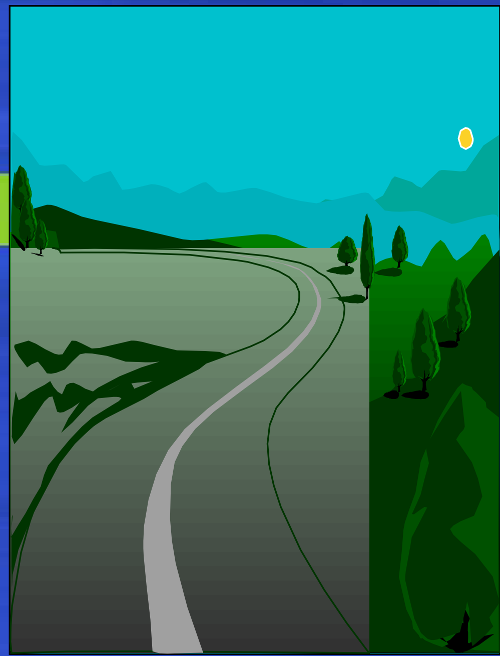
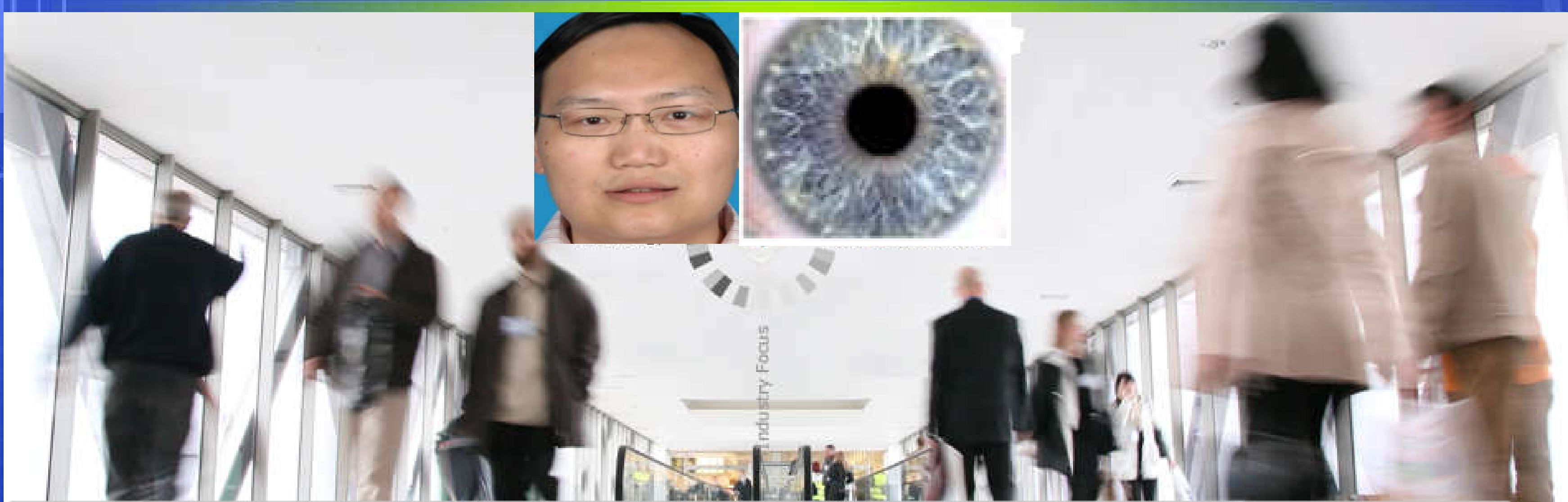
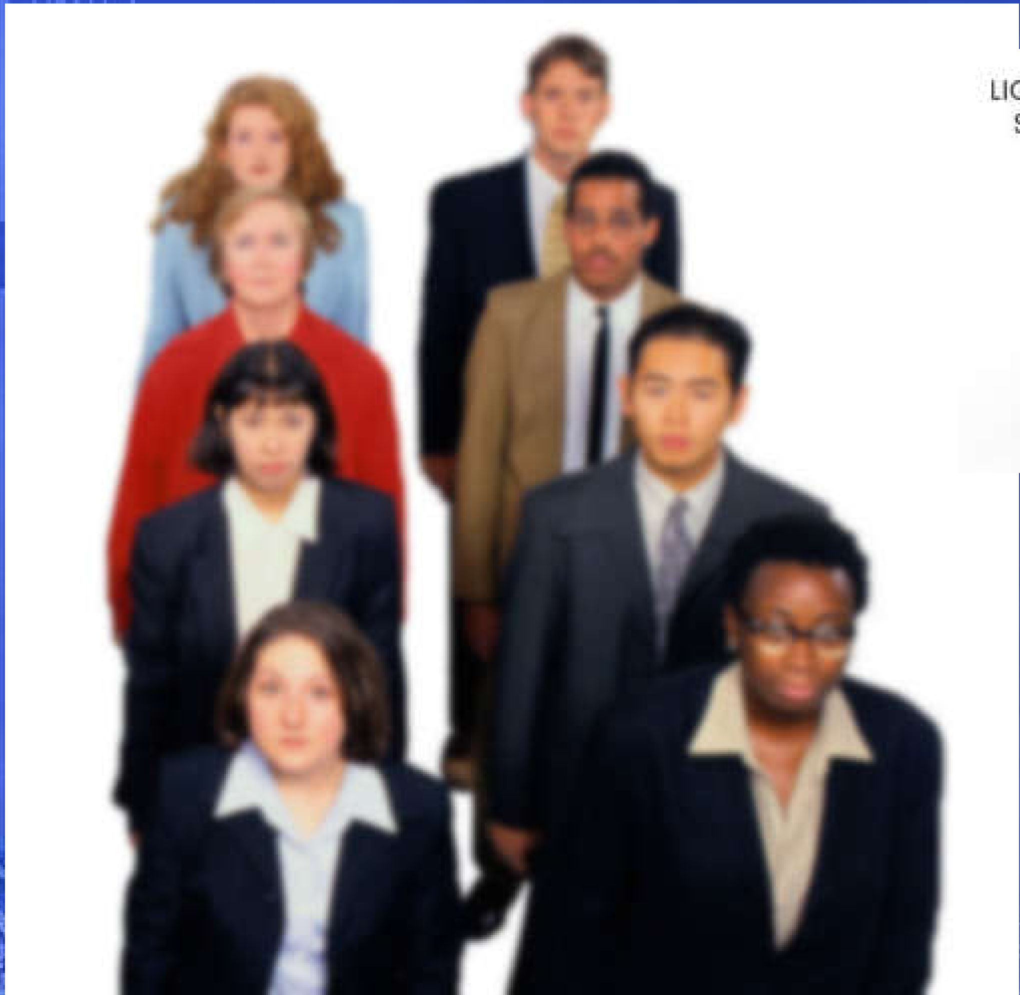


