

Iris Recognition: Sensors, Algorithms and Applications

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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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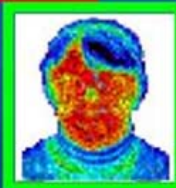


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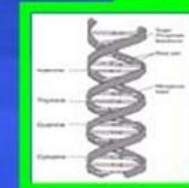
Iris in the context of biometrics

Who am I?

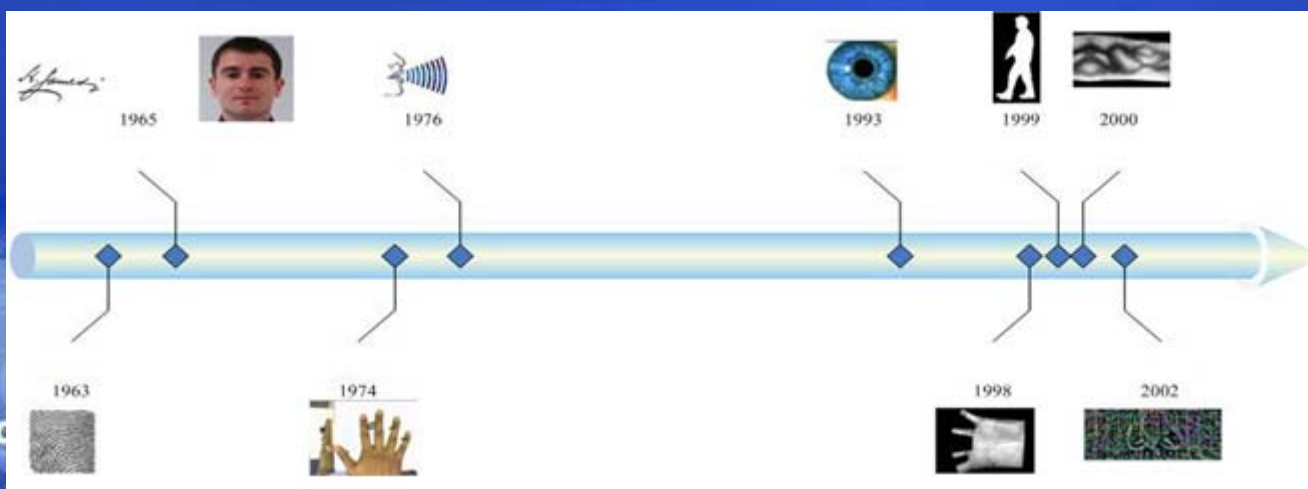
Behavioral modalities



Physiological modalities

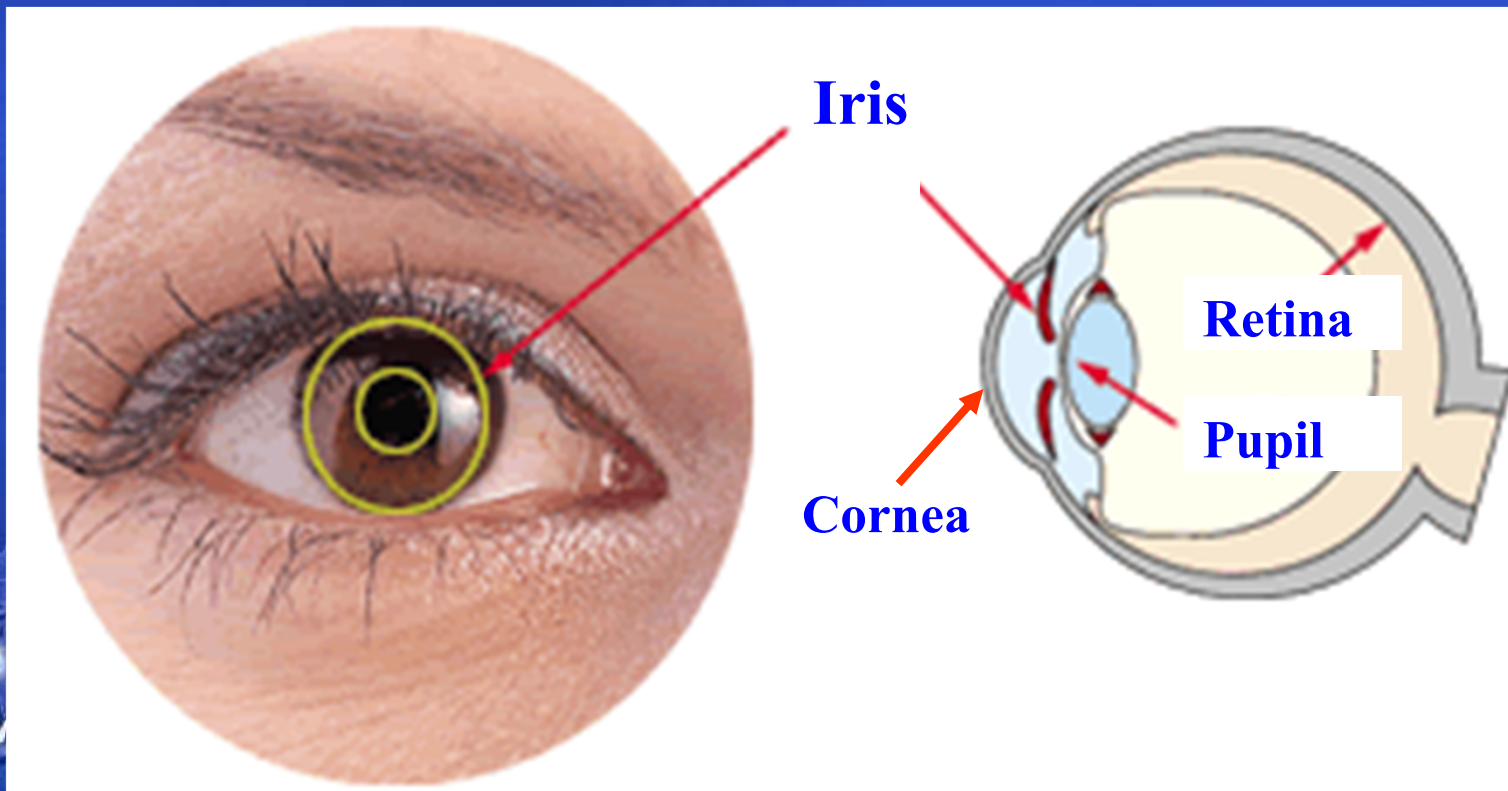


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What is iris?

- 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

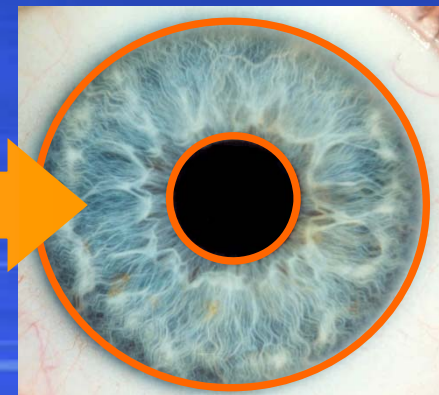


Who are you?

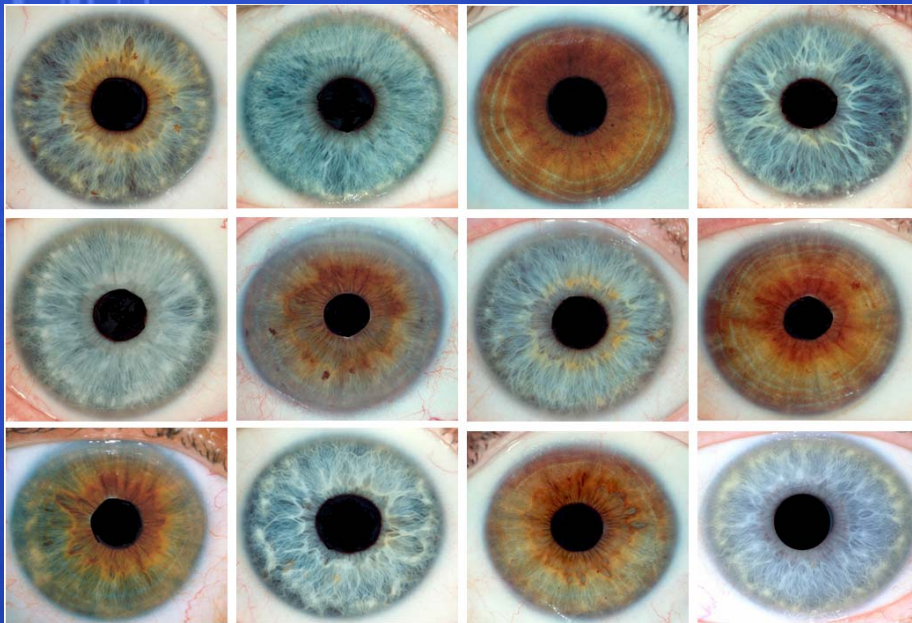


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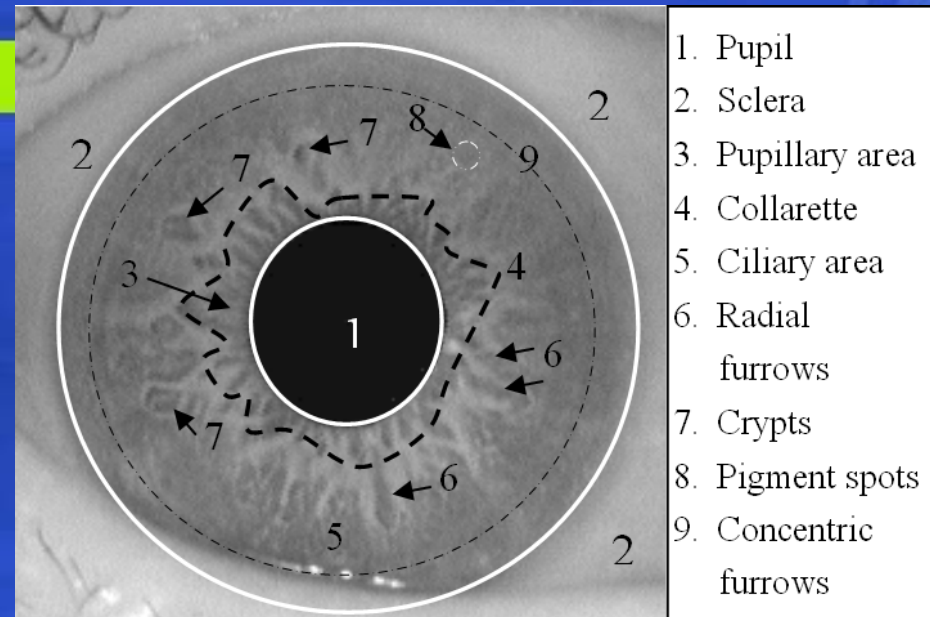
Iris



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

NATIONAL GEOGRAPHIC MAGAZINE

INTERACTIVE EDITION

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April 2002

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NGM online: the past six years.

► Features List

A table of contents linking to this month's feature stories.

► Final Edit

The picture rescued from the cutting room floor.

► Flashback

A photo from the past, browse our archives.

► Global Getaways

International editors'

NATIONAL GEOGRAPHIC

A LIFE REVEALED

Found
After 17 Years
An Afghan Refugee's Story

April 2002 FEATURES

- A Life Revealed
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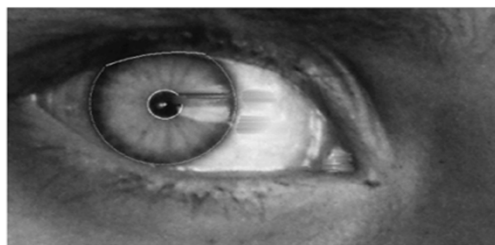
Identification of Gula Using Iris Recognition

注册过程



1984年

↓ 图像预处理



↓ 特征提取

Gula =

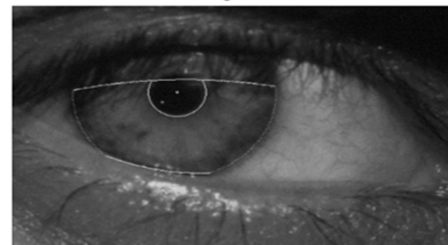


识别过程



2002年

↓ 图像预处理



↓ 特征提取



特征匹配

↓
0.76

匹配分数

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.

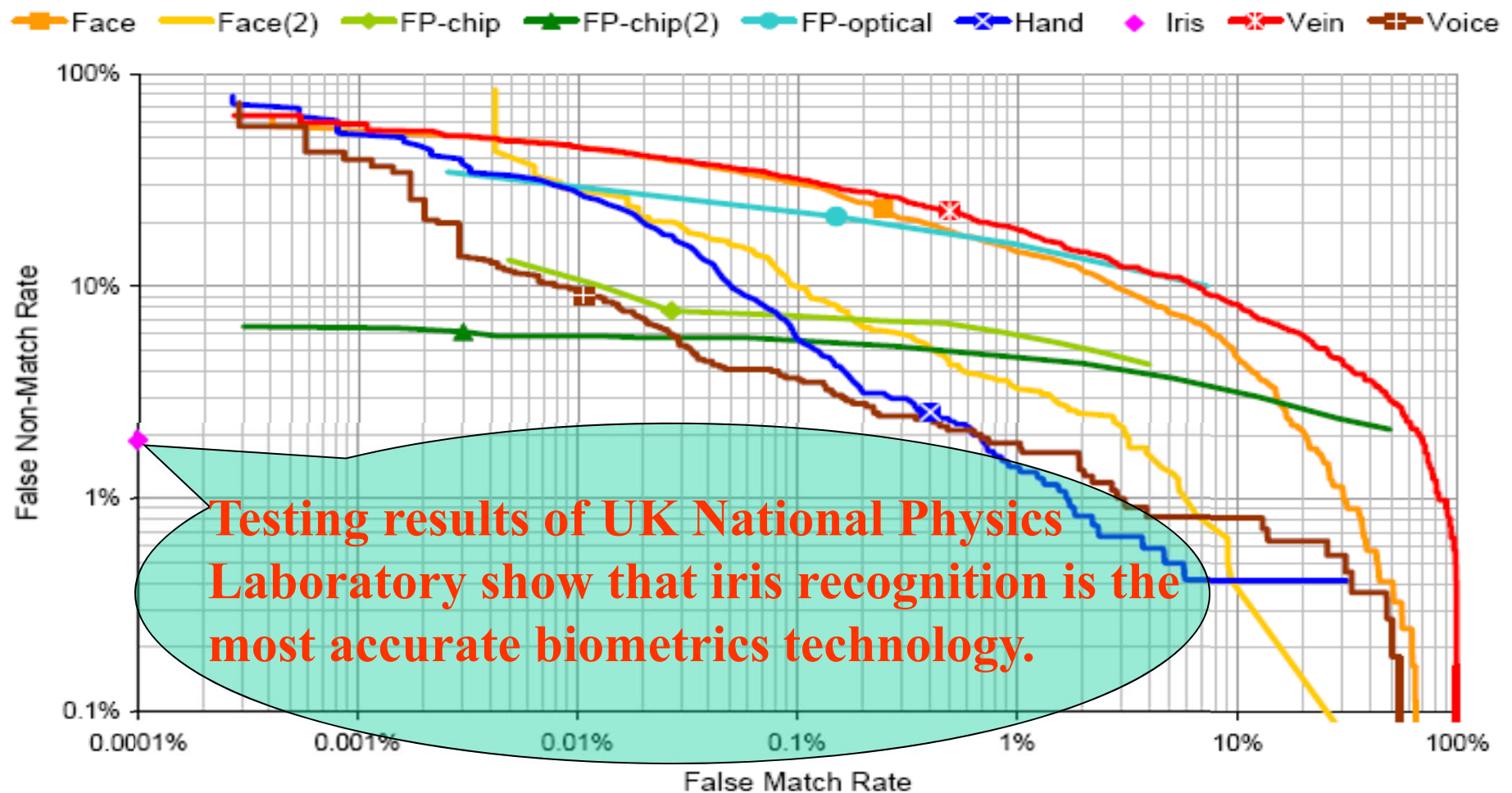
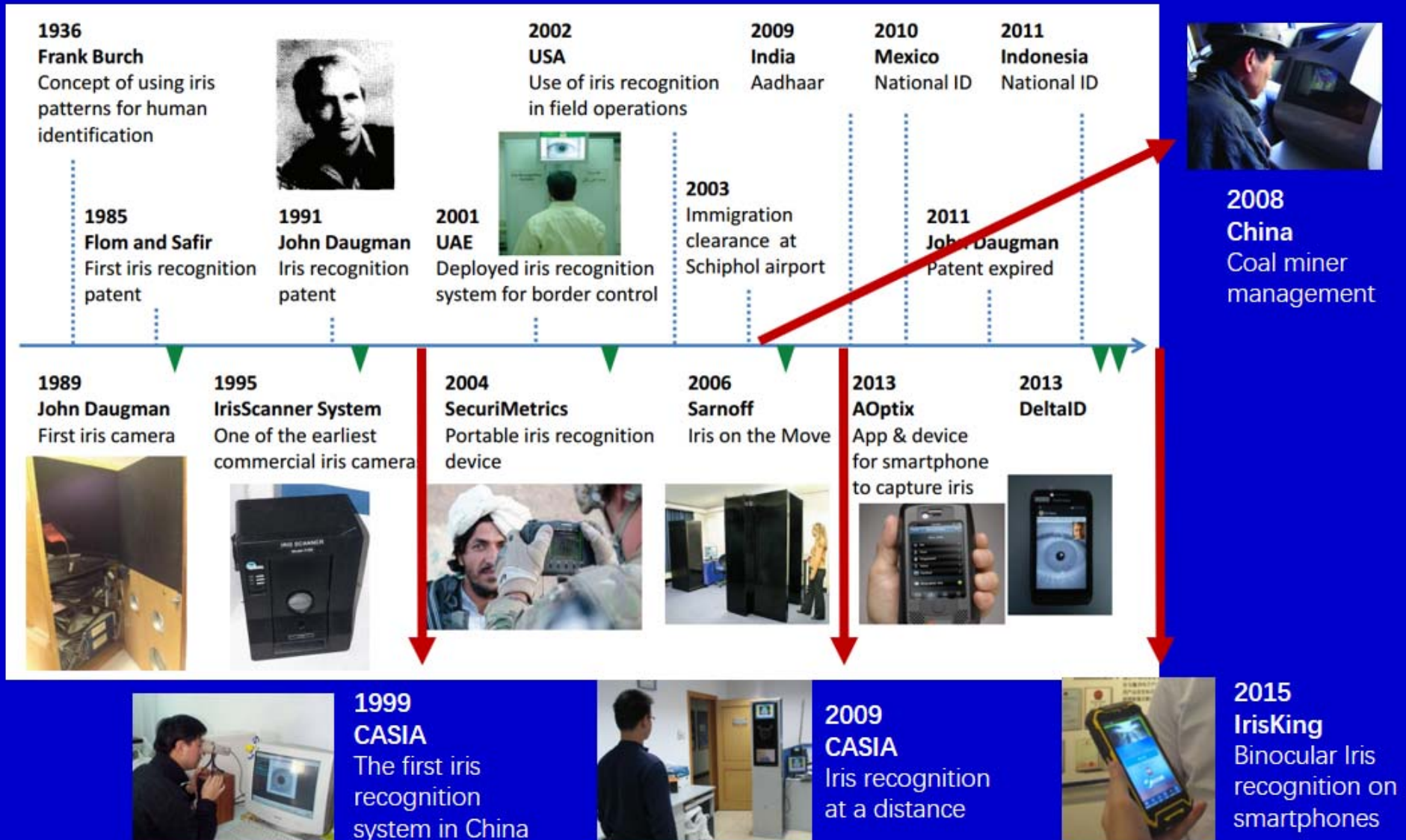


Figure 4. Detection error trade-off: FMR vs FNMR

History of Iris Recognition



Global Market of Iris Recognition

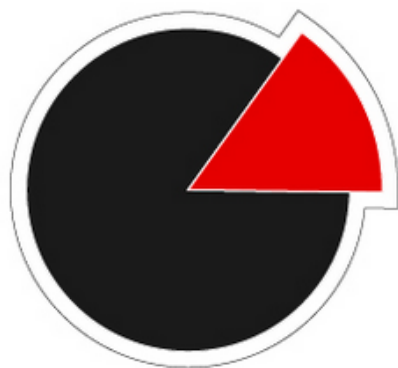


Global Industry Analysts, Inc.

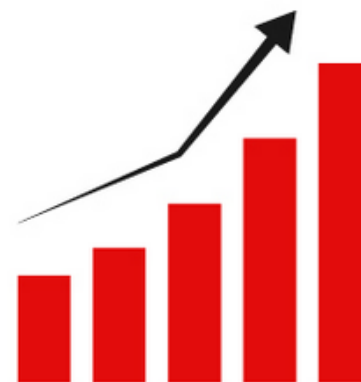
A Worldwide Business Strategy & Market Intelligence Source

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.

Global Market Share, Size & Demand Forecasts



- The United States: The Largest Market
- The Middle East: The Fastest Growing Market at 21.2% CAGR



- Market projected to reach US\$1.8 billion by 2020



//www

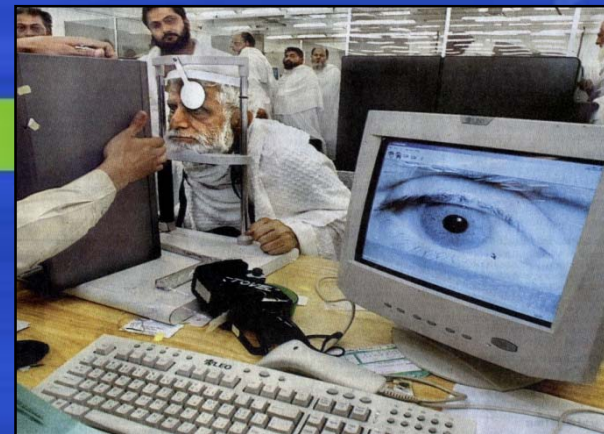
Applications of iris recognition



Access control



Airport



Homeland security



Welfare distribution

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Missing children identification



ATM



印度身份证管理

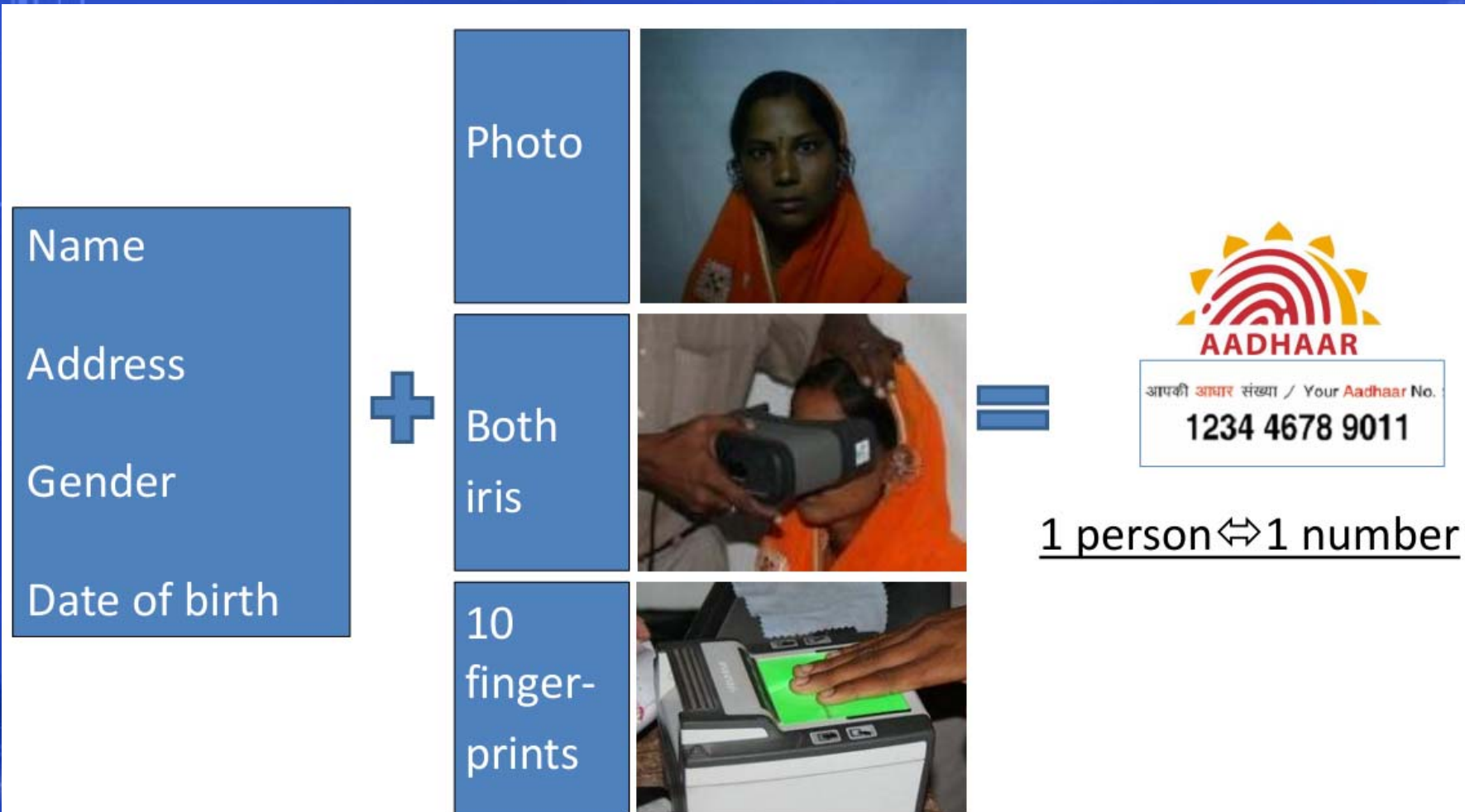
<http://www.uidai.gov.in/>



[//www.ia](http://www.ia)

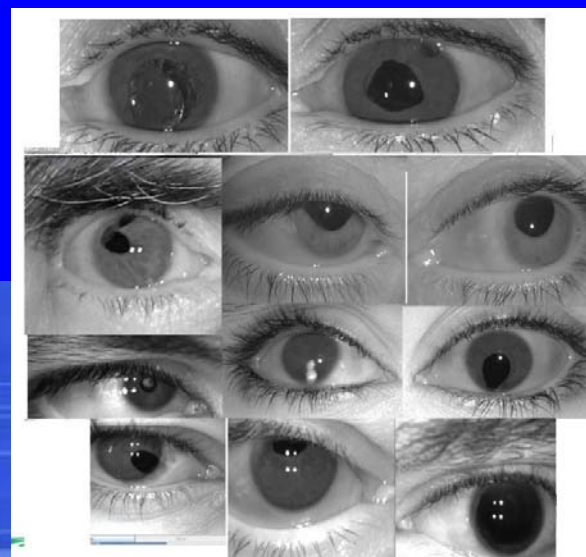
CASIA

UID编码



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%



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

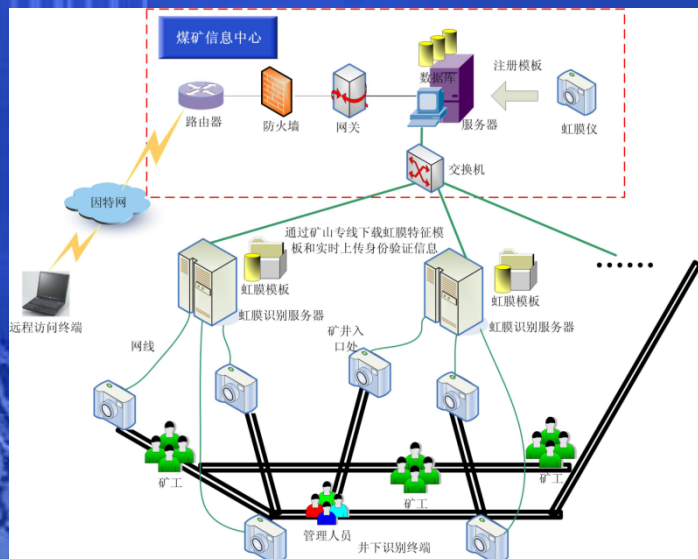


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Iris Recognition for Criminal Investigation



Iris Recognition for Coal Miner Identification



<http://www.IrisKing.com>

Iris Recognition for Secure Bank Transactions



Cairo Amman Bank
Egypt



[//www.ia.ac.cn](http://www.ia.ac.cn)



Cooperative & Agricultural Credit Bank
Yemen

Iris Recognition for Prison Management



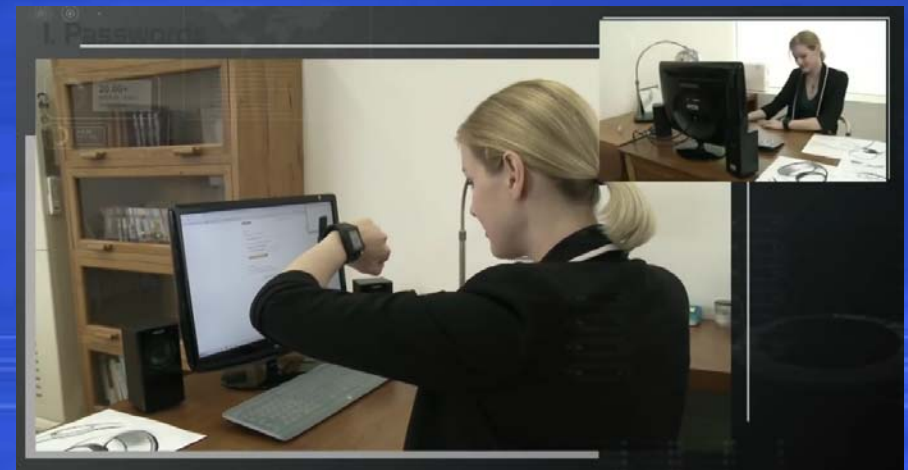
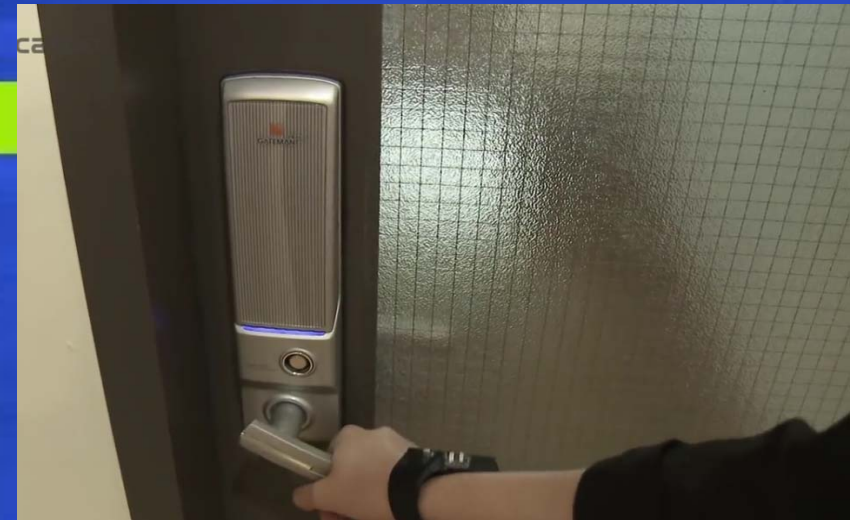
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Iris Recognition on Mobile Devices



平板虹膜信息注册过程

Iris Recognition in Smart Watch



Basic Modules of IR System

Eye



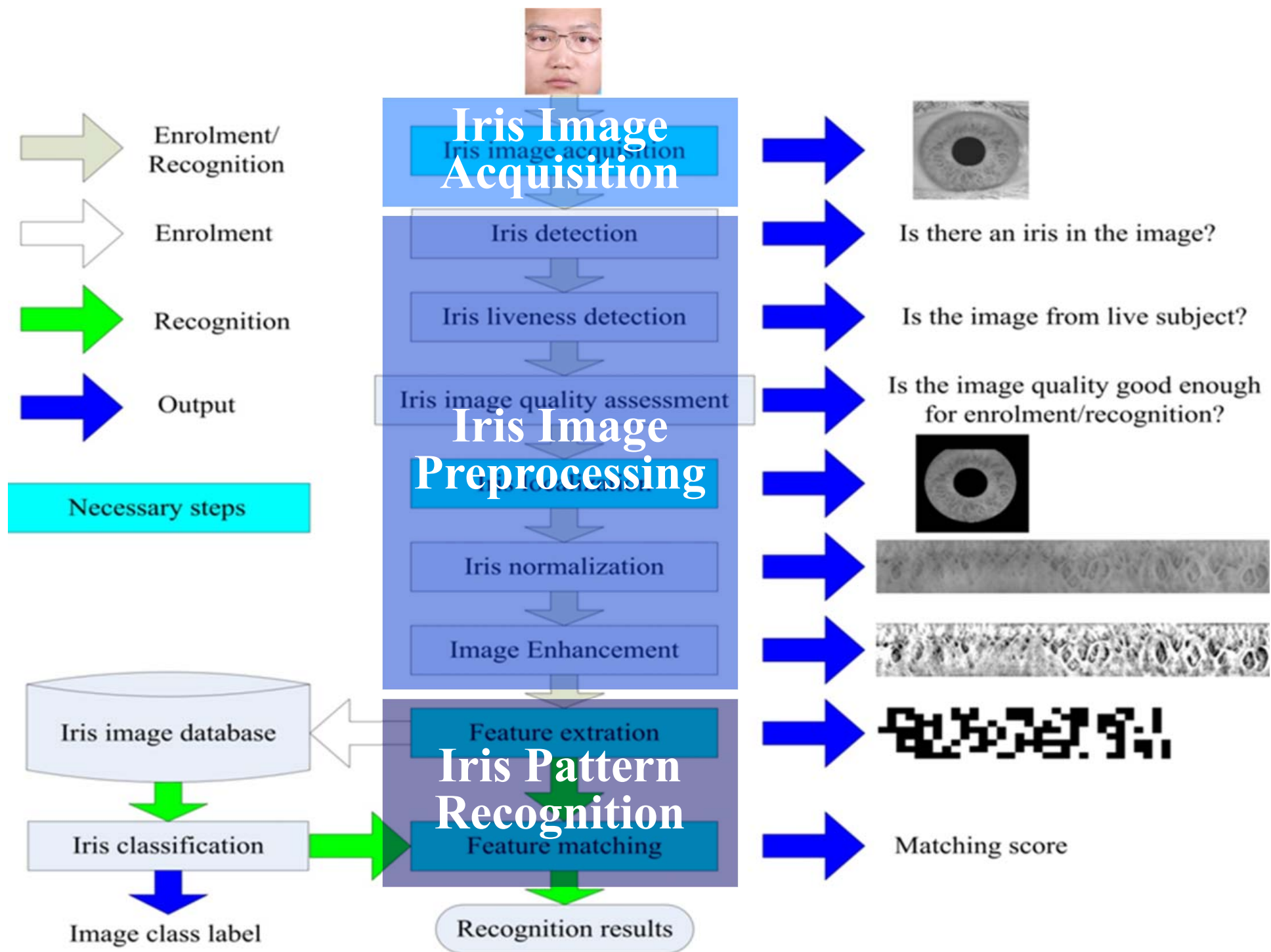
IR System

?

Identity



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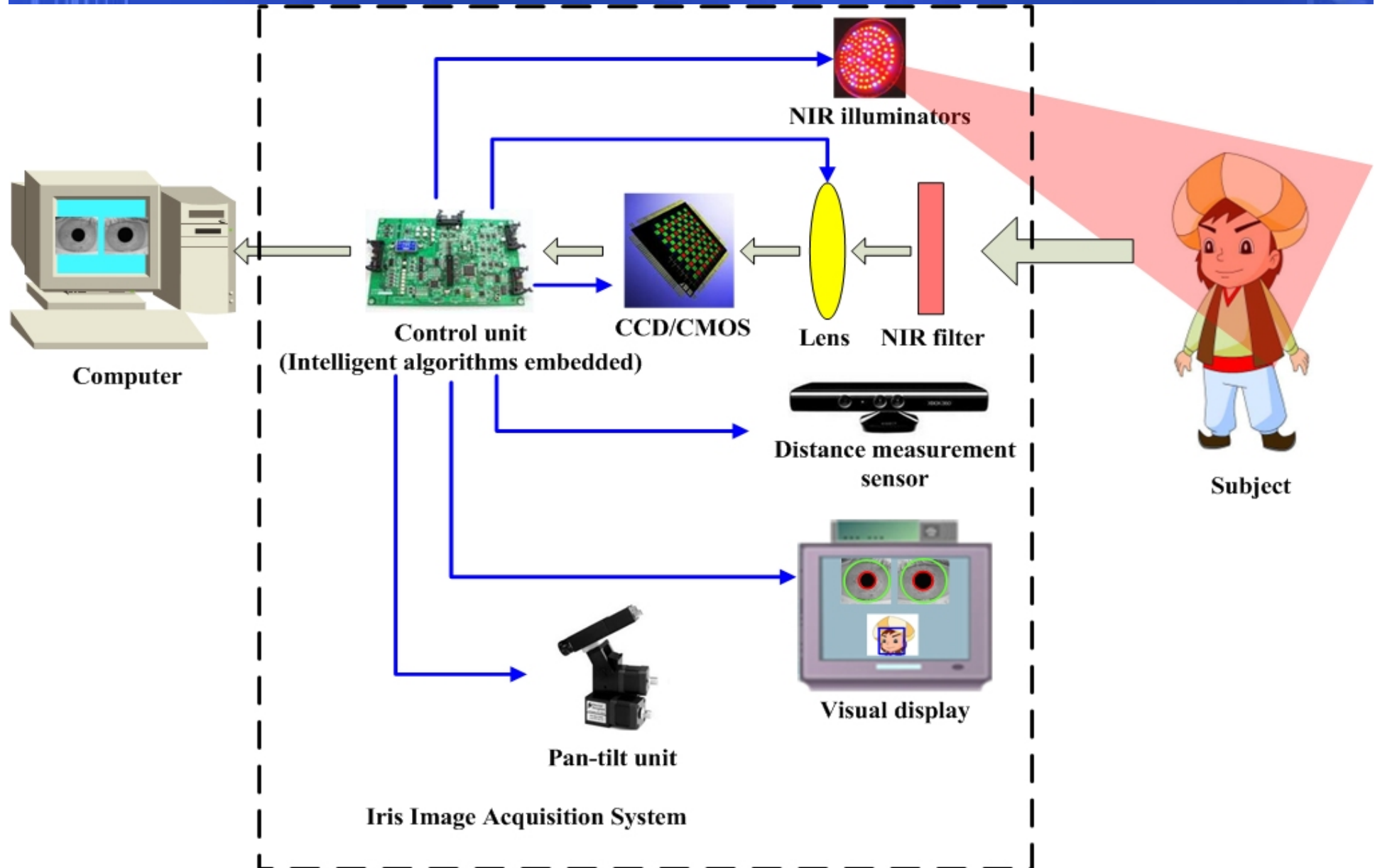
Difficulties of iris image acquisition



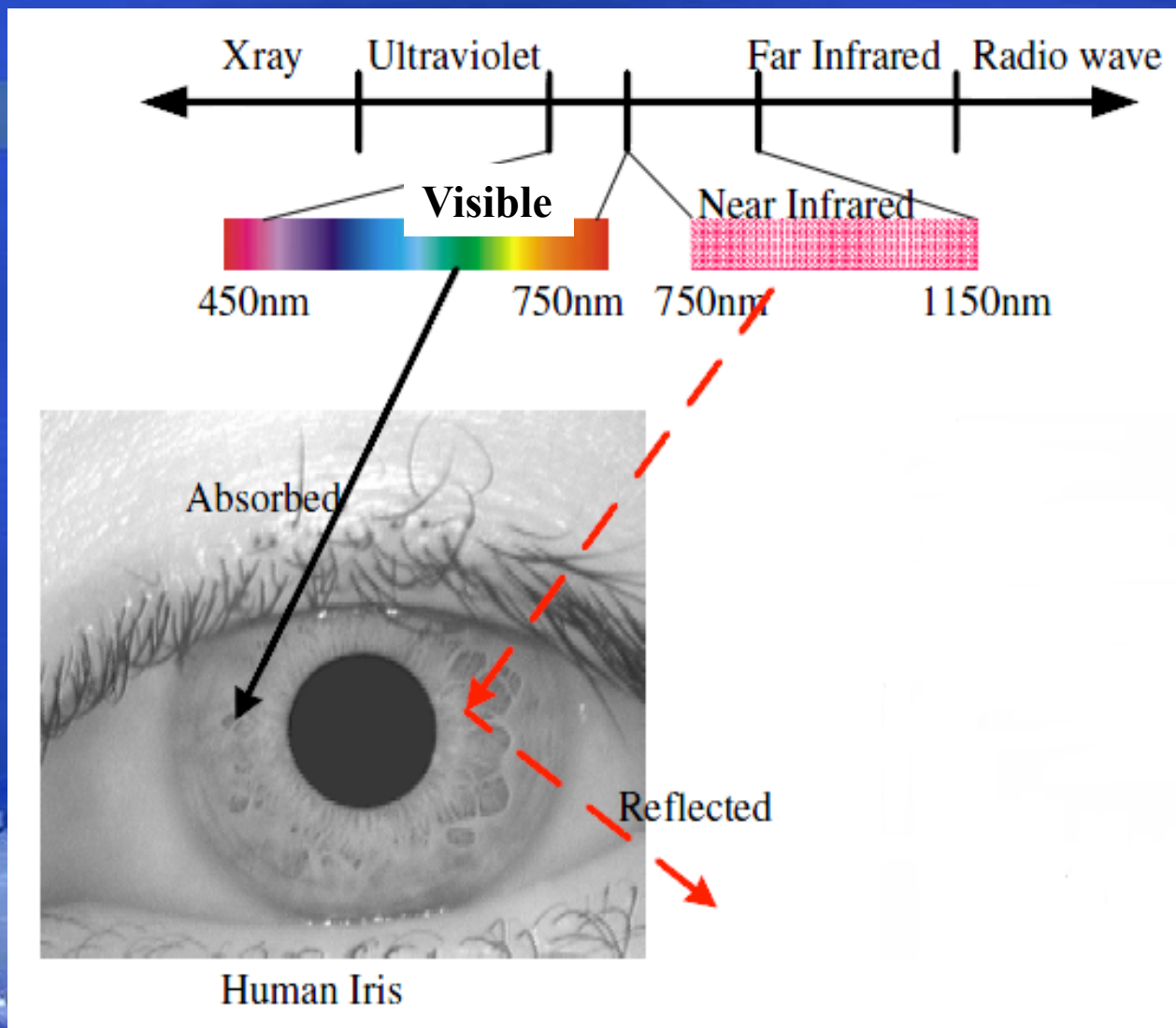
- Small size (11mm)
- Sufficient resolution (200 pixels)
- Narrow depth of field
- Must be optically on-axis
- Stop and stare

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

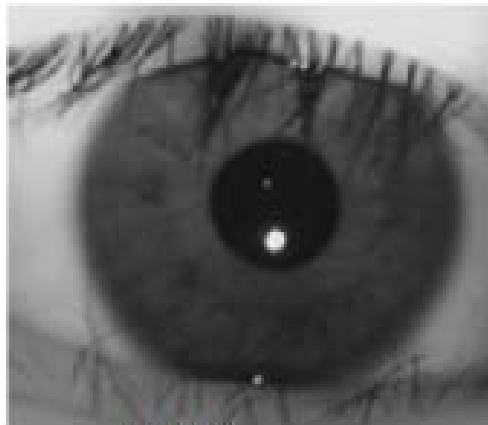


Optical characteristics of human iris



//www.ia.