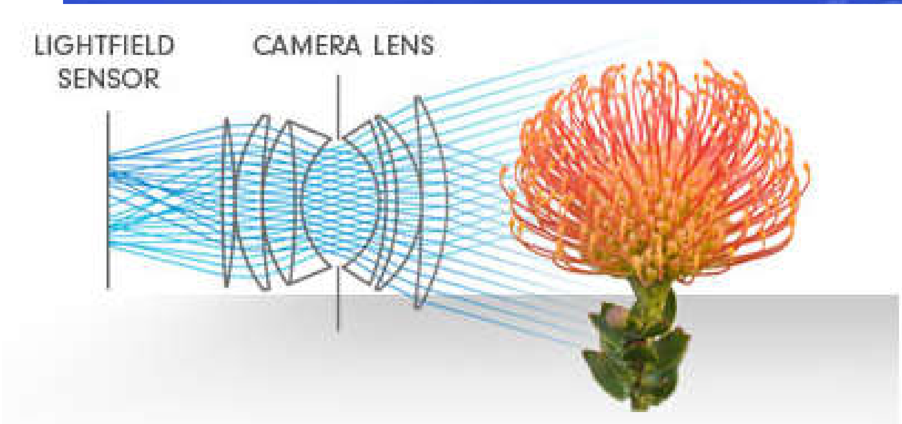
# Open problems and future directions in IR

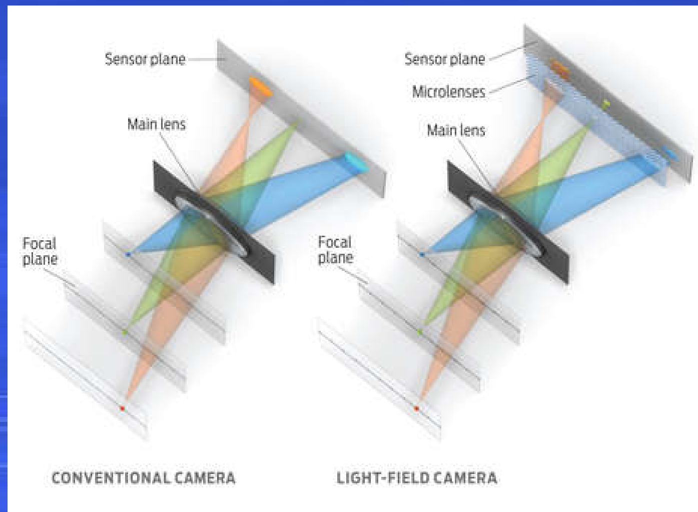
# Less or unconstrained iris image acquisition



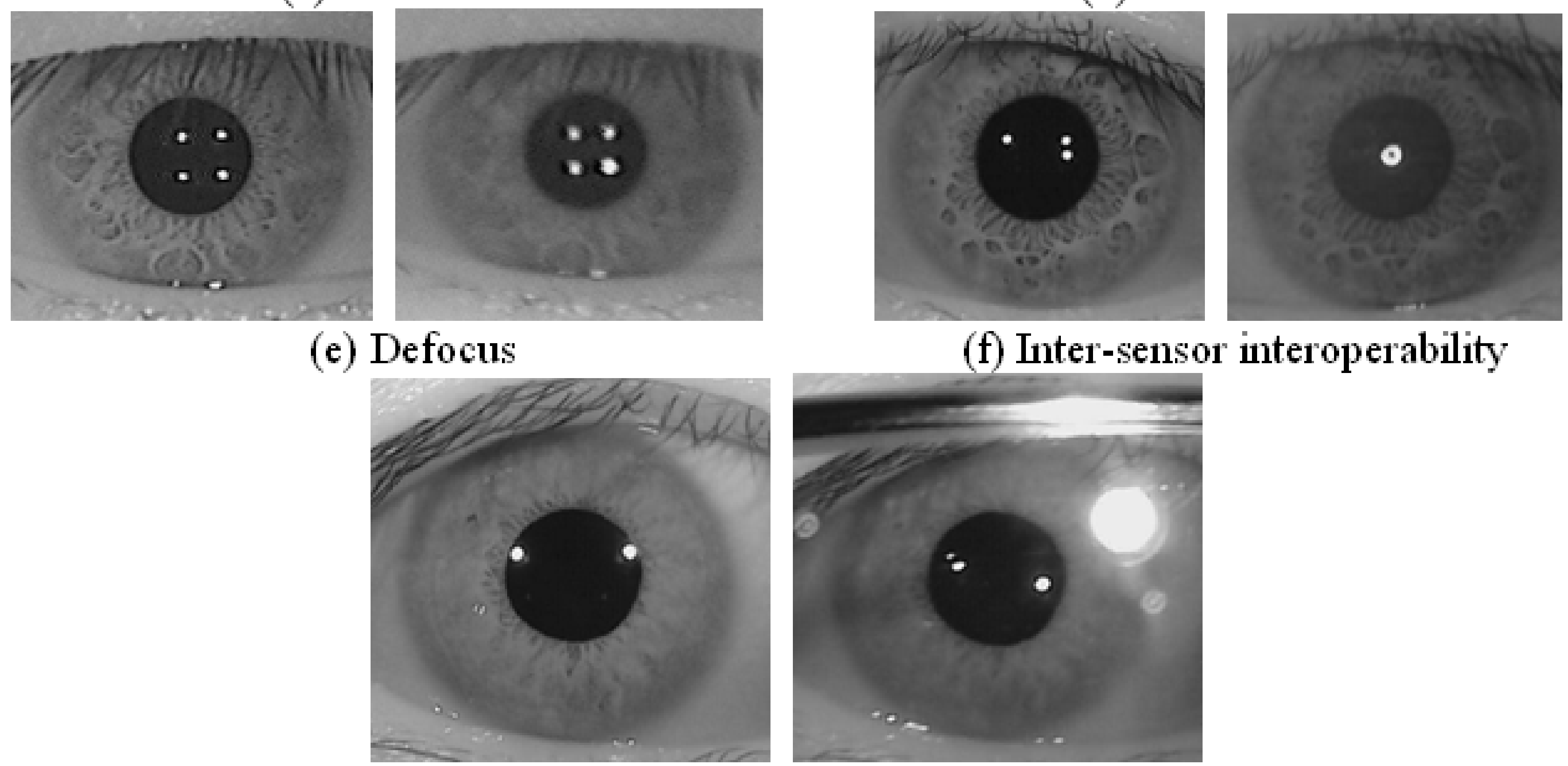
# Light field photography for iris image acquisition