Iris images captured at different wavelength



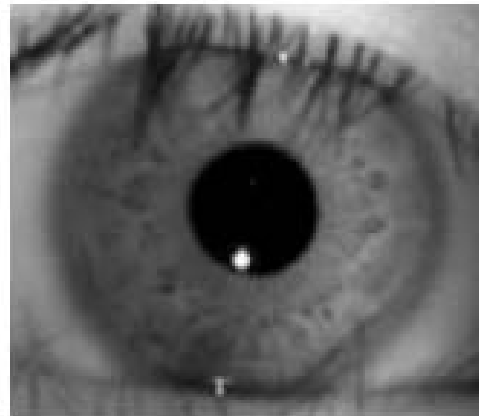
700nm



810nm



850nm



880nm



940nm

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



//www

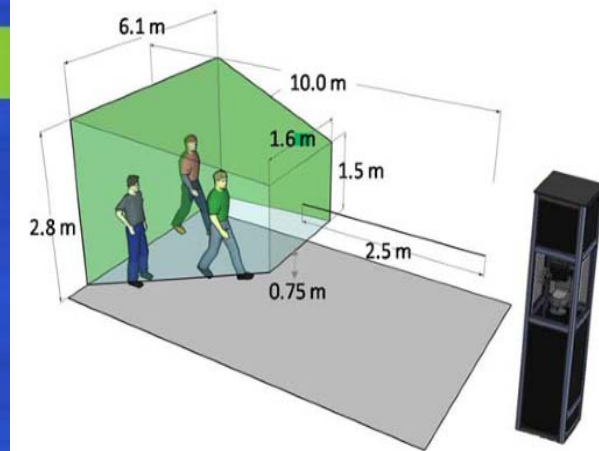
Long-range iris devices



Aoptix InSight



EyeLock HBOX



Eagle-eyes

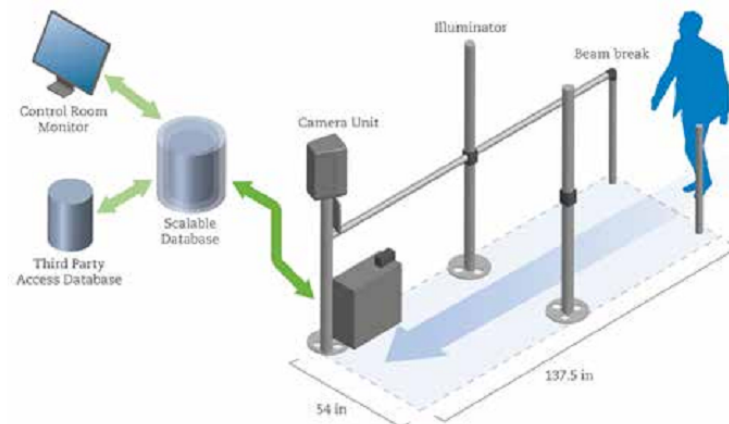


IOM PasThru

System Diagram

IOM PassPort SL with floor kit assembly

IOM PassPort



IrisID iCAM D1000

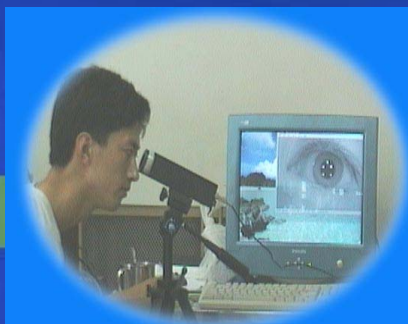


CASIA

Iris image acquisition devices of CASIA



1999



2000



2001



2004



2005



2007



2008



2009



2014



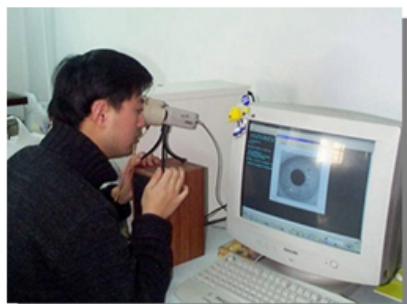
2015



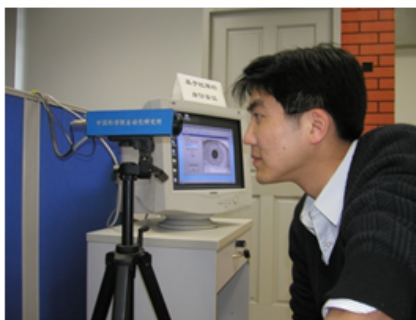
2016

Technology Roadmap of Iris Recognition

从无到有



1999: 打破国外技术封锁, 实现零的突破

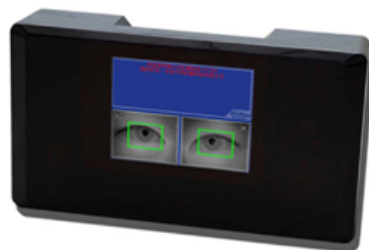


2001: 虹膜图像质量达到国际先进水平

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

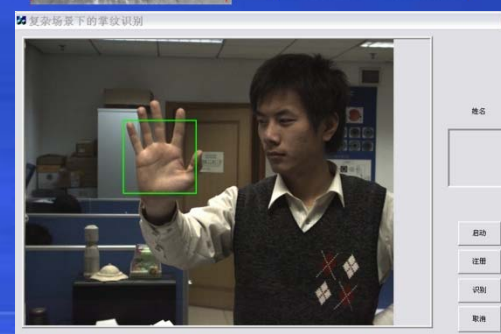
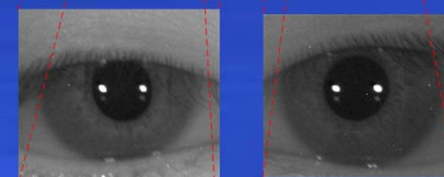
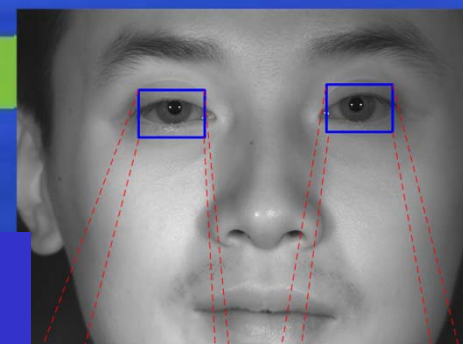


2014: 便携式虹膜识别仪



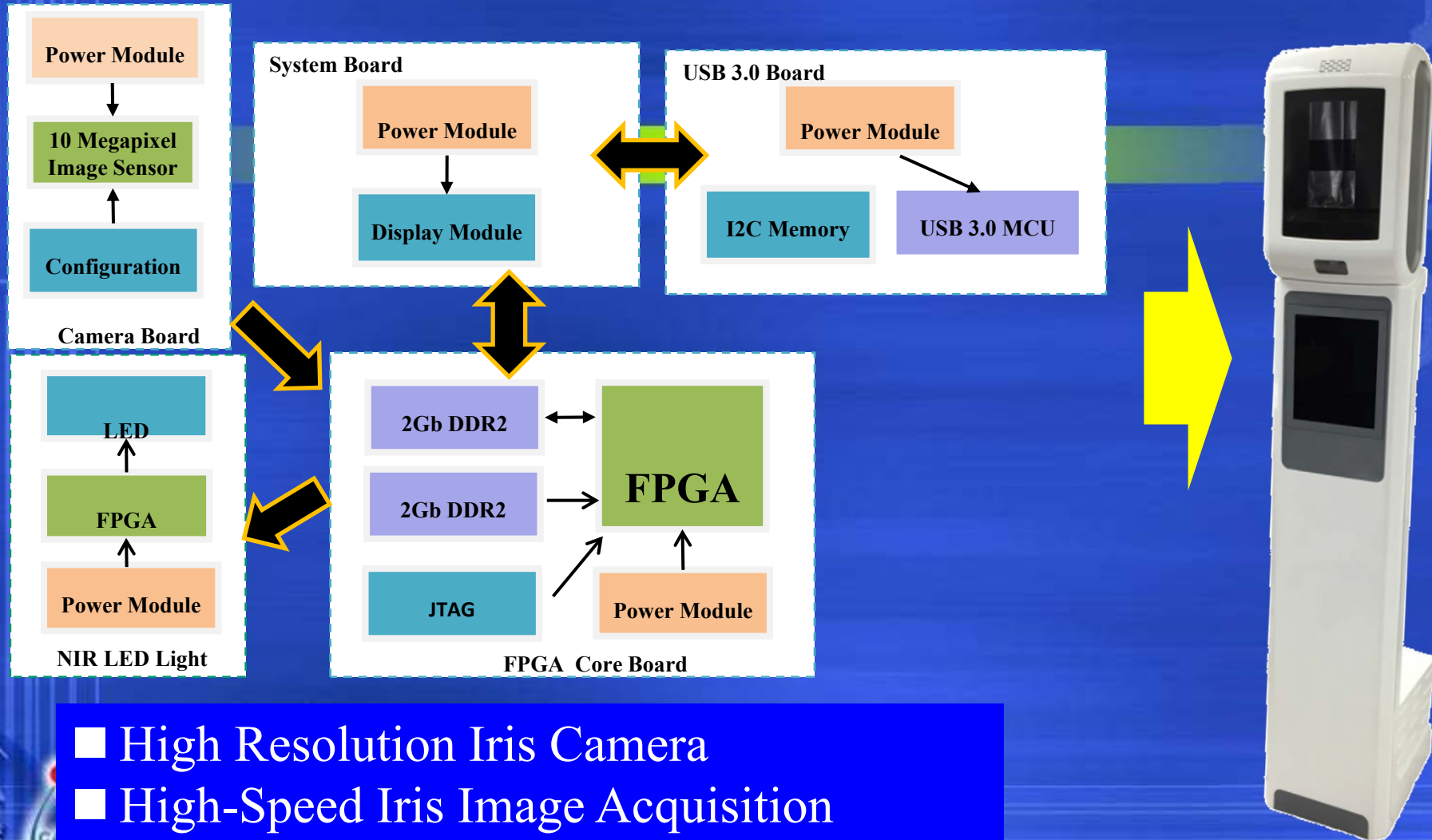
2015: 虹膜识别手机

Multi-modal biometric recognition at a distance



Iris/Face/Palmprint recognition for friendly personal identification

Long-range Iris/Face Recognition System

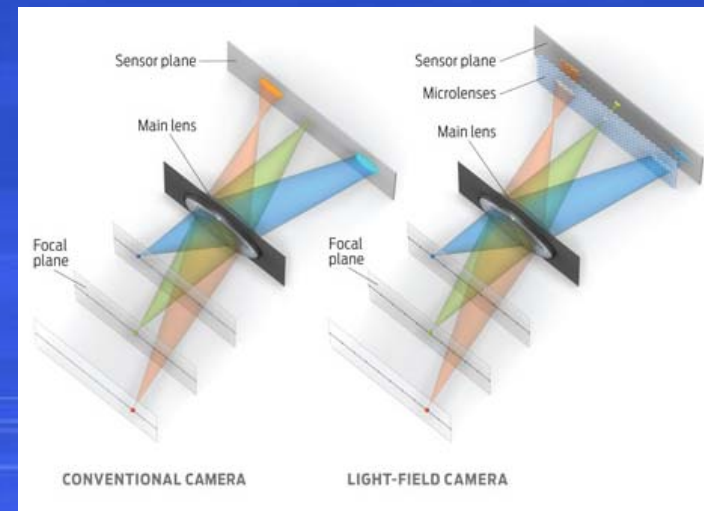
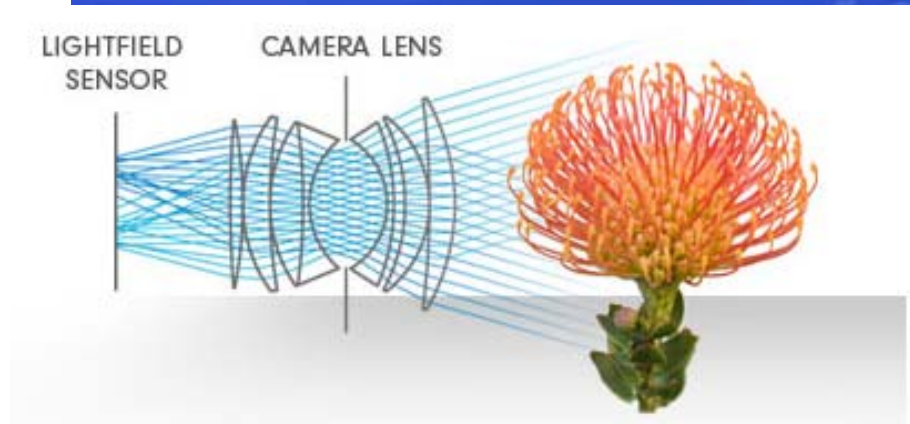


- High Resolution Iris Camera
- High-Speed Iris Image Acquisition
- NIR Illumination Optimization
- Fast Recognition Procedure

Demo of Iris Recognition at a Distance



Light field photography for iris image acquisition



Iris recognition on mobile devices



- Chip level solution of iris imaging
- Iris image acquisition under complex conditions
- Iris image quality assessment and enhancement
- Improvement of usability with friendly interface and advanced algorithms
- Secure processing and storage of iris information in mobile operating systems

Successful applications of iris recognition on mobile devices

2016年1月
展讯紫潭安全手机S1
政府、公安行业安全终端



中国第一款量产的虹膜识别智能终端

2016年9月
达闼巨象E1
金融行业终端



菲律宾第一款面向消费市场的虹膜识别智能终端

2016年12月
菲律宾Cherry Mobile智能手机



2017年2月
达闼DATA
金融行业终端



中国第一款基于可信计算的虹膜识别智能终端

2017年3月
FERO mobile
Iris 智能手机



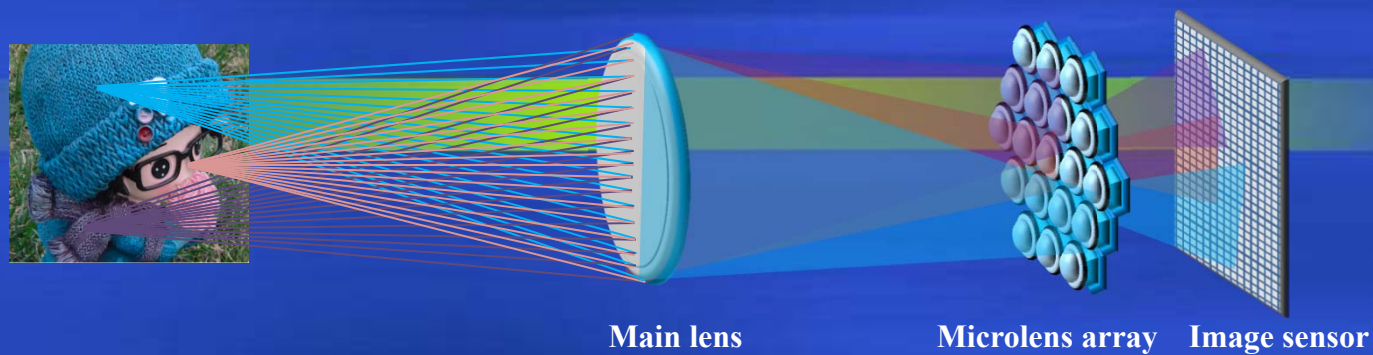
非洲第一款面向消费市场的虹膜识别智能终端

2017年4月
国美第一款智能终端K1

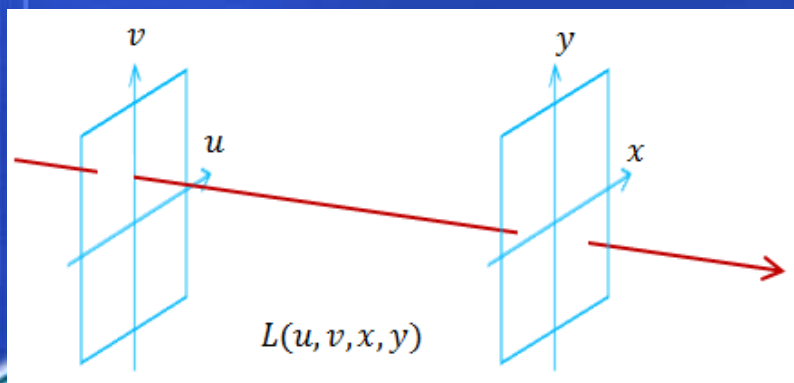


中国第一款面向消费市场的虹膜识别智能终端

Light-Field (LF) Imaging



Light-field Camera (Plenoptic Camera)

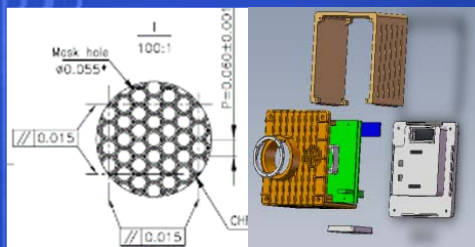


4D LF data

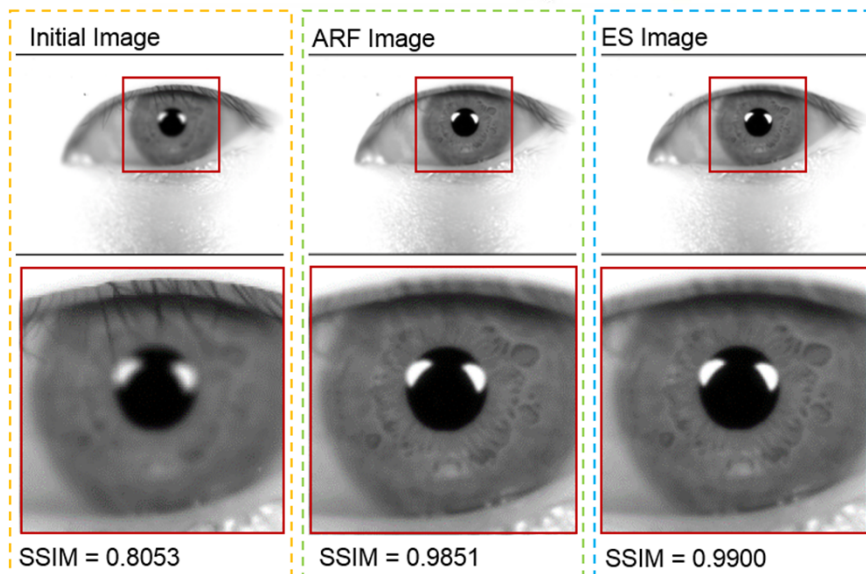
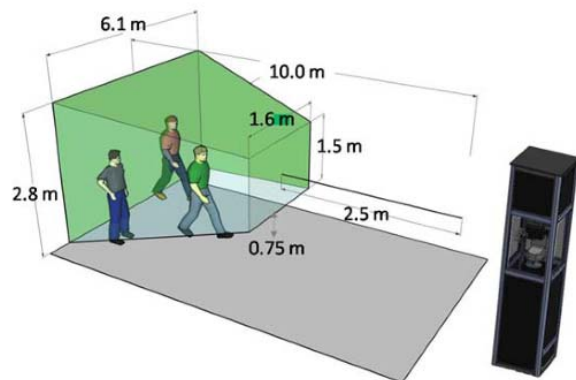


Development of light field cameras

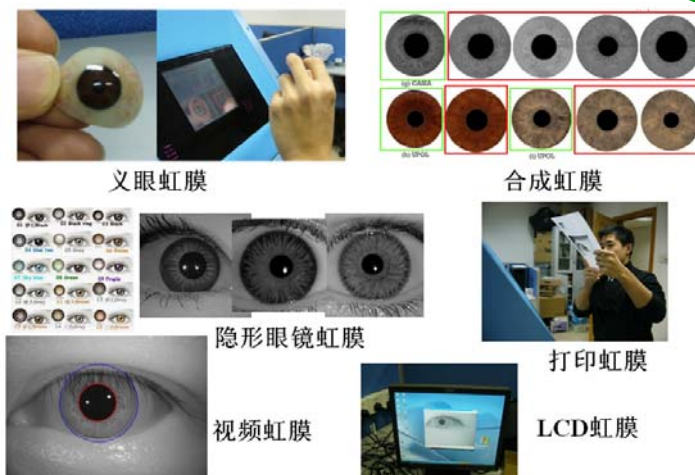
- High-resolution cameras with micro-optical lenslets
- Computational imaging algorithms (refocusing, depth estimation)



Promising applications of light field imaging in iris recognition



**Extending depth-of-field
(6X)**



Focus value variations of refocused image regions around human eyes

Genuine



Fake



Liveness detection

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



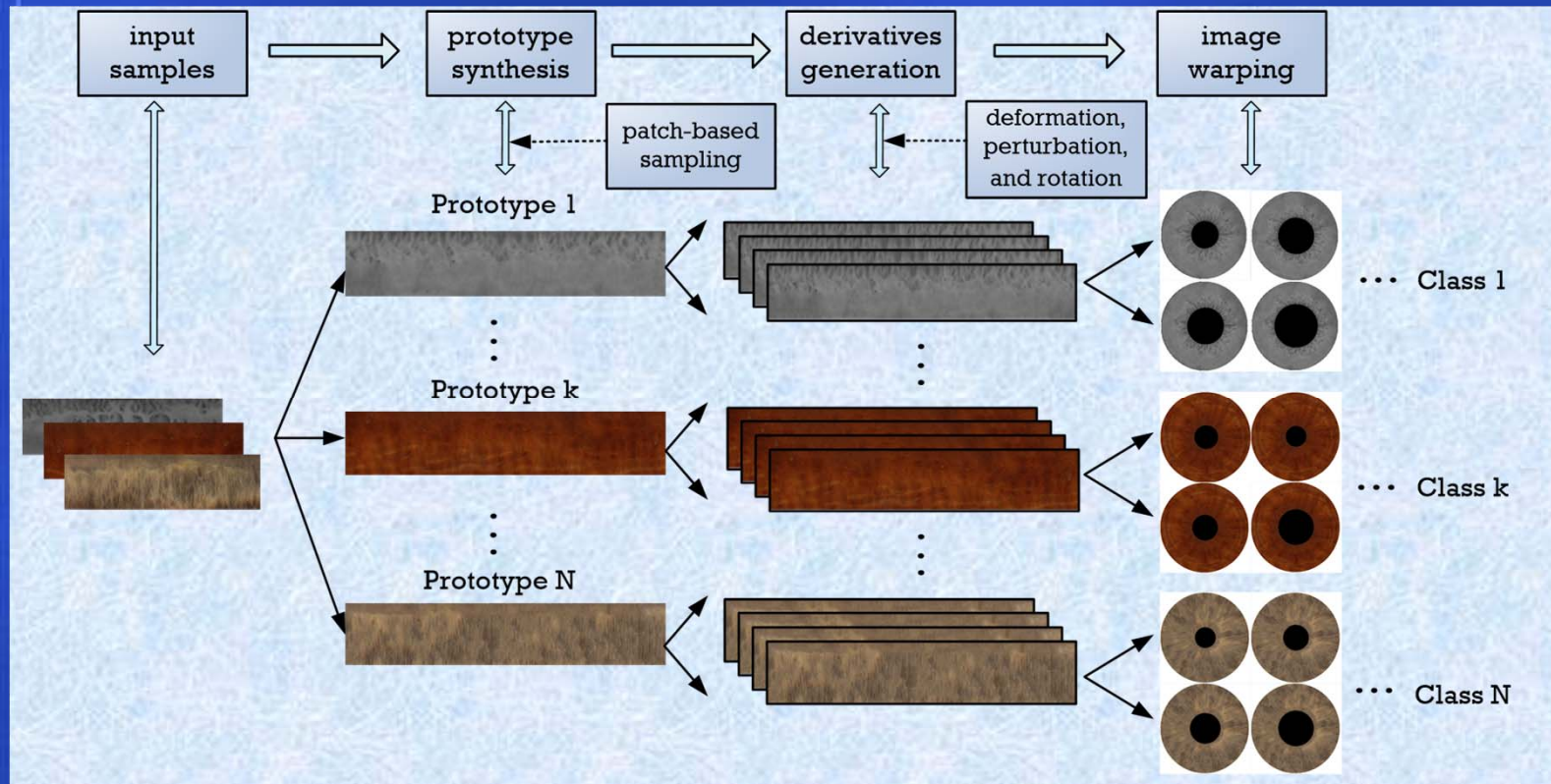
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Challenges of Iris Image Synthesis

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

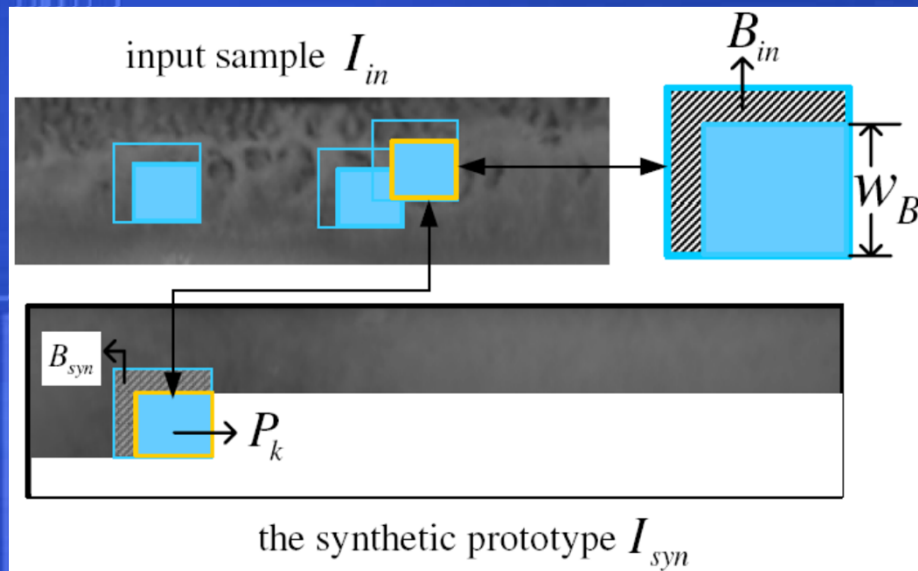


Iris image synthesis from exemplars

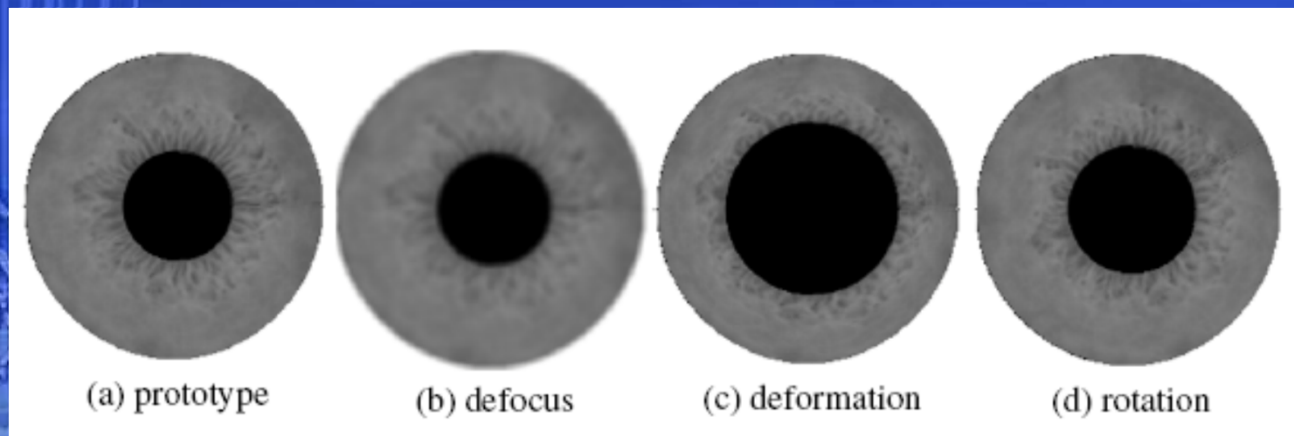


- 1) An input sample image is formed.
- 2) A prototype image is created.
- 3) Multiple images with intra-class variations are generated from the prototype.
- 4) The generated images are warped into annular shape.

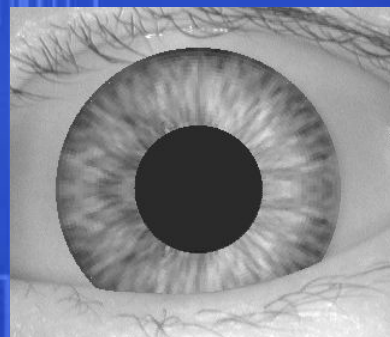
Techniques of iris image synthesis



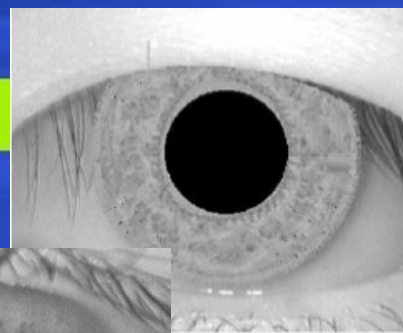
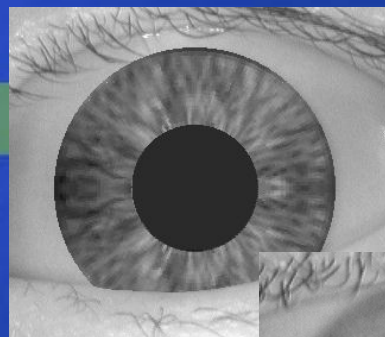
- Patch-based sampling is applied to synthesize iris prototype;
- Different strategies are deployed to create multiple samples.



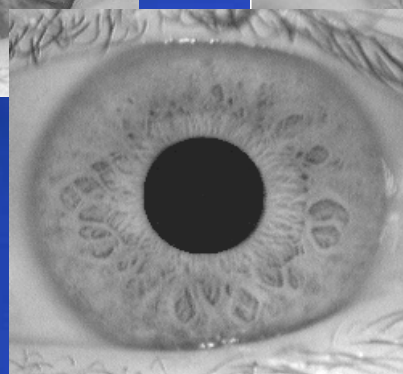
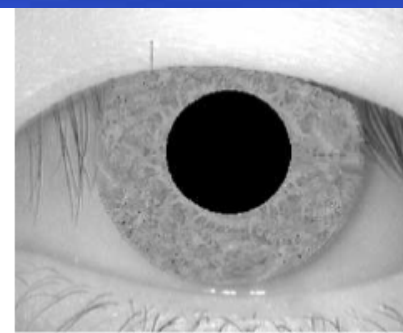
Realism of Synthetic Iris Images



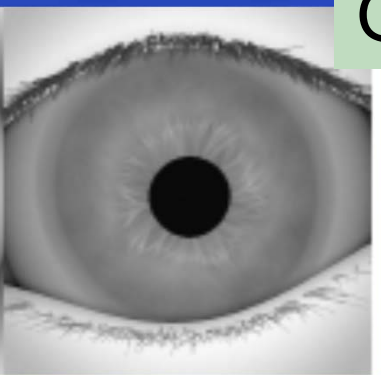
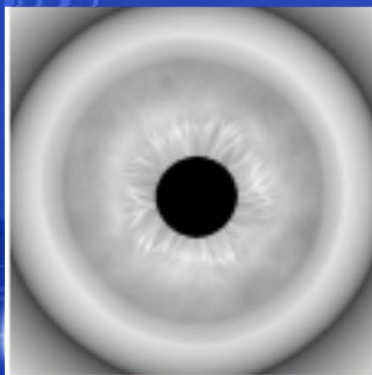
PCA



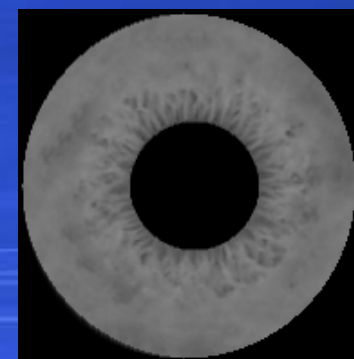
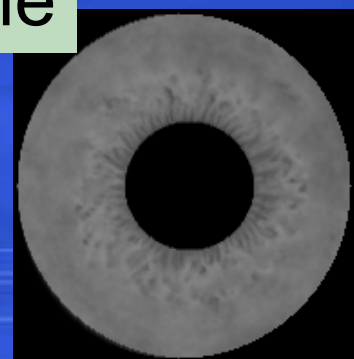
MRF



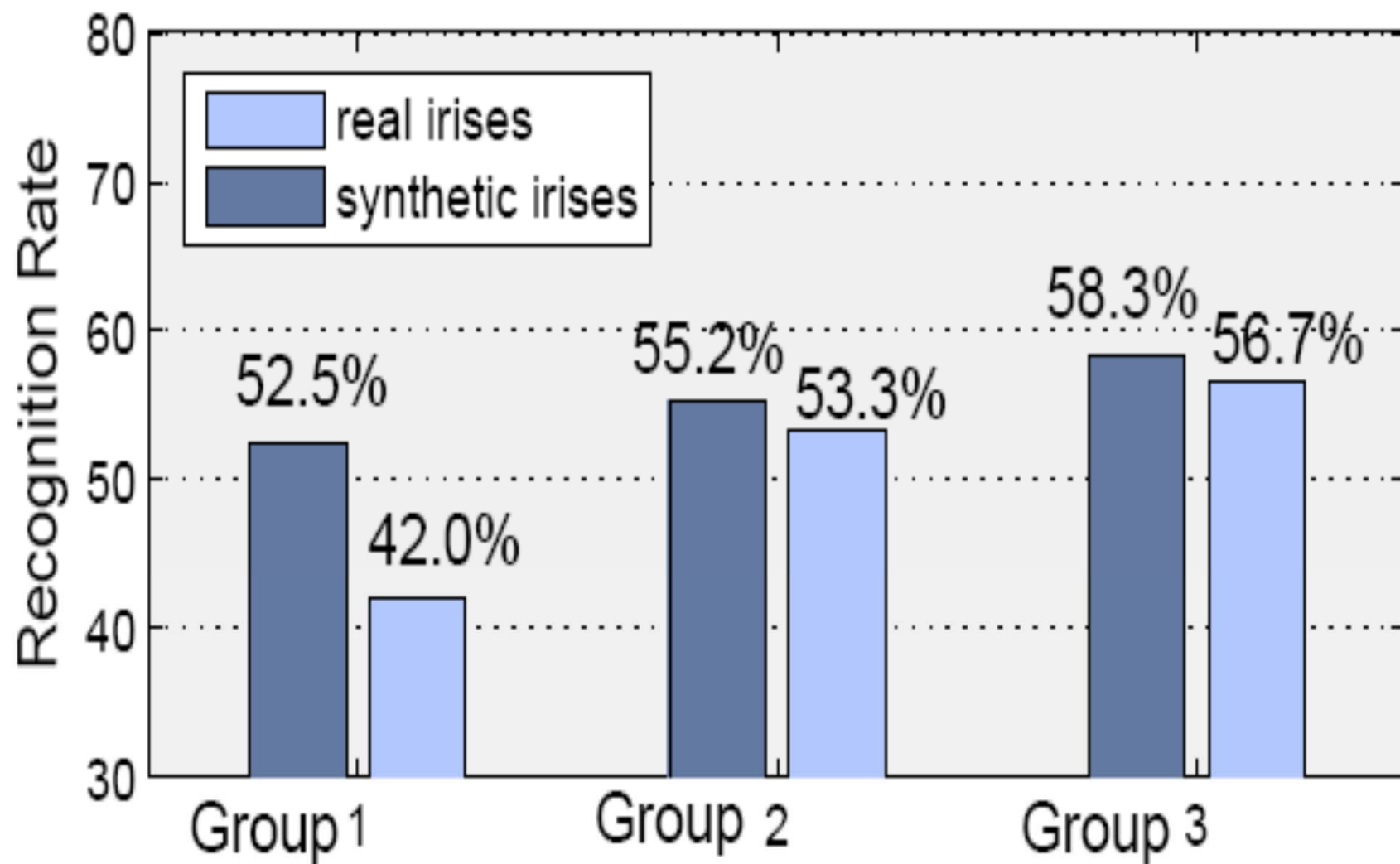
Genuine



Model based

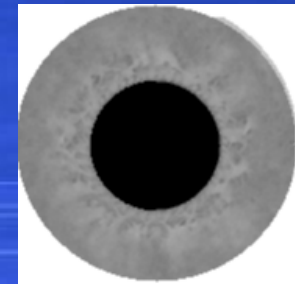
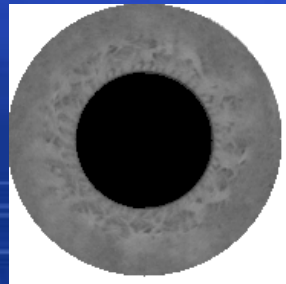
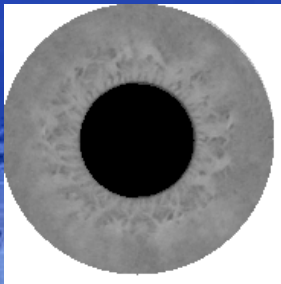
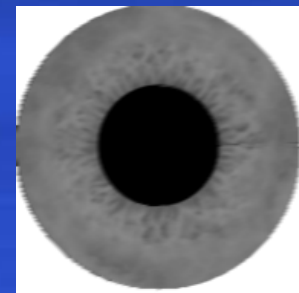


Patch sampling

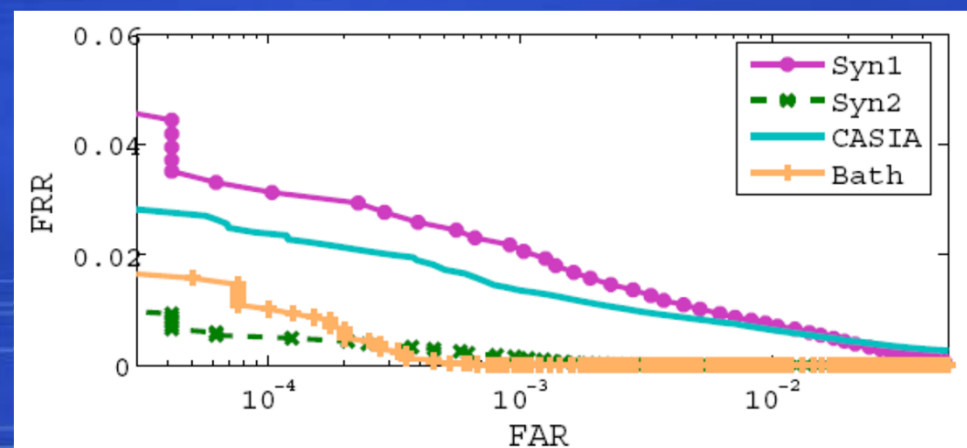
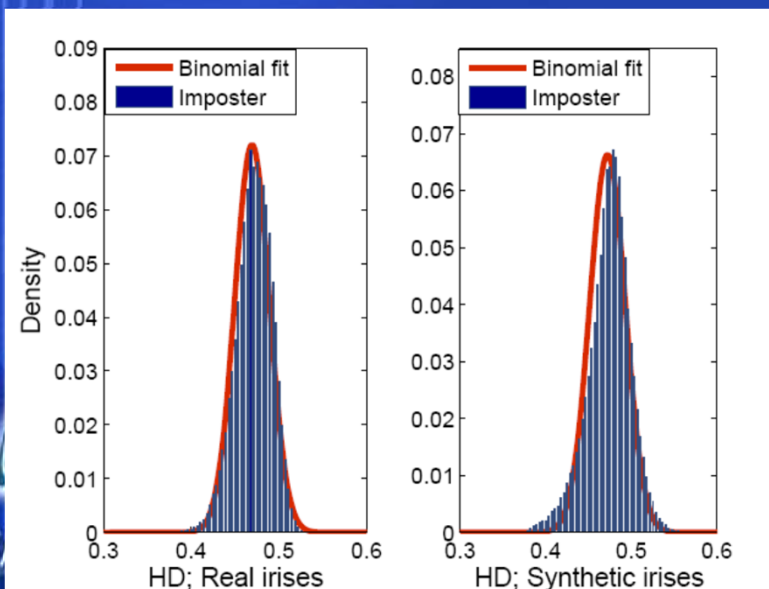
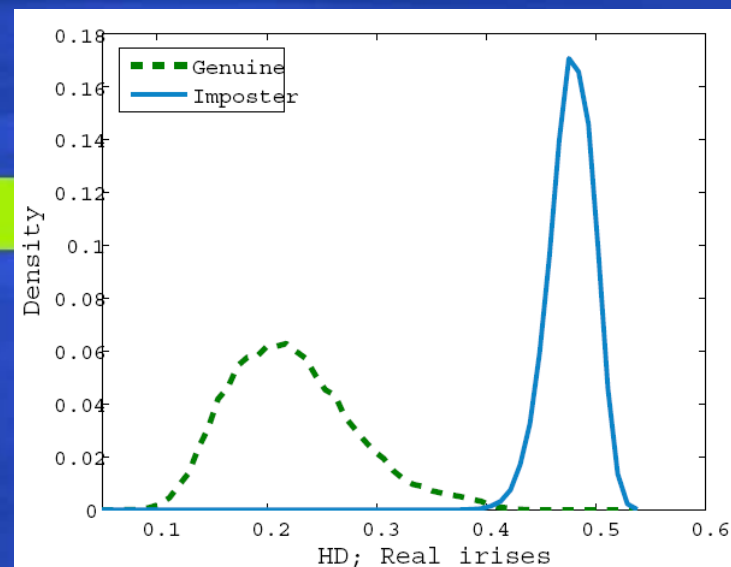
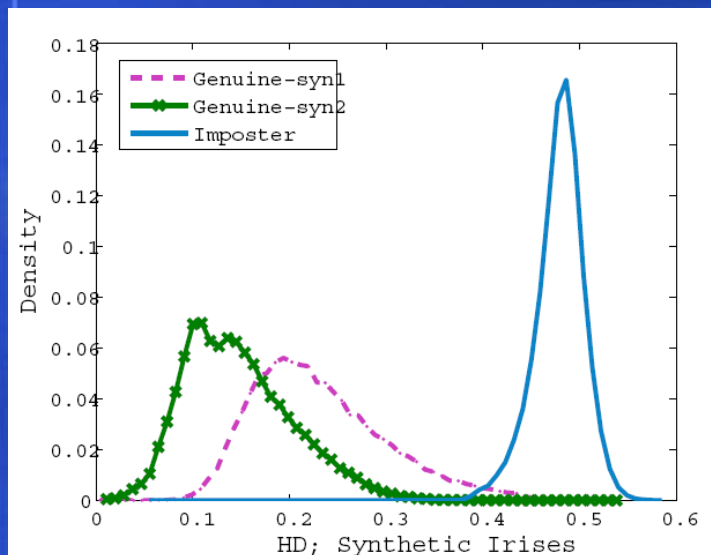


Database synthesis

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



Statistical similarity

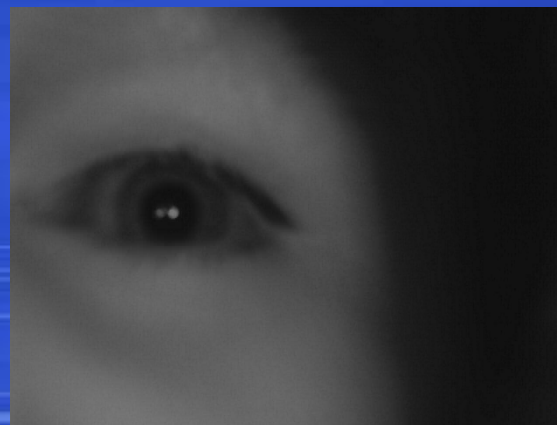


Outline of Talk

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

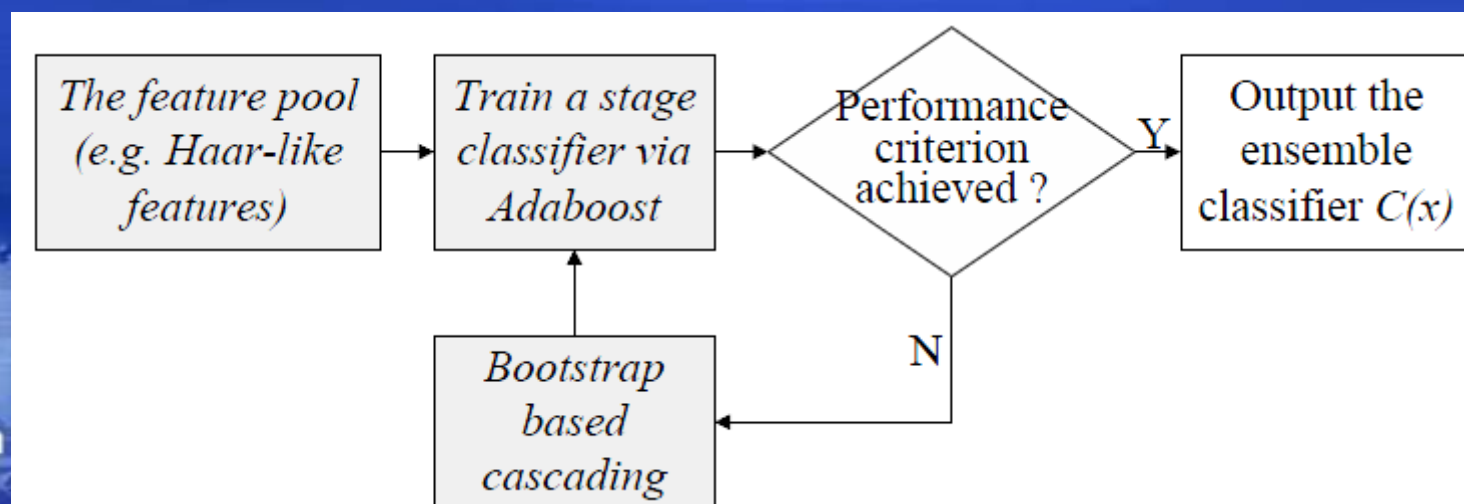
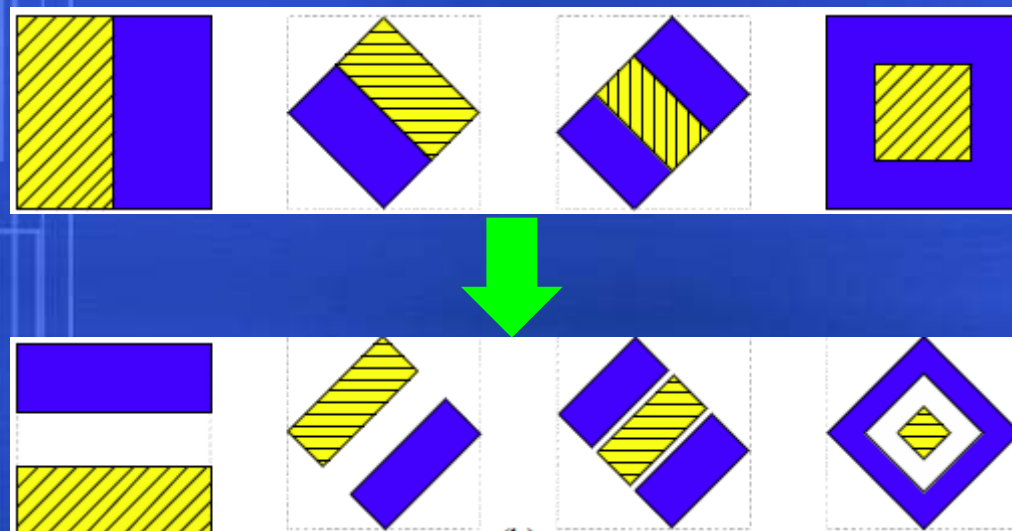
Iris detection

Is there an iris in the input image?

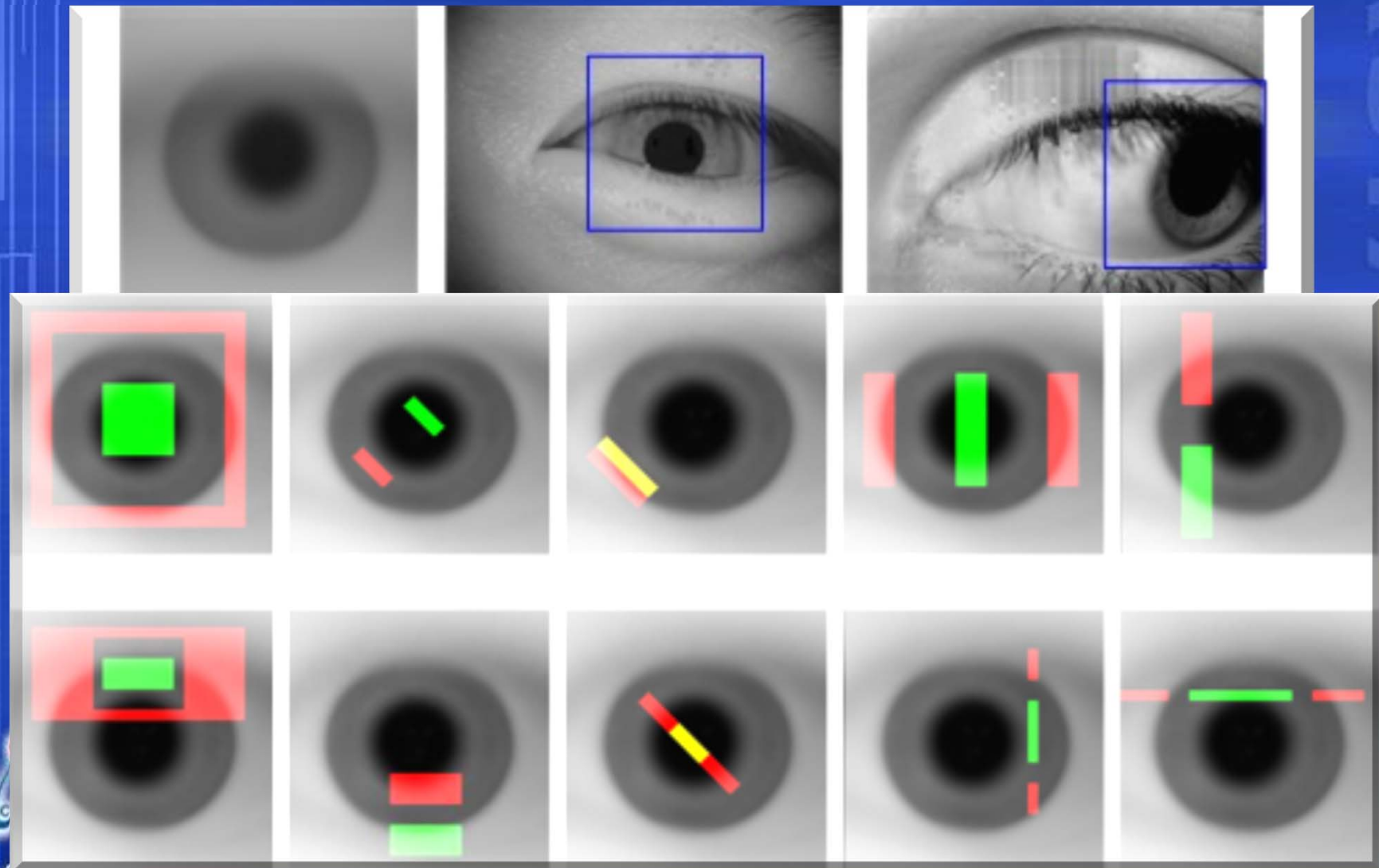


//www.ia.ac

Solution to iris detection: Extended Haar features + Boosting learning

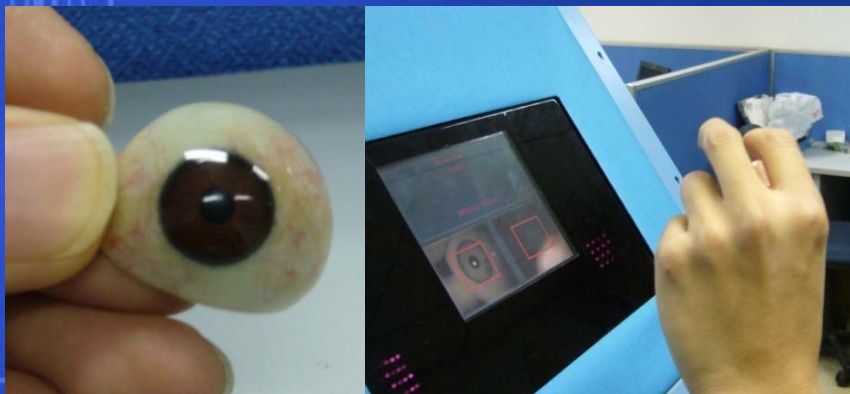


Iris detection results

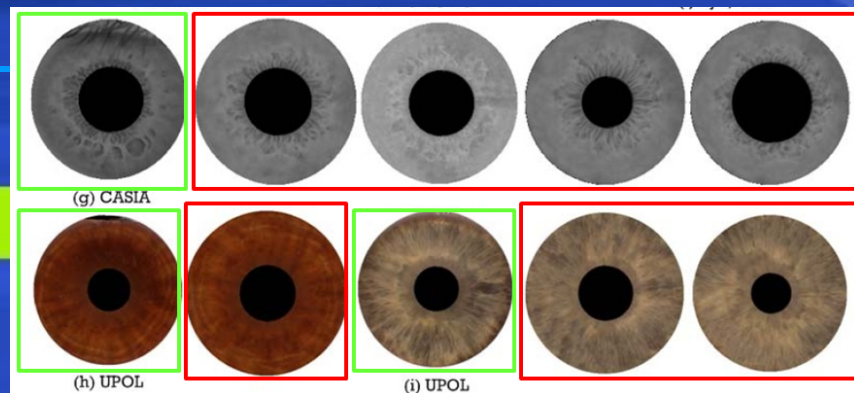


Correct detection rate is 99.2% on a database of 60,000 iris images

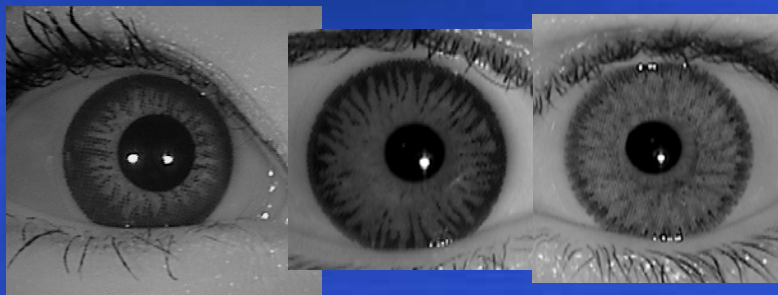
Risk of Fake Iris Attacks



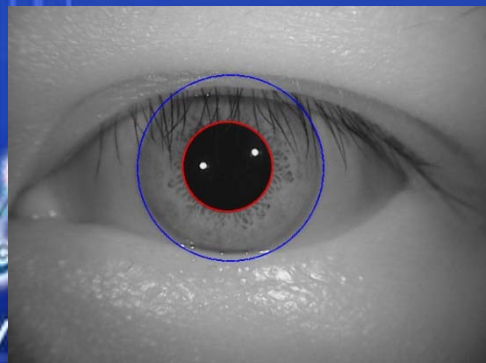
Well-made eye model



Synthetic iris



Contact lens



Video iris



LCD iris

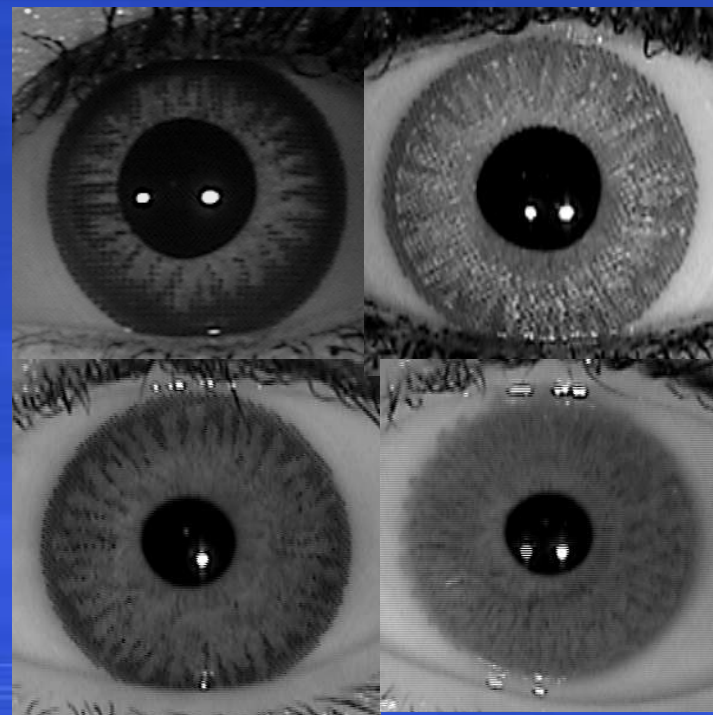
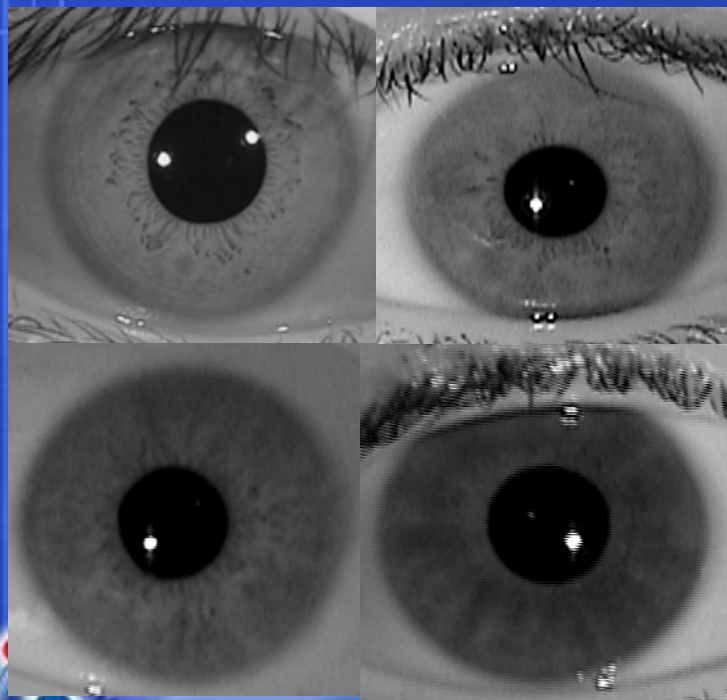