# ●Robust iris recognition of poor quality iris images

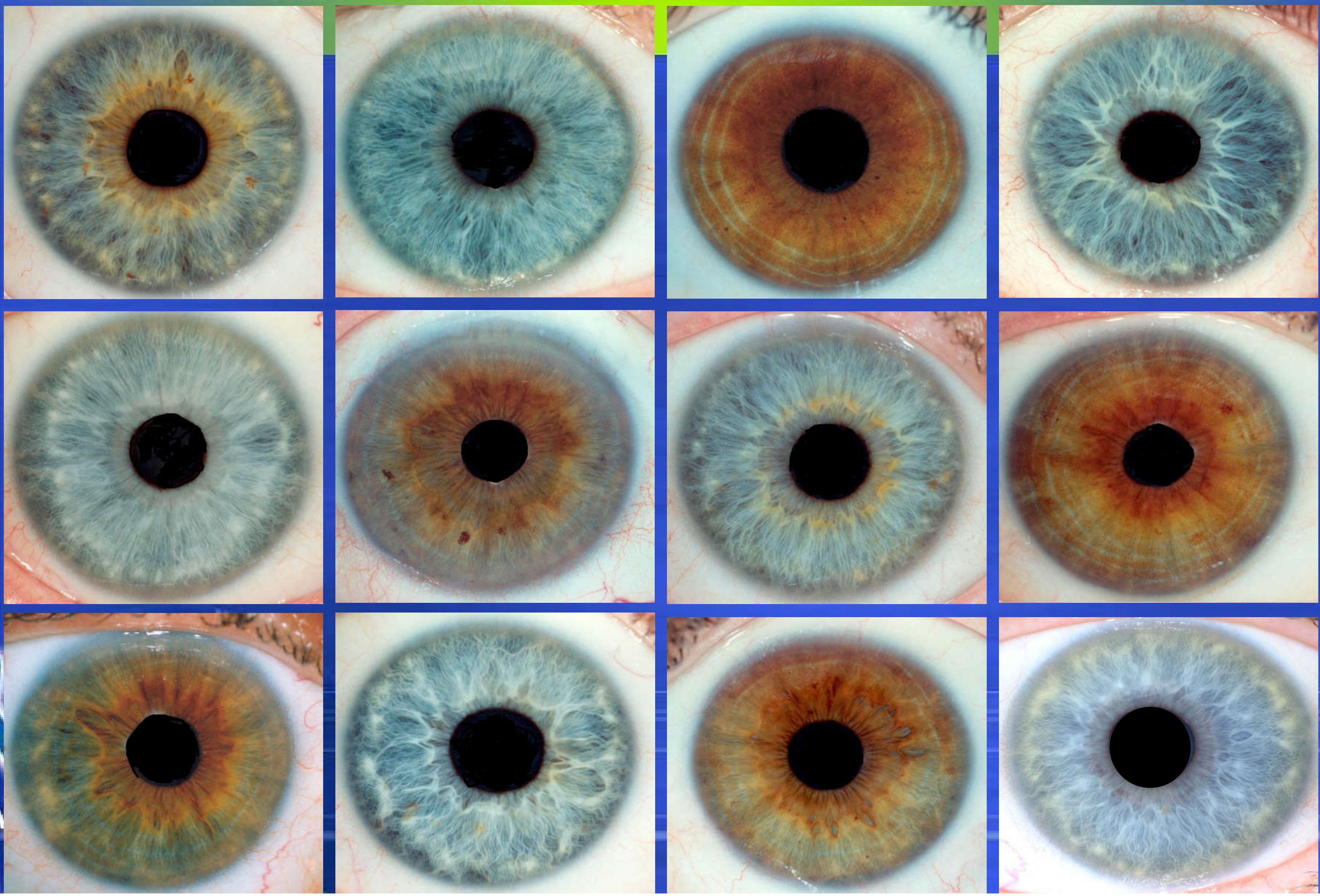


(e) Defocus

(f) Inter-sensor interoperability

(g) Eyeglasses

# ●Iris classification and large scale iris image database retrieval

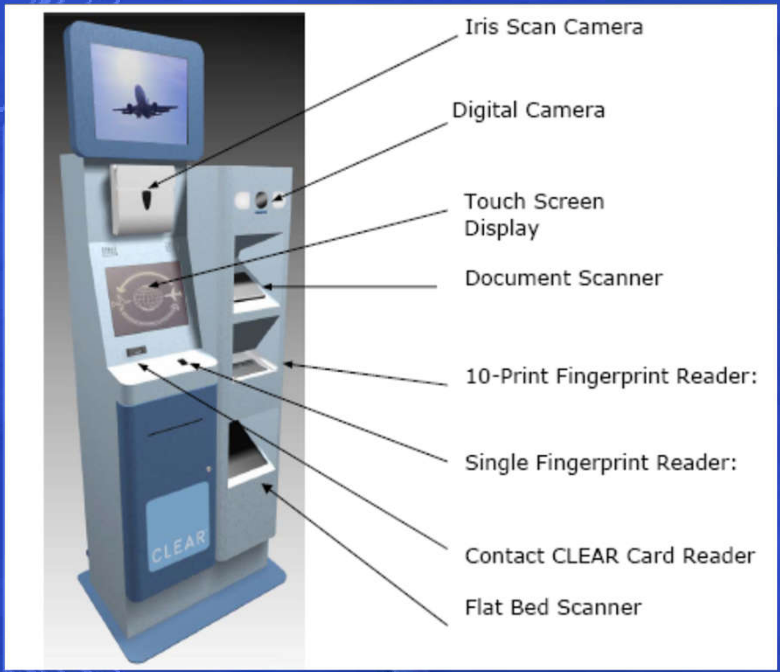


# ●Iris recognition on mobile devices

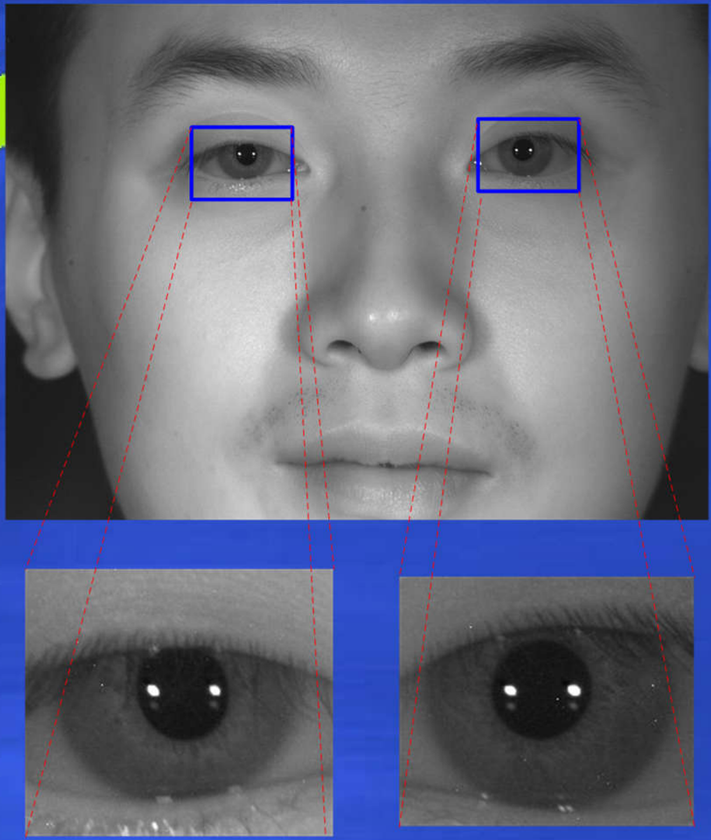

# Iris recognition for forensic applications


Iris recognition

# Multi-modal biometrics

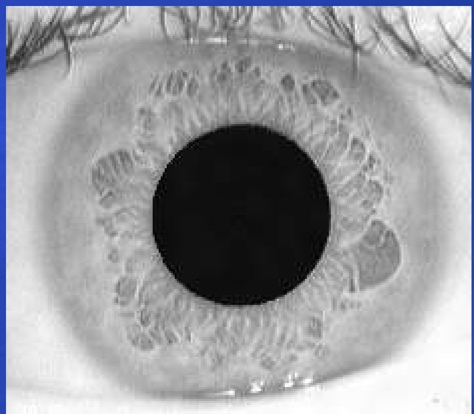



Iris/face/fingerprint



Iris/face/skinprint from one single image

# ●Iris biometrics for information security



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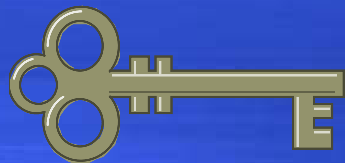
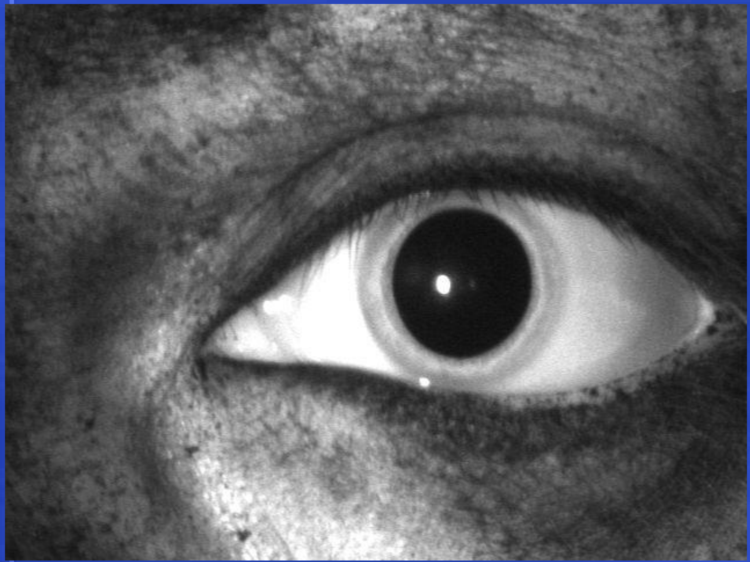


Biometric key

Watermarking,  Information hiding, IP protection, …

## ● Application specific problems



**Iris images of coal miners**

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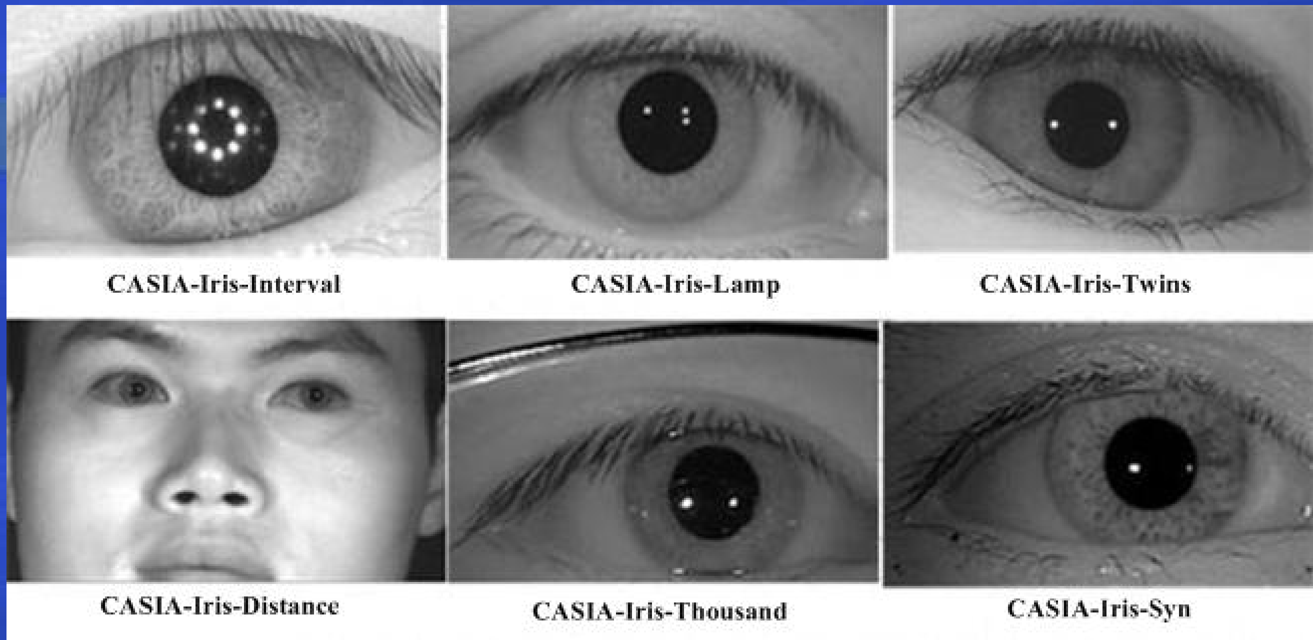
# CASIA Iris Image Database V4.0