Printed iris

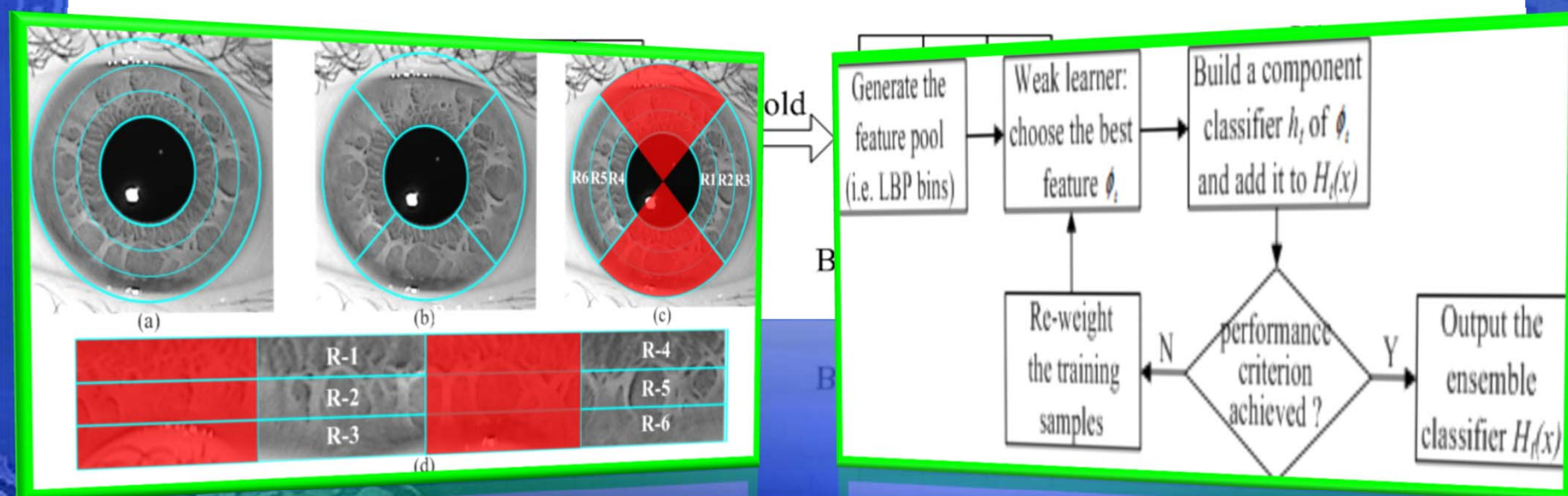
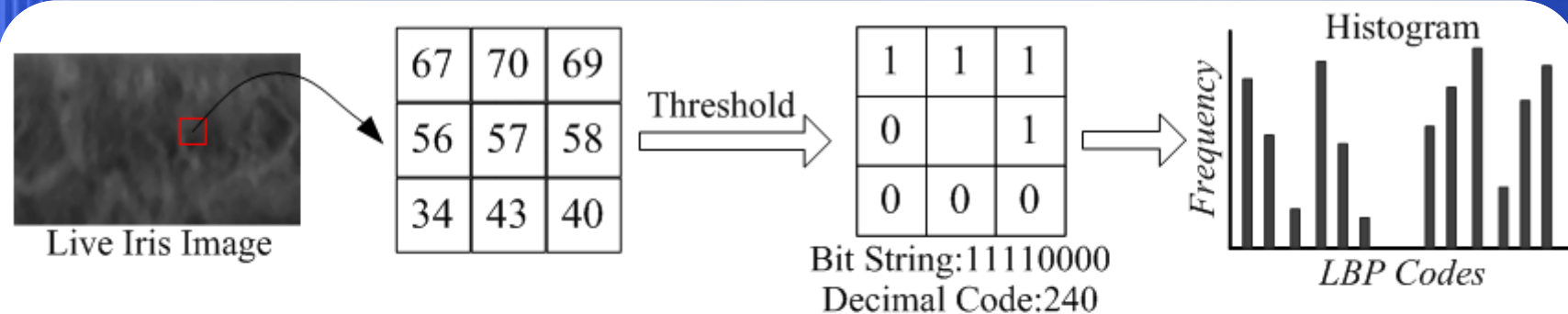
Iris liveness detection: a texture solution

Smooth texture

Coarse texture

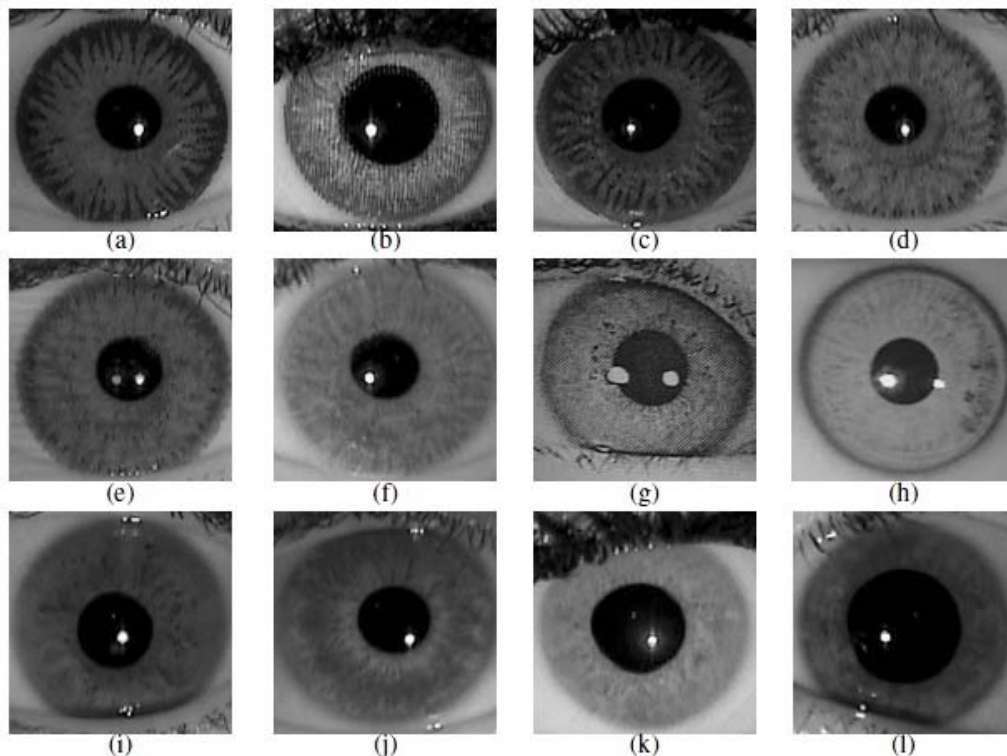


LBP+Boosting



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

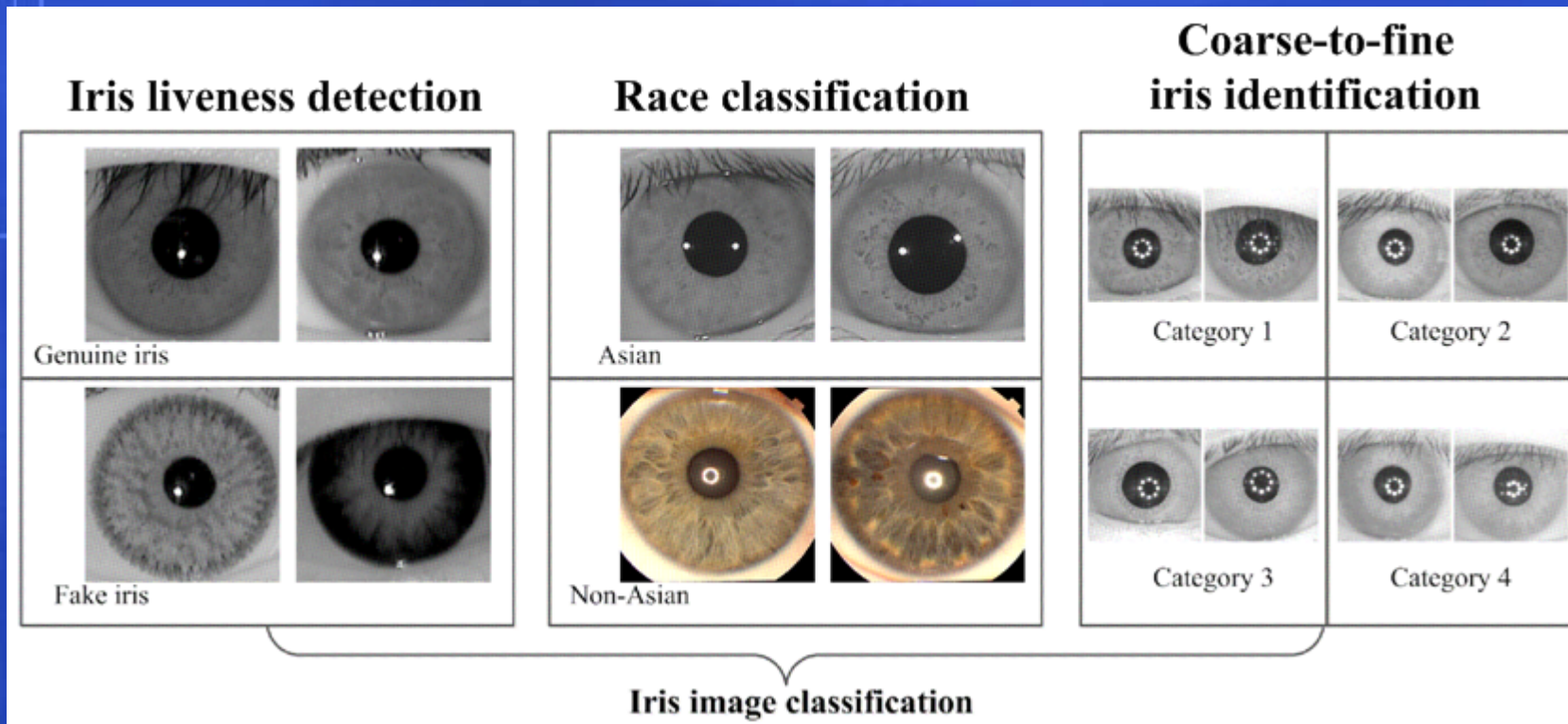
- 300 fake iris images
- 4000 genuine iris images



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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

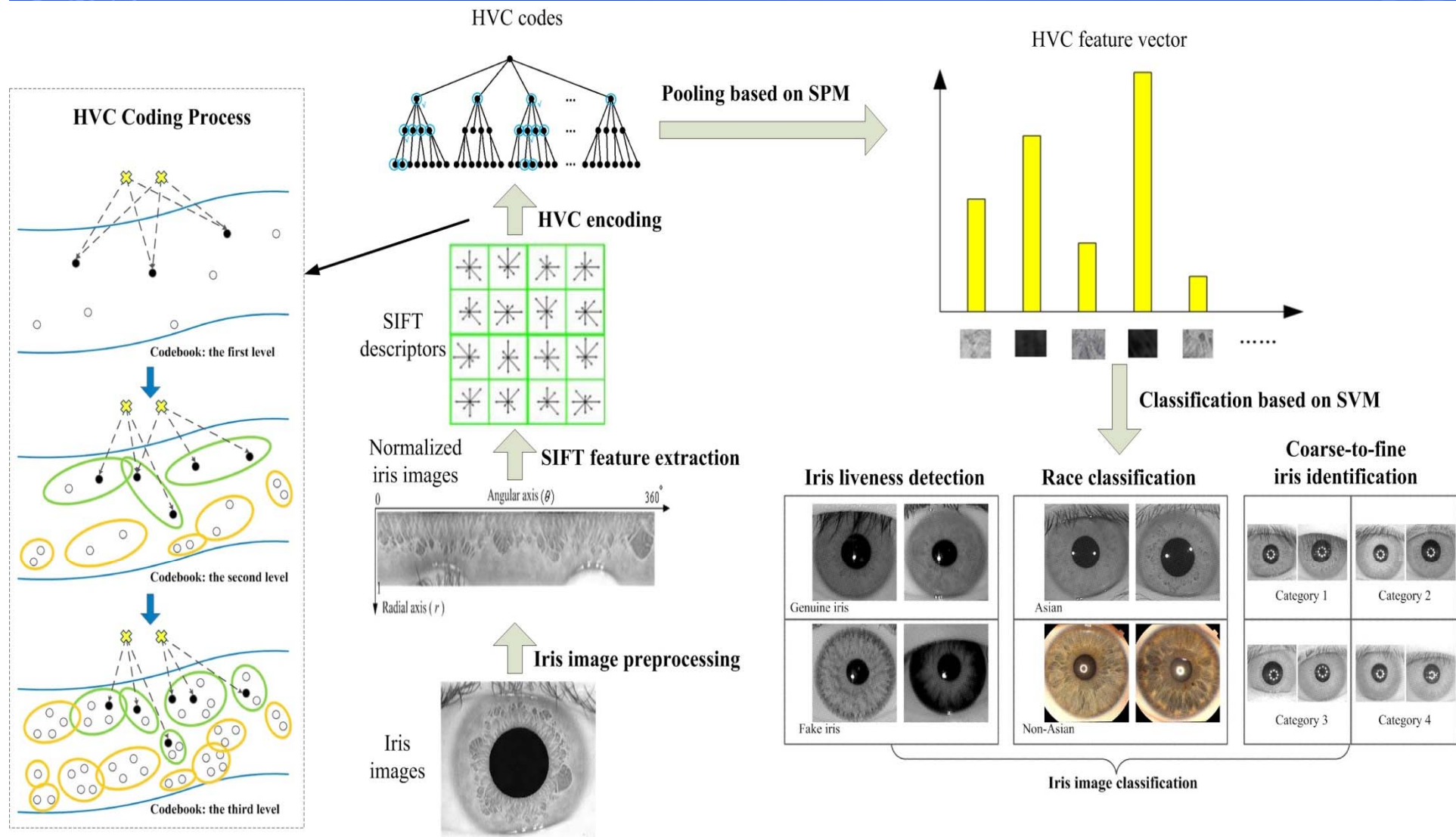
Iris image classification: one solution to multiple problems



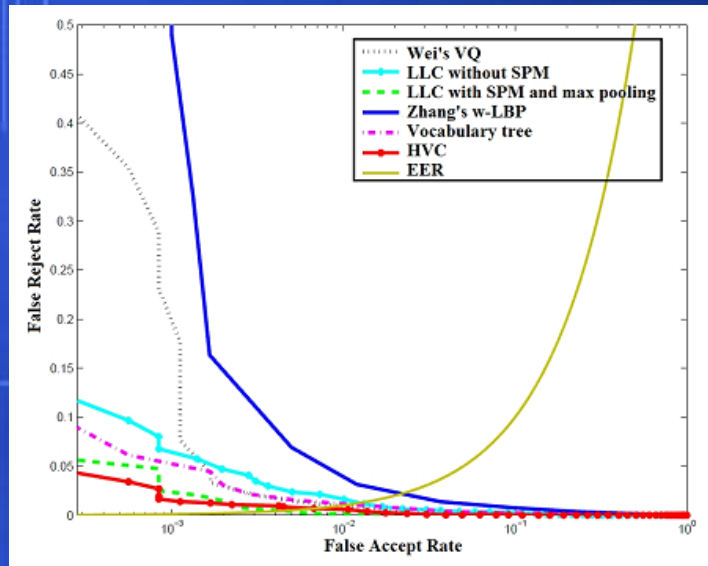
Iris image classification:

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

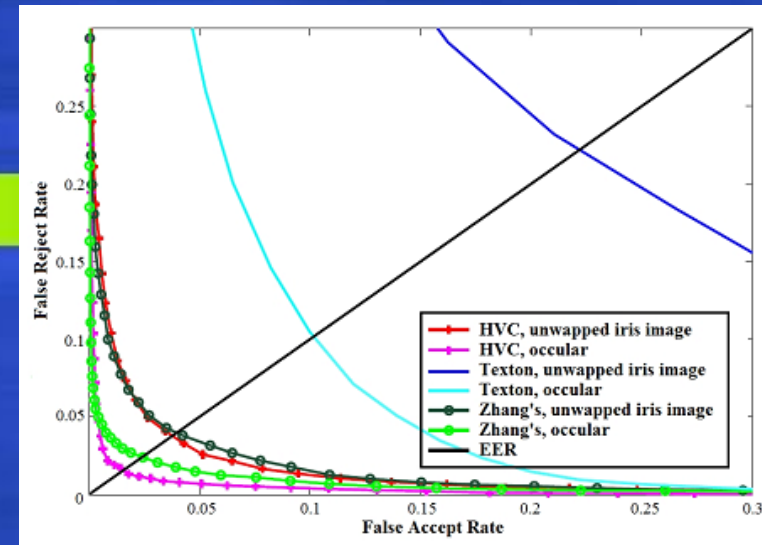
Iris Image Classification Based on Hierarchical Visual Codebook (HVC)



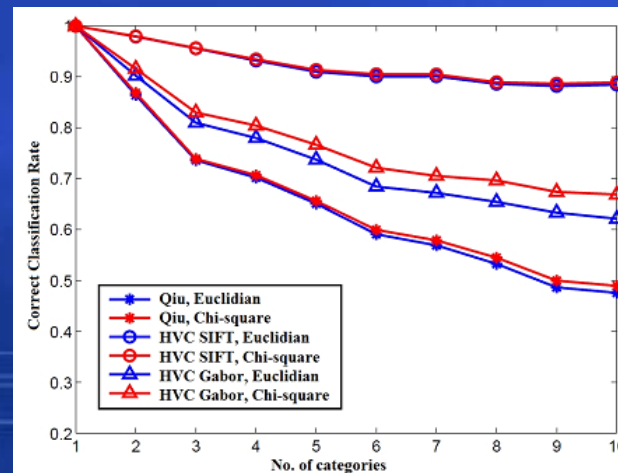
Experimental results



Iris liveness detection



Race classification

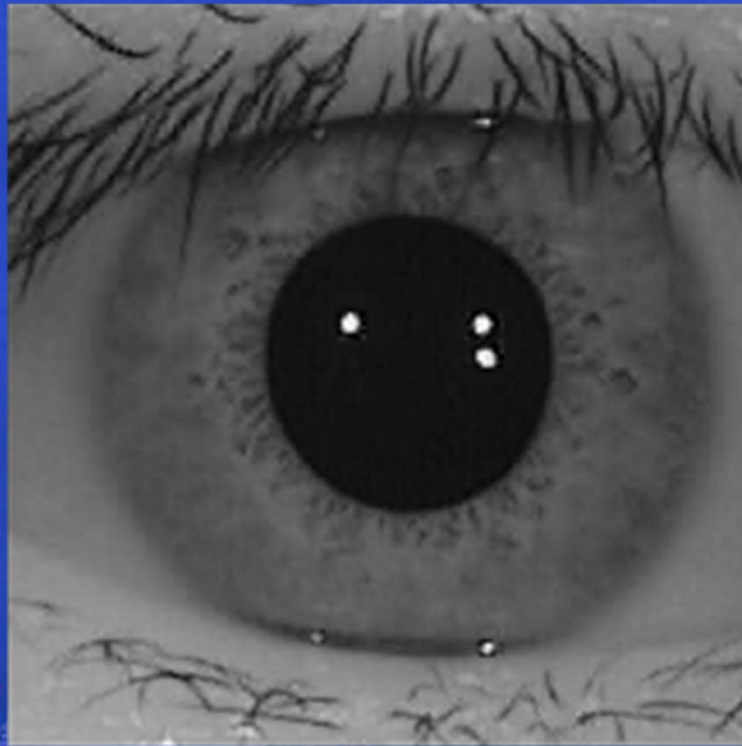


Classification of iris images in large database

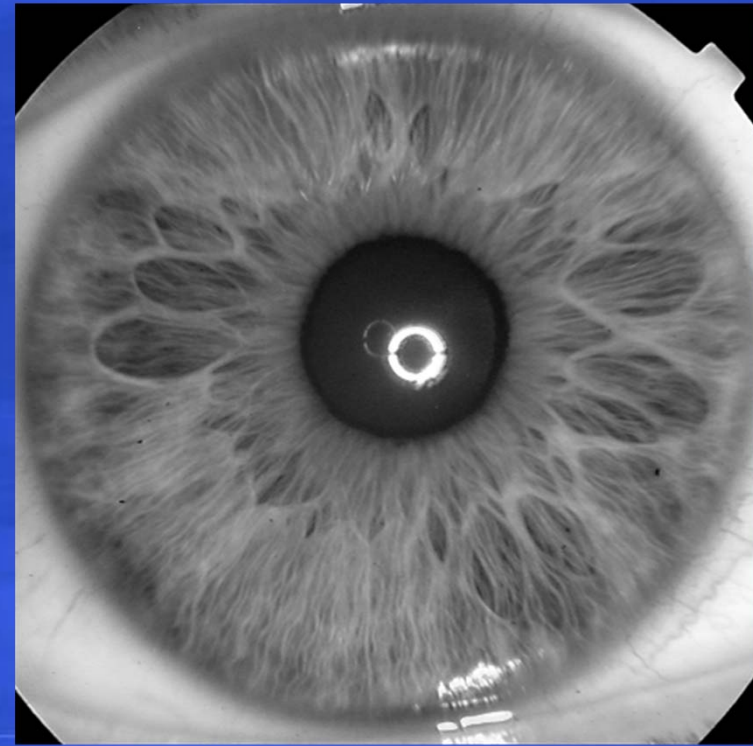


[//www.iq.ac.cn](http://www.iq.ac.cn)

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.



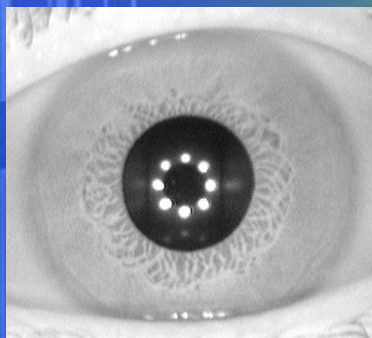
Asian



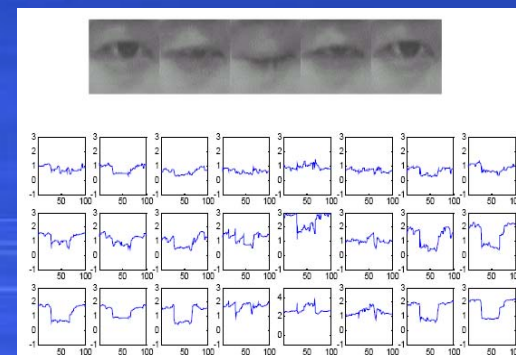
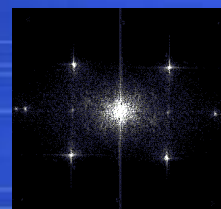
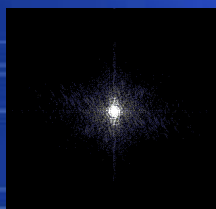
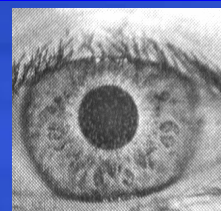
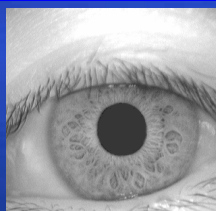
Non-Asian



Other possible ways for iris liveness detection

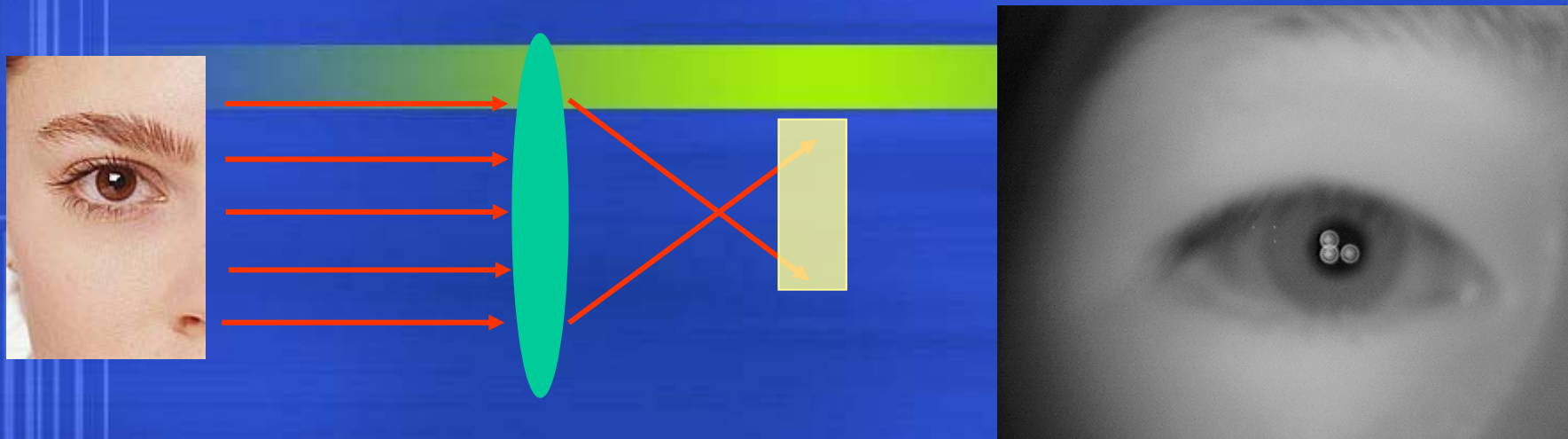


1. Spectrographic properties of physiological components of eye
2. Specular reflections caused light spots
3. Eyelid movement
4. Challenge-response
5. Facial features, head movement, body sway, etc.
6. Multi-biometrics

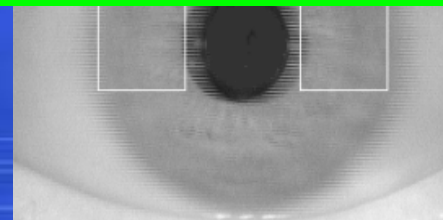
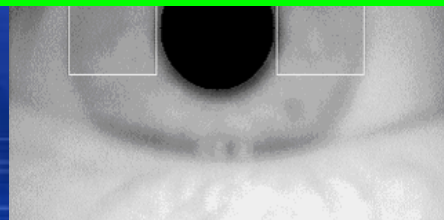


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Iris image quality assessment



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



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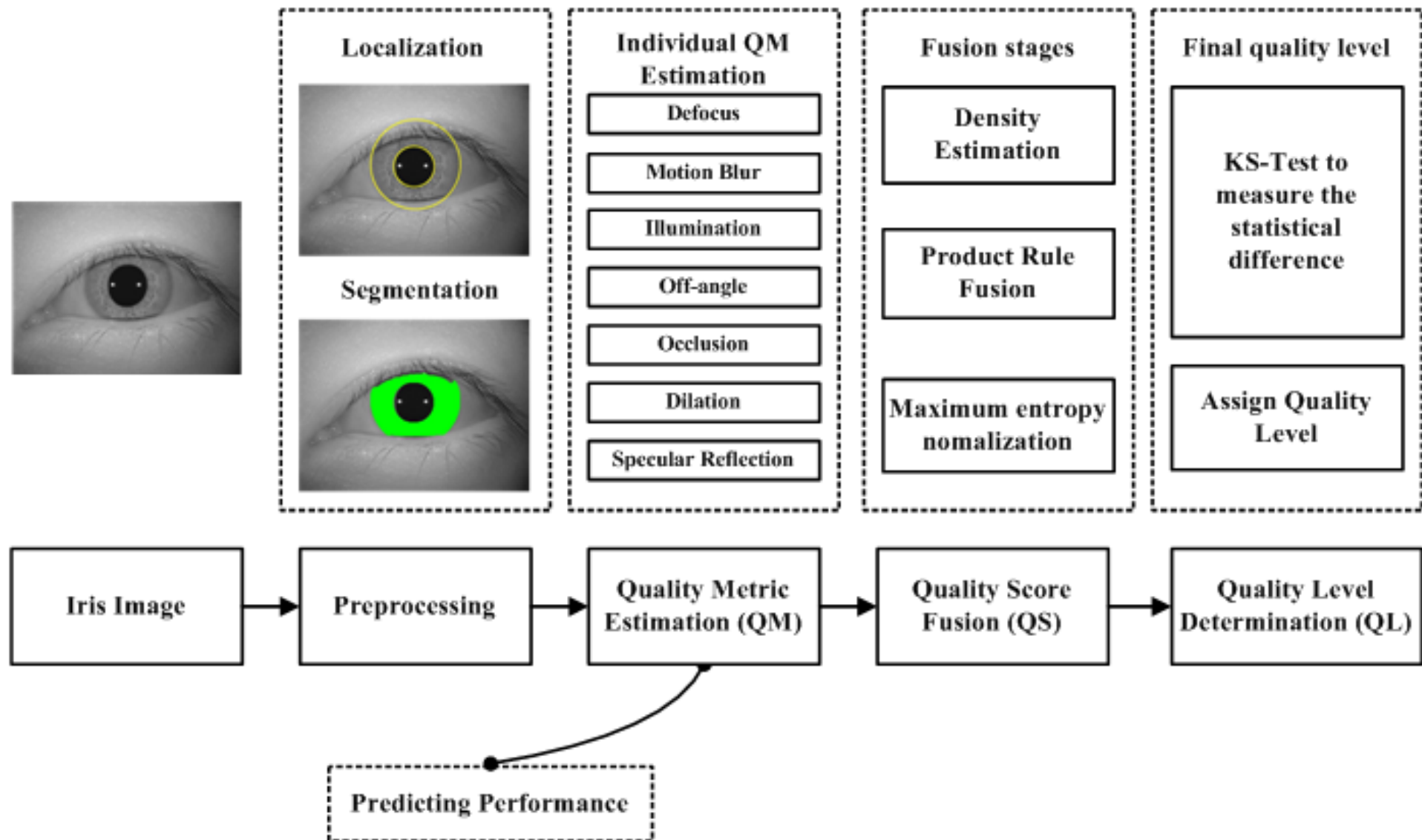
Clear

Defocused

Motion blurred

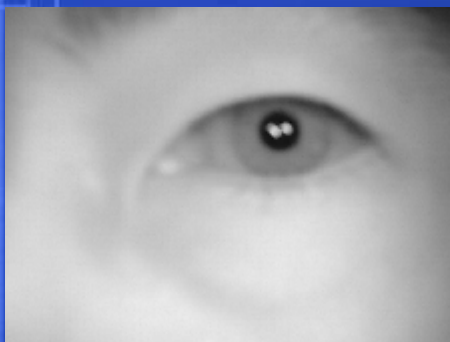
Occluded

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



The first Q: quality metric estimation

Defocus



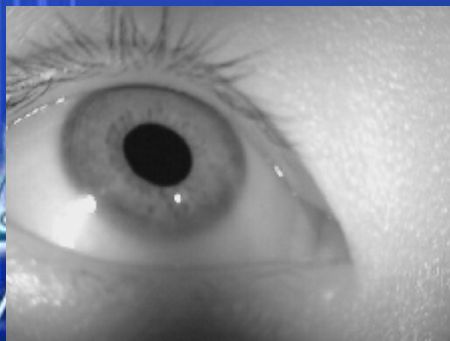
Motion blur



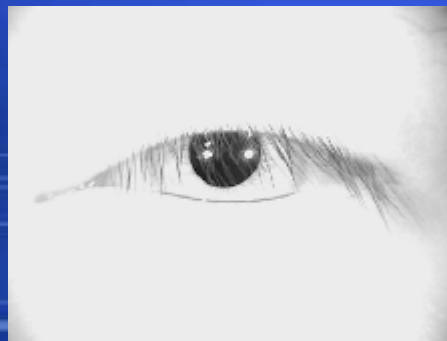
Valid area



Off-angle



Illumination



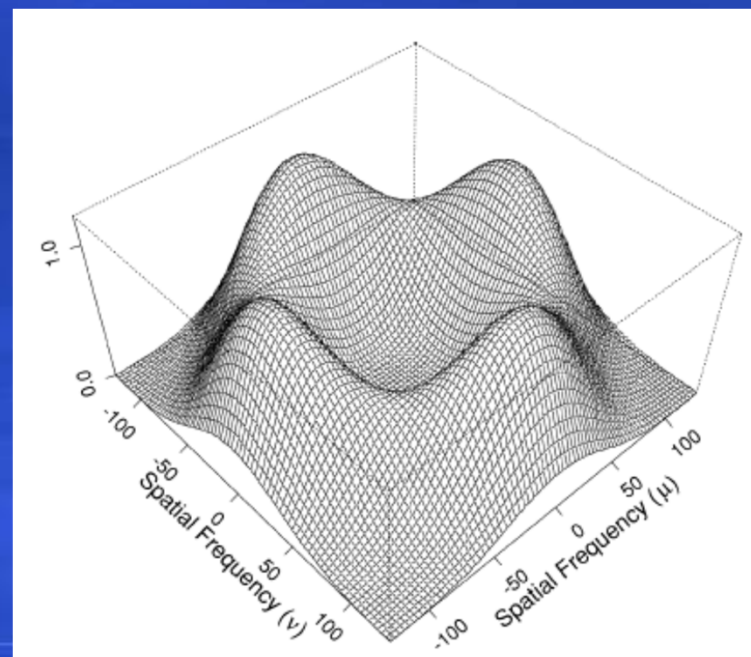
Dilation



Defocused blur assessment

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

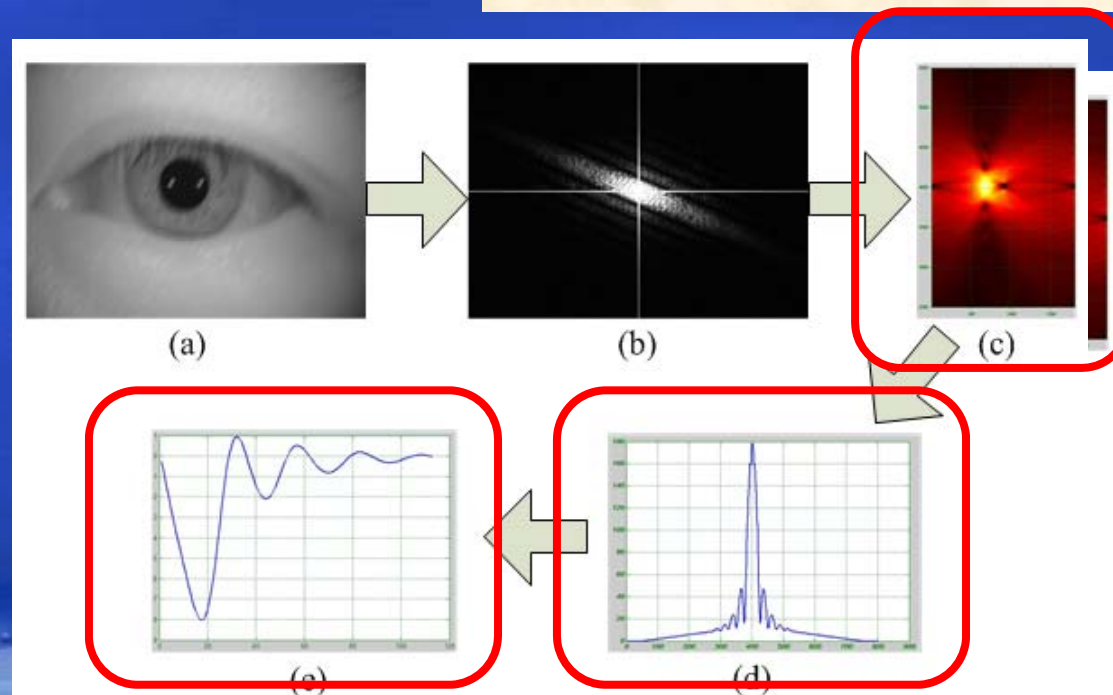
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1



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

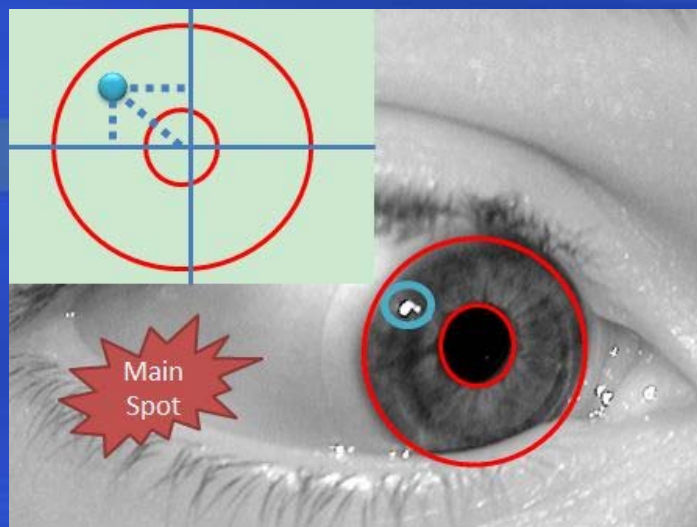
$$R_{p,\theta} = \iint_D f(x,y) \delta(P - x \cos \theta - y \sin \theta) dx dy$$



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

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

Off-angle iris image identification

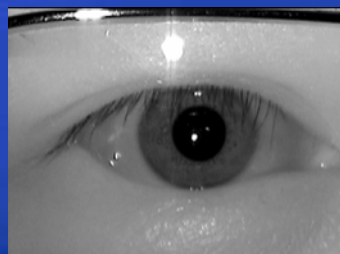


Geometric
Information

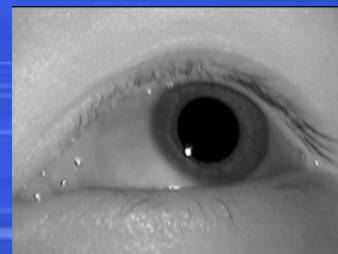
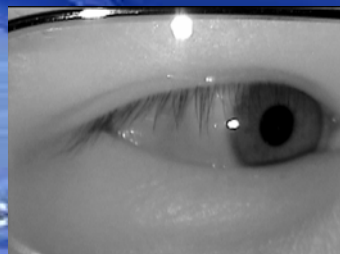


Classifier

Frontal iris
images

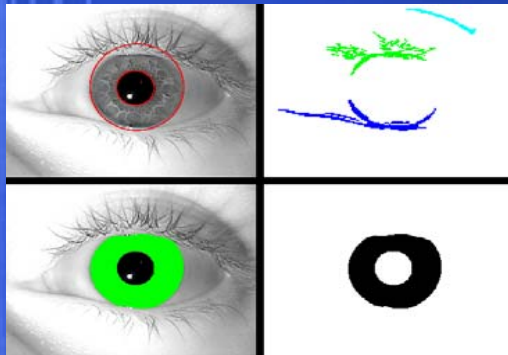


Off-angle iris
images

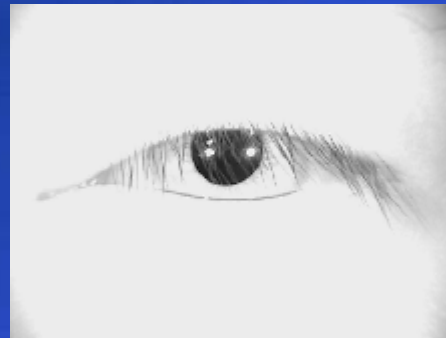


Other quality metrics

Valid area

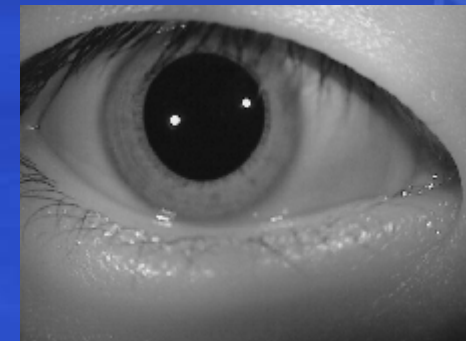


Illumination



Mean gray value in the valid
iris region

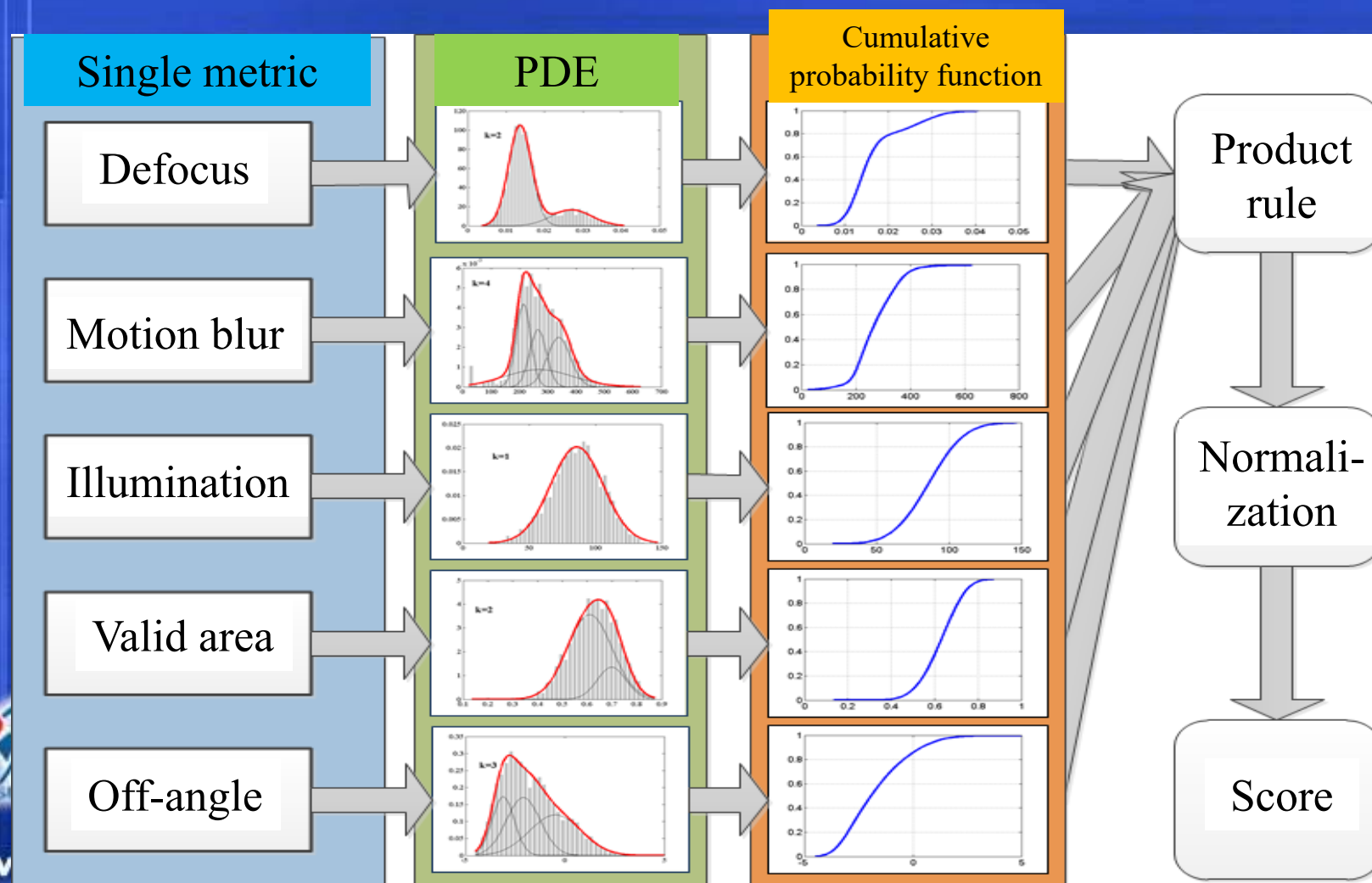
Dilation



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

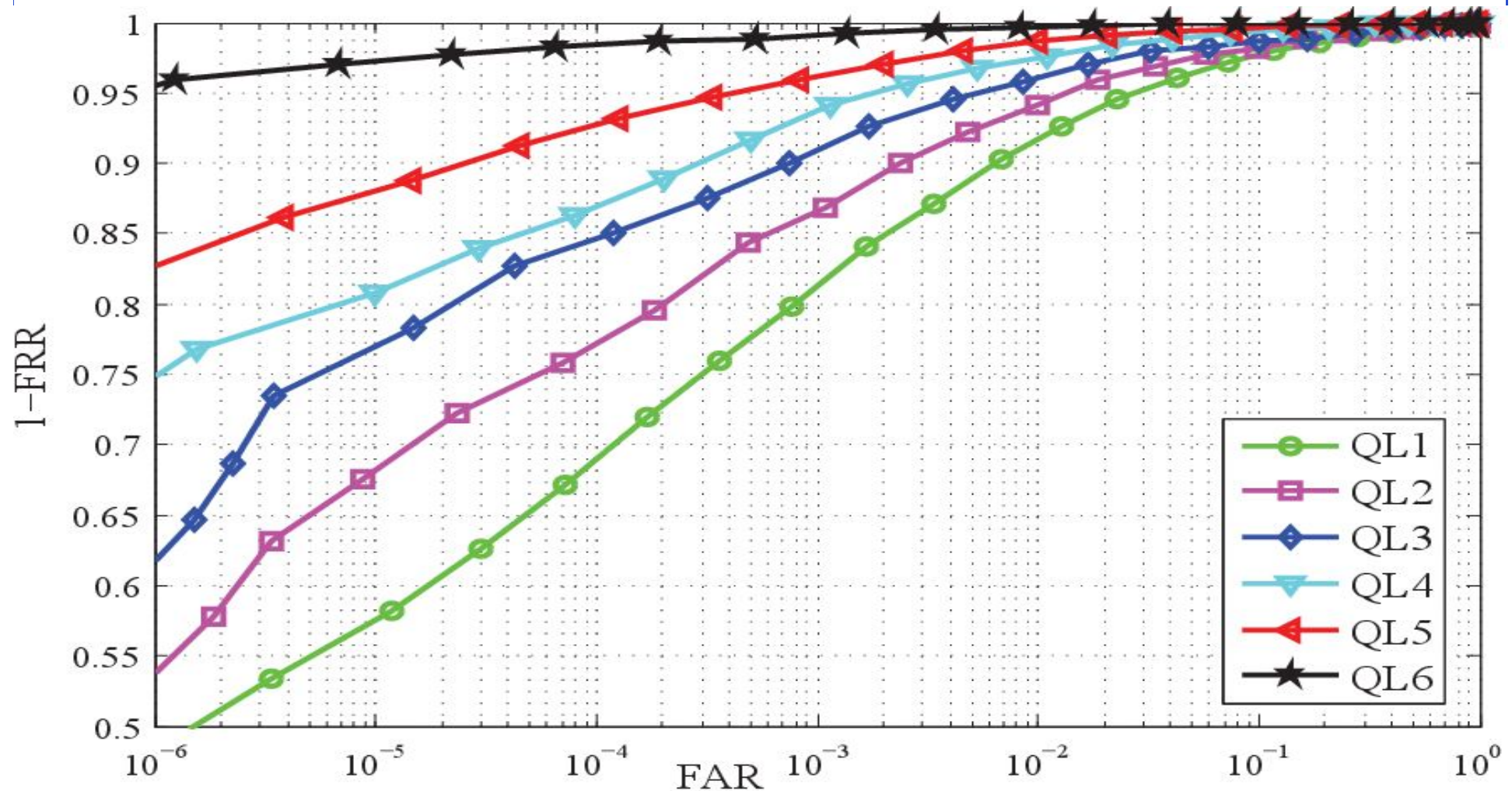


The second Q: quality score fusion from multiple metrics



The third Q: quality level determination

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



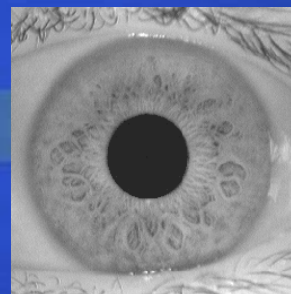
Applications of iris image quality assessment