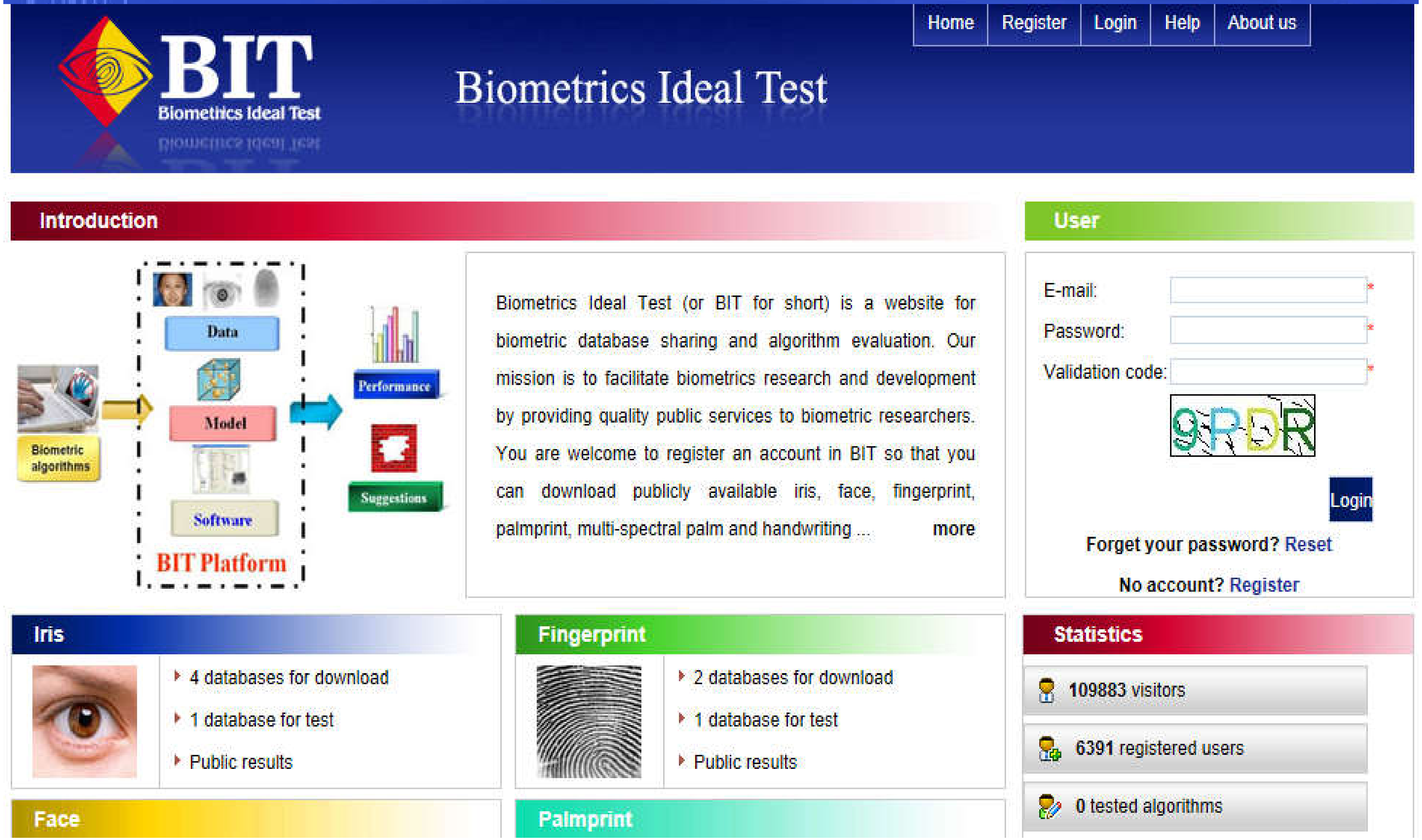



## Highlights:

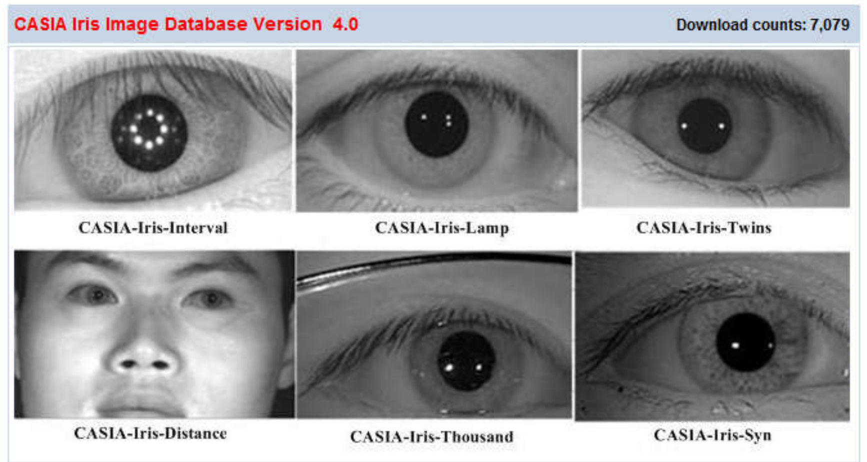
- Interval: cross-session, clear texture iris images
- Lamp: deformed iris images
- Twins: iris image dataset of twins
- Distance: long-range and high-quality iris/face images
- Thousand: large scale iris image dataset of one thousand subjects
- Synthesis: large scale synthesized iris image dataset

**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.**

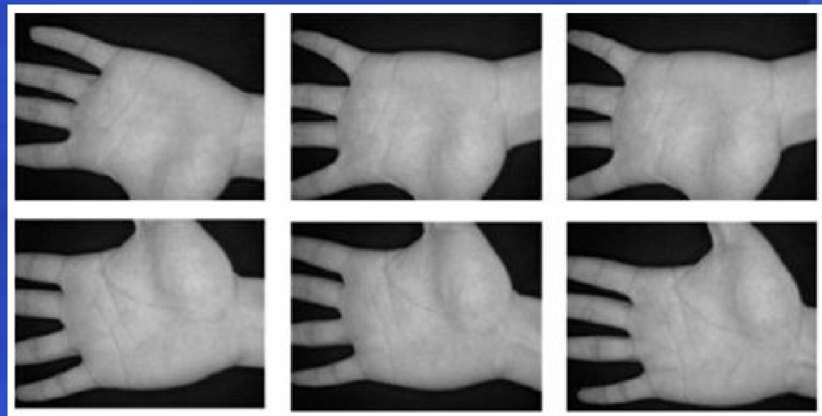
# BIT: A website for biometric database sharing and algorithm evaluation (Http://biometrics.idealtest.org)

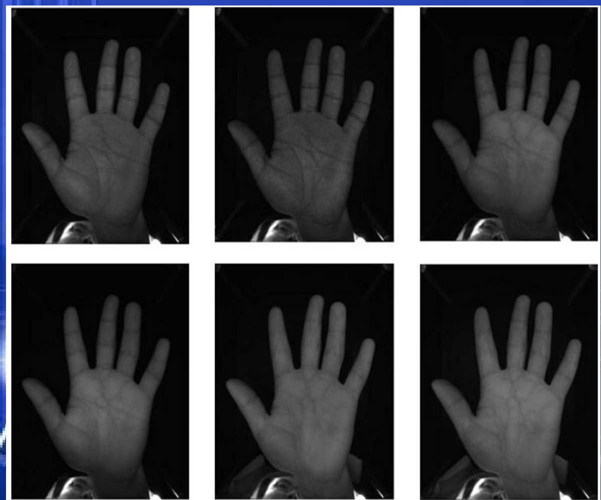


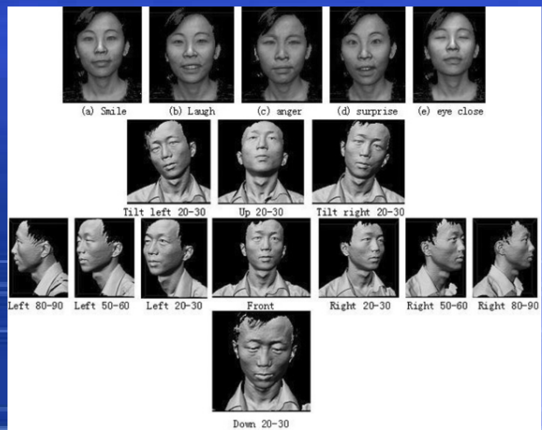
# Downloadable biometrics databases

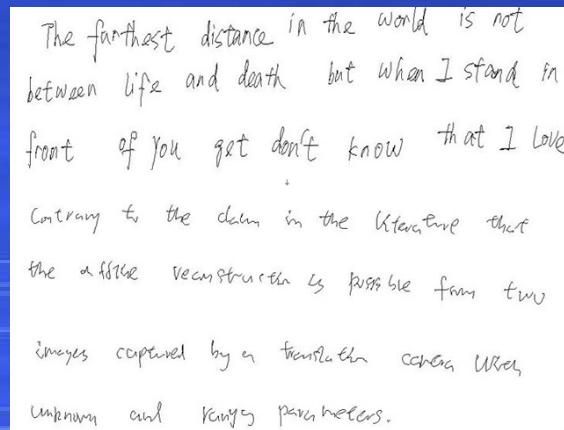








# Conclusions

- 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!**

# Thank you！