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

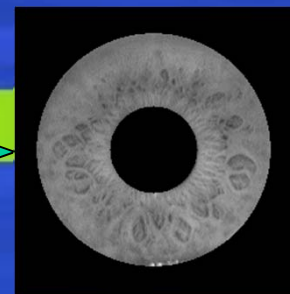


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Iris image preprocessing



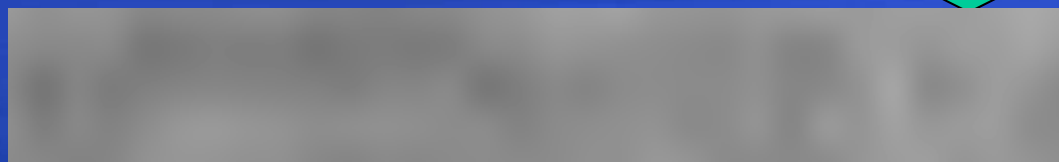
Iris localization/
segmentation



Iris normalization



Illumination
estimation

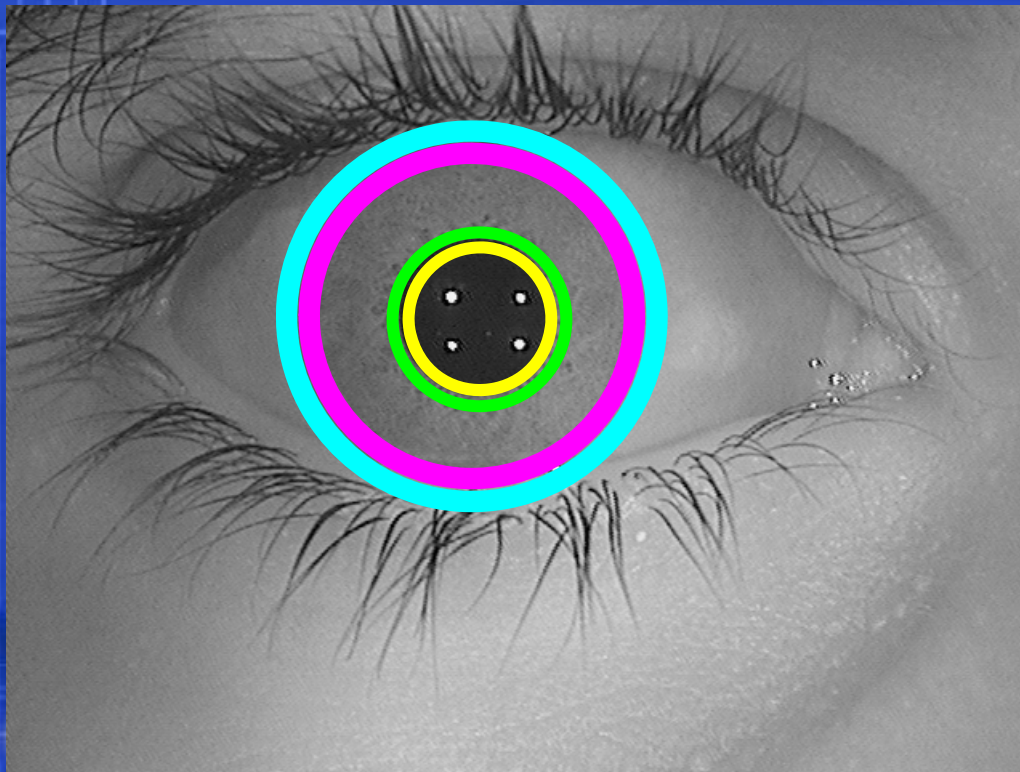


Enhancement



Iris localization

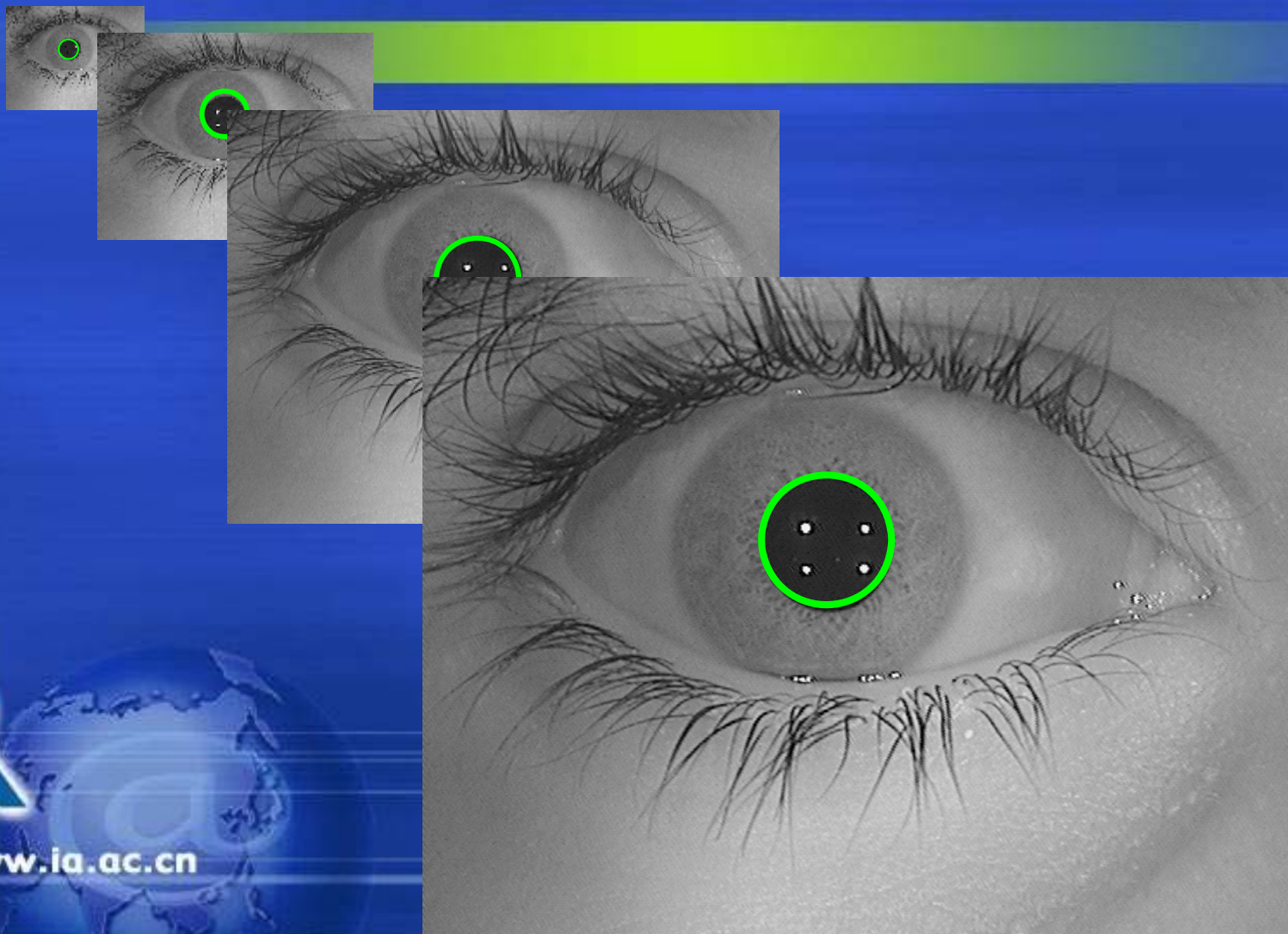
—Daugman's algorithm—



Integral-differential operator

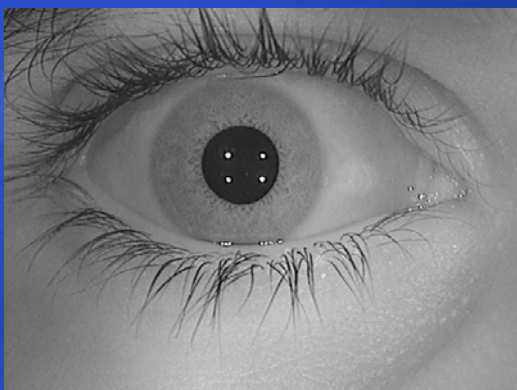
$$\max_{(r, x_0, y_0)} \left| G_{\sigma}(r) * \frac{\partial}{\partial r} \oint_{r, x_0, y_0} \frac{I(x, y)}{2\pi r} ds \right|$$

Coarse to fine strategy

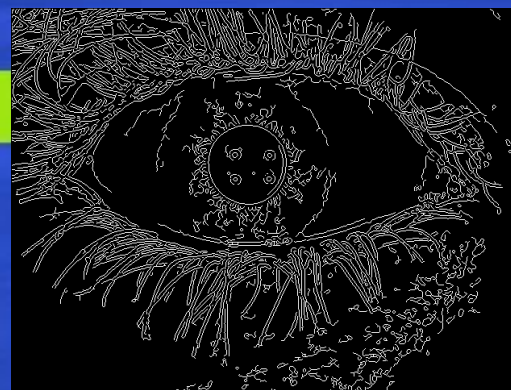
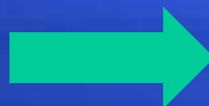


Iris localization

—Wildes' algorithm—



Edge
detection



Hough transform



253 edge
points
support me

761 edge
points
support me

65 edge
points support
me



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The main challenges of iris image segmentation

Eyeglass frames

Low contrast boundary

Specular reflections

Occlusion

Deformation (Off-angle)

Related works

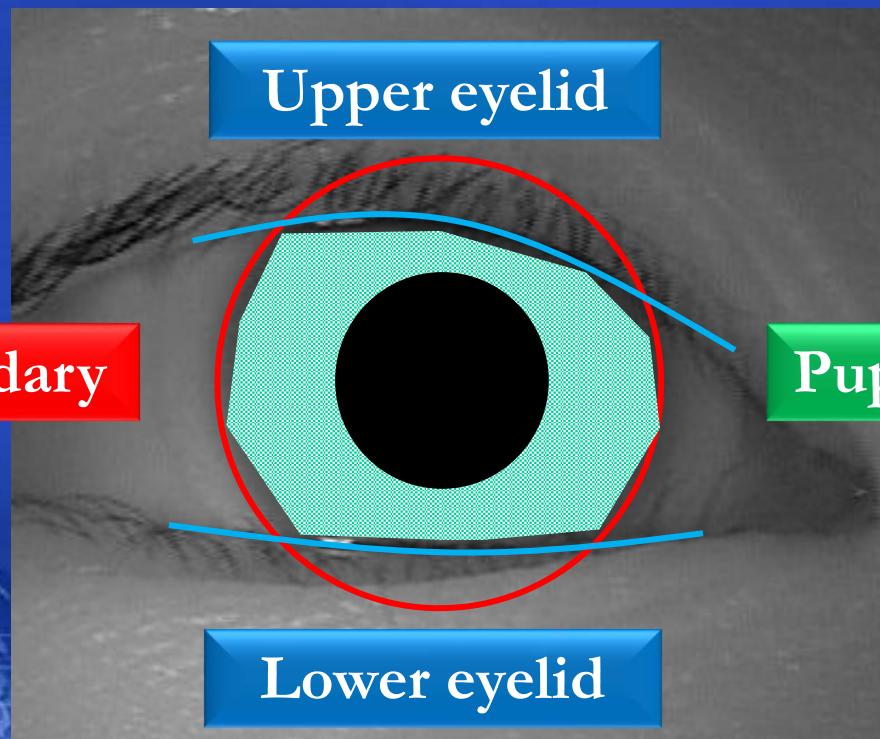
Region Based Methods

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)

Limbic boundary



Pupillary boundary

Lower eyelid



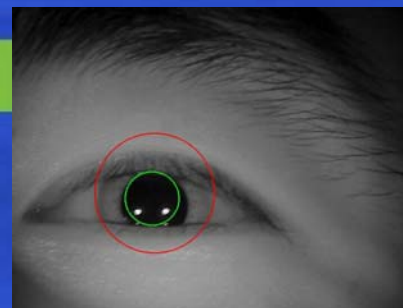
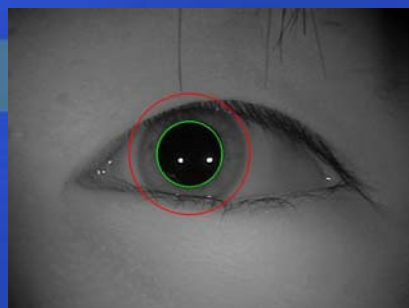
The main problems of edge based methods

Unclear boundary

Eyeglasses

Occlusion

Original



Gradient



Canny edge



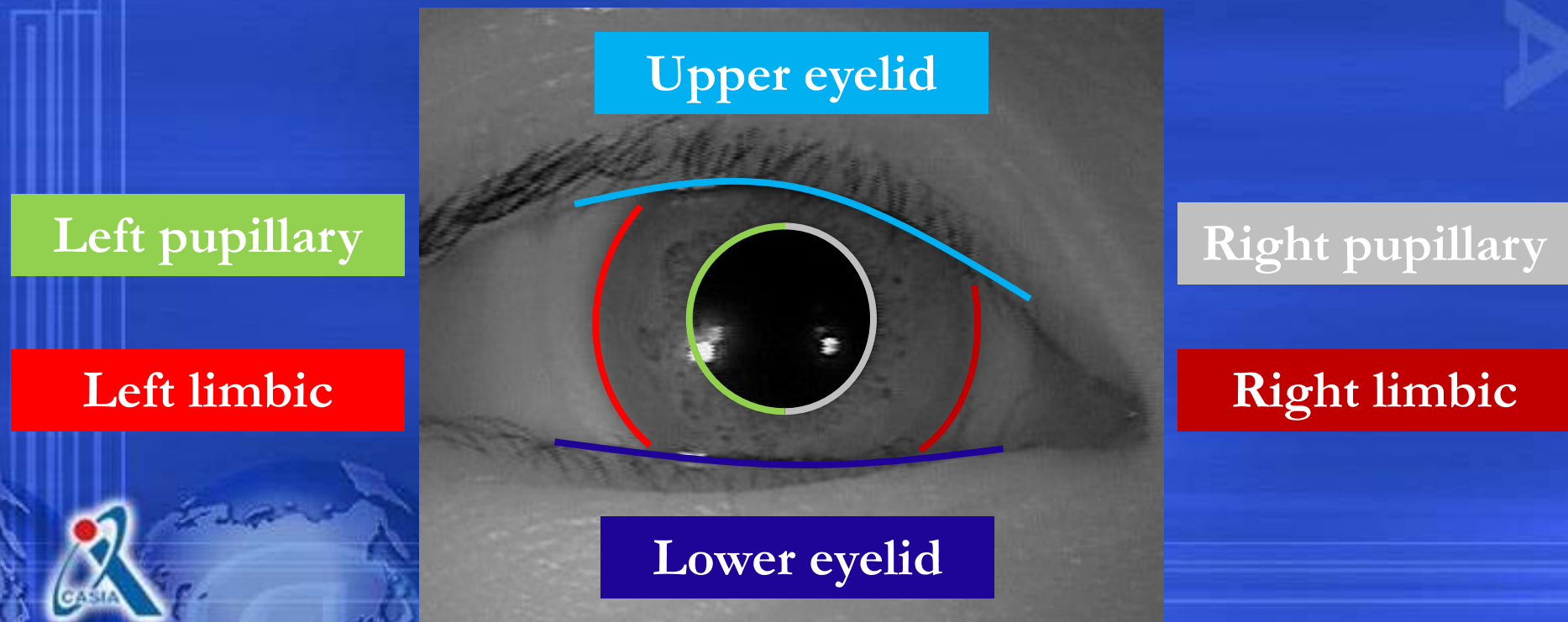
How to identify the edges on the iris boundaries?



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

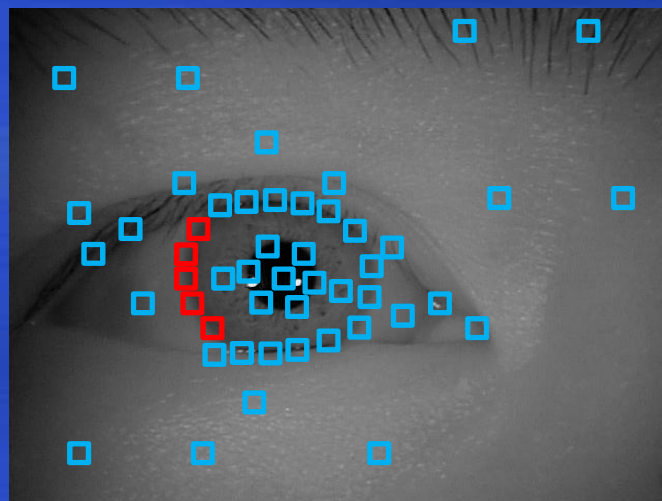
Learned Boundary Detectors (LBDs)

Main idea: **Generic** to **Specific** edge detector



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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

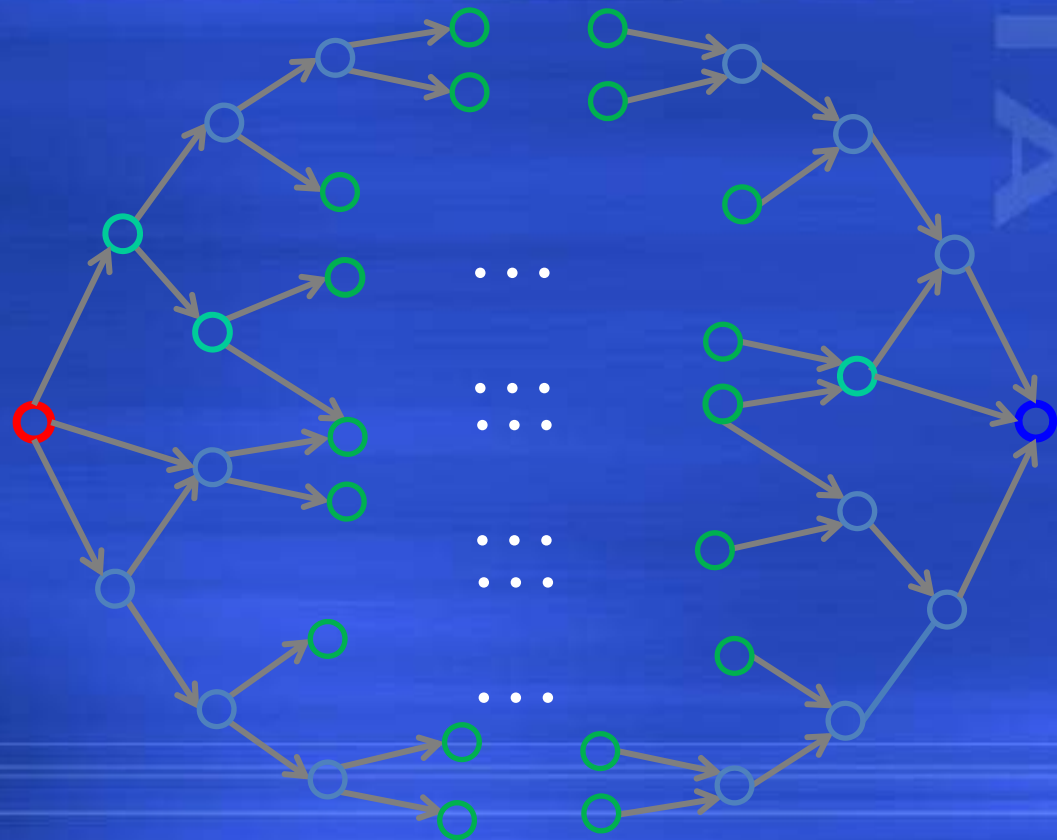
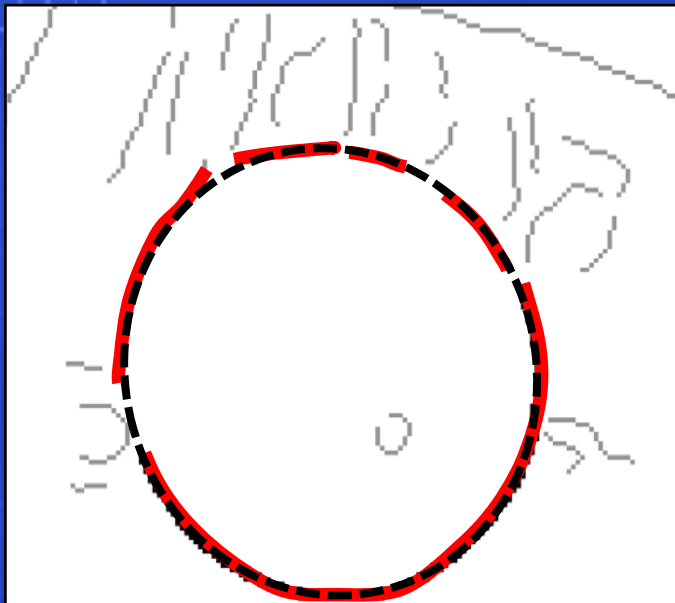
14091 features
in total

Integer intensities

All features can be computed efficiently

Contour connection based on energy minimization

$$\mathcal{C} = w_{LBD} \mathcal{C}_{LBD} + w_d \mathcal{C}_d + w_{\theta} \mathcal{C}_{\theta}$$



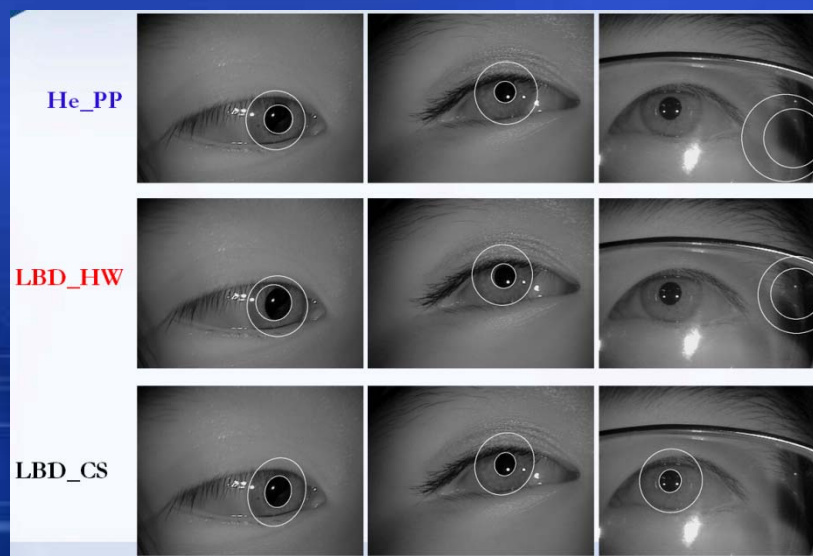
Performance of iris localization

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

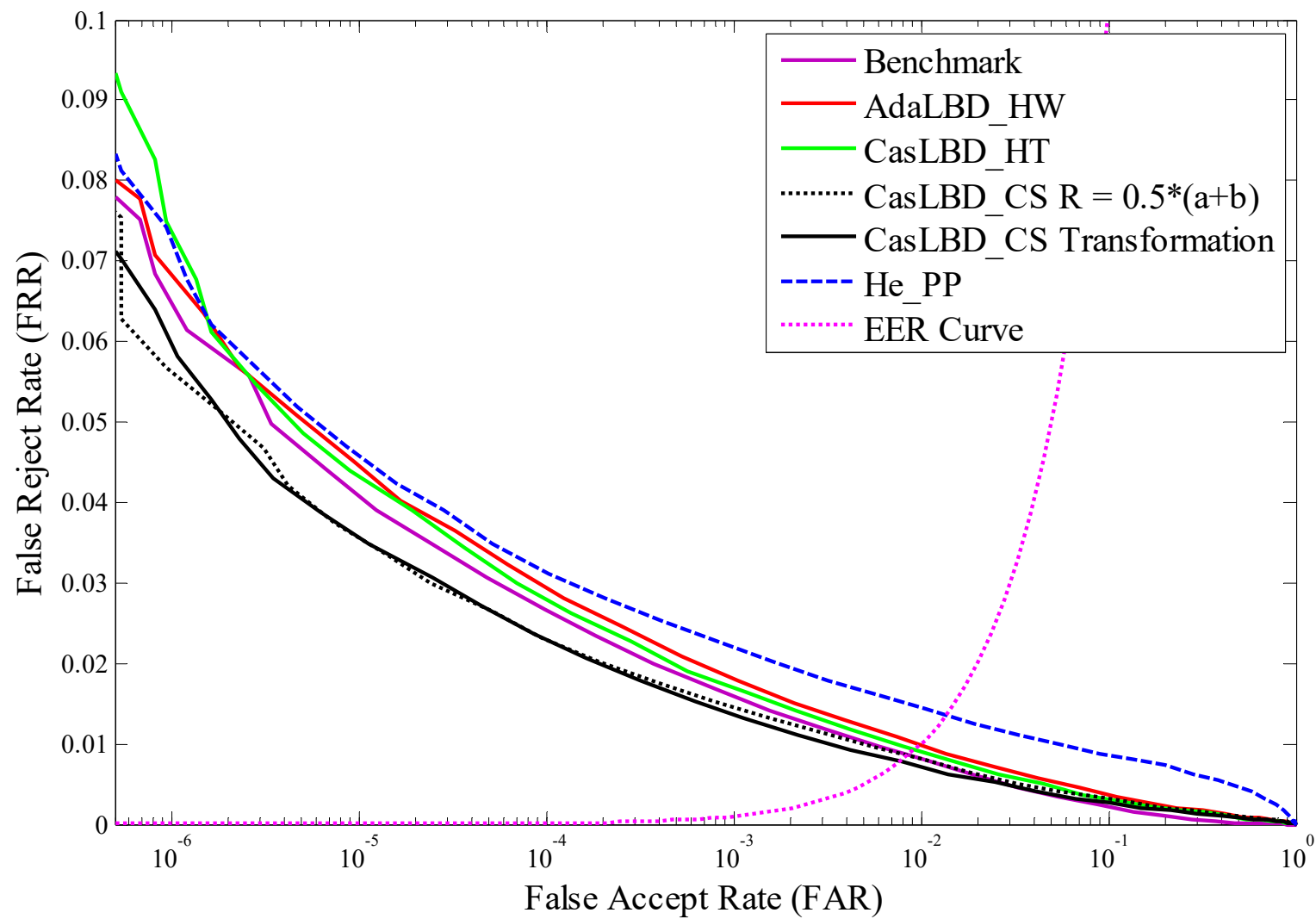
Accuracy Rate:

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

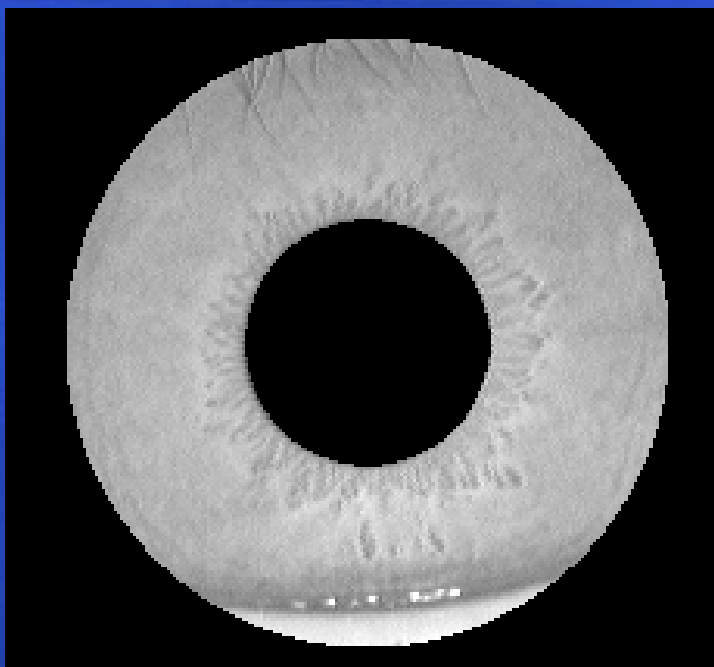
He_PP (He, Tan et al. TPAMI 2009)	95.30%
CasLBD_HT (Cascaded LBDs + Hough Transform; ICB 2012)	99.13%
CasLBD_CS (Cascaded LBDs + Contour Segments; ICPR 2012)	99.28%



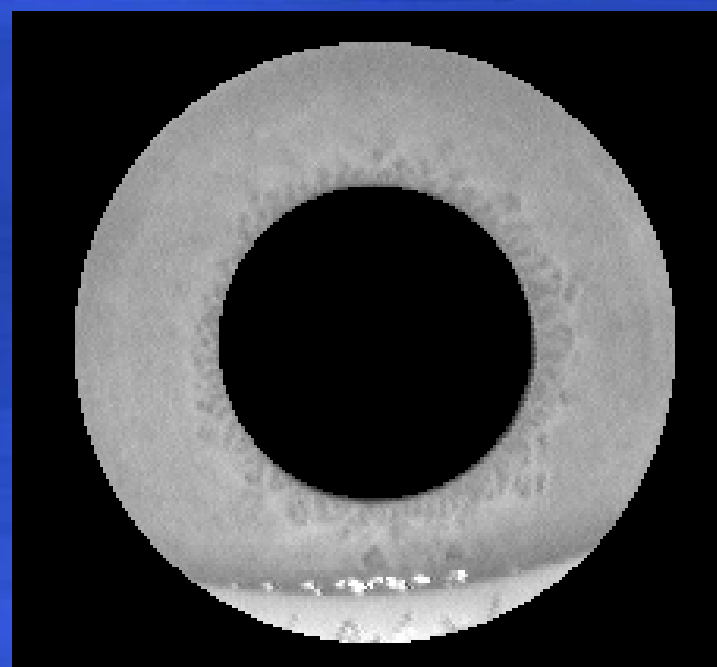
[//www.ia.ac.cn](http://www.ia.ac.cn)



Nonlinear iris deformation



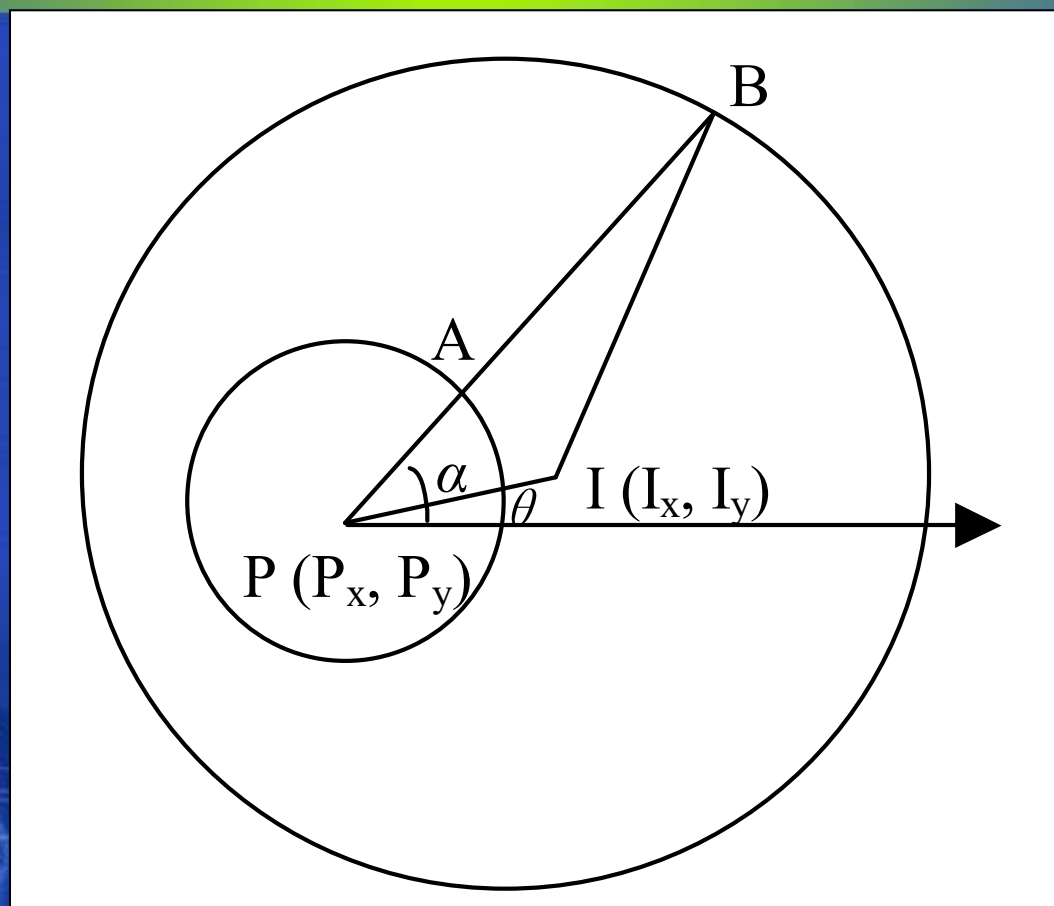
Normal illumination



Weak illumination



Iris normalization



Iris normalization model

Linear mapping model:

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

Piecewise-linear mapping model:

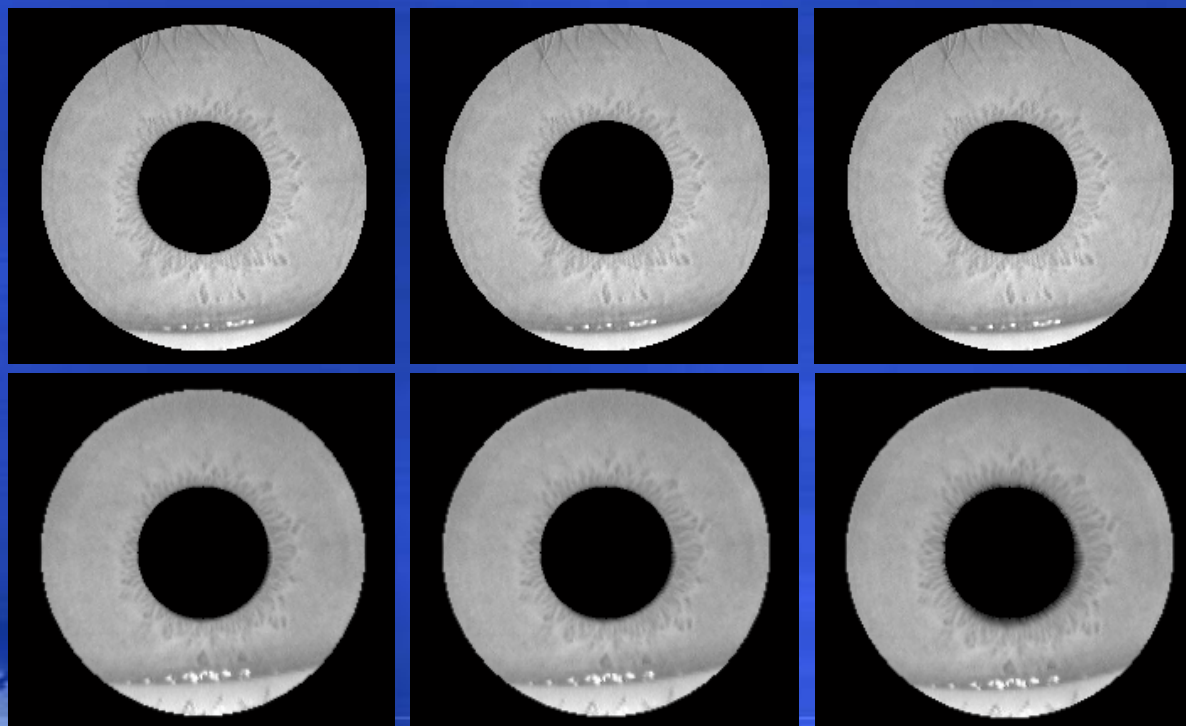
$$f(x) = \begin{cases} \frac{nkR + (1-k)(R-r)}{nkr} x & x \in [0, kr] \\ \frac{R-r}{n} + \frac{nR - (R-r)}{nr} x & x \in (kr, r] \end{cases}$$

Nonlinear mapping:

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



Iris normalization results



Linear

Piecewise-linear

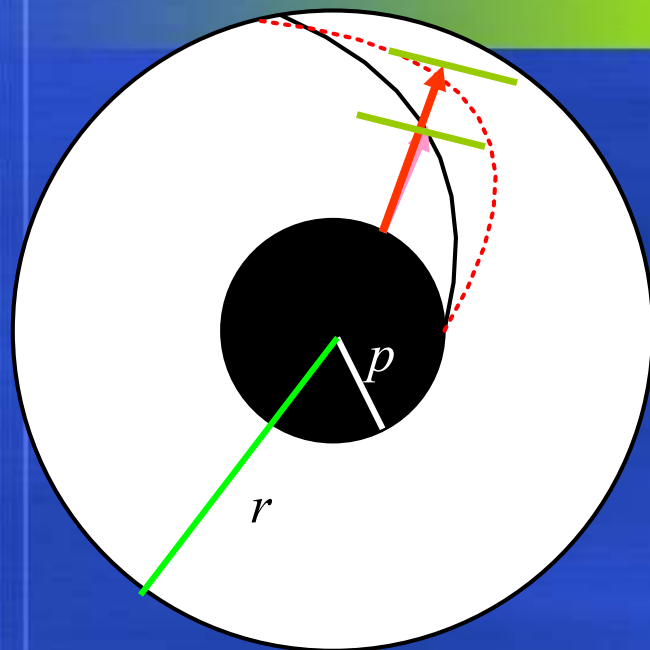
Nonlinear



[//www.ia.ac.cn](http://www.ia.ac.cn)

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:

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

↑ R_{linear}

Linear stretch position

↑ $R_{nonlinear}$

Nonlinear stretch position

↑ $\Delta R(p, r)$

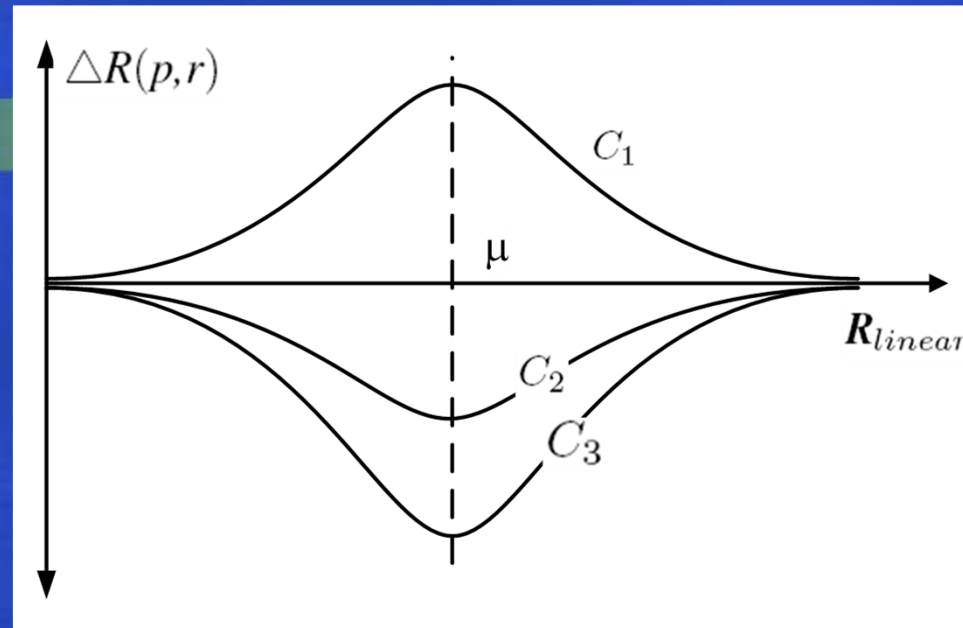
Additive item



Iris linear stretch

Iris nonlinear stretch

Our solution: Gaussian function to model the additive component



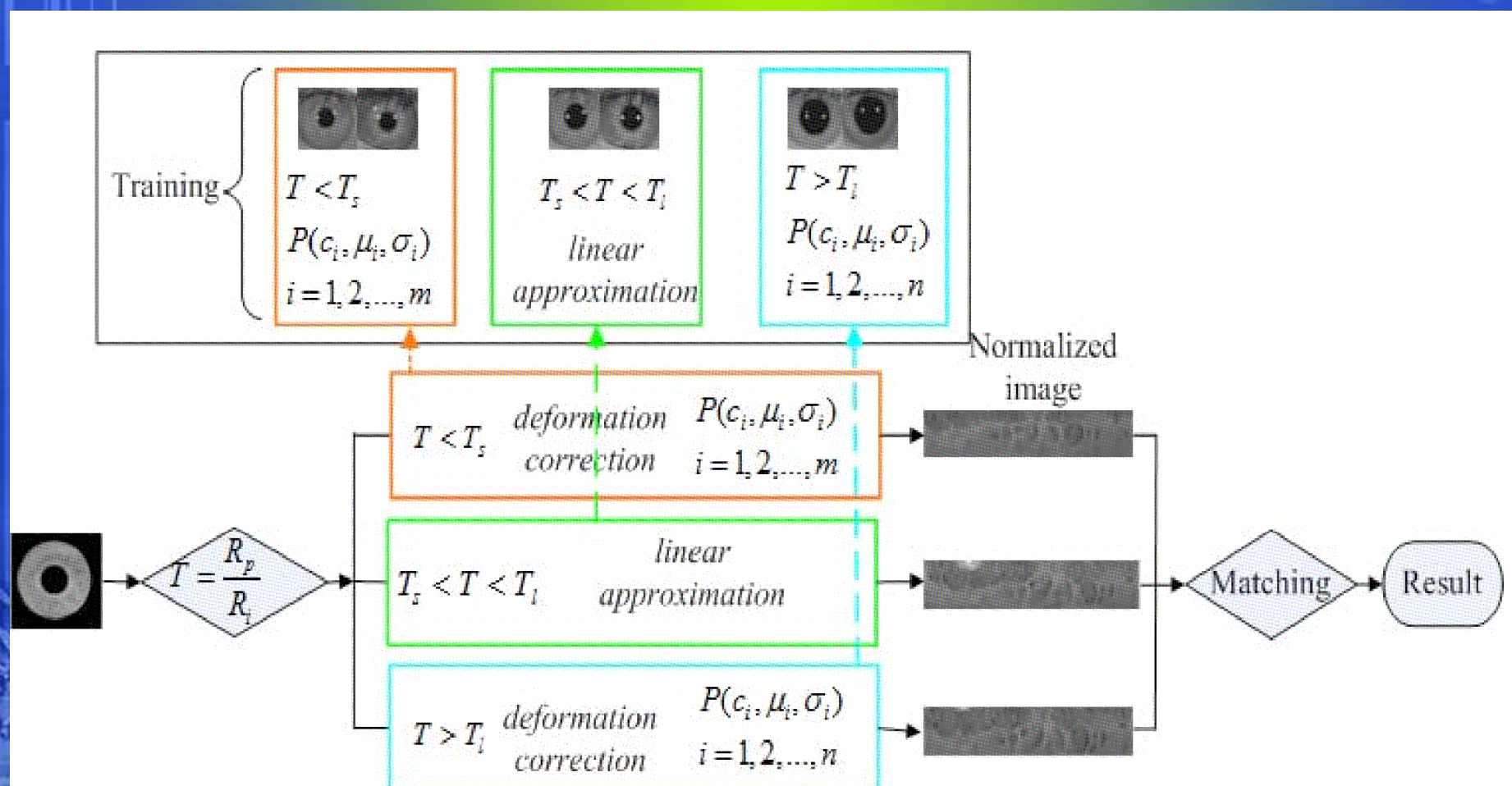
$$\Delta R = C \times \exp\left[-\frac{1}{2} \times \frac{(R_{linear} - \mu)^2}{\sigma^2}\right]$$

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

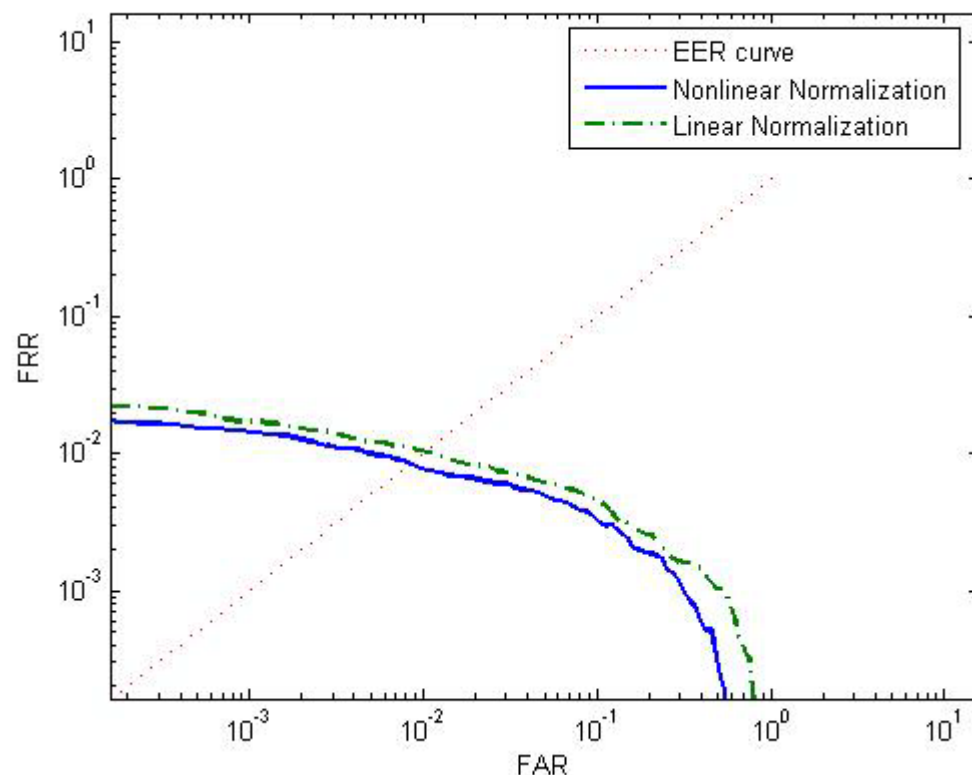
where λ is the standard ratio of pupil radius per iris radius



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

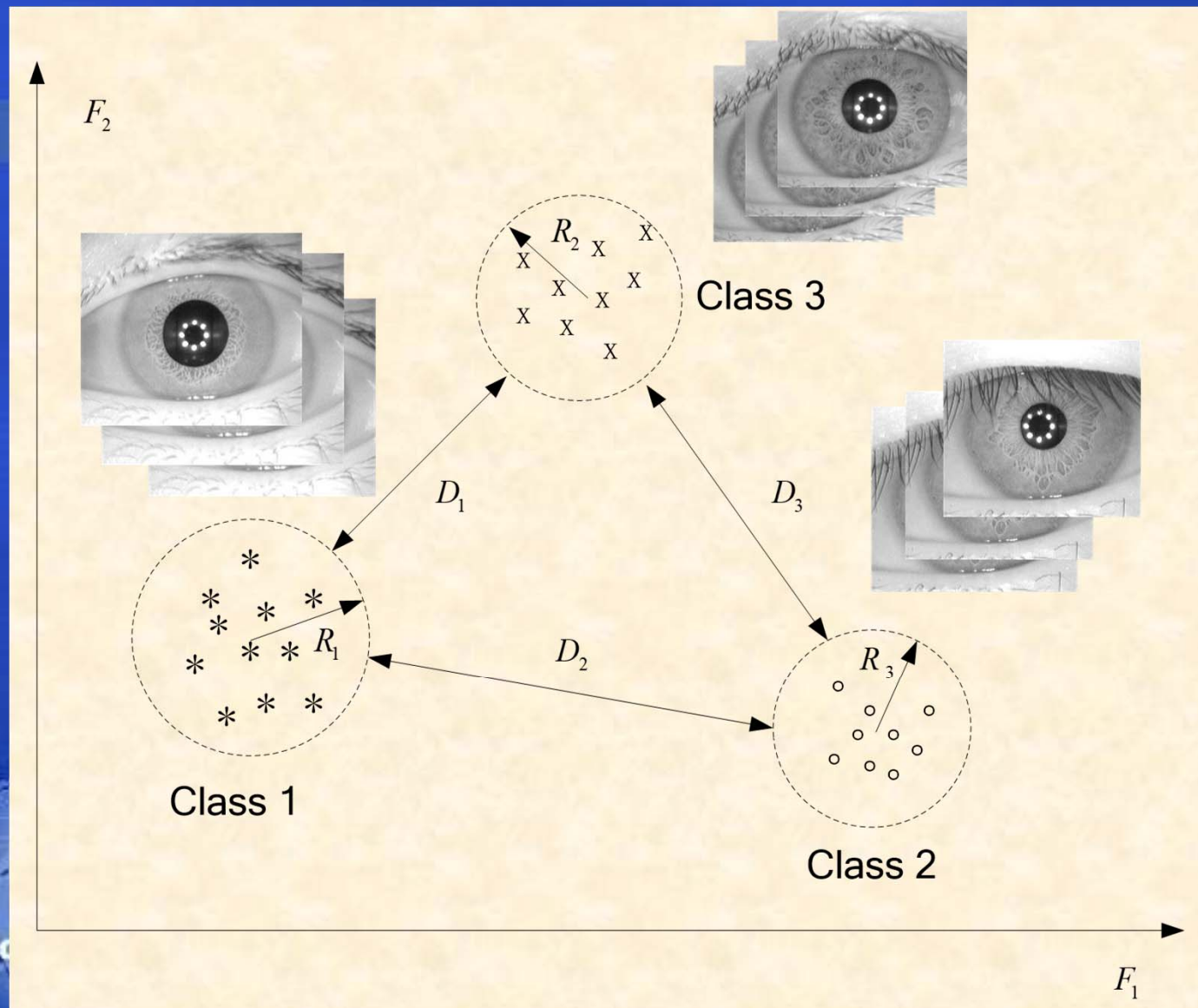
Outline of Talk

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



//w

Objective of iris pattern recognition



//www.id

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

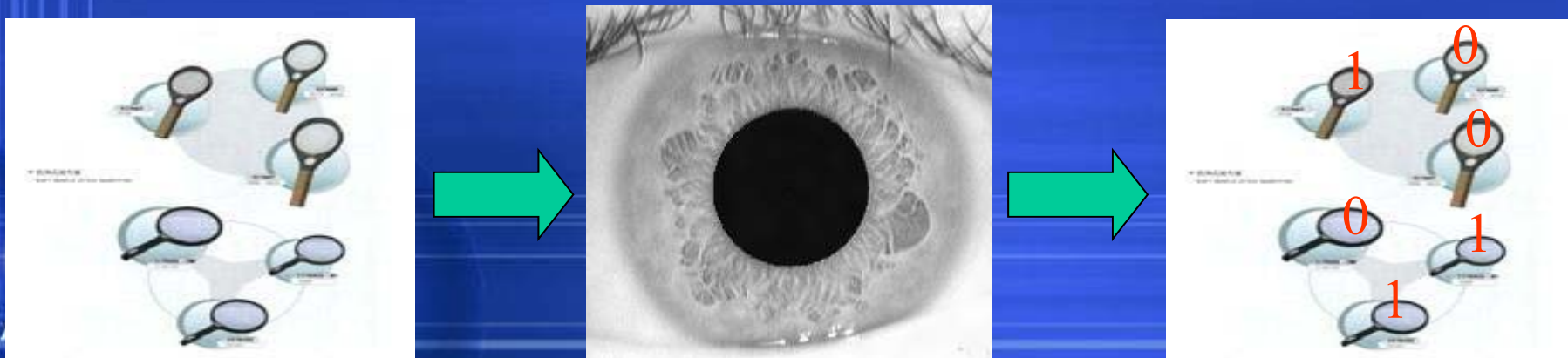
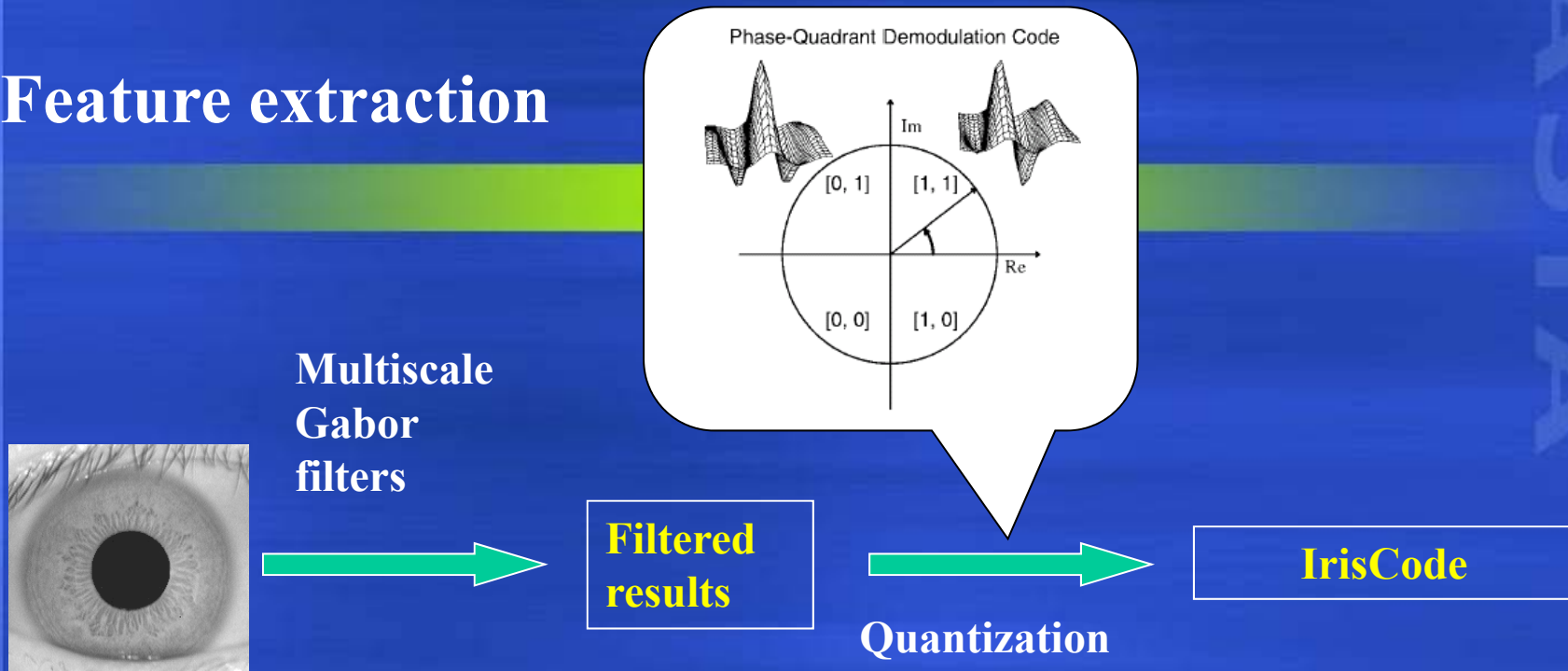
Email: John.Daugman@CL.cam.ac.uk



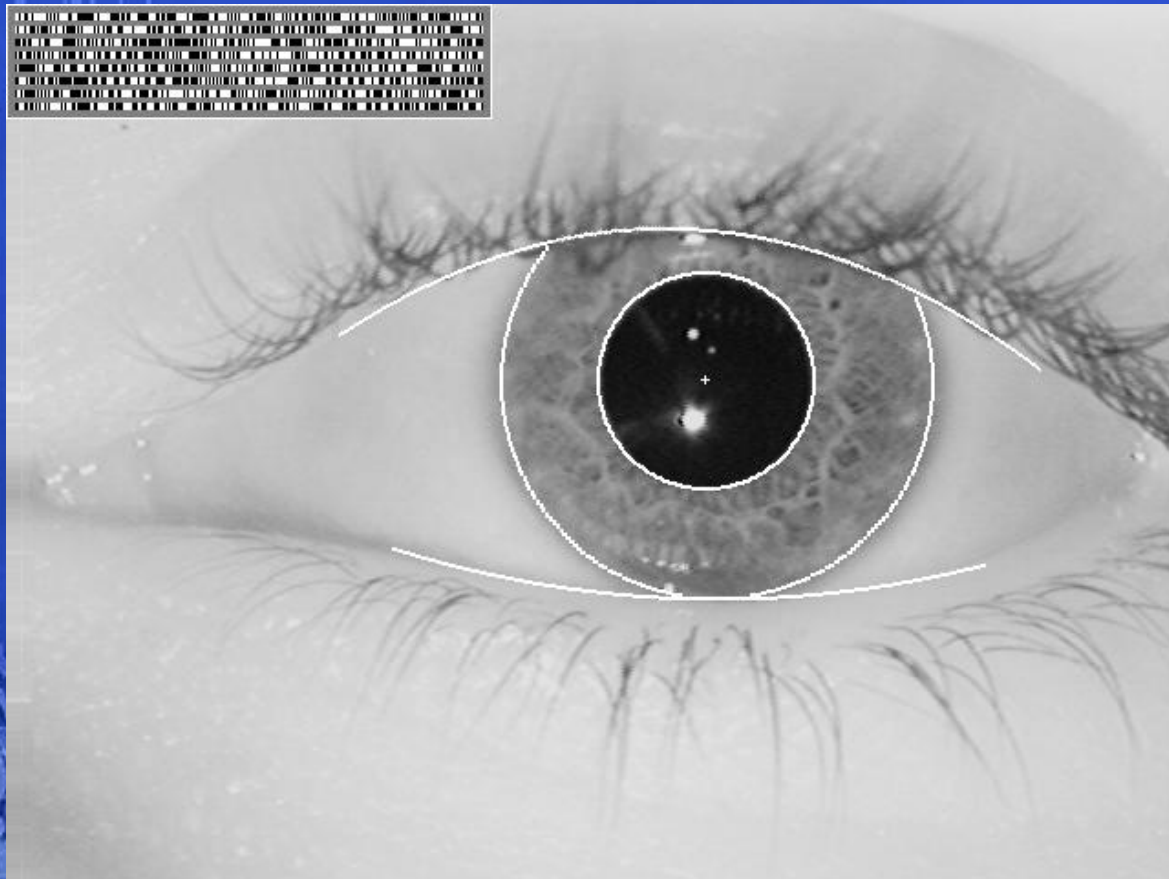
//www.ia.c

Daugman's method: IrisCode

Feature extraction



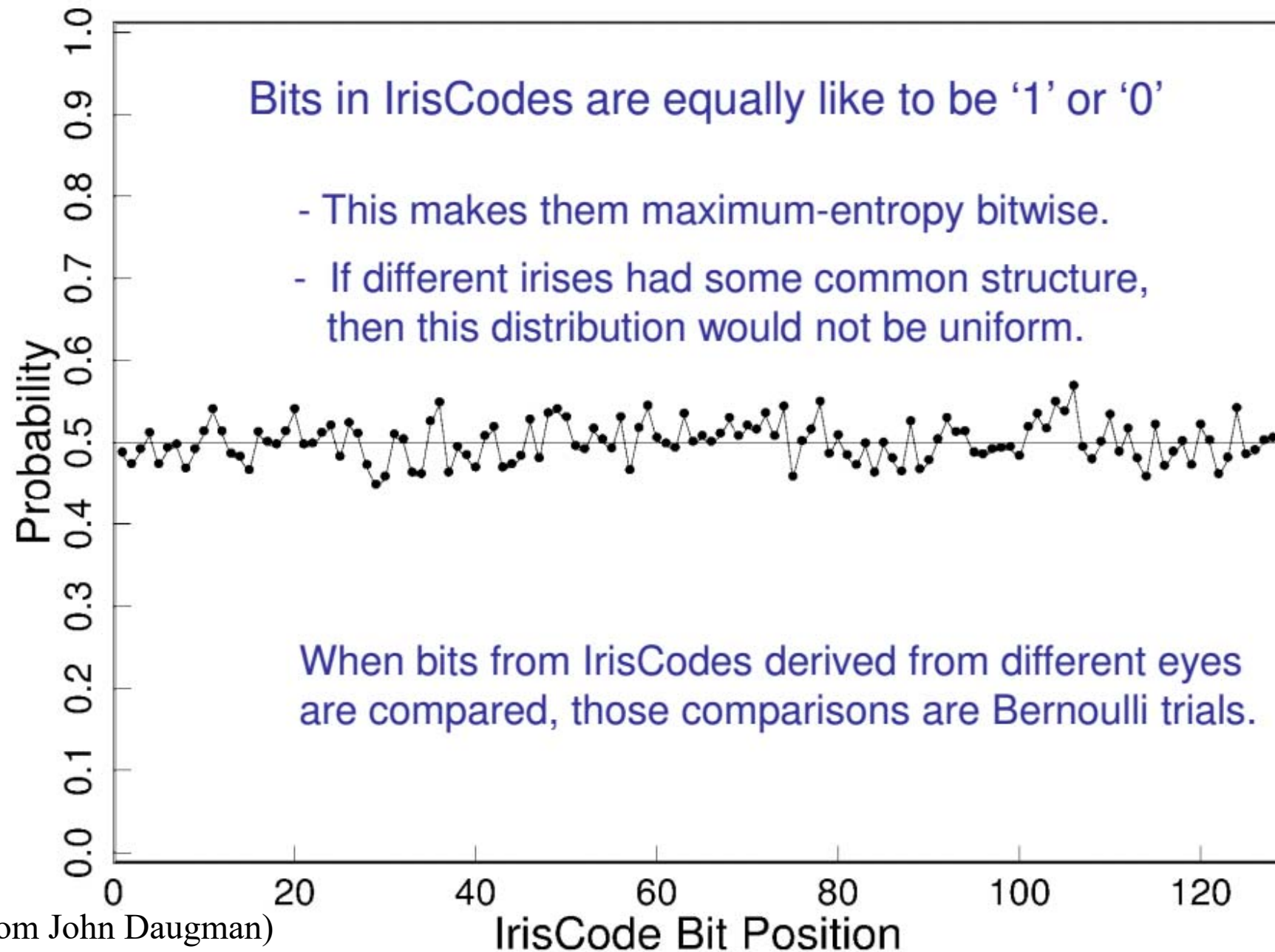
Examples of IrisCodes



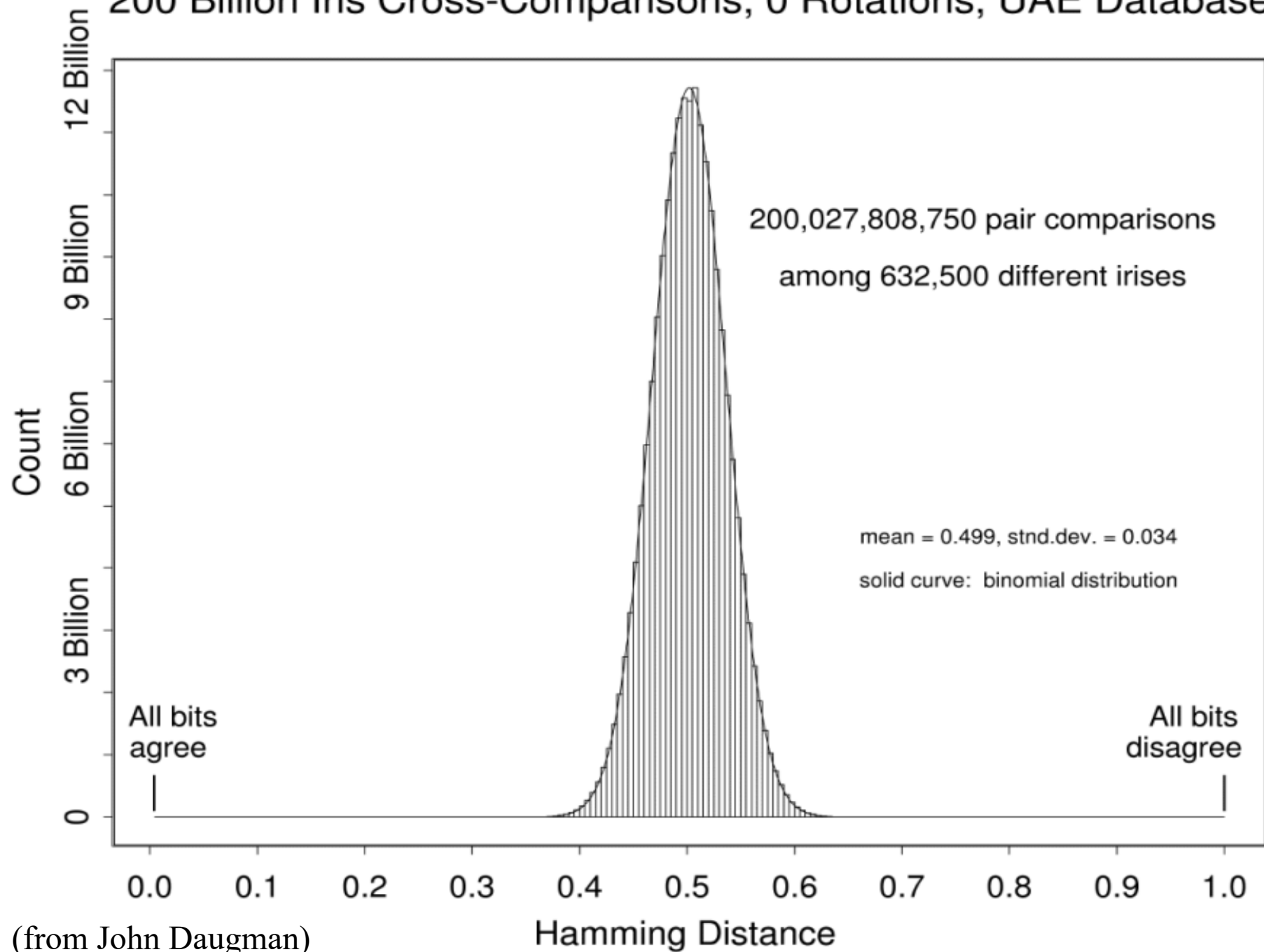
Pictorial Examples of four IrisCodes



IrisCode Bit Probabilities



200 Billion Iris Cross-Comparisons, 0 Rotations, UAE Database



(from John Daugman)

IrisCode Bit Comparisons are Bernoulli Trials

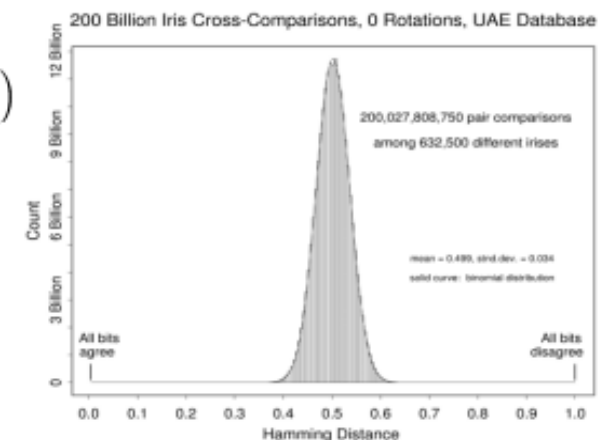
Jacob Bernoulli (1645-1705) analyzed *coin-tossing* and derived the binomial distribution. If the probability of “heads” is p , then the likelihood that a fraction $x = m/N$ out of N tosses will turn up “heads” is:

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

(from John Daugman)



University of Groningen



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:

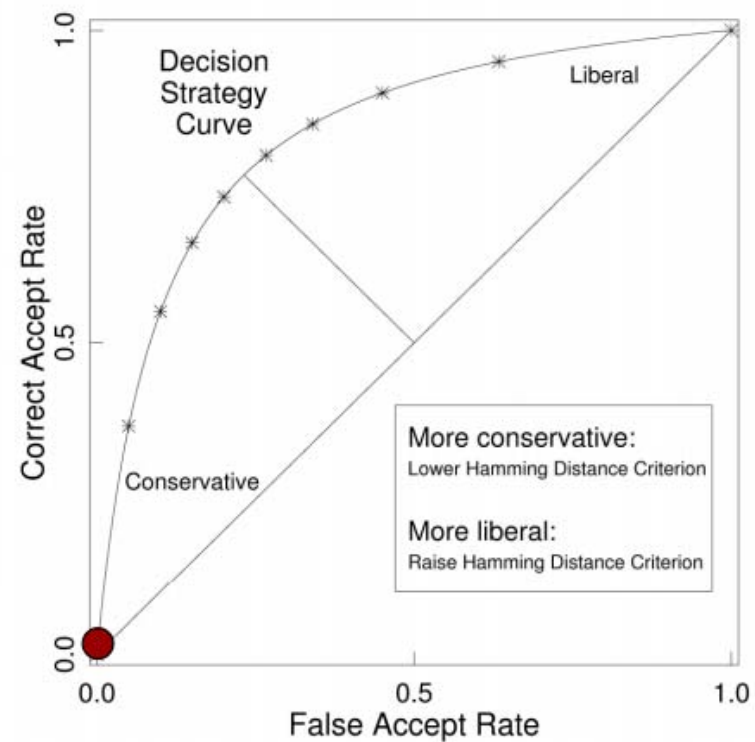
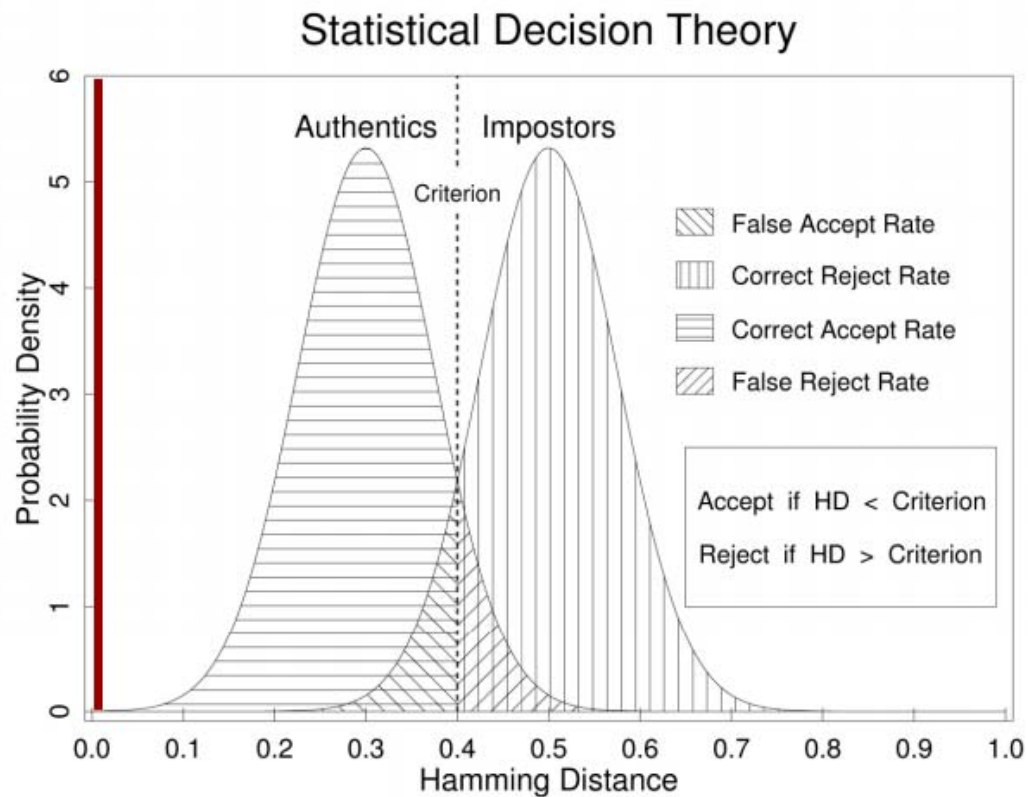
$$HD_{\text{norm}} = 0.5 - (0.5 - HD_{\text{raw}}) \sqrt{\frac{n}{911}}$$

Decision Criterion normalisation by database size and query rate:

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

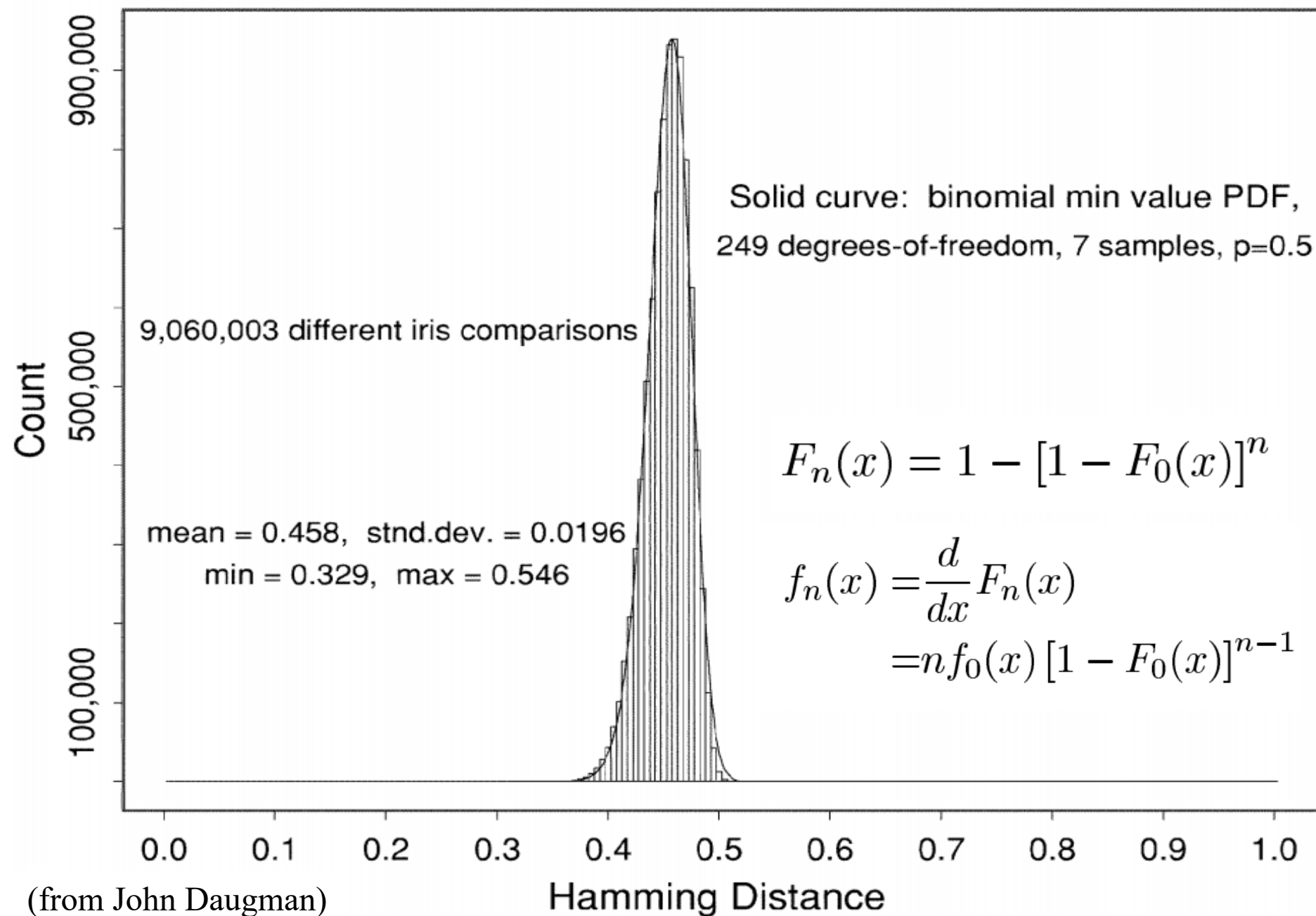
where N is the search database size, M is the number of queries to be compared against the full database, while requiring nil False Matches

Distribution of HDs and Decision

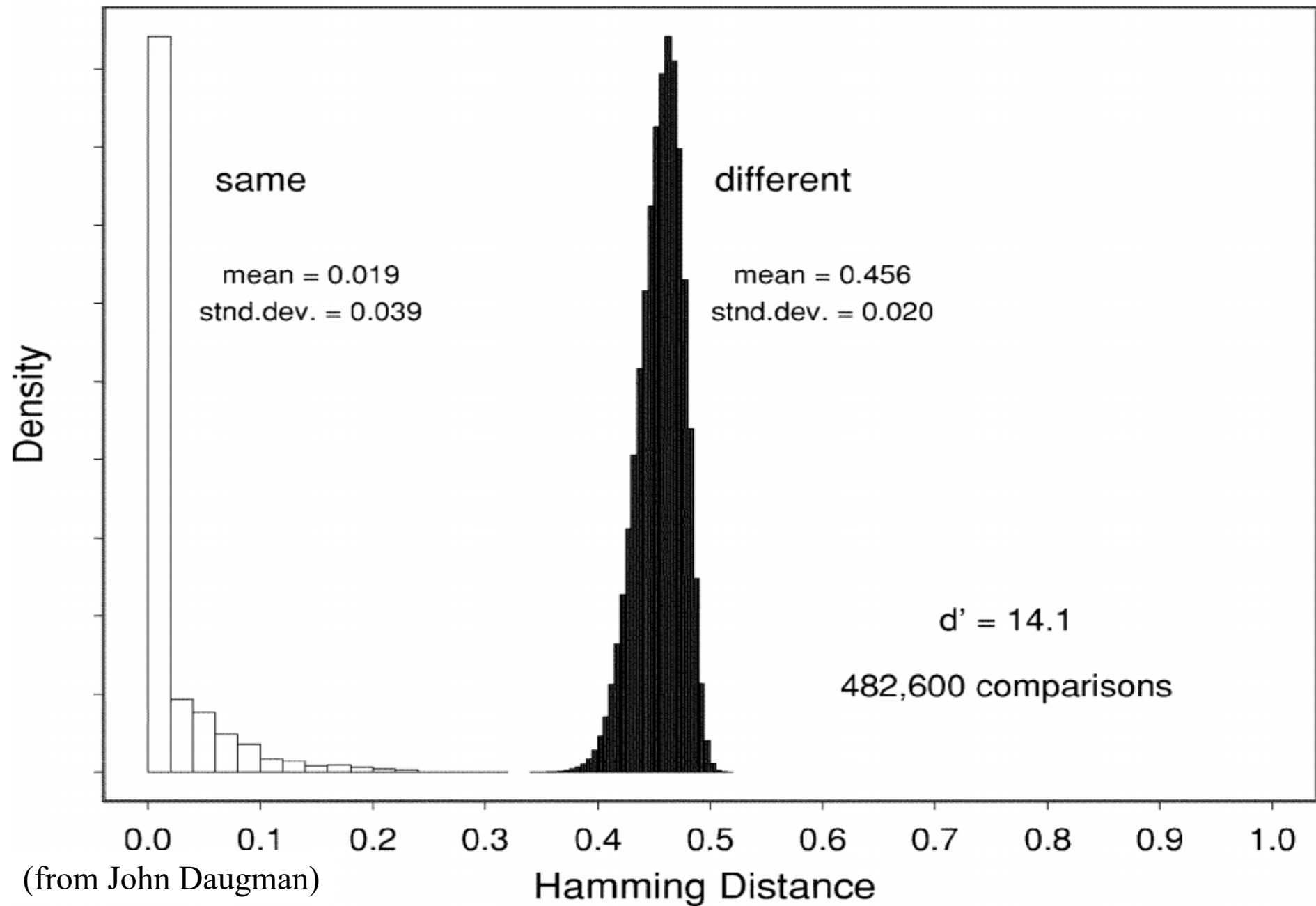


(from John Daugman)

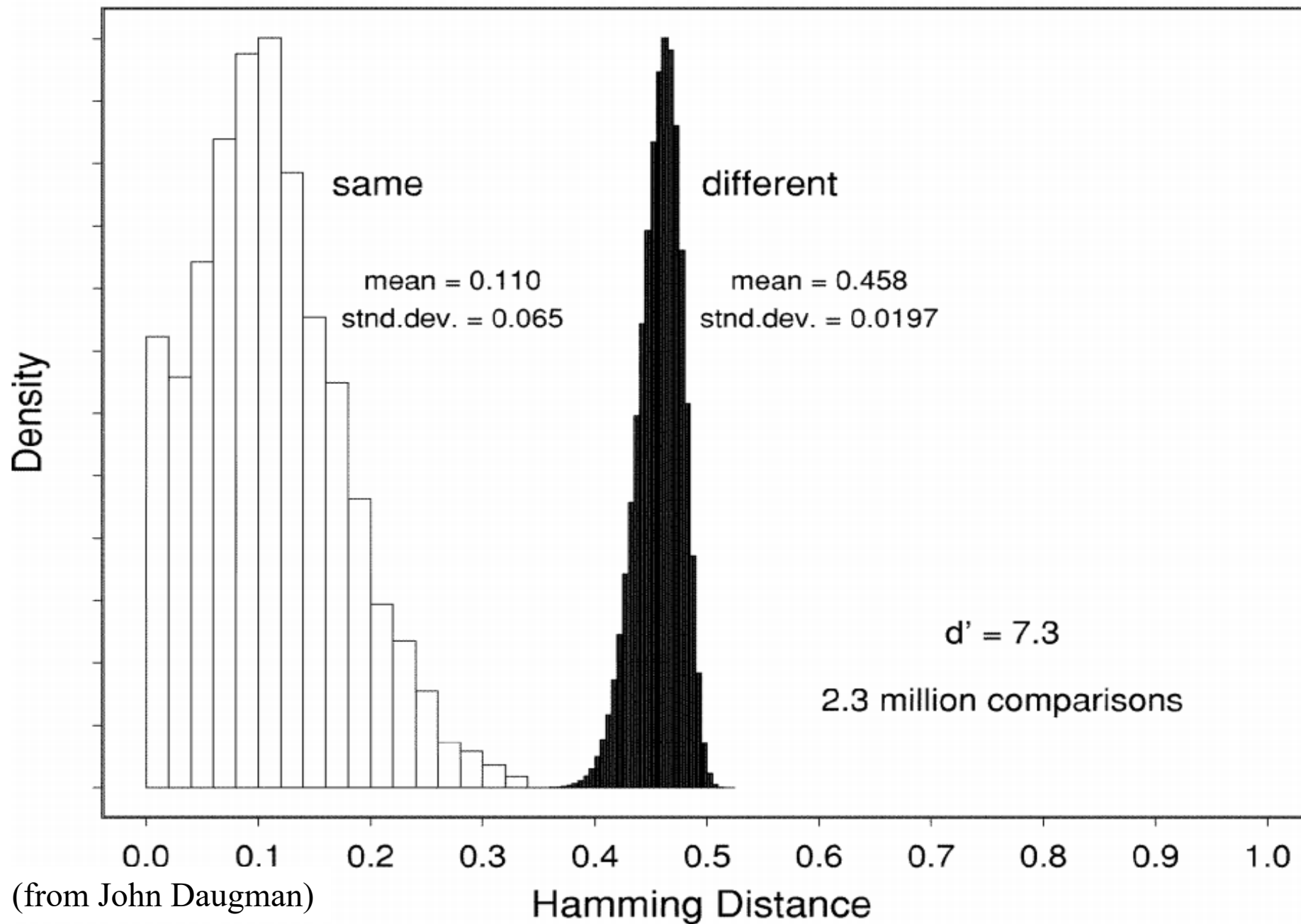
IrisCode Comparisons after Rotations: Best Matches



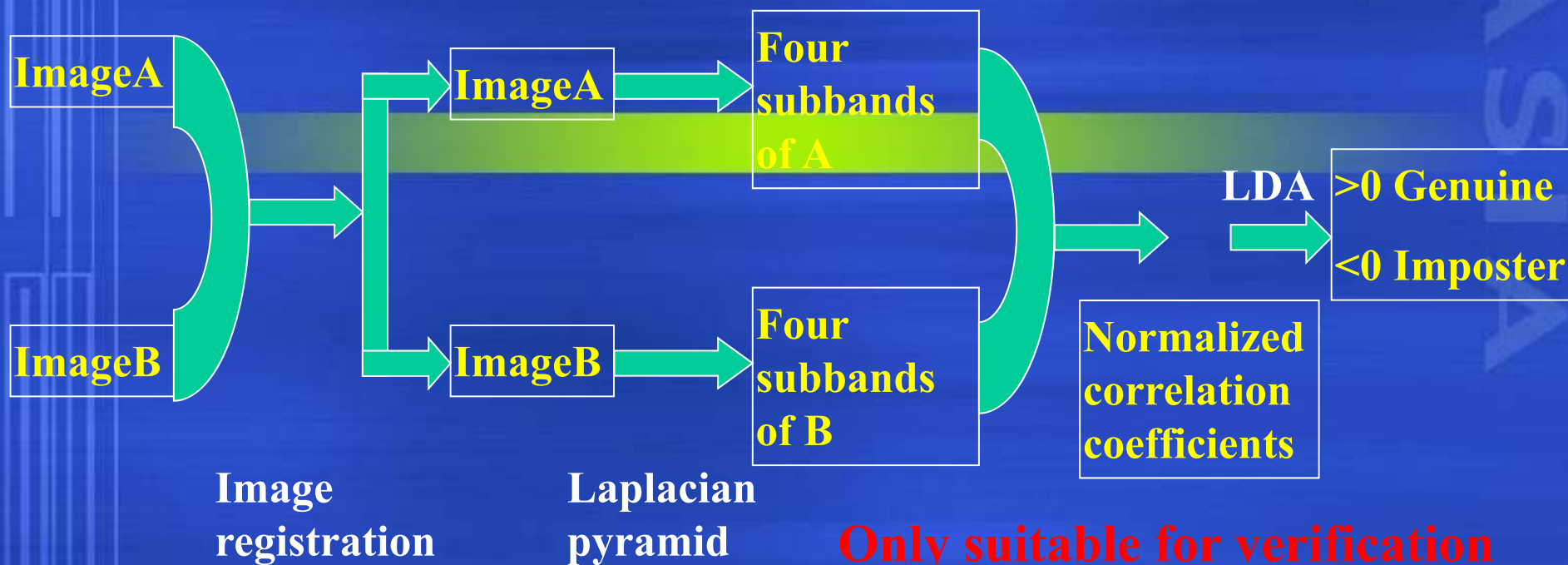
Decision Environment for Iris Recognition: Ideal Imaging



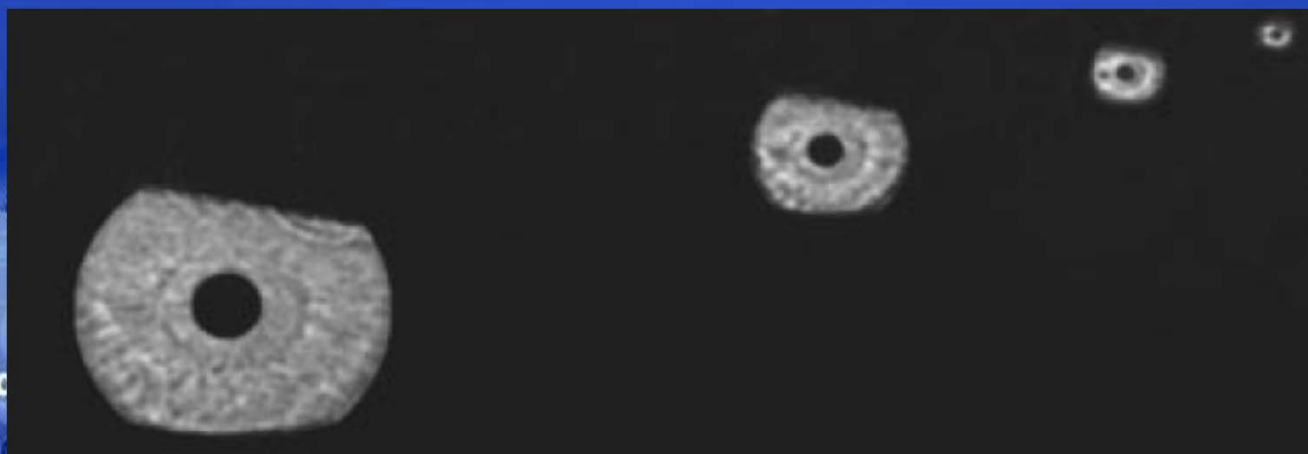
Decision Environment for Iris Recognition: Non-Ideal Imaging



Wildes' method

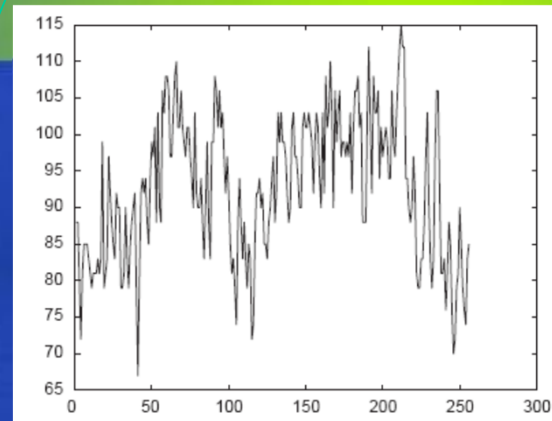
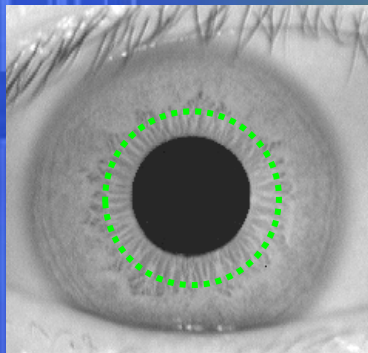


//www.ia.c

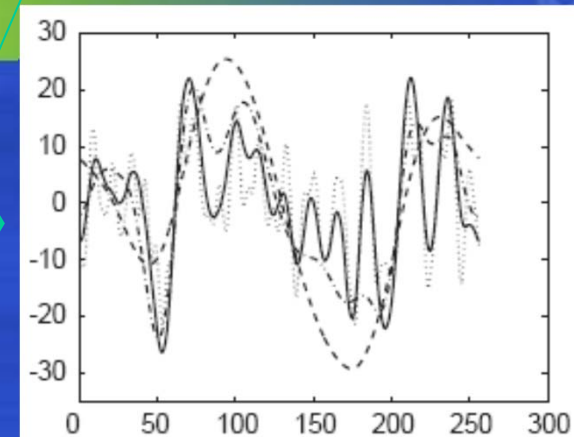


Boles' method

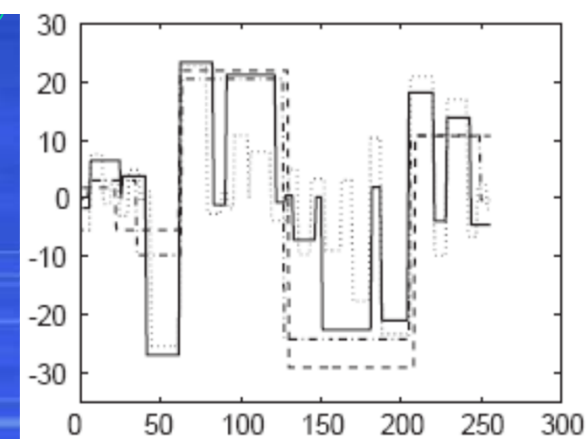
1D Signal
Sampling



Wavelet
transform



Zero-crossing
representation



Feature
matching

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

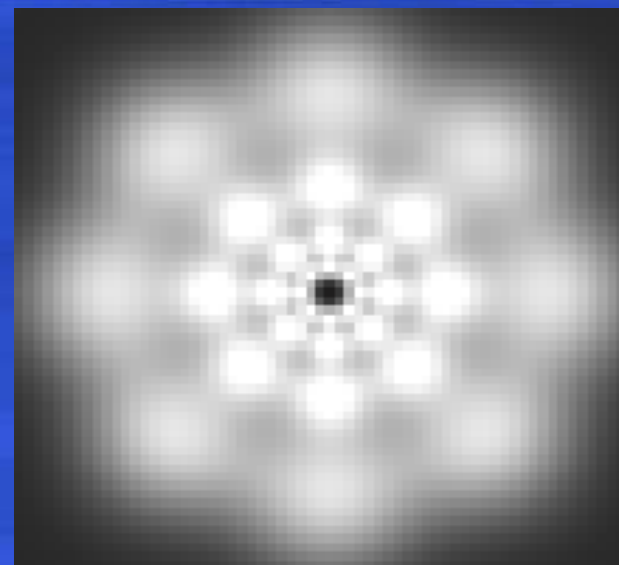
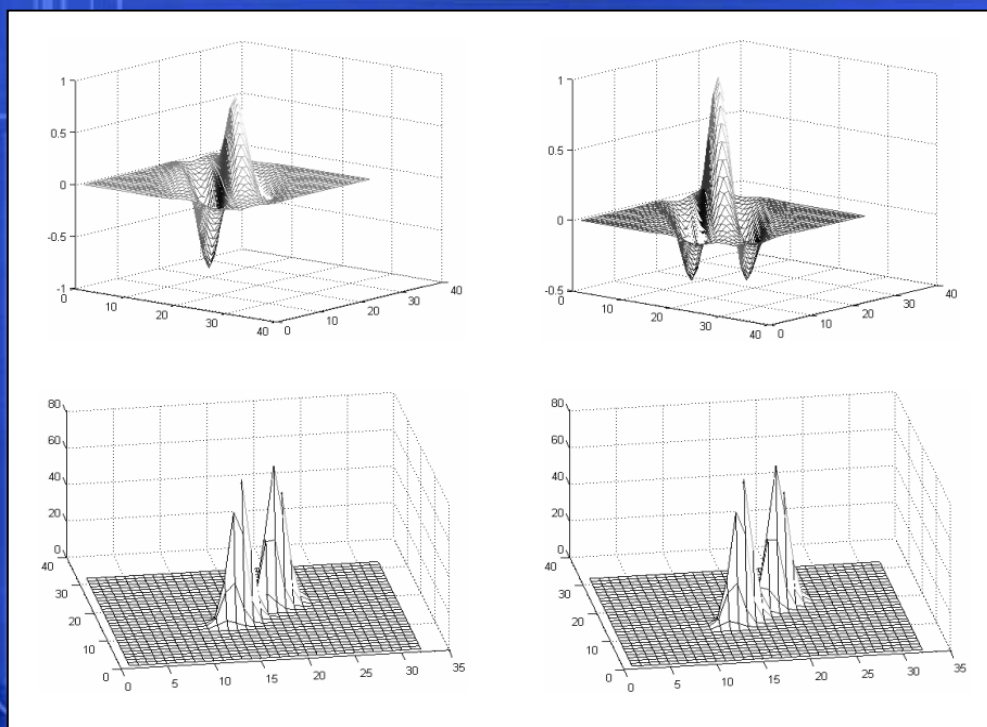
$$m \in [0, N-1]$$

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

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

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°	45°	90°	135°	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.

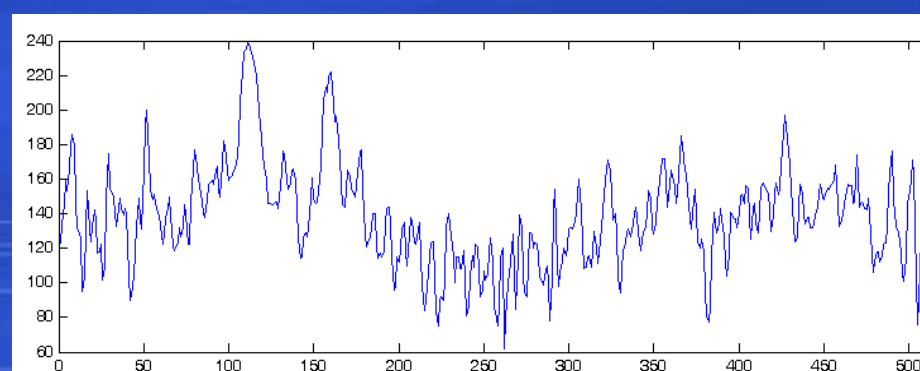
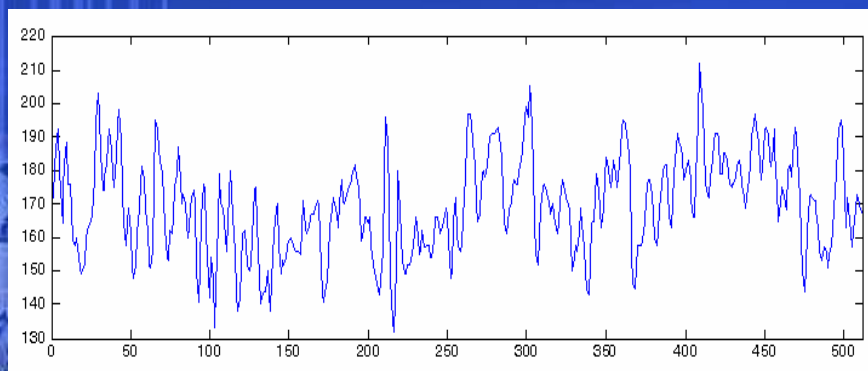
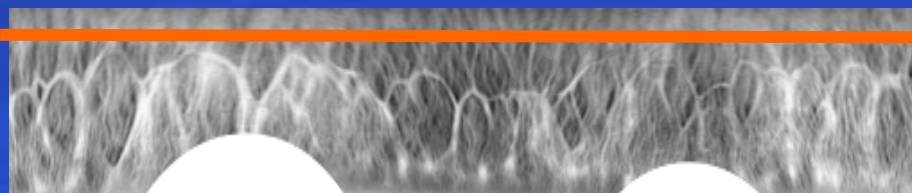
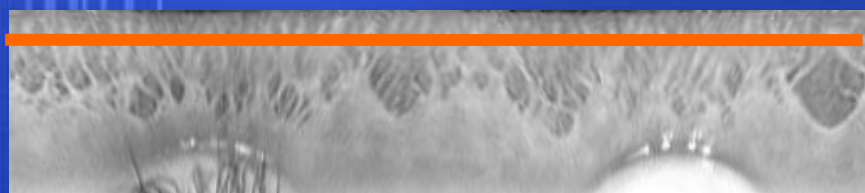
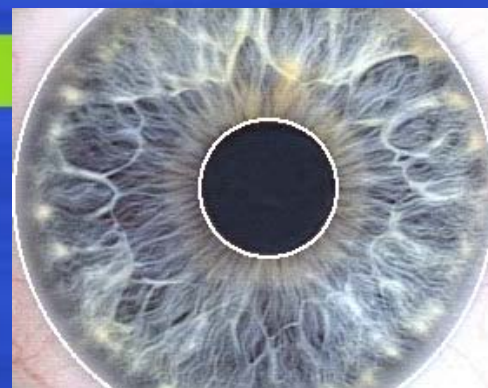
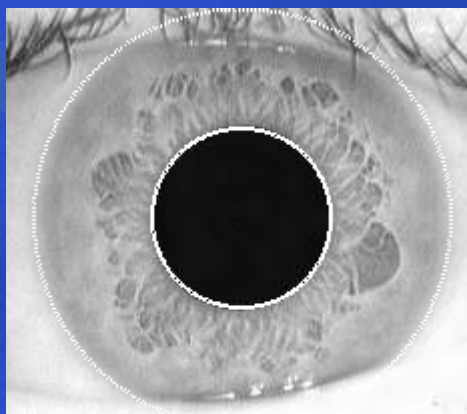
Recognition results as a function of Gabor frequency

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.

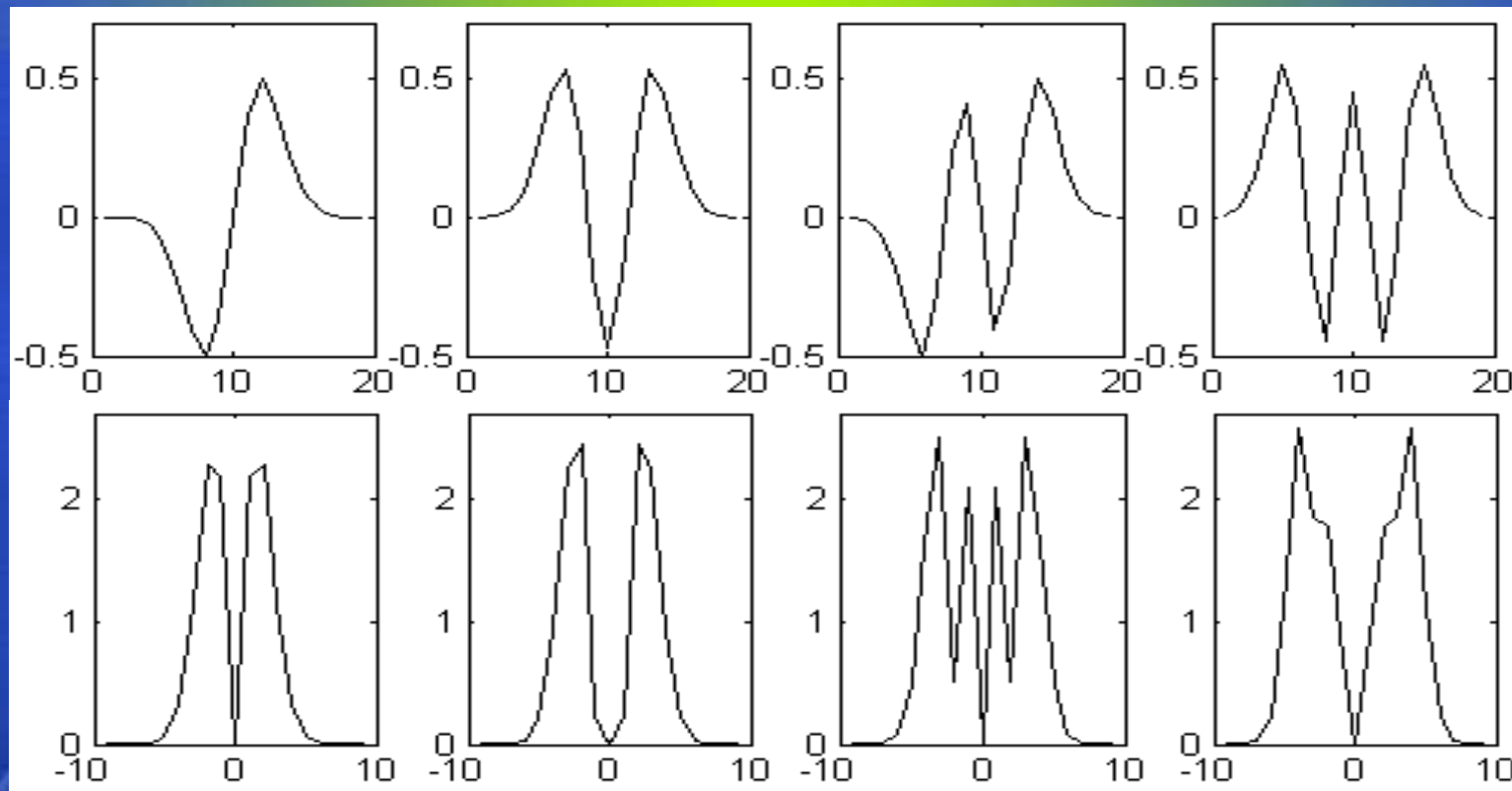
Gaussian-Hermite moments based method

— 1D signal representation —



Gaussian-Hermite moments based method

—GH moments used for shape analysis—



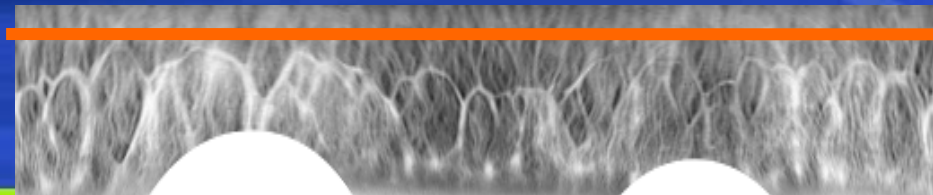
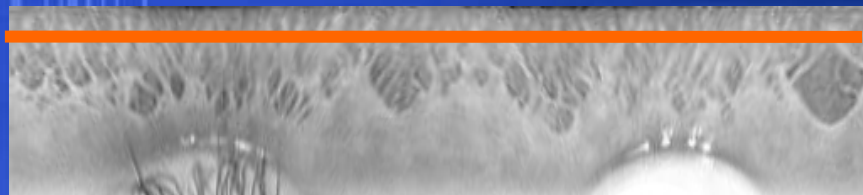
L. Ma, T. Tan, D. Zhang and Y. Wang, "Local Intensity Variation Analysis for Iris Recognition", Pattern Recognition, Vol.37, No.6, pp. 1287-1298, 2004.

Gaussian-Hermite moments based method

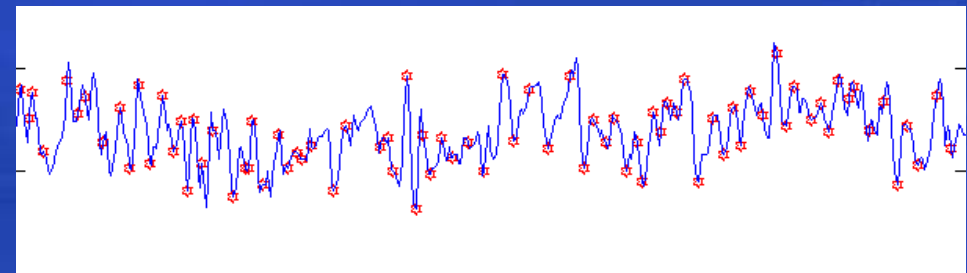
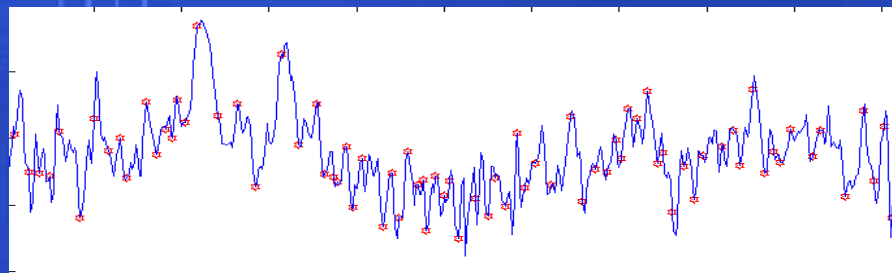
— Conclusions —

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.

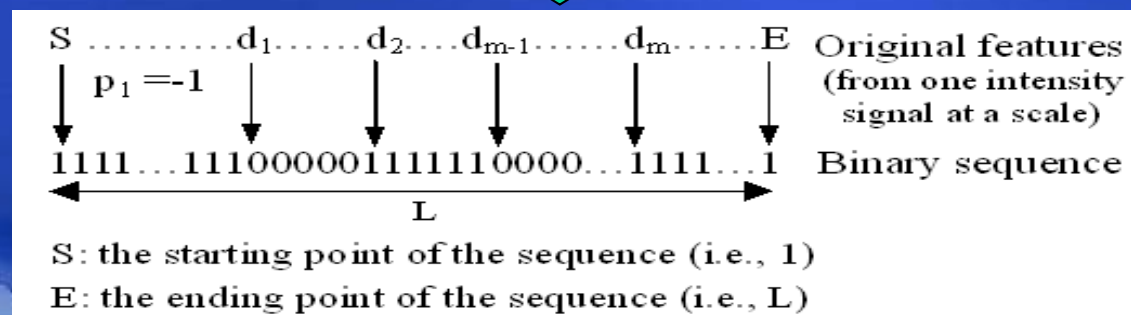
Local sharp variation based method



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



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Ordinal measures (OM) in everyday life



Height



Weight



//www.ia.ac.cn



$$D > B$$

$$C > E$$

$$F > D$$

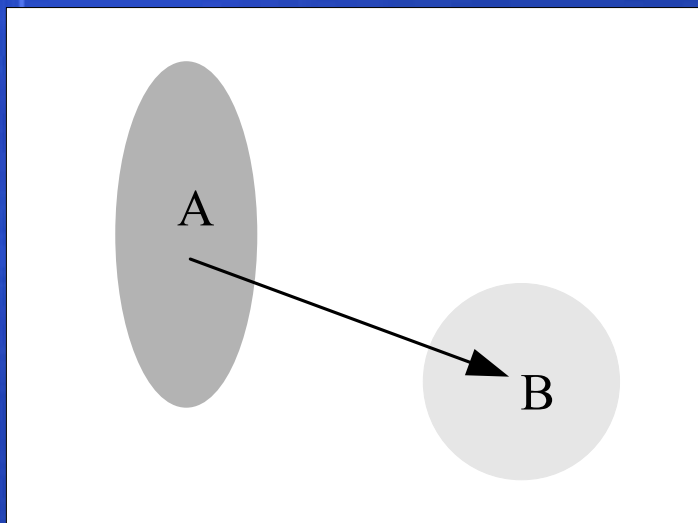
$$2C > B + D$$

$$C + D + F >$$

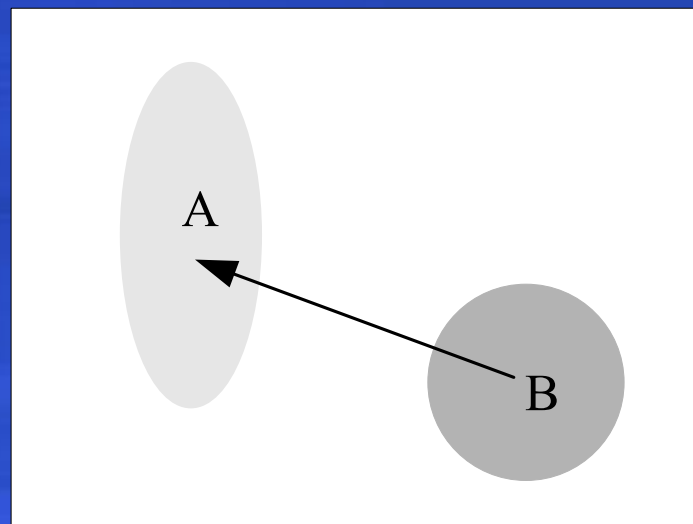
$$A + B + E$$

.....

Ordinal measures in visual images



$A < B$



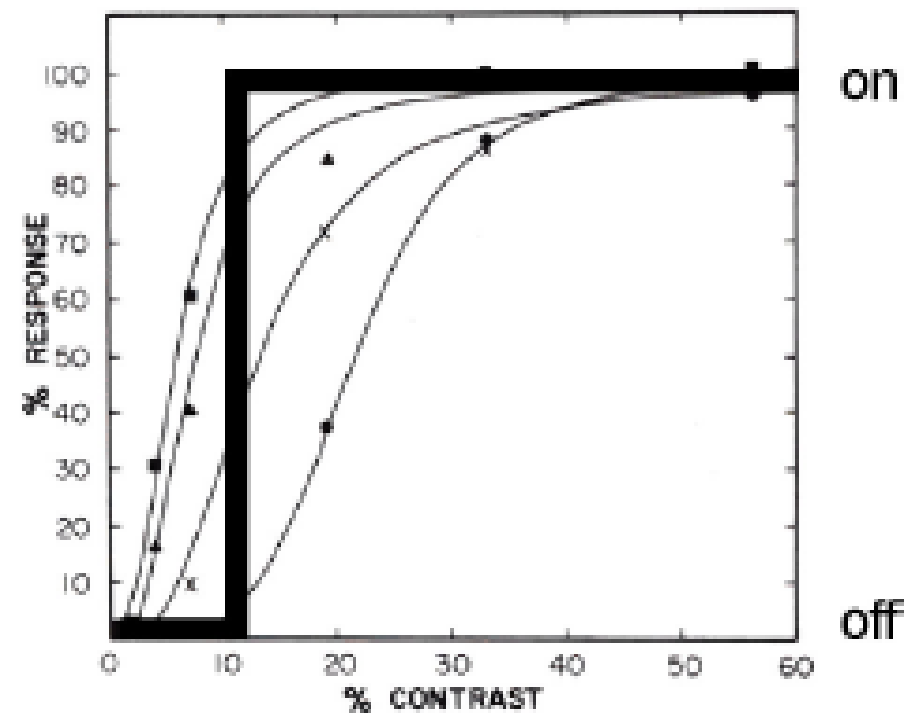
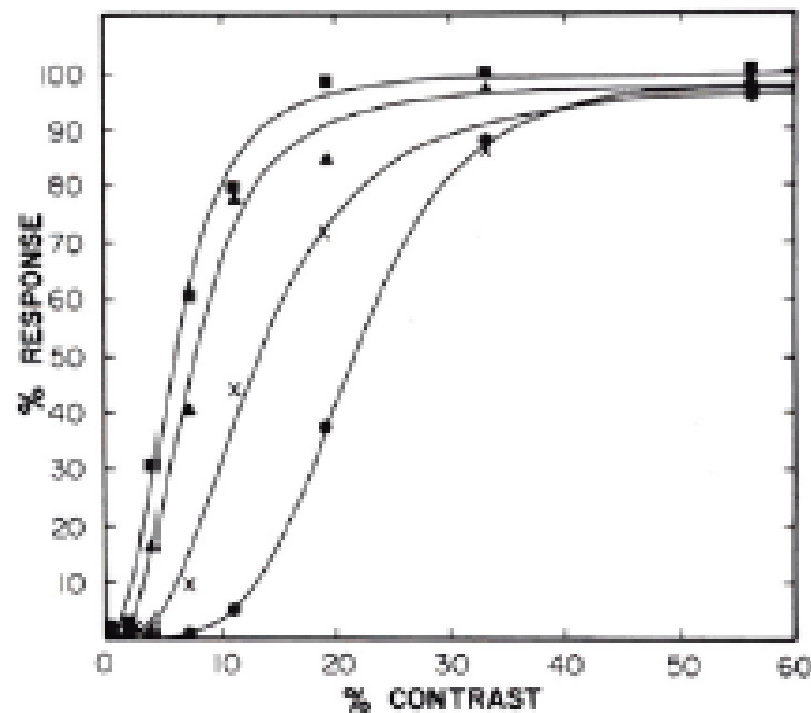
$A > B$



[//www.ia.ac.cn](http://www.ia.ac.cn)

1 one bit code **0**

OM in the biological vision system



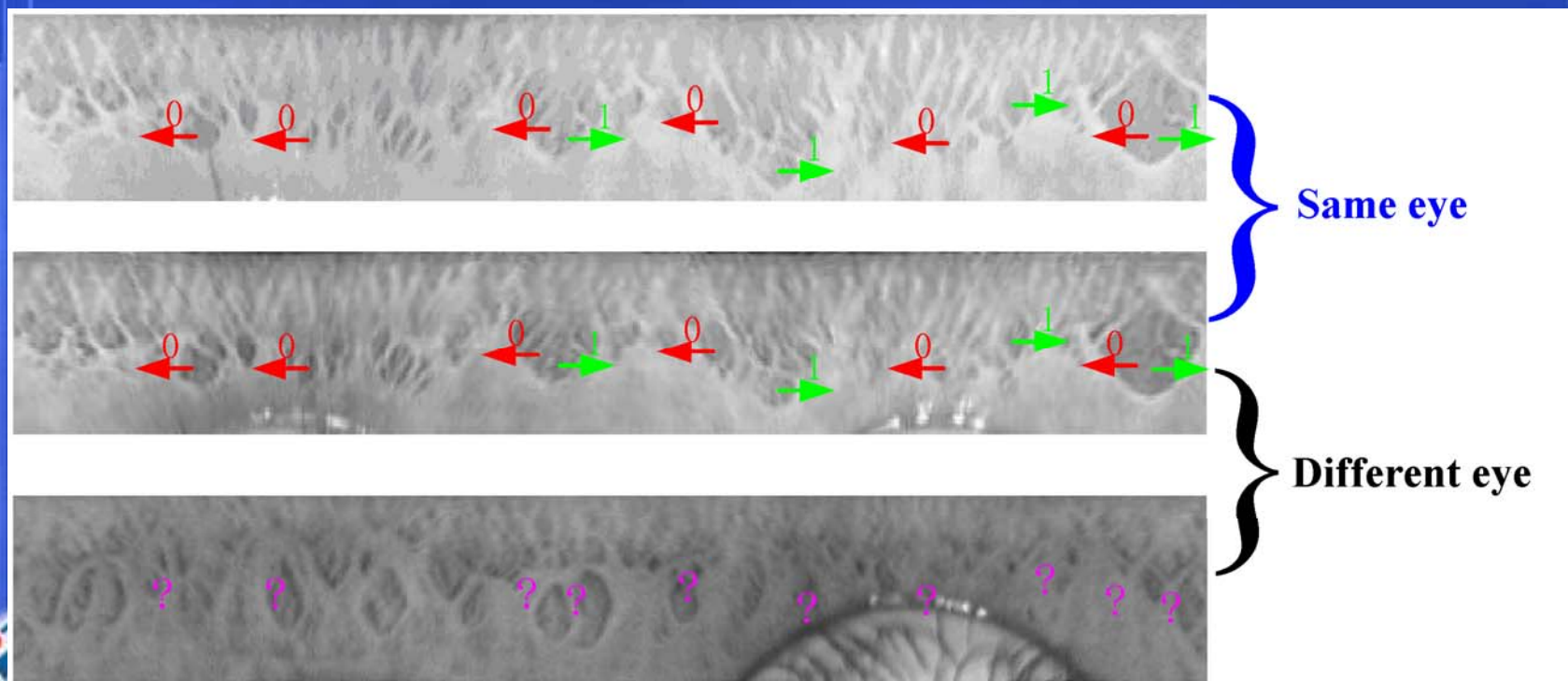
Duane G. Albrecht and David B. Hamilton. Striate cortex of the monkey and cat: Contrast response function. *Journal of Neuroscience*, 48(1):217–237, July 1982.

Desirable properties of ordinal representation

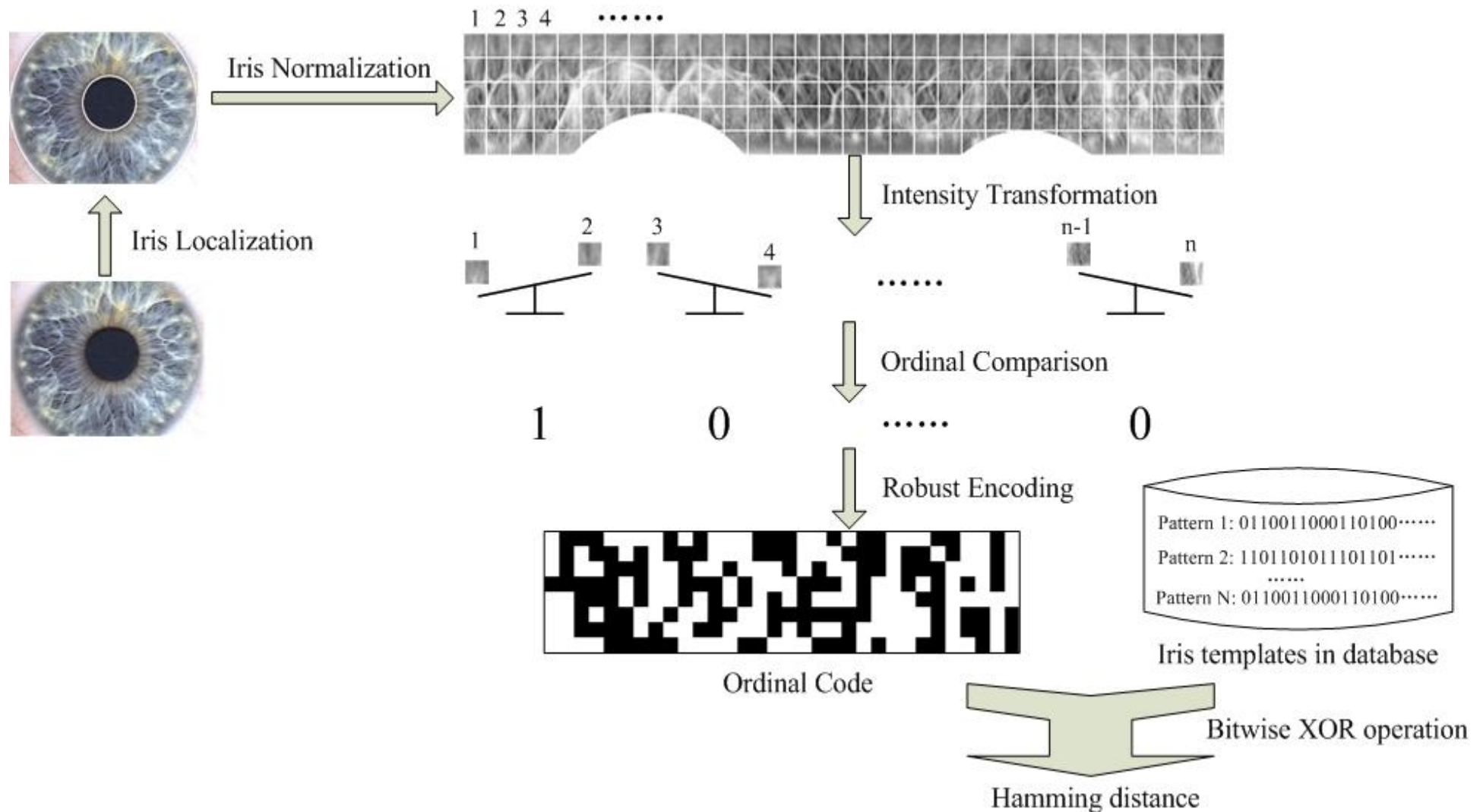
- Discriminating
- Robust
- Computationally simple
- Memory efficient
- Biologically plausible



Ordinal measures in iris images

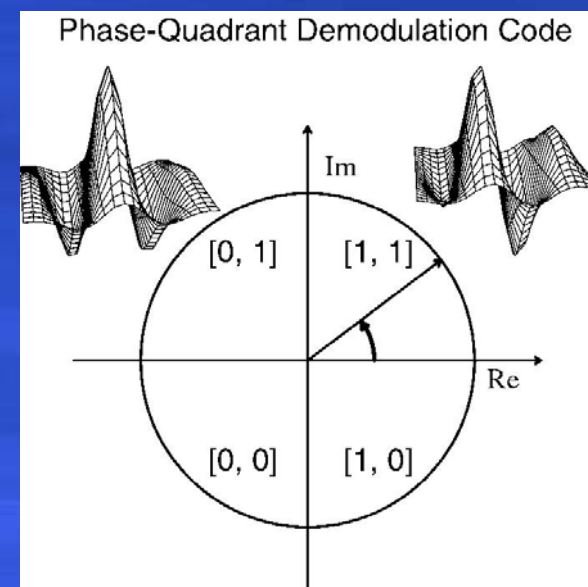
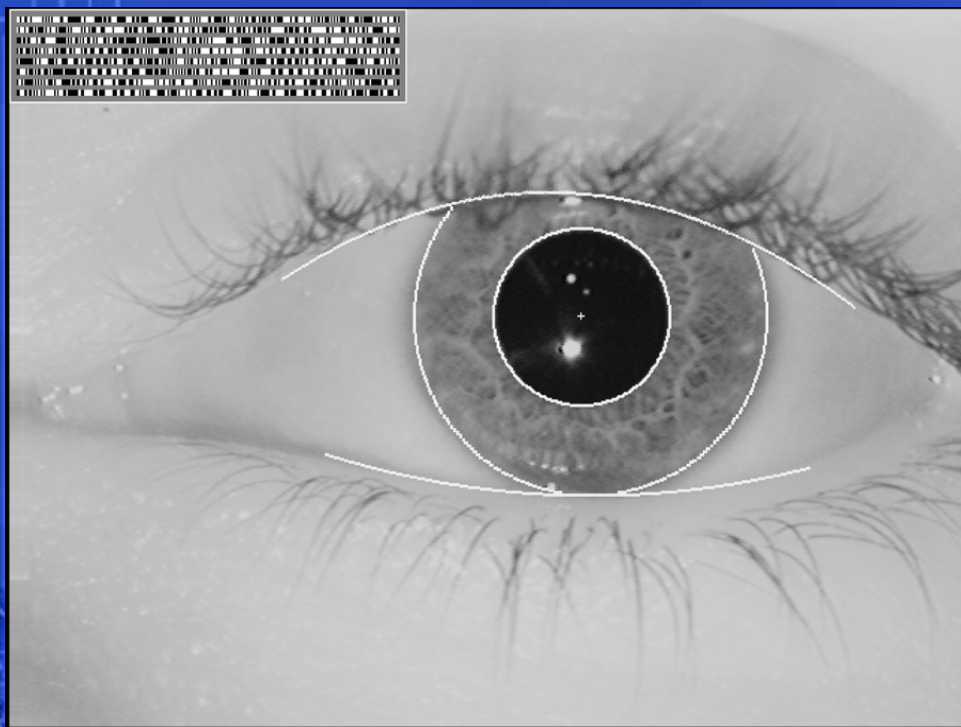


A General Framework for Iris Recognition Based on OM



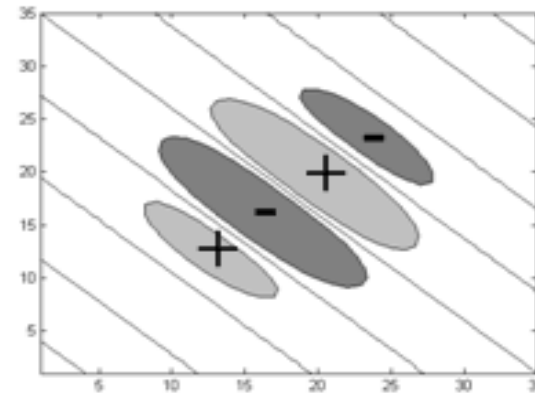
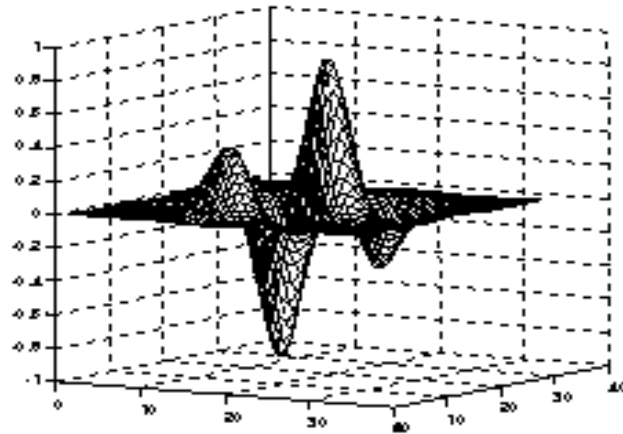


Phase demodulation based on Gabor filters (Daugman)

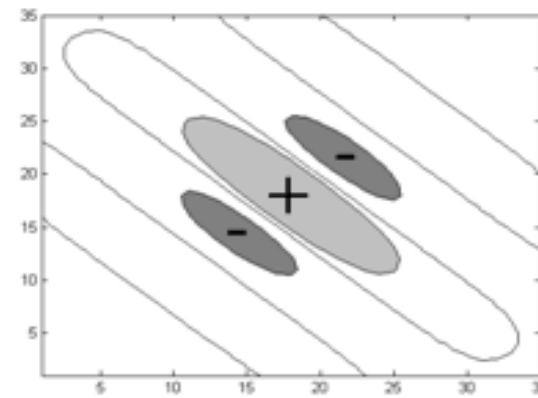
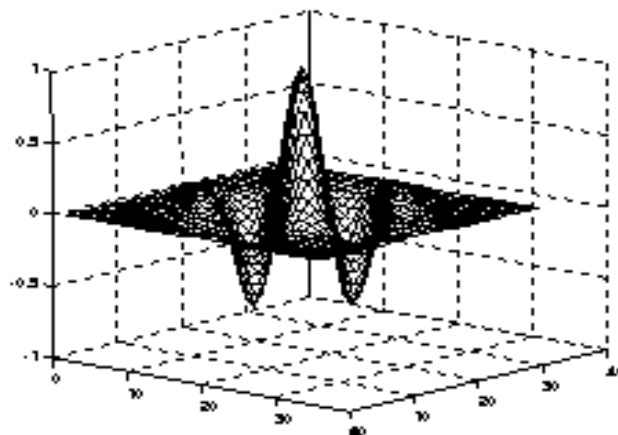


$$HD = \frac{\|(codeA \otimes codeB) \cap maskA \cap maskB\|}{\|maskA \cap maskB\|}$$

Gabor filter + phase demodulation is an ordinal operator



Odd Gabor filter

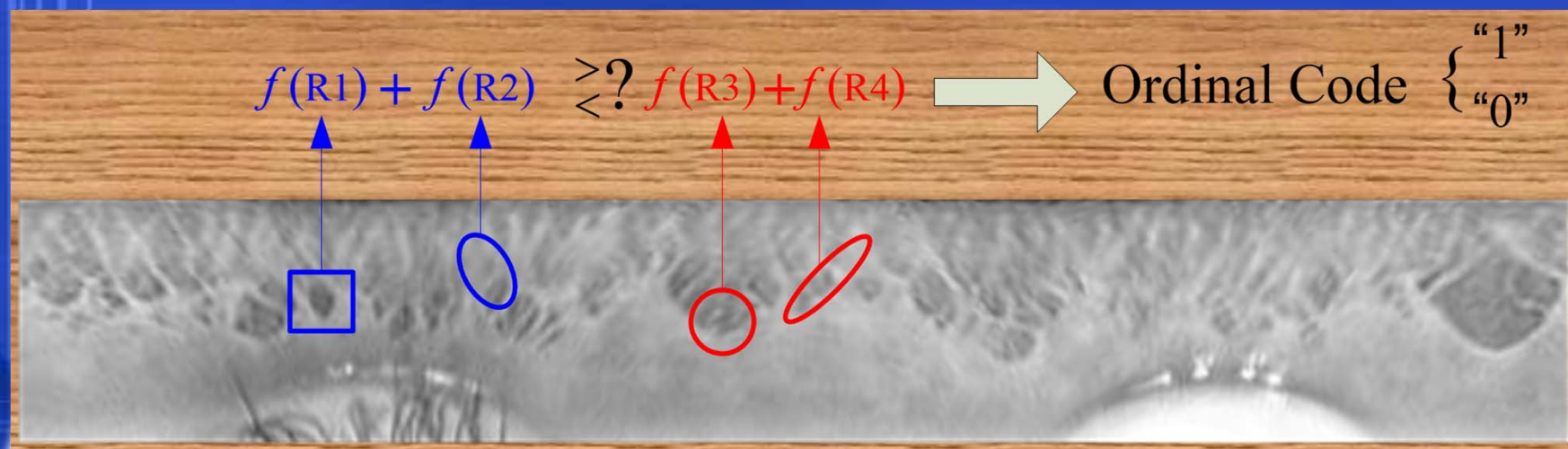


Even Gabor filter



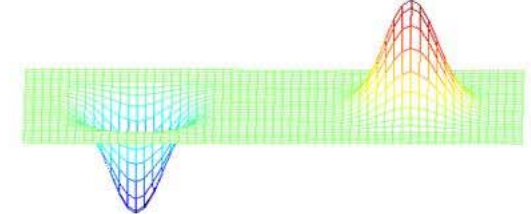
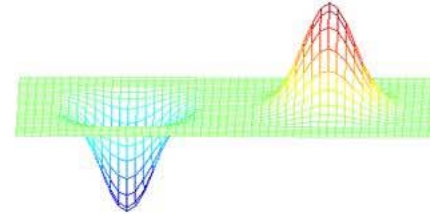
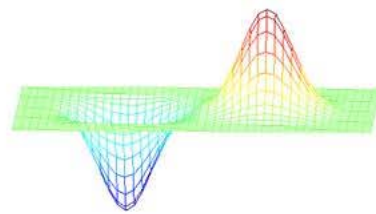
Variables in ordinal feature extraction

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

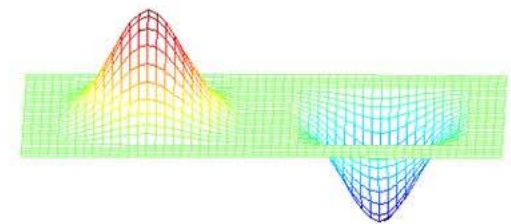
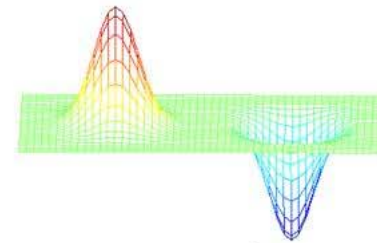
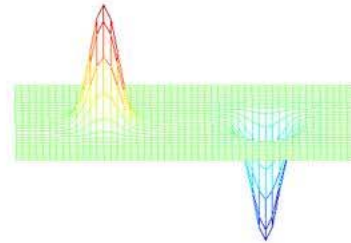


Dissociated Multi-Poles

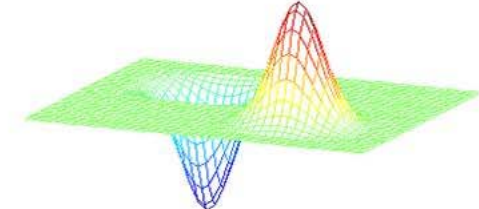
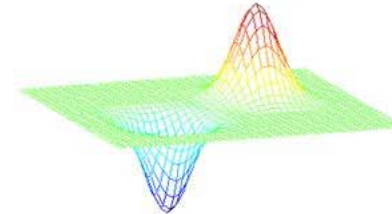
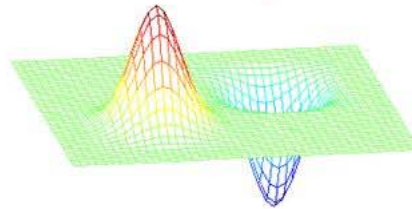
Distance



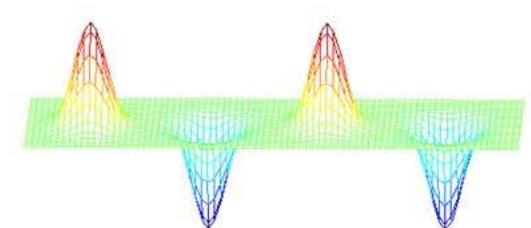
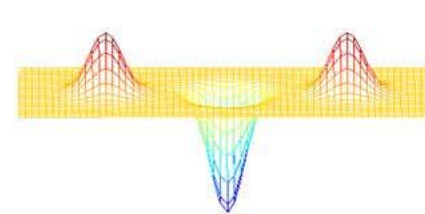
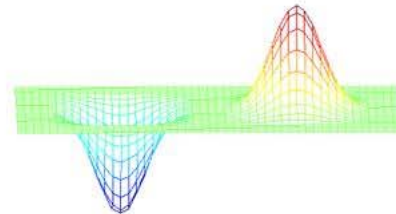
Scale



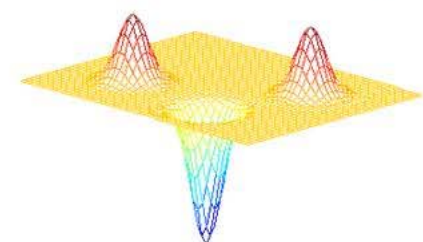
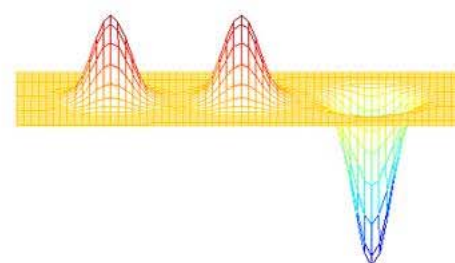
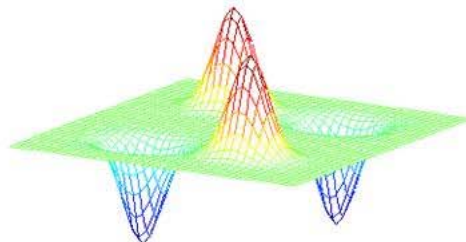
Orientation



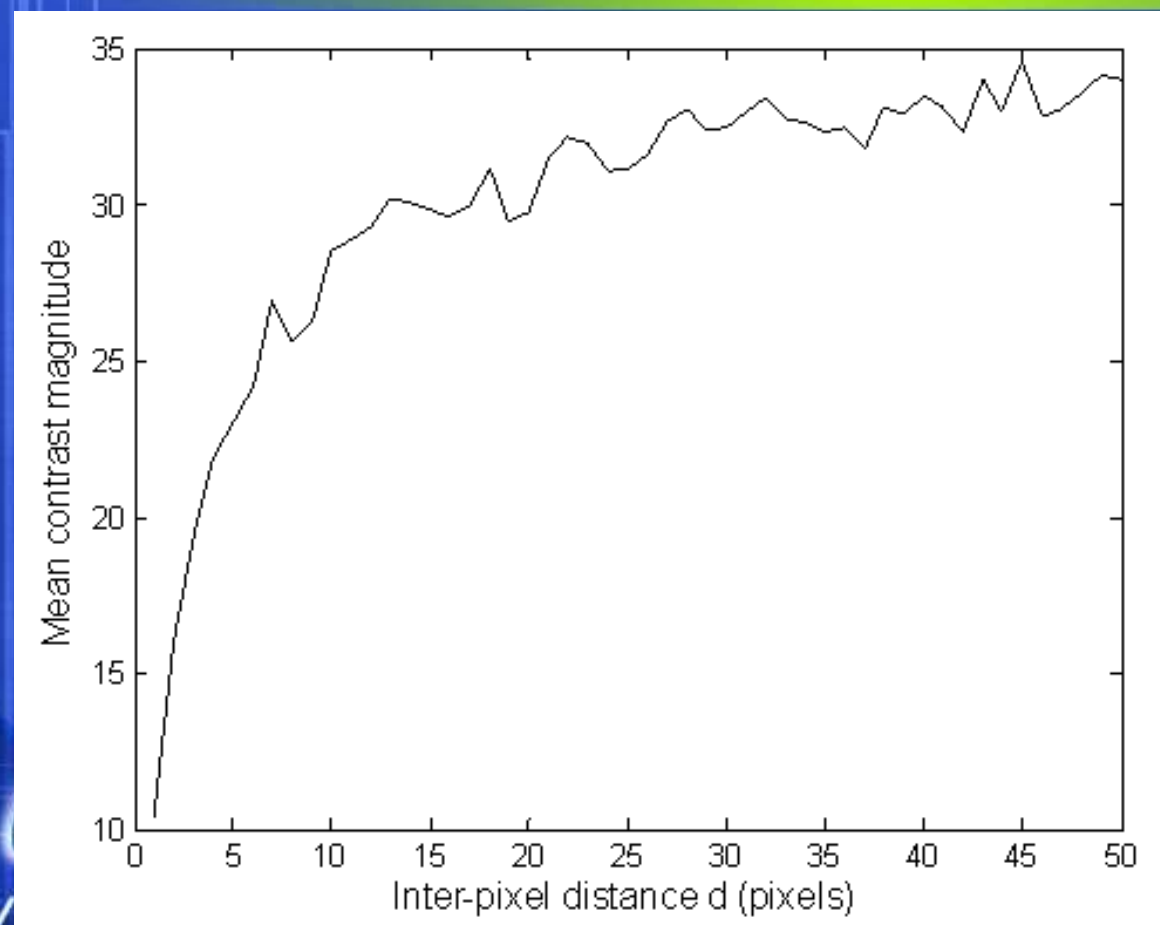
Number



Location



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



Larger distance



Less correlation

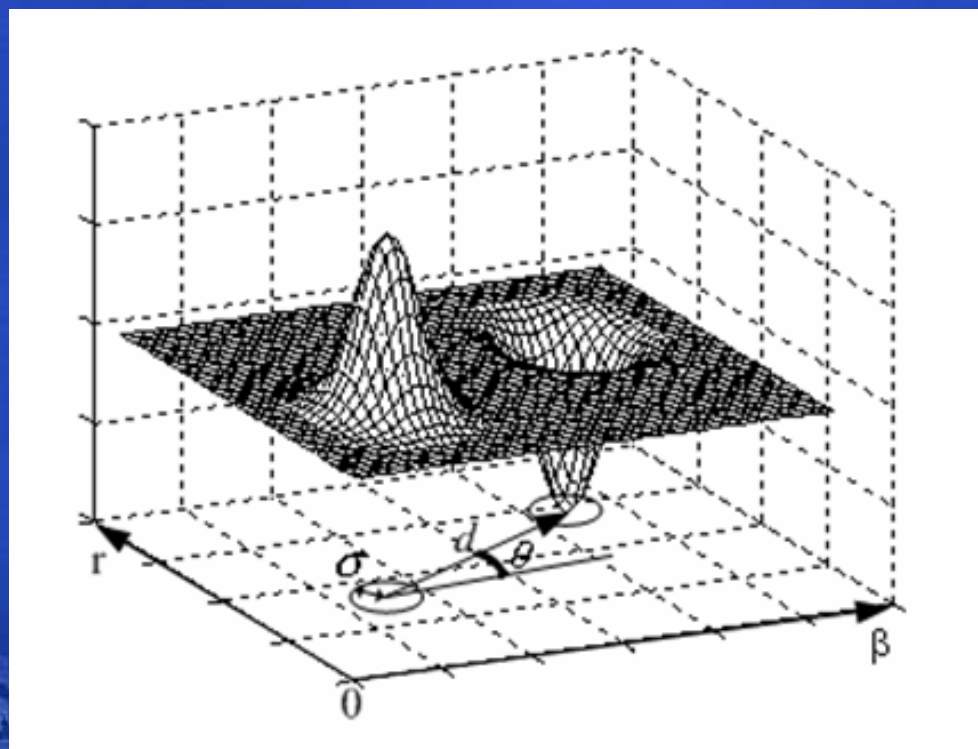


Higher contrast



More robust OM

Local ordinal measures vs. Non-local ordinal measures

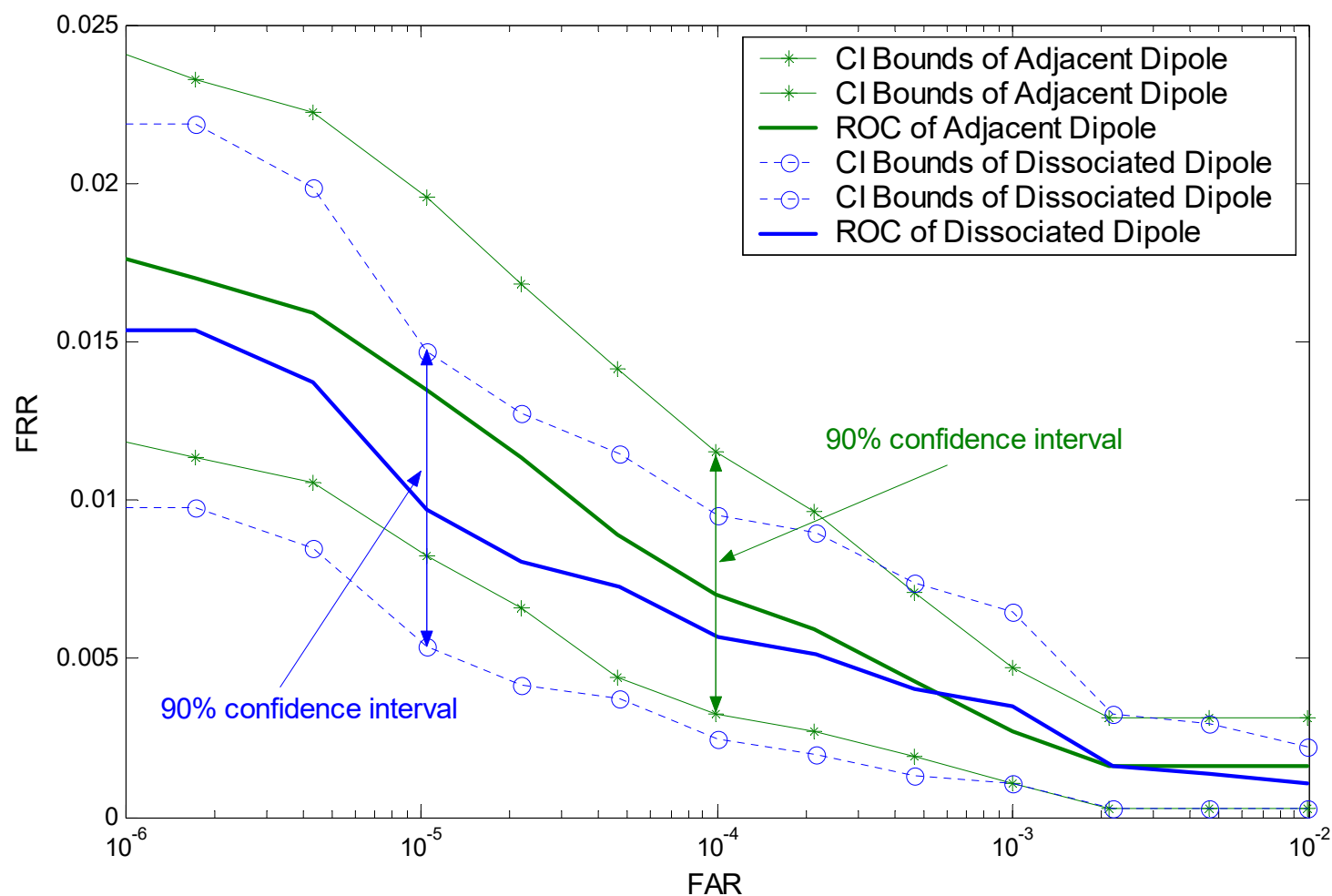


Dissociated Dipoles (from P. Sinha)

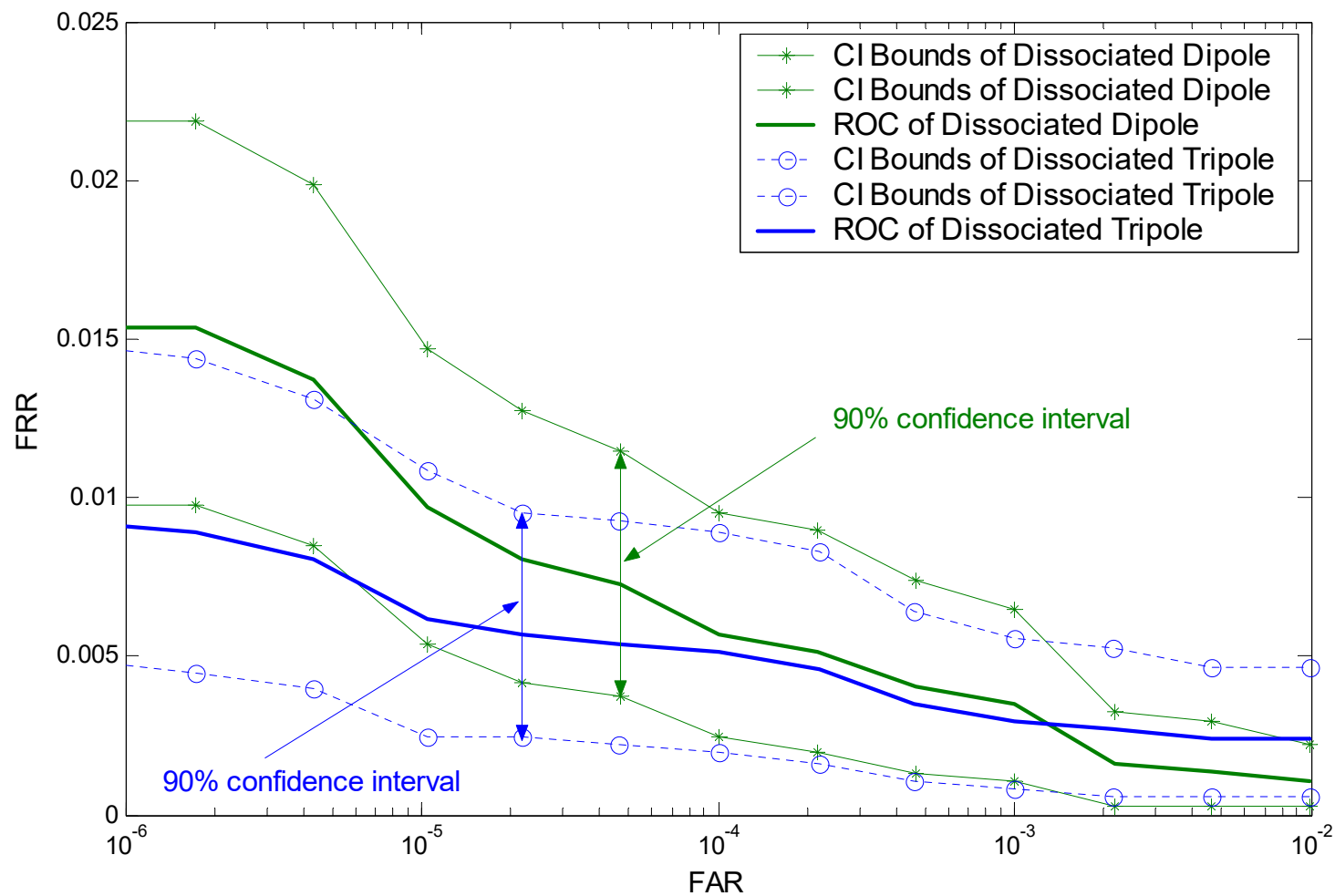


[//www.ia.ac.cn](http://www.ia.ac.cn)

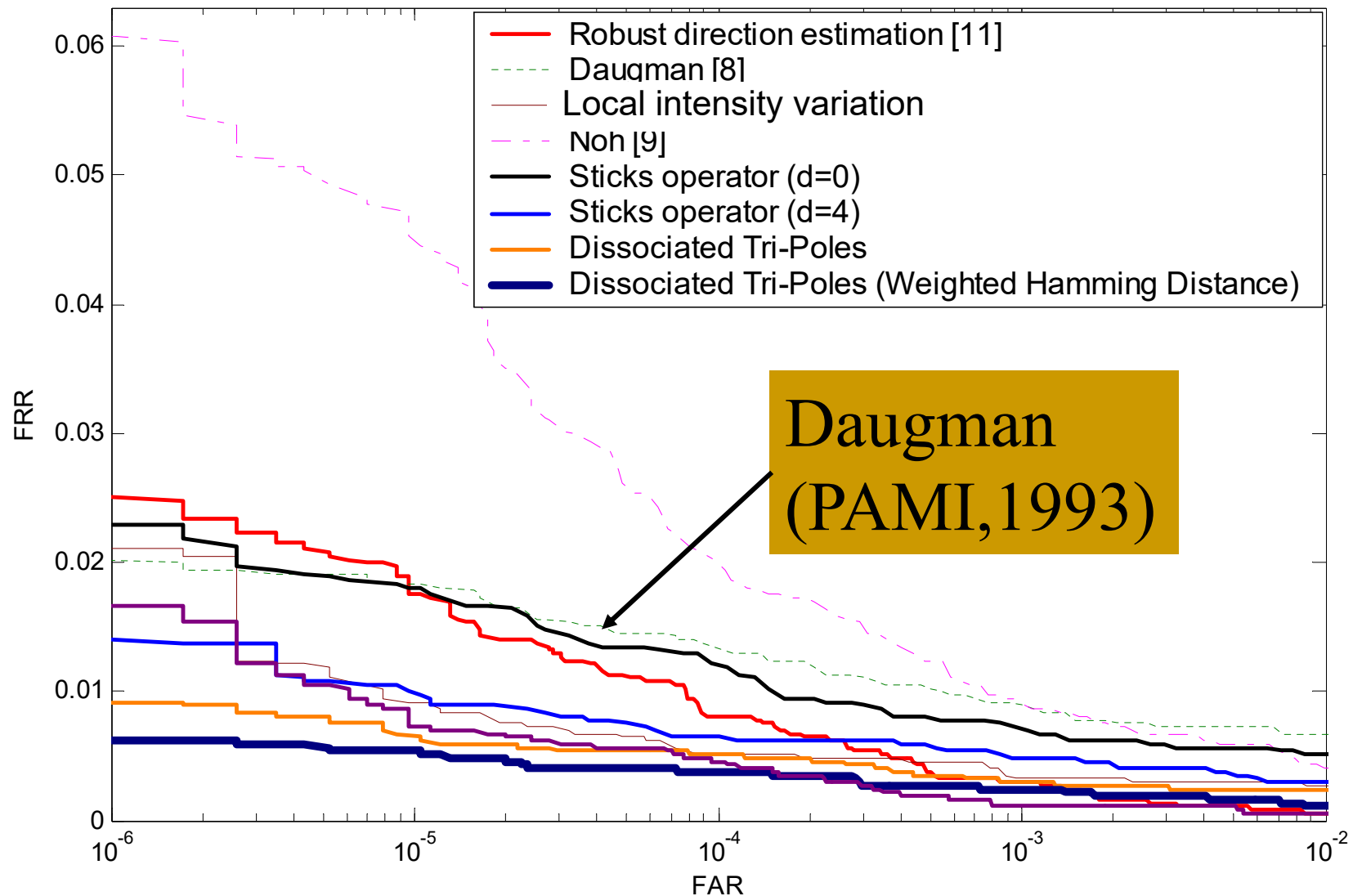
Local ordinal measures vs. Non-local ordinal measures

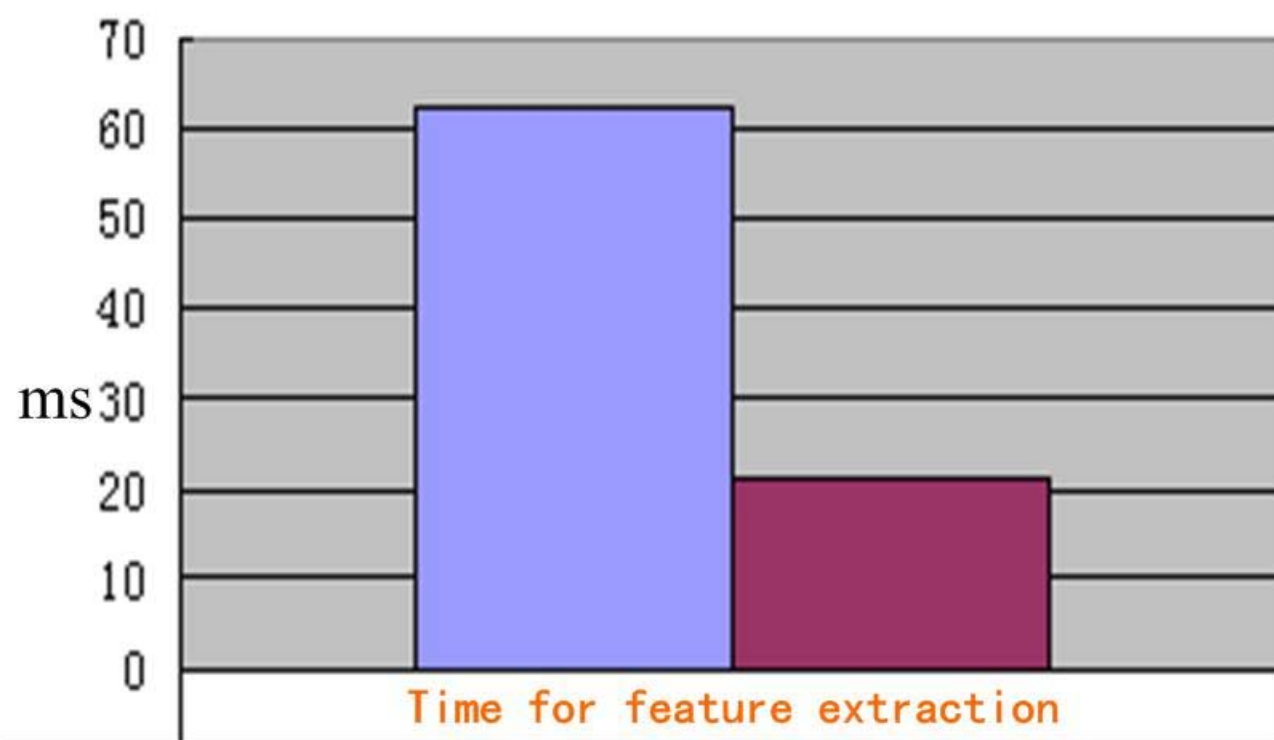


Dissociated Dipoles vs. Dissociated Tri-poles



State-of-the-art iris recognition performance





■	Daugman's	62	ms
■	Ordinal code	21	ms

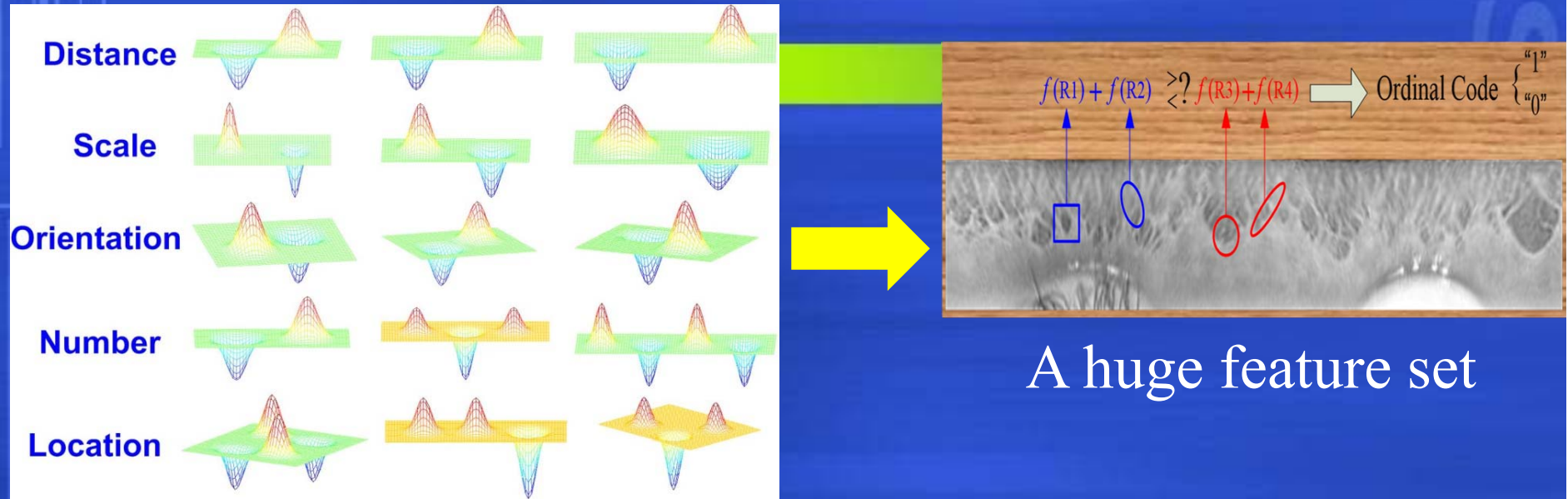


Ordinal Iris Representation: Conclusions

- 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.



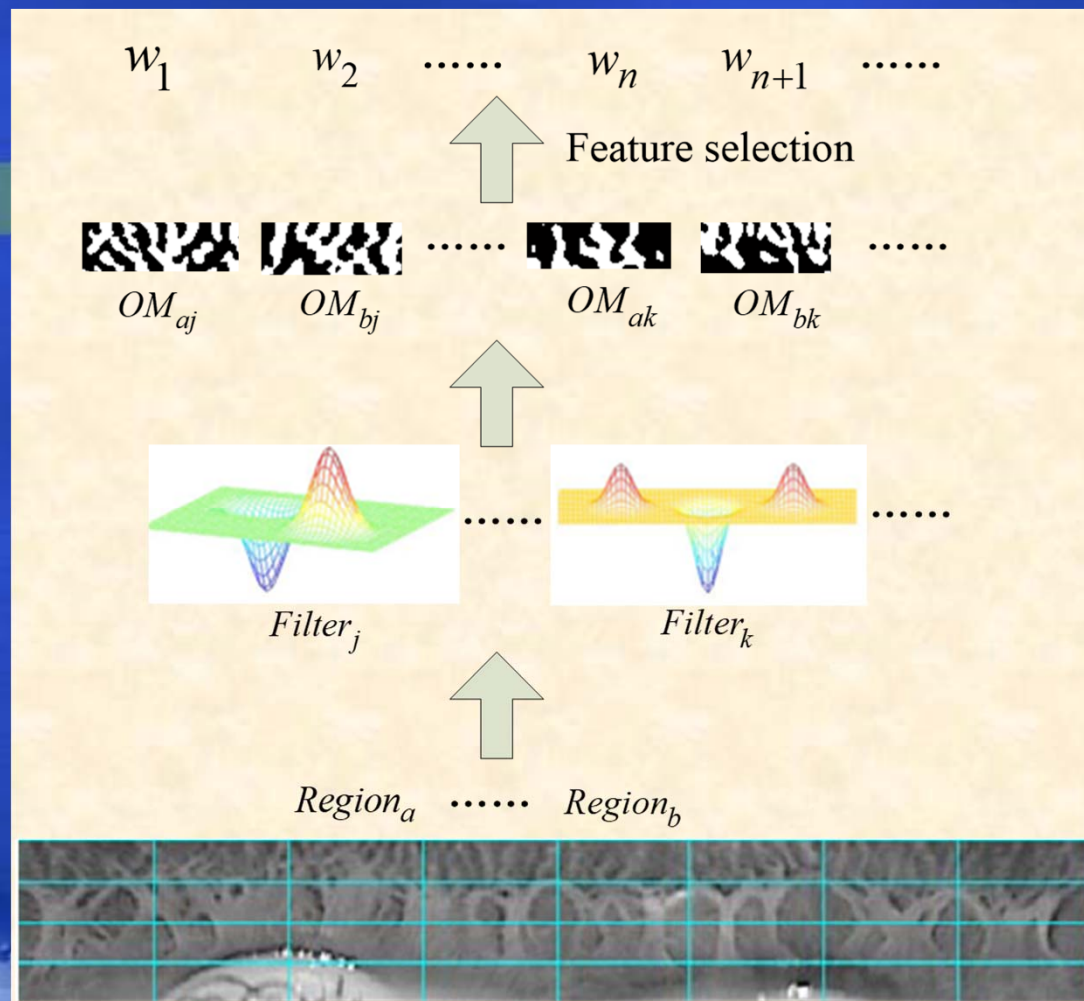
The importance of feature selection



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



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

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:

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

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

$$\xi_j^+ \geq 0, \quad j = 1, 2, \dots, N^+$$

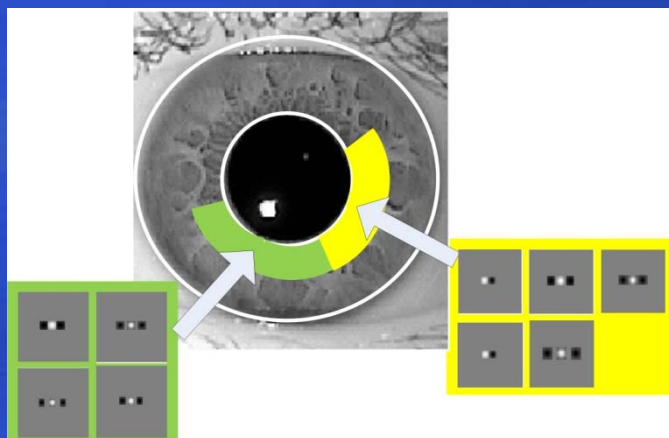
$$\xi_k^- \geq 0, \quad k = 1, 2, \dots, N^-$$

$$w_i \geq 0, \quad i = 1, 2, \dots, D$$

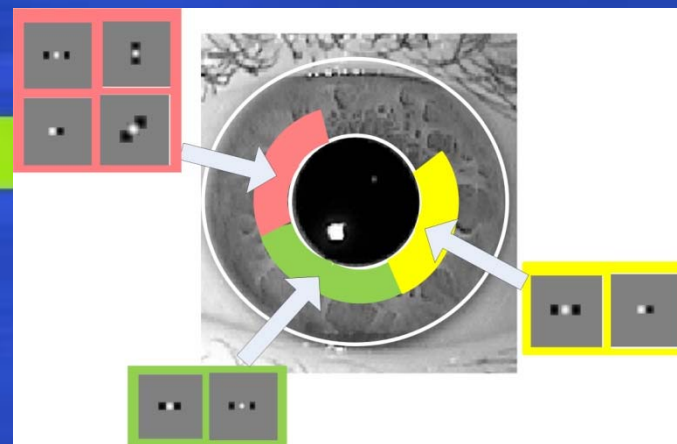
All intra- and inter-class matching samples should be well separated based on a large margin principle

Slack variables

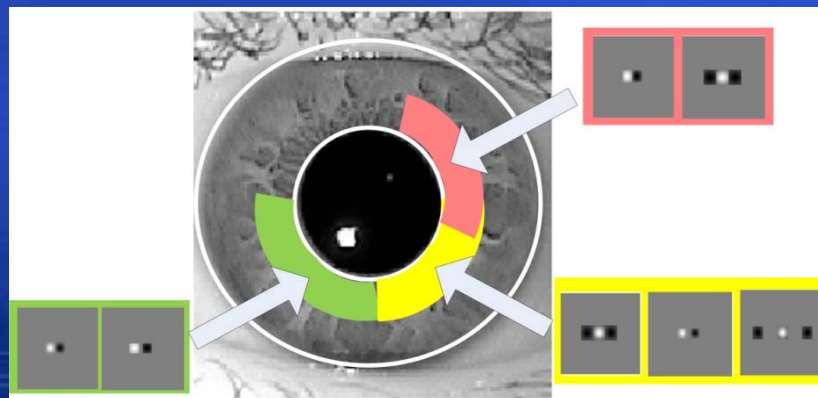
Feature selection results for iris biometrics



LP-OM



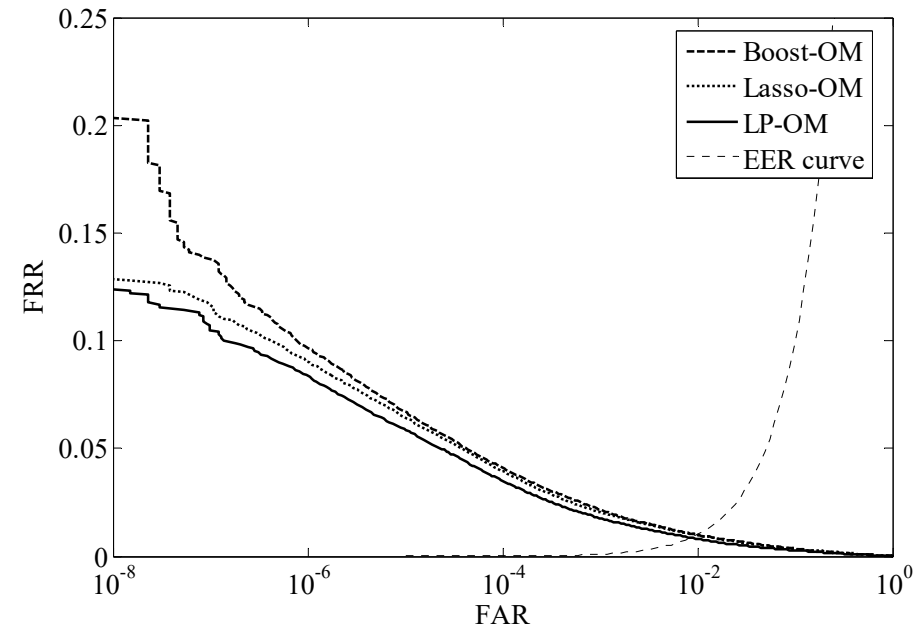
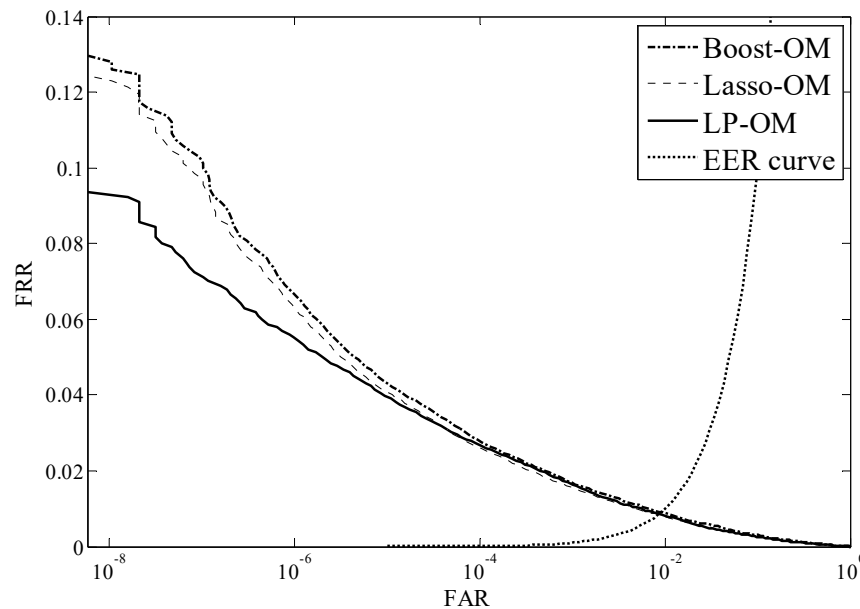
Lasso-OM



Boost-OM



Performance comparison for iris recognition



CASIA-Iris-Thousand

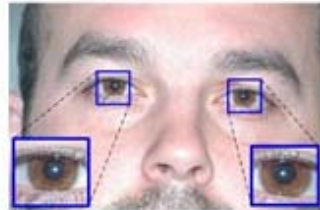
[//www.ia.ac.cn](http://www.ia.ac.cn)

CASIA-Iris-Lamp

Heterogeneous Iris Images



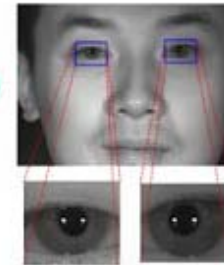
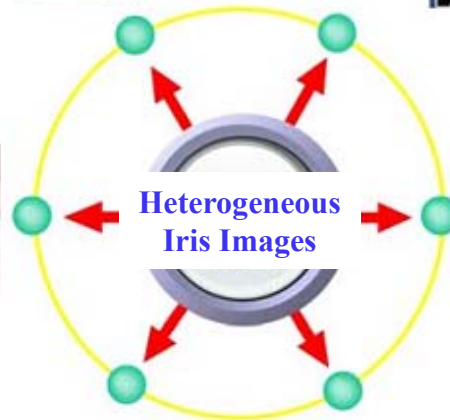
Surveillance



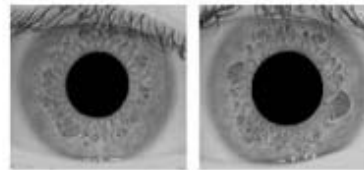
Internet



Mobile



Iris at a distance



Close-range iris sensors



//www

Recognition of Heterogeneous Iris Images

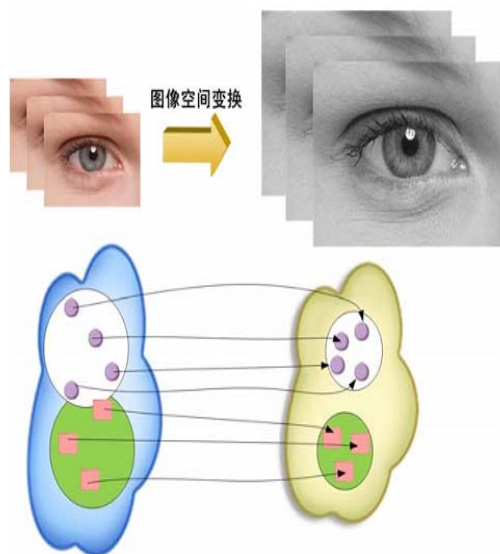
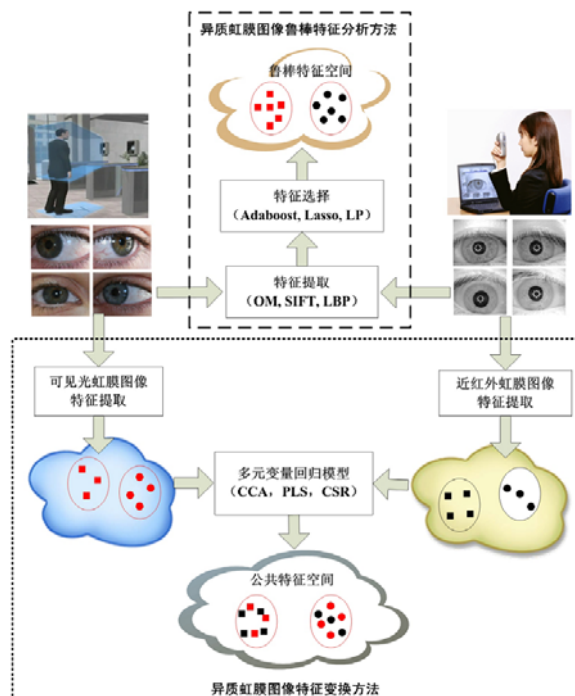
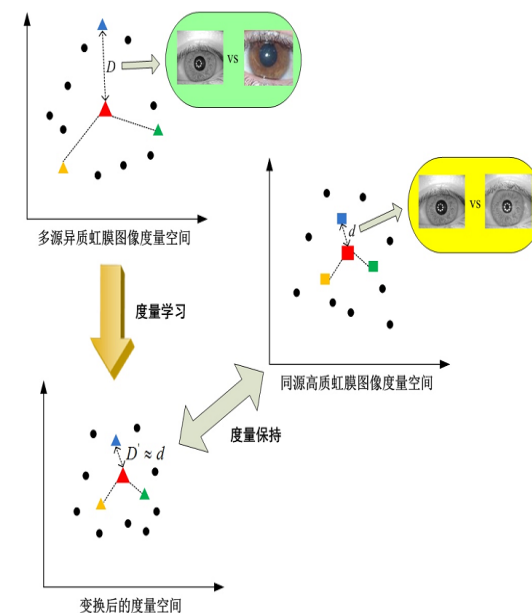


Image level

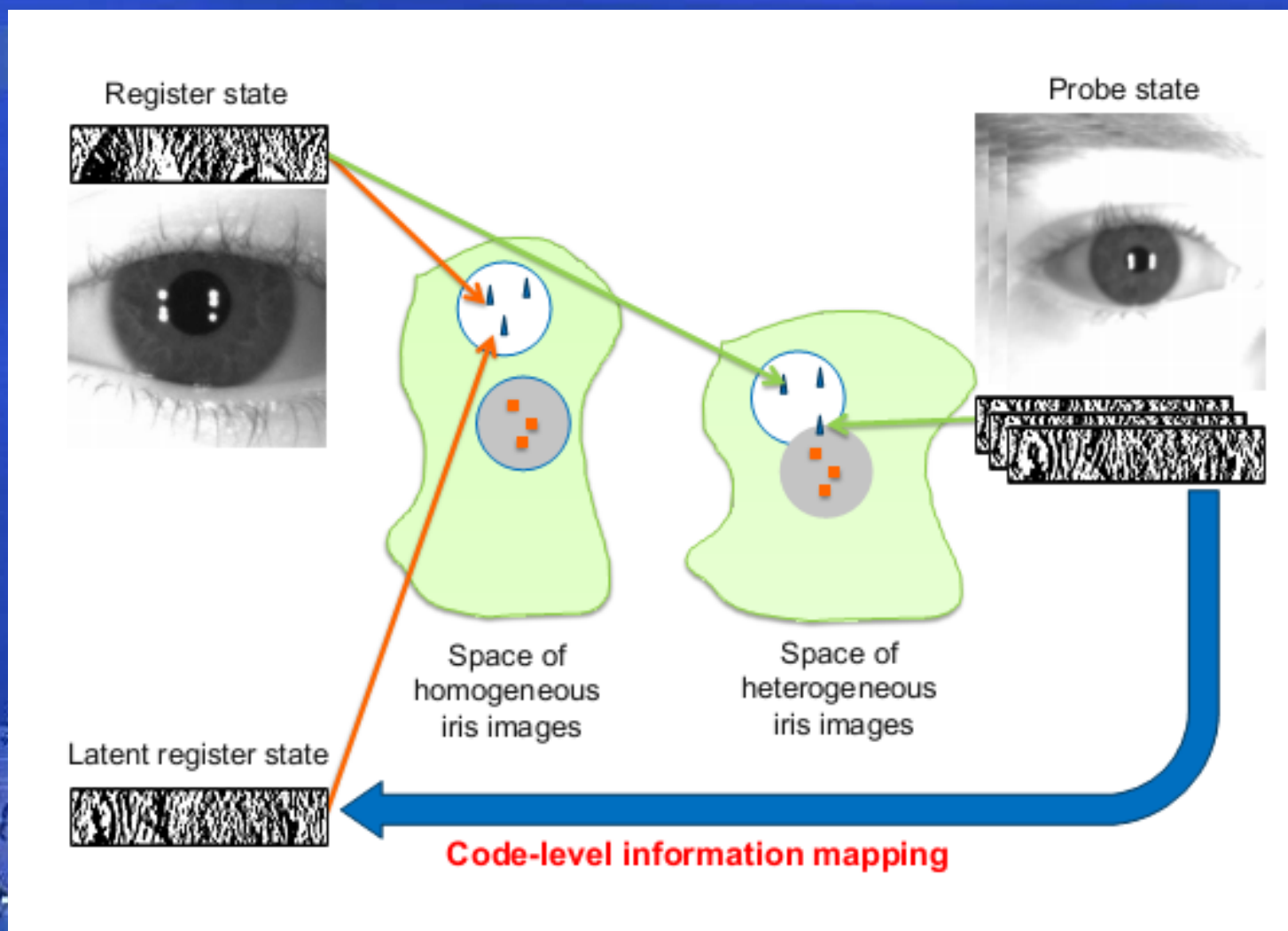


Feature level



Metric level

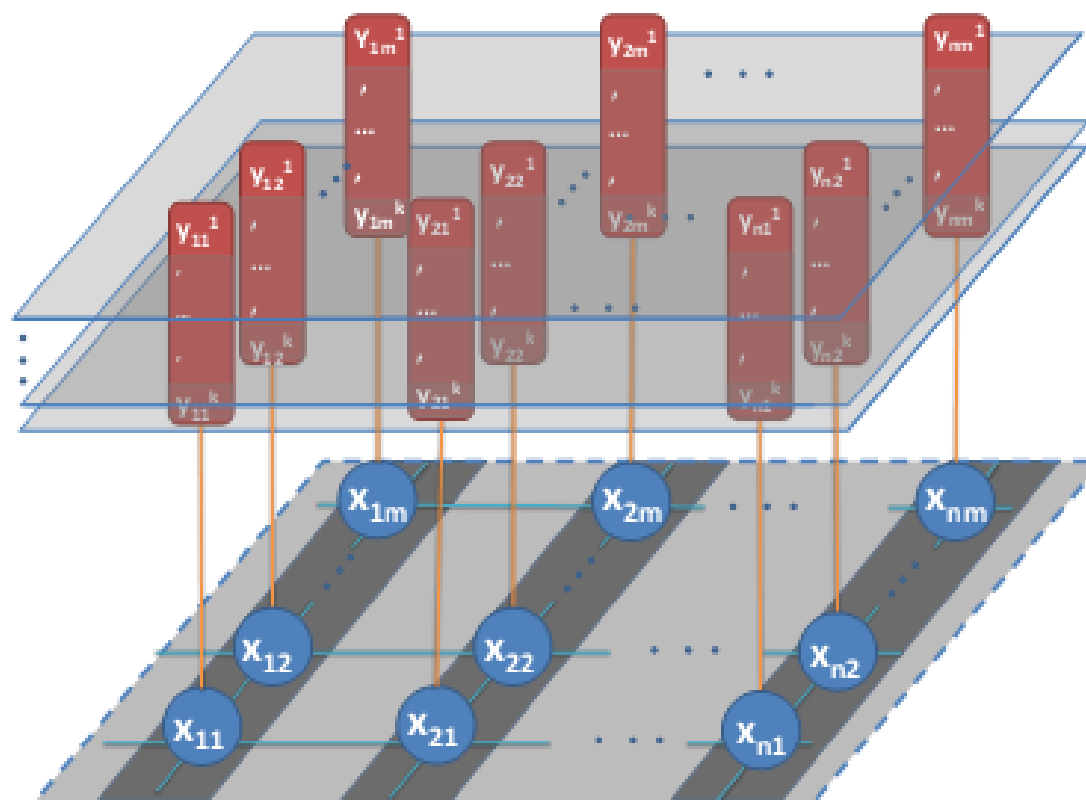
Code-level Information Mapping for Heterogeneous Iris Recognition



//www.

Markov network

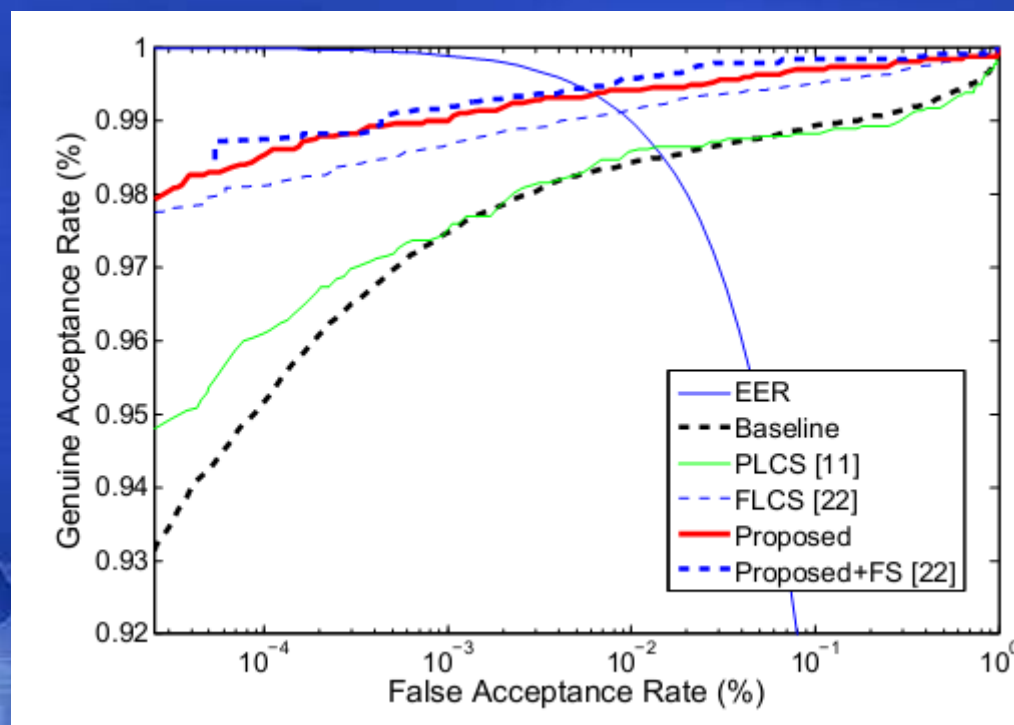
The probe-state iris codes, $y^i, i = 1, 2, \dots, M$



The latent register-state iris code, x



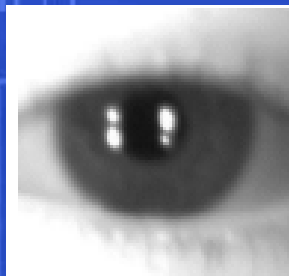
Cross-sensor Iris Recognition



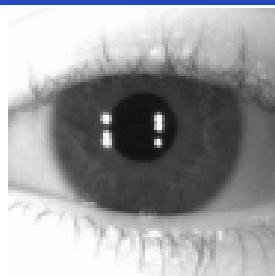
[11] S. S. Arora, M. Vatsa, R. Singh, and A. Jain, "On iris camera interoperability," in *Int'l Conf. on Biometrics: Theory, Applications and Systems. (BTAS)*. IEEE, 2012, pp. 346–352.

[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.

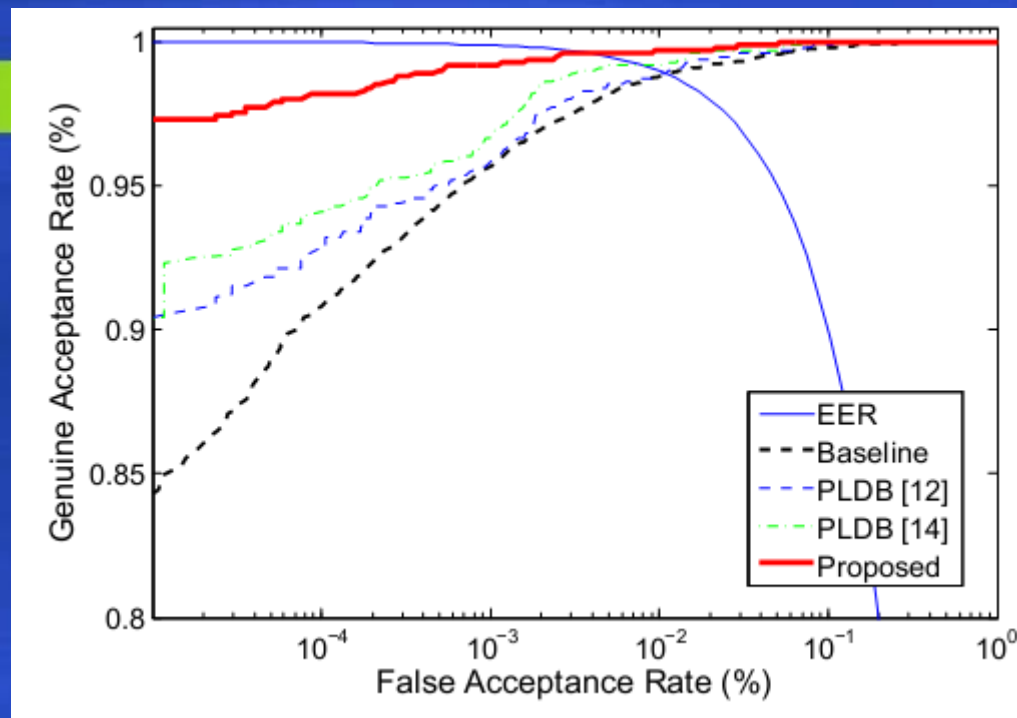
Cross-quality Iris Recognition



Defocused



Clear



//www.ia.

[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.

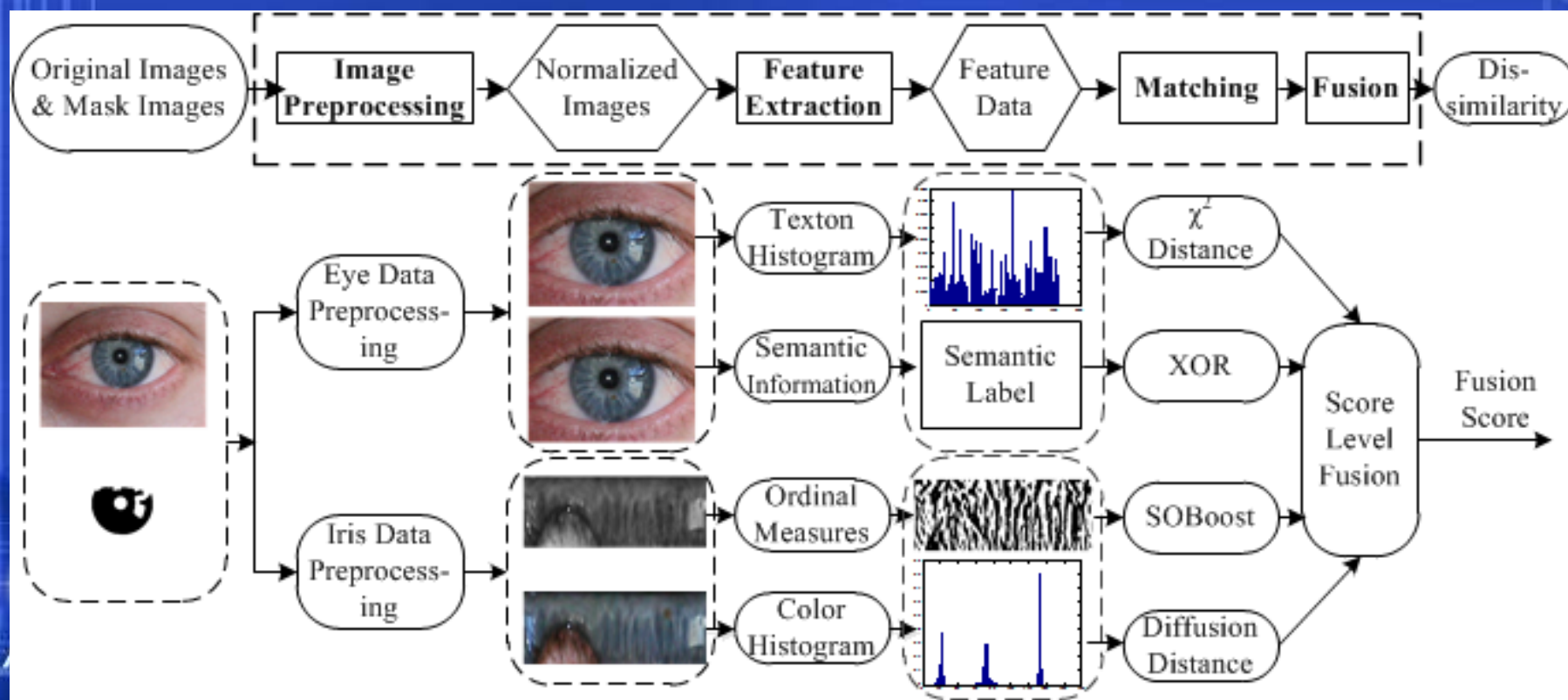
[14] J. Liu, Z. Sun, and T. Tan, “Iris image deblurring based on refinement of point spread function,” in *Biometric Recognition*. Springer, 2012, pp. 184–192.

Noisy Iris Image Matching by Using Multiple Cues



Motivations:

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



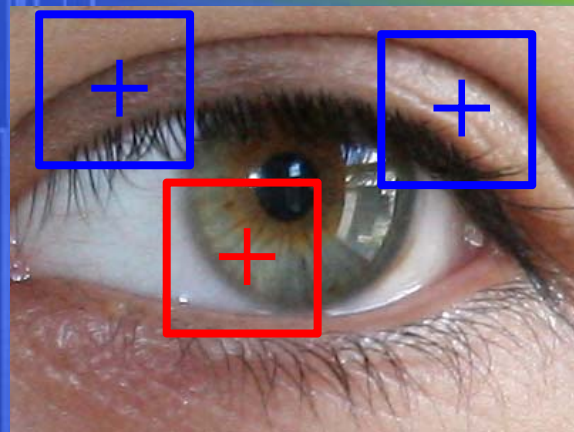
Deep Learning for Iris Recognition

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



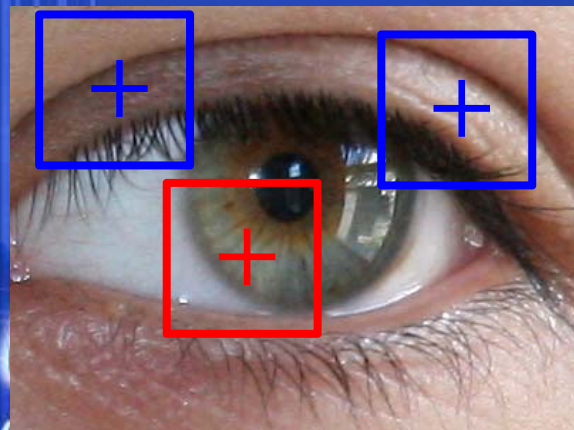
Iris Segmentation Based on Deep CNNs

CNNs: Convolutional Neural Networks



Handcrafted
Features
+
Classifier

Non-iris Non-iris



Learned
Features
+
Classifier

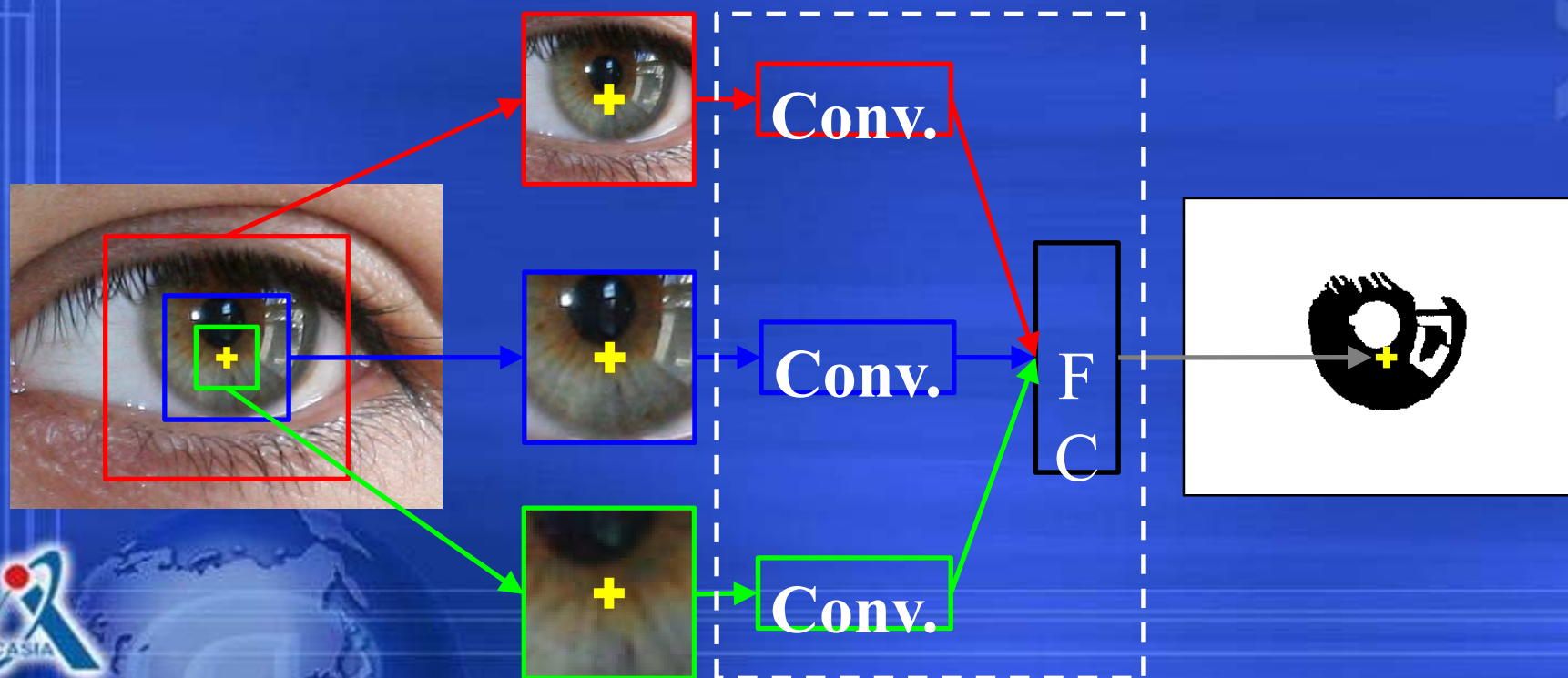
Non-iris Non-iris



Iris Segmentation Based on Deep CNNs

CNNs: Convolutional Neural Networks

Hierarchical Deep CNNs



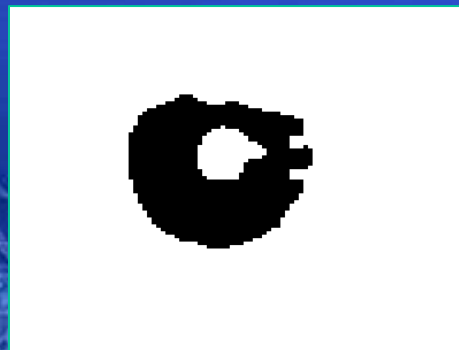
Iris Segmentation Based on Deep CNNs

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

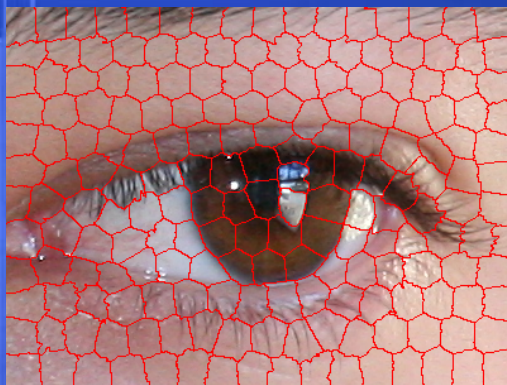


Iris Segmentation Based on Deep CNNs

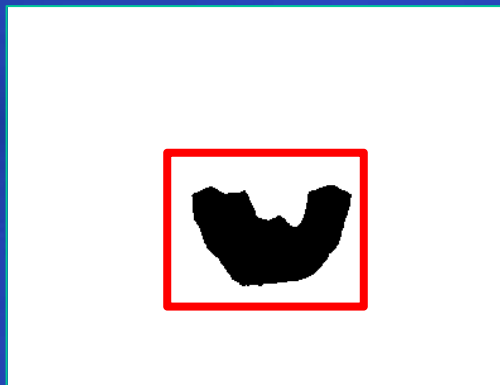
Hardware: one NVIDIA TITAN GPU and one Intel i7 CPU

Elapsed time: about 30s per image

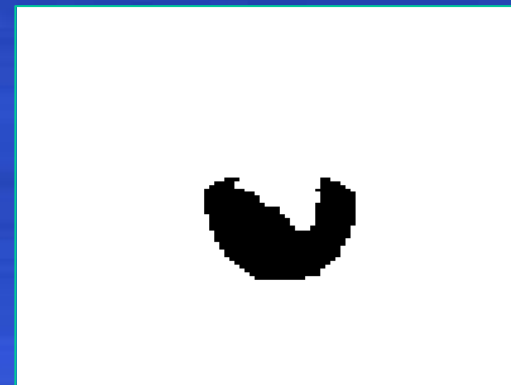
Reduce the number of pixels that need to be classified.



Superpixels



Coarse Loc.



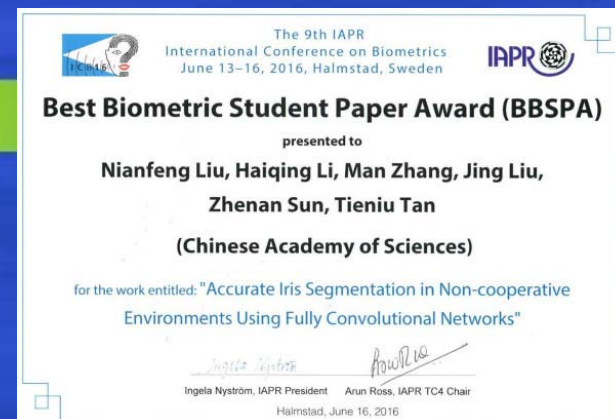
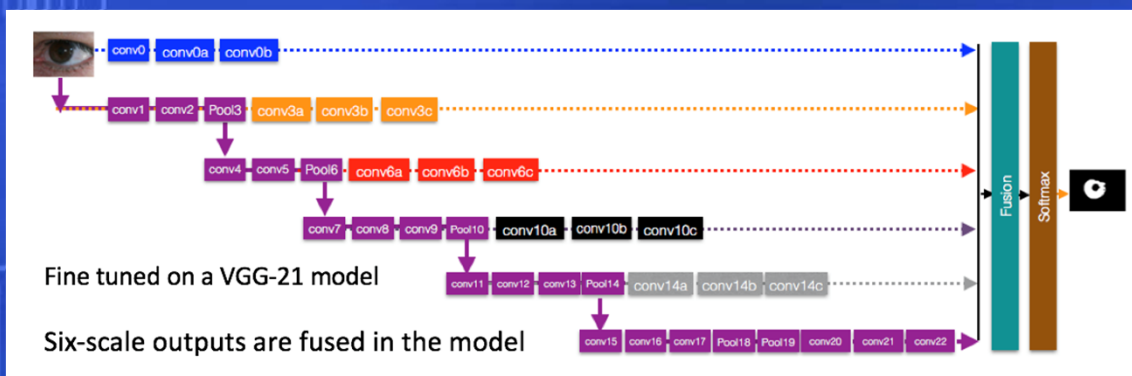
Fine Seg.

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



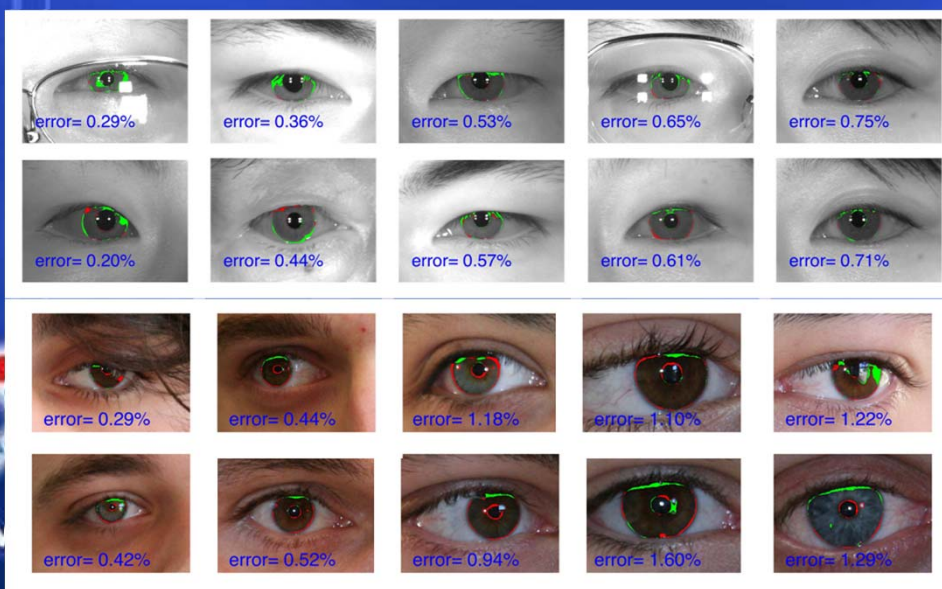
基于深度神经网络的噪声虹膜图像分割

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

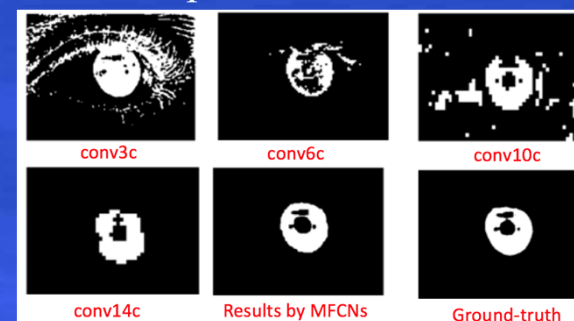


Segmentation results

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



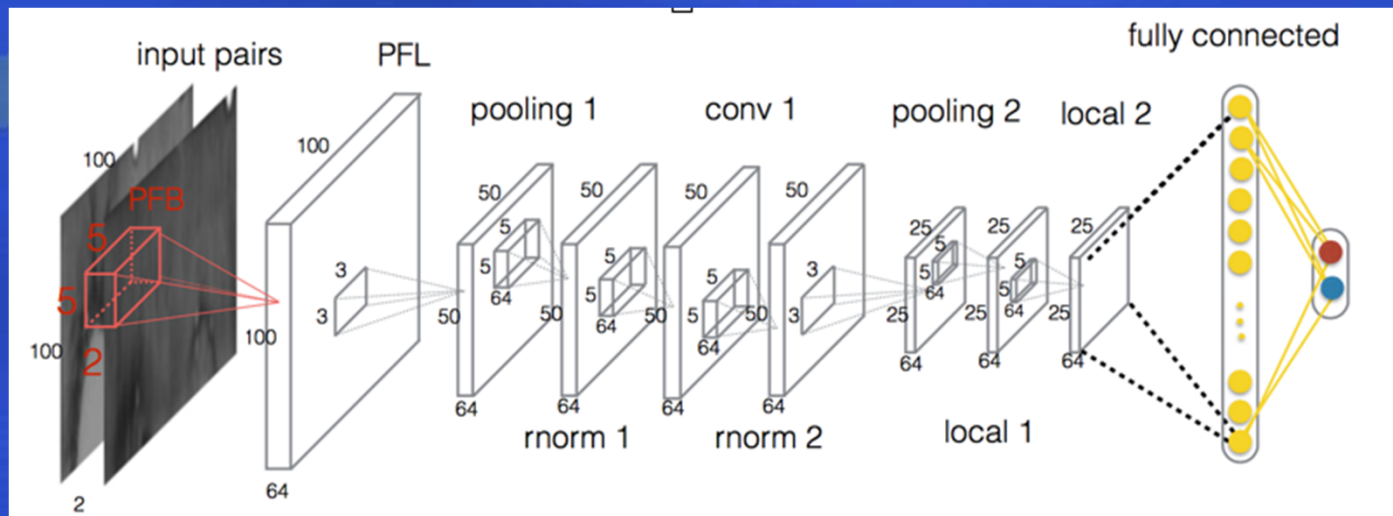
Feature maps from shallow to deep



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 <i>et al.</i> , 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:



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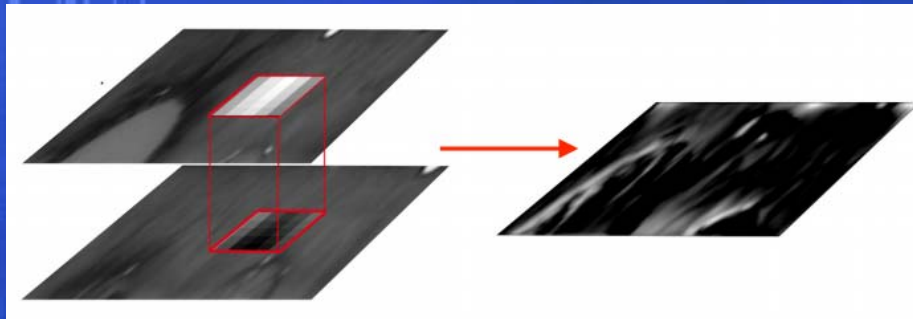
Localization

Normalization

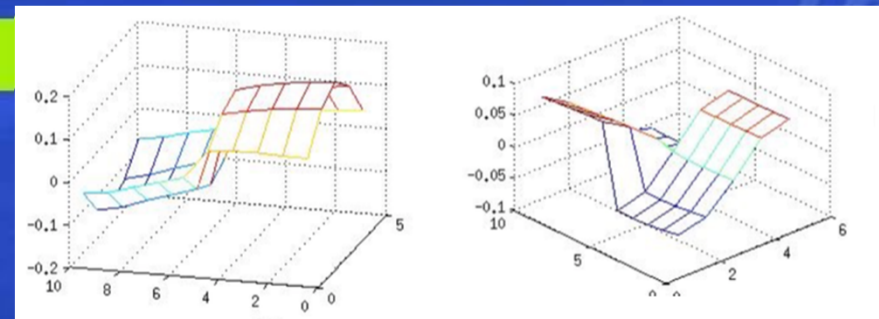
Mean image
Subtract the
mean image

Iris Verification Based on Deep CNNs

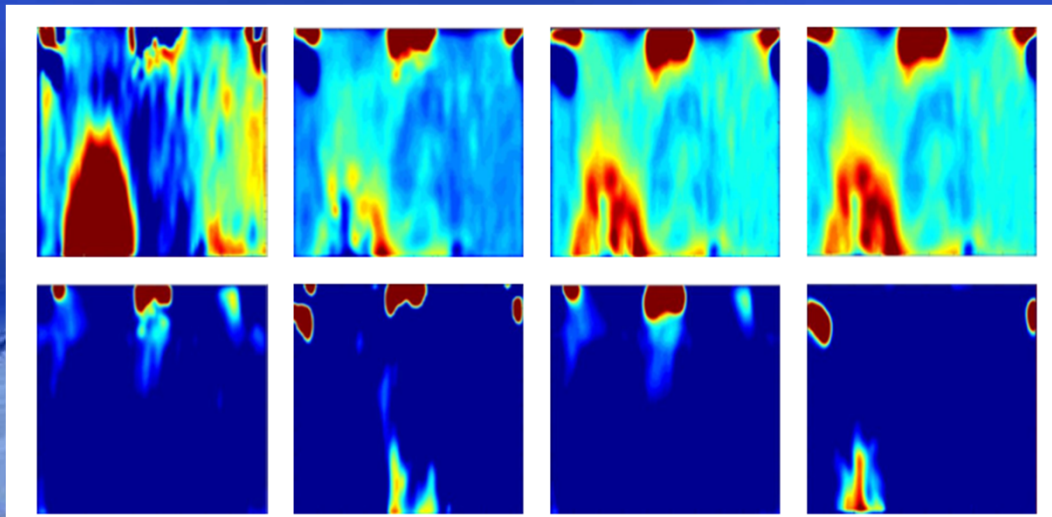
The first convolutional layer



Learned differential filters



The feature maps after the first layer filtering



Inter-class

Intra-class



//www.ia.ac

Iris Verification Based on Deep CNNs

Test on the QFIRE database

images are captured at different distance

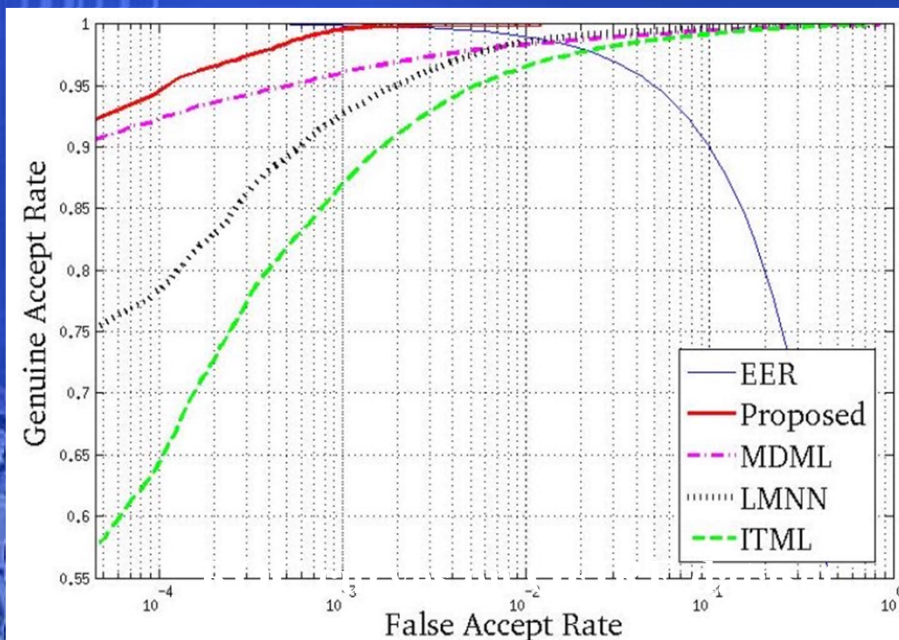
	number of classes	number of images
05 feet-train	100	1680
05 feet-test	60	911
11 feet-train	100	1568
11 feet-test	60	966



5
feet



11
feet



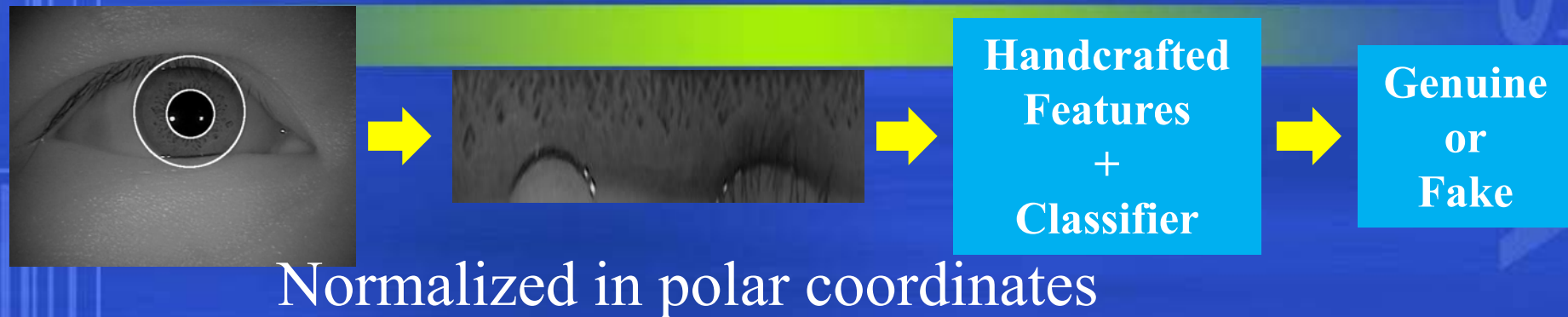
Hardware: one NVIDIA Titan GPU and one Intel i7 CPU

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



Our CNN based iris liveness detection method



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	<i>CNNs</i>
CCR (%)	95.34	98.93	99.51	99.79	99.48

Test on the LIVDET-IRIS-2013 Warsaw database

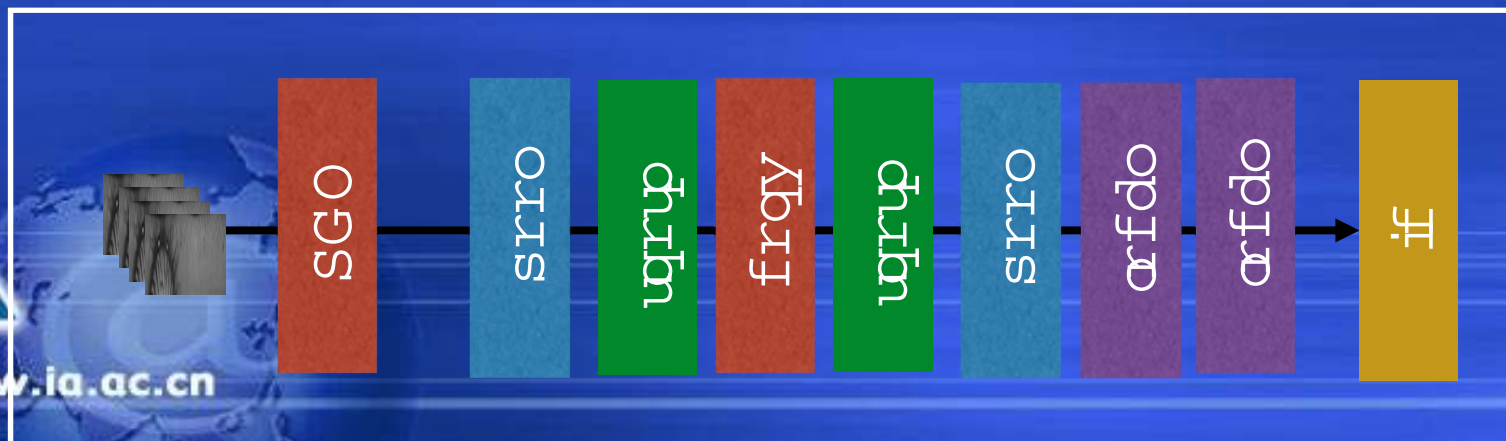
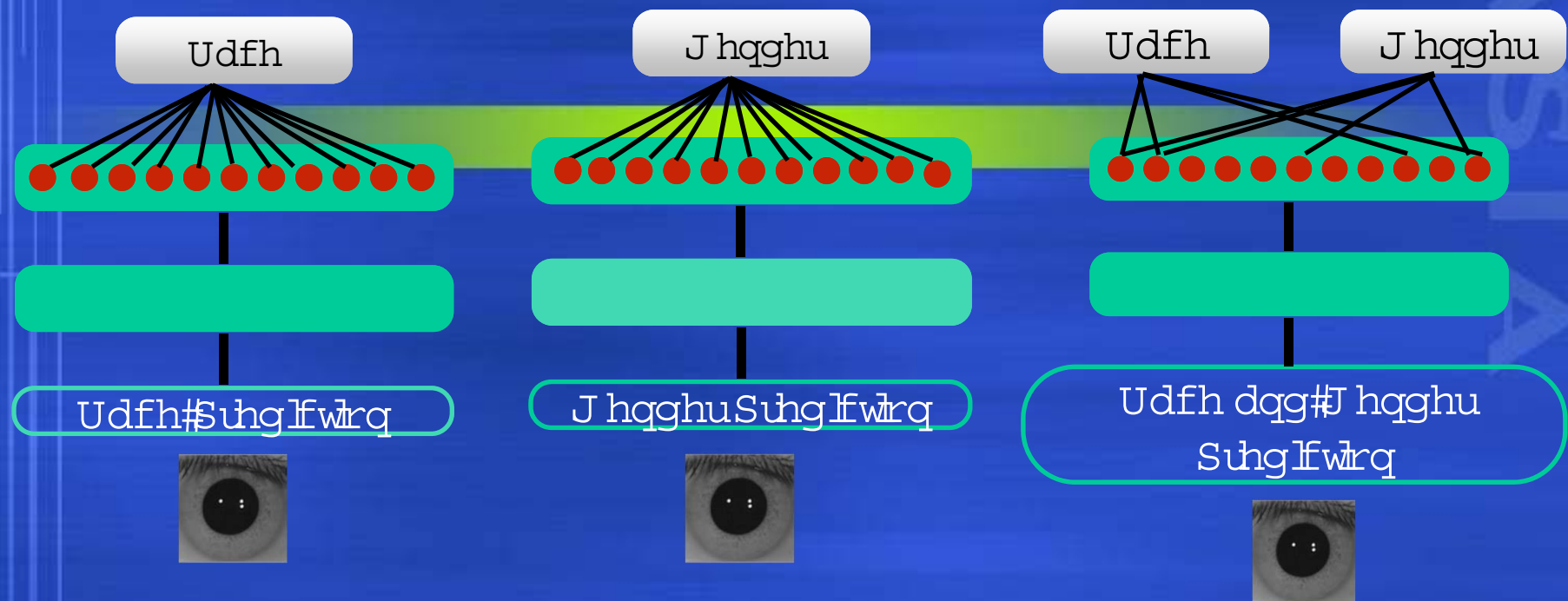
FAR: Rate of misclassified live iris images

FRR: Rate of misclassified spoof iris images

Method	ATVS	Federico	Porto	<i>CNNs</i>
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

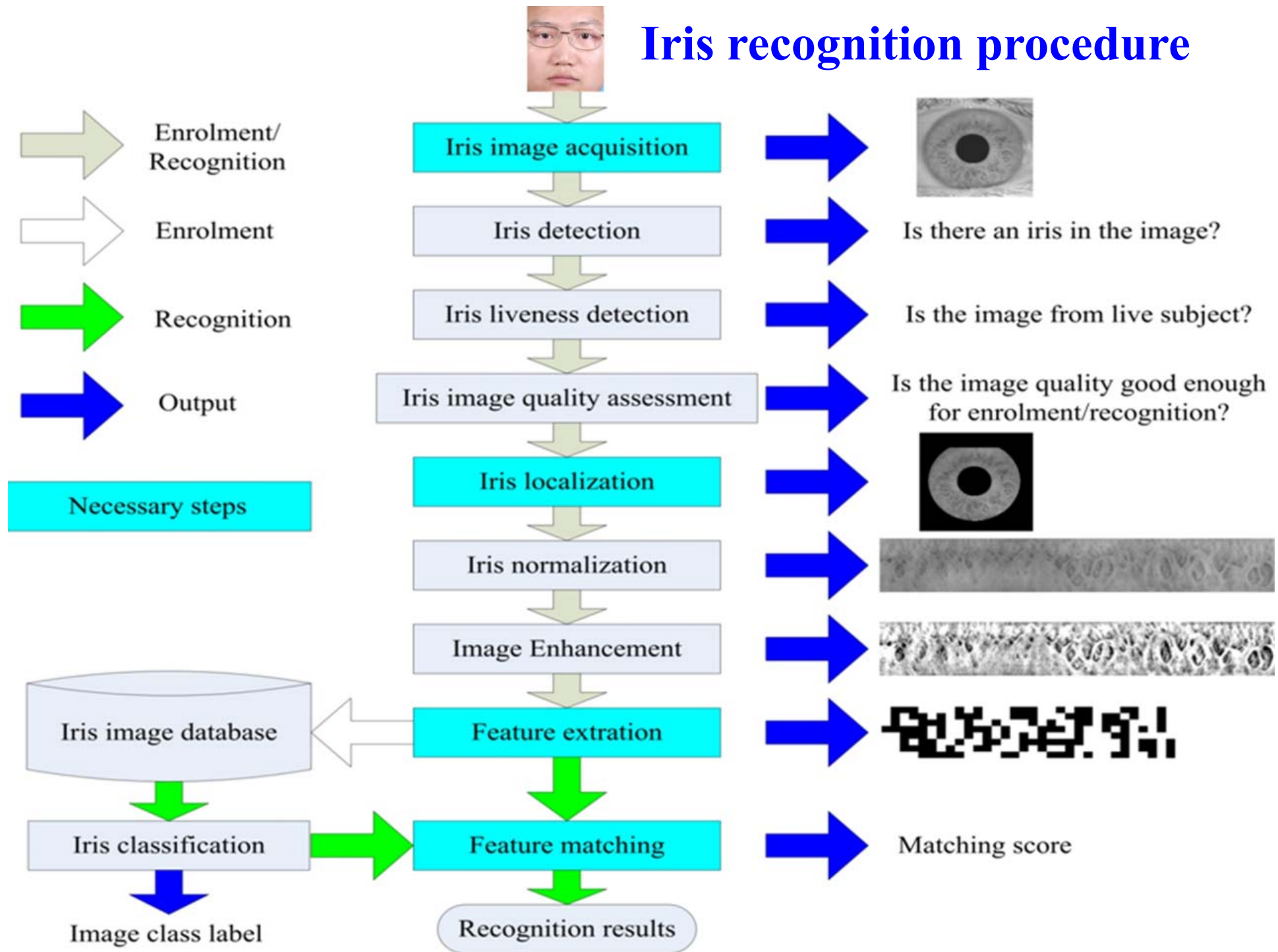
Iris Attributes Analysis Based on Deep CNNs

Correct classification rate:

Udfh#suhglfwrq	< ; 13 < (
J hqghu#suhglfwrq	< ; 179 (
Udfh#lqg#j hqghu# +P xovdvn,	Udfh# < 138 (J hqghu# < 156 (



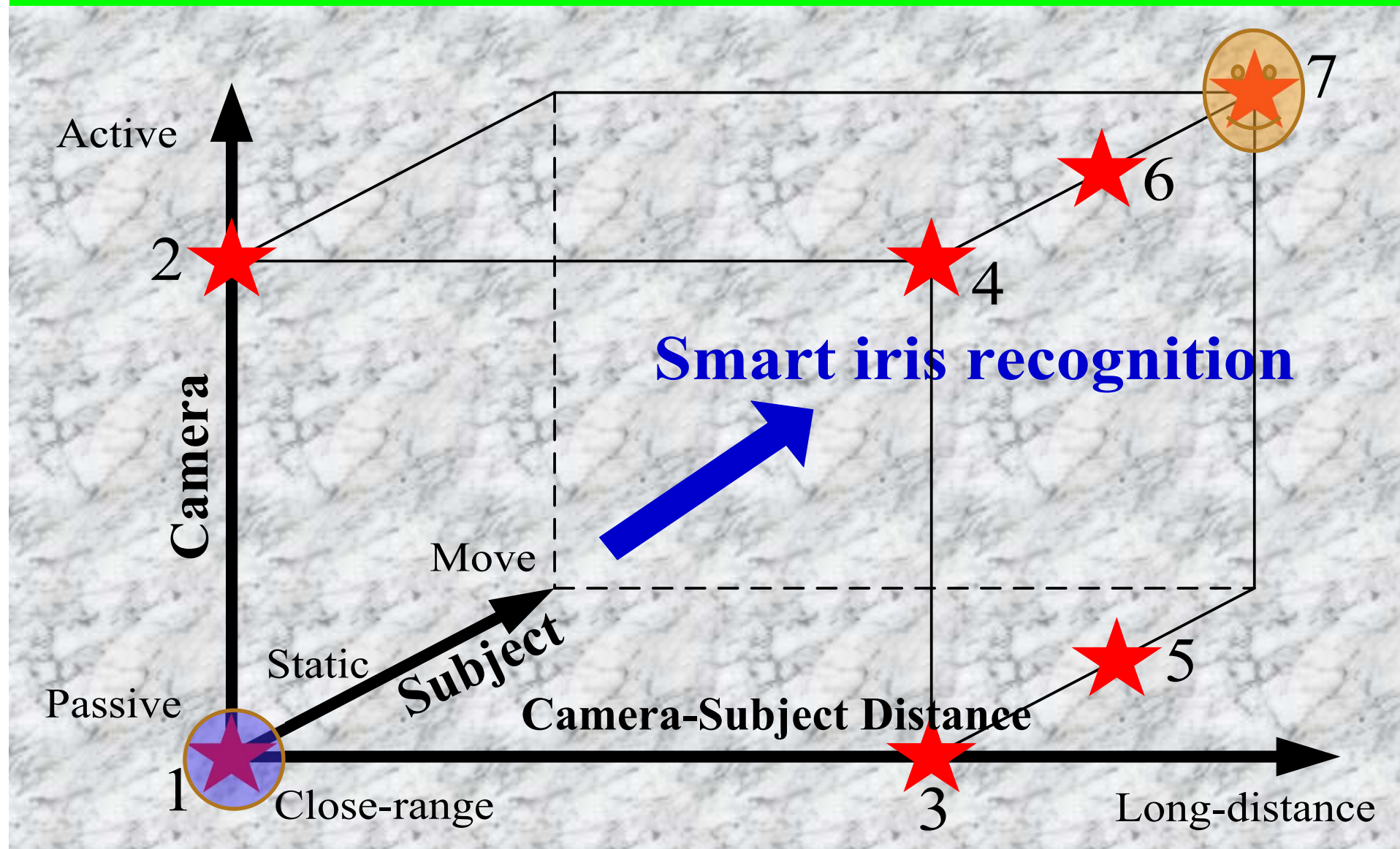
Iris recognition procedure

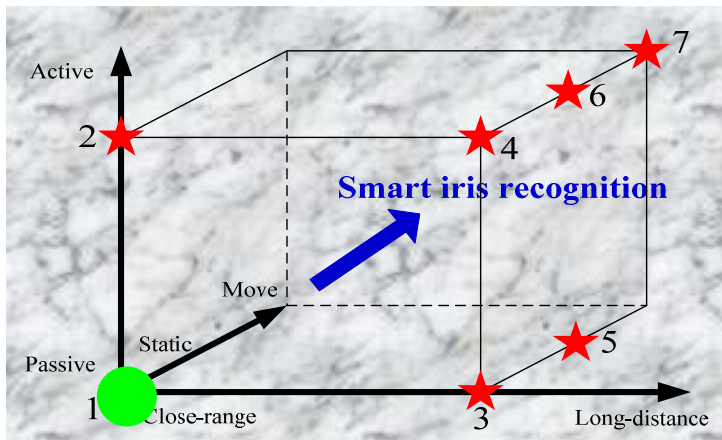


Outline of Talk

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

Where Now and What Next: IR Roadmap



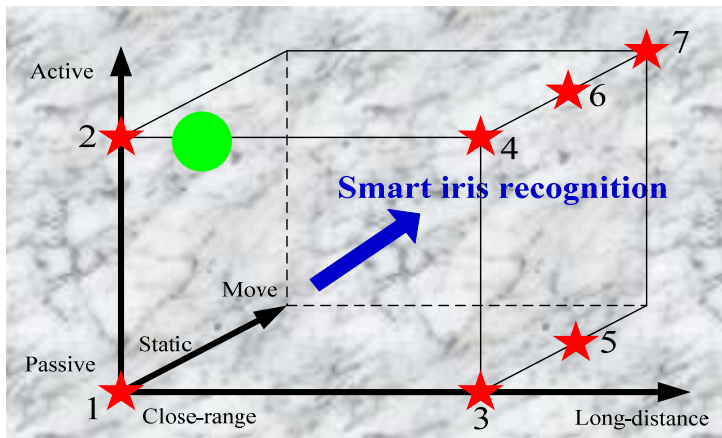


Stage 1: Close-range iris recognition

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

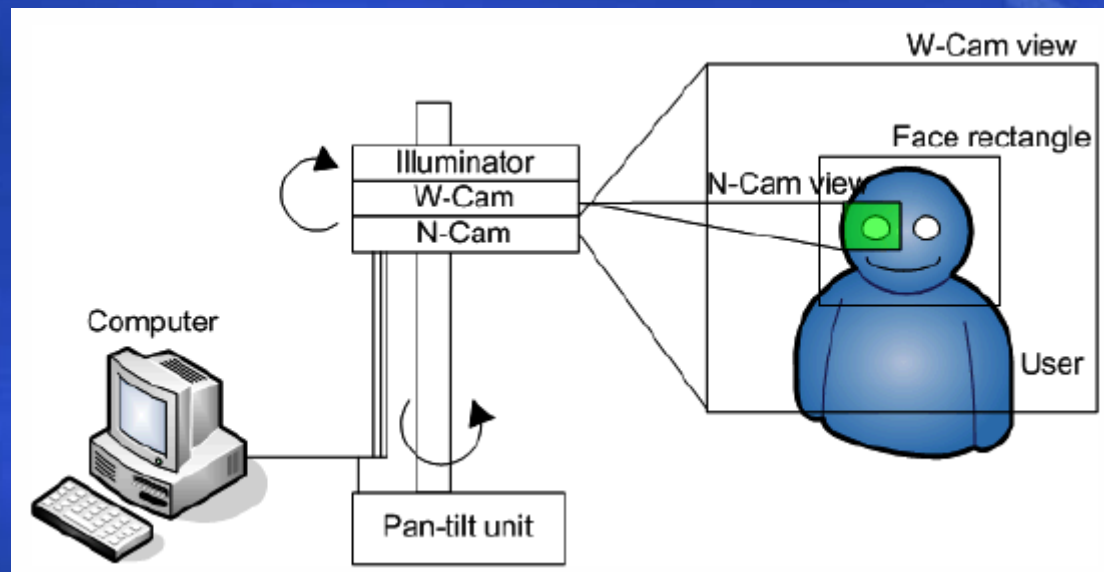
Camera: Active (PTZ, face + iris camera)

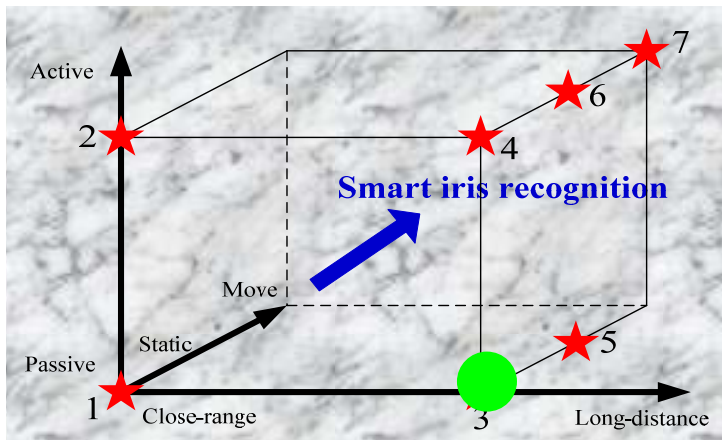
Distance: close to mid-range

Depth of field: Large

Motion: Static

Subject: Single





Stage 3: Iris recognition at a distance

Main features

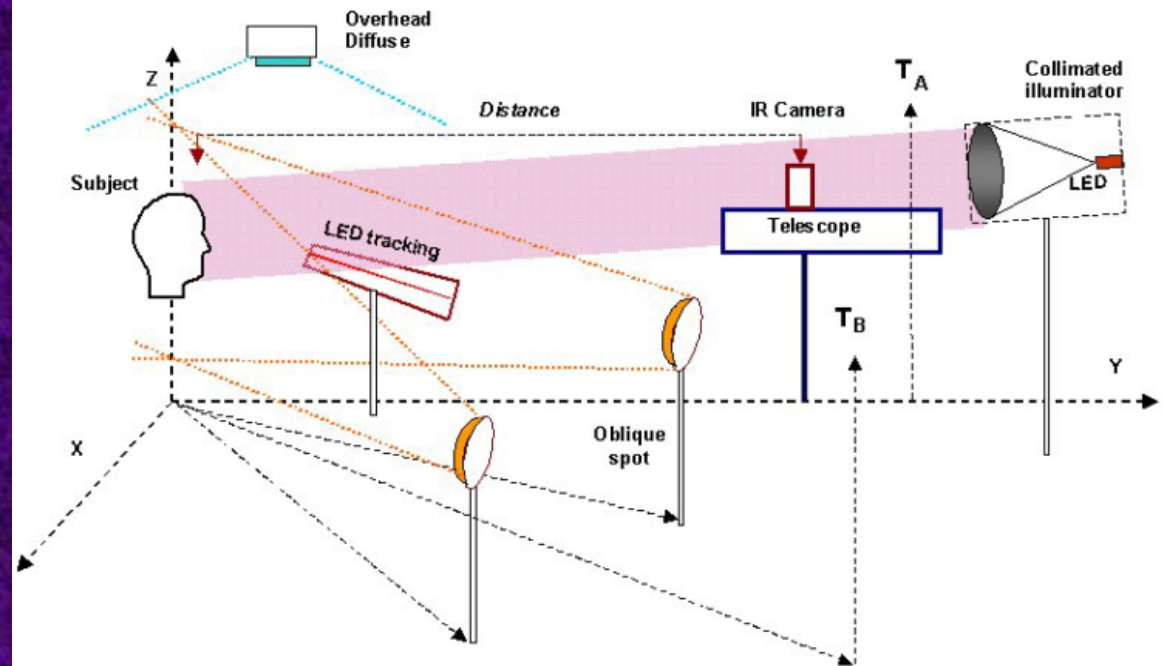
Camera: Passive
(one fixed lens cam)

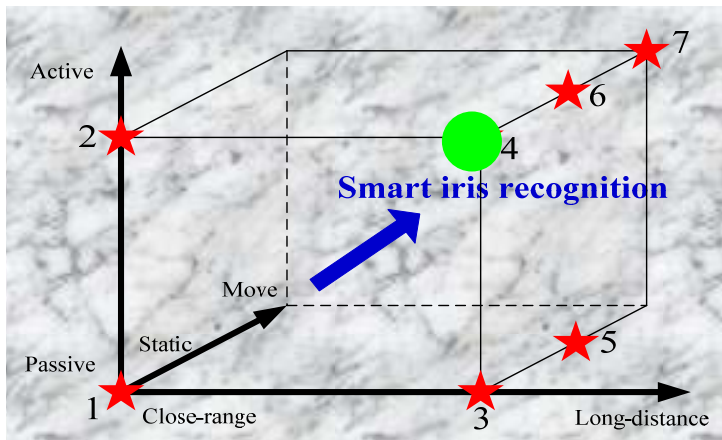
Distance: Long-range

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)

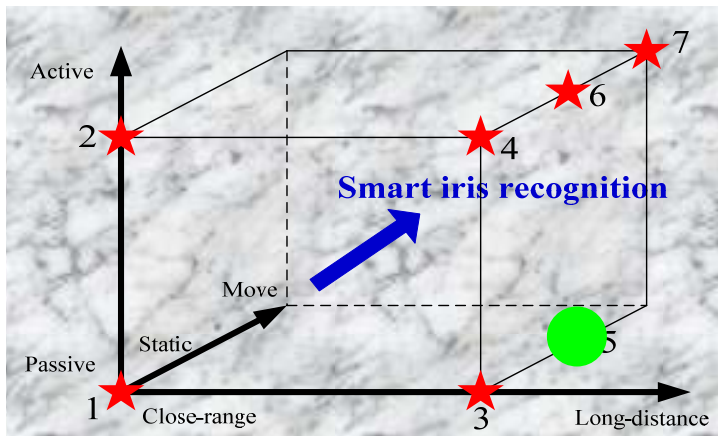
Distance: Long-range

Depth of field: Small

Motion: Static

Subject: Single





Stage 5: Passive IR on the move

Main features

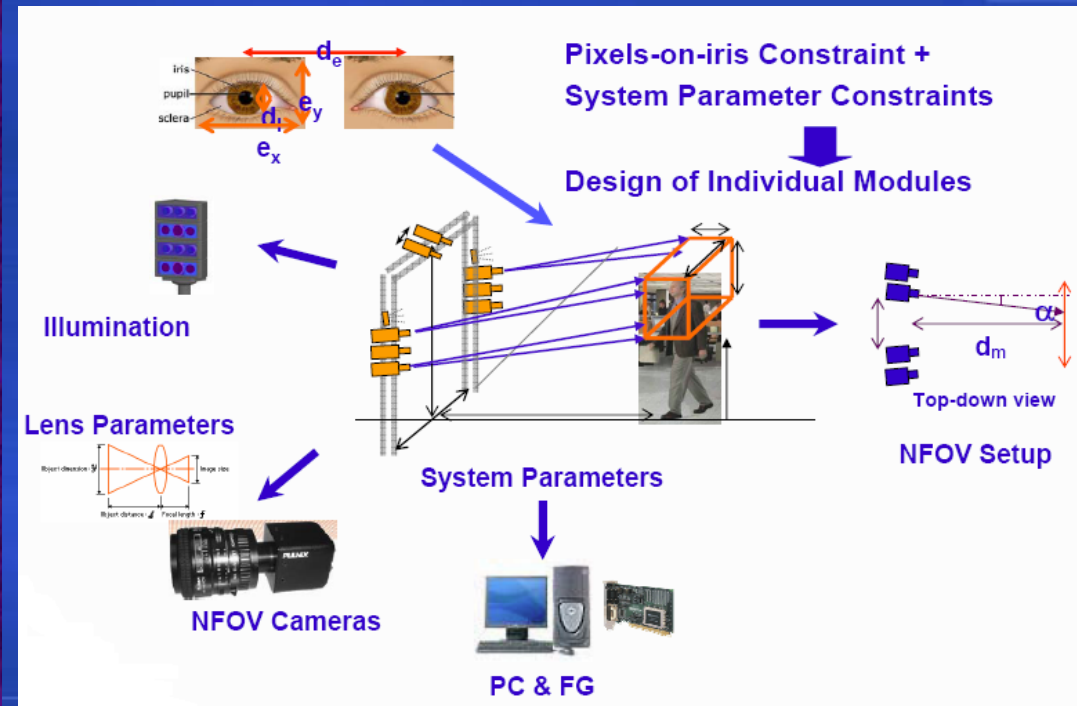
Camera: Passive
(Multi high-res iris cams)

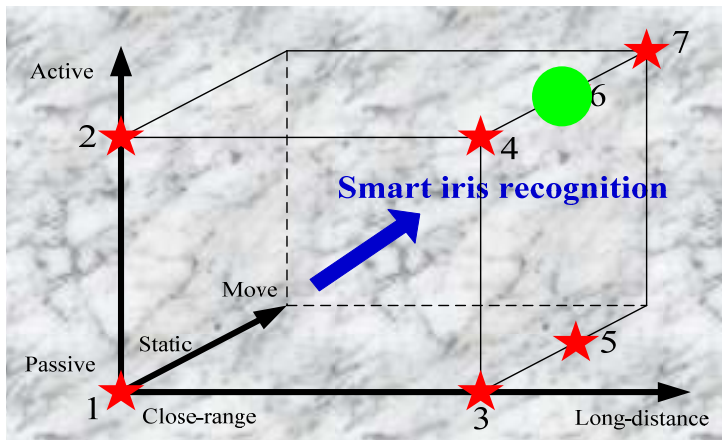
Distance: Long-range

Depth of field: Small

Motion: Walk on defined
path

Subject: Single





Stage 6: Active IR on the move

Main features

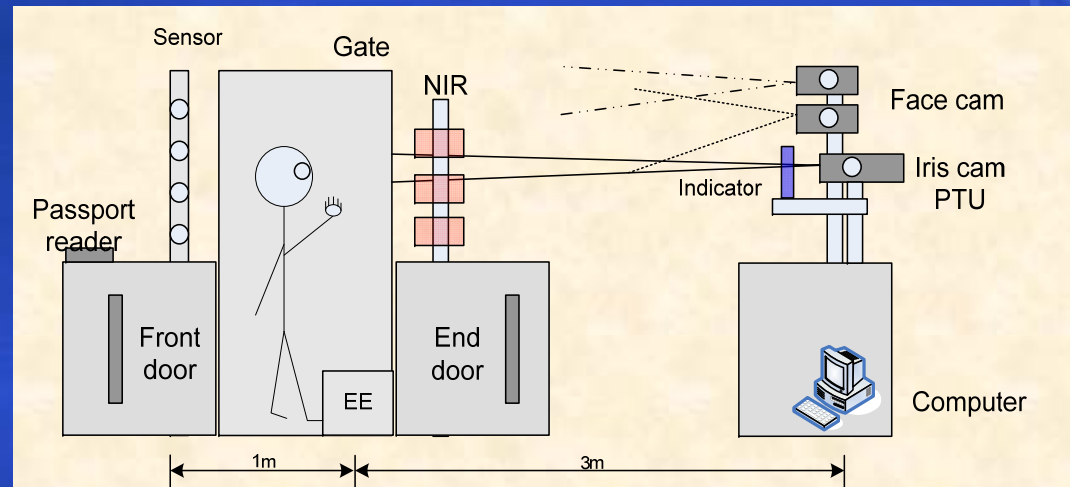
Camera: Active
(PTZ, face+iris cam)

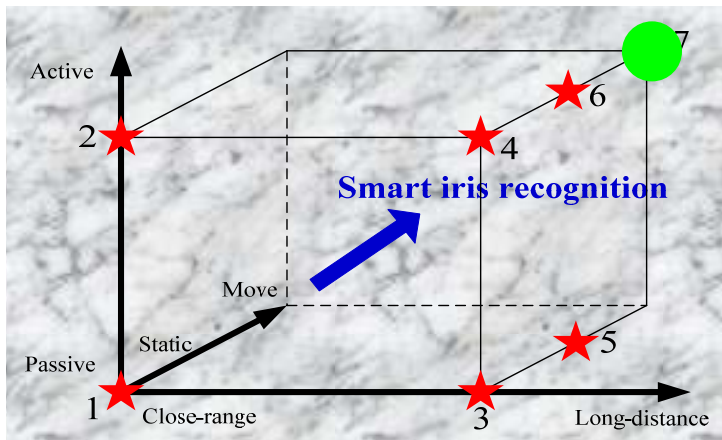
Distance: Long-range

Depth of field: Large

Motion: Walk on
defined path

Subject: Single





Stage 7: Iris recognition for surveillance

Main features

Camera: Active

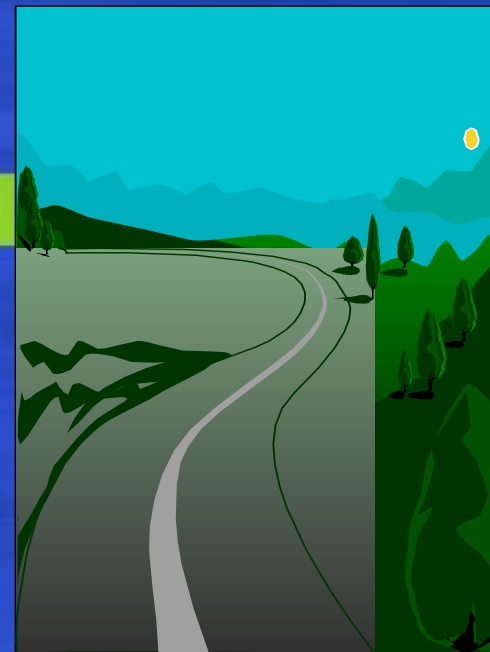
Distance: Long-range

Depth of field: Large

Motion: Free movement

Subject: Multiple





Open problems and future directions in IR



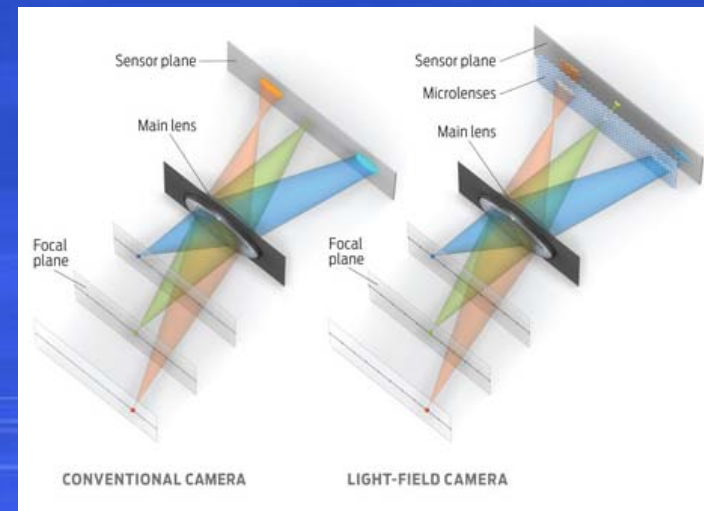
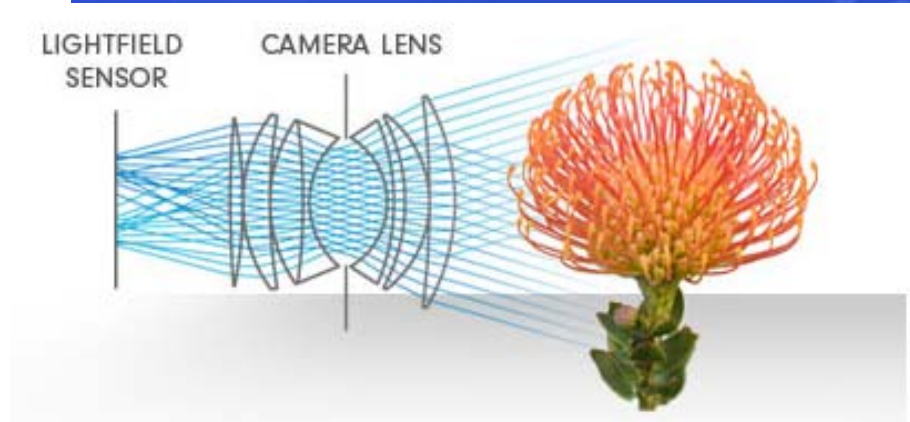
[//www.ia.ac.cn](http://www.ia.ac.cn)

Less or unconstrained iris image acquisition

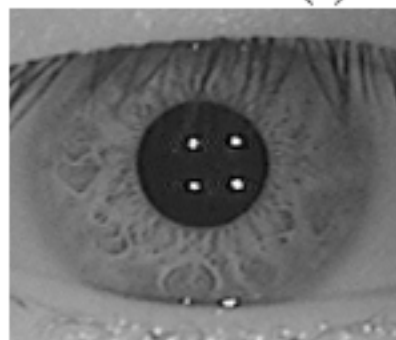


[//www.ia.ac.cn](http://www.ia.ac.cn)

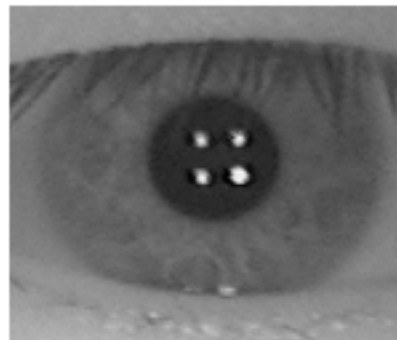
Light field photography for iris image acquisition



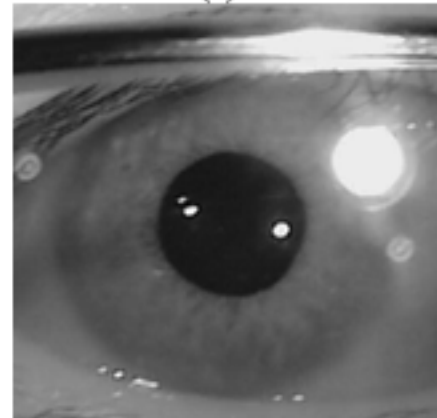
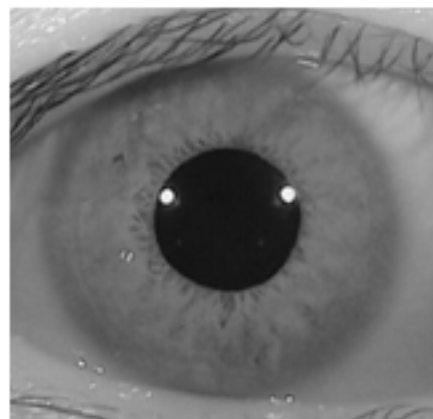
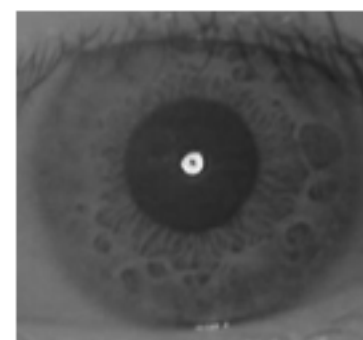
● Robust iris recognition of poor quality iris images



(e) Defocus

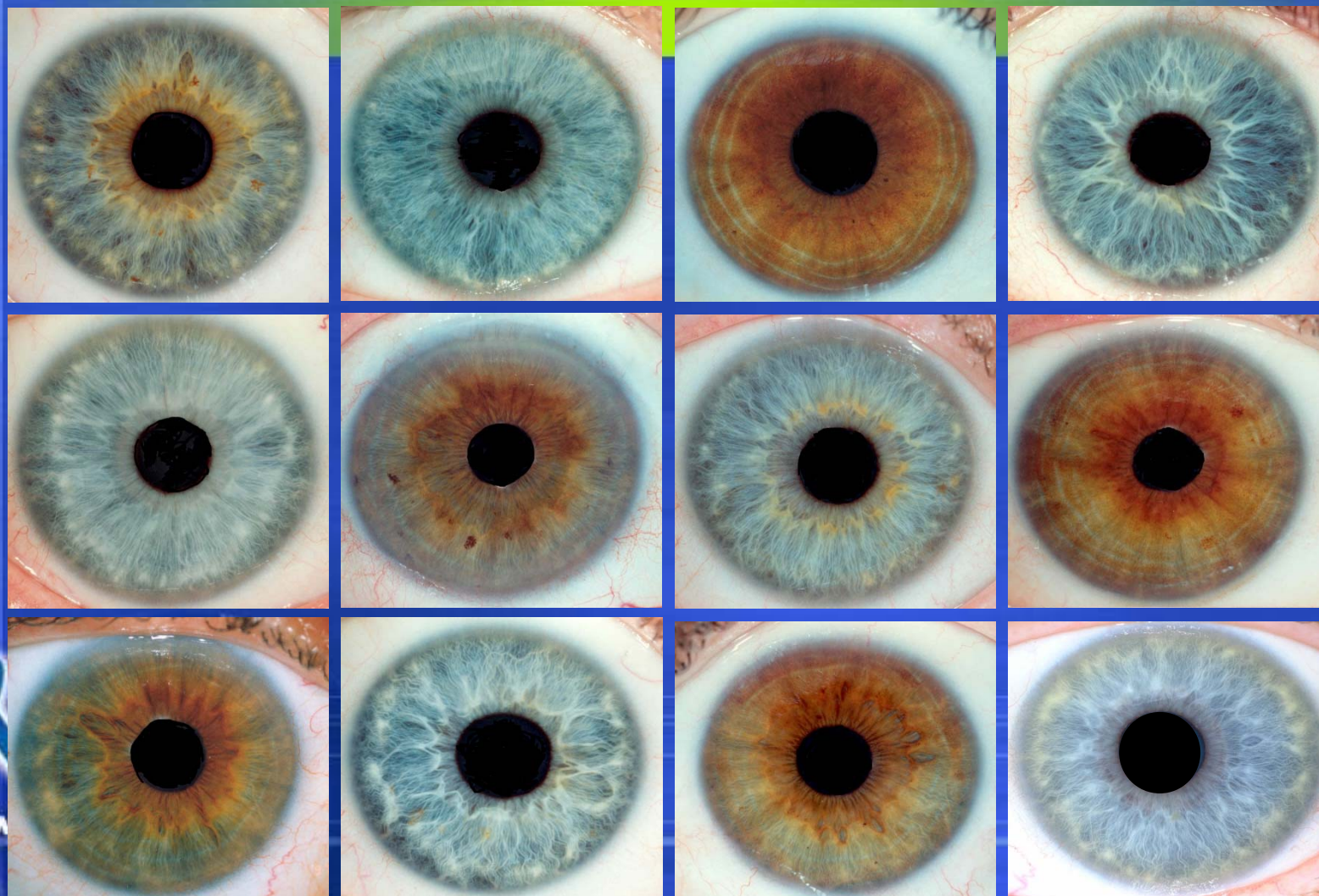


(f) Inter-sensor interoperability



(g) Eyeglasses

● Iris classification and large scale iris image database retrieval



● Iris recognition on mobile devices



e-Bank



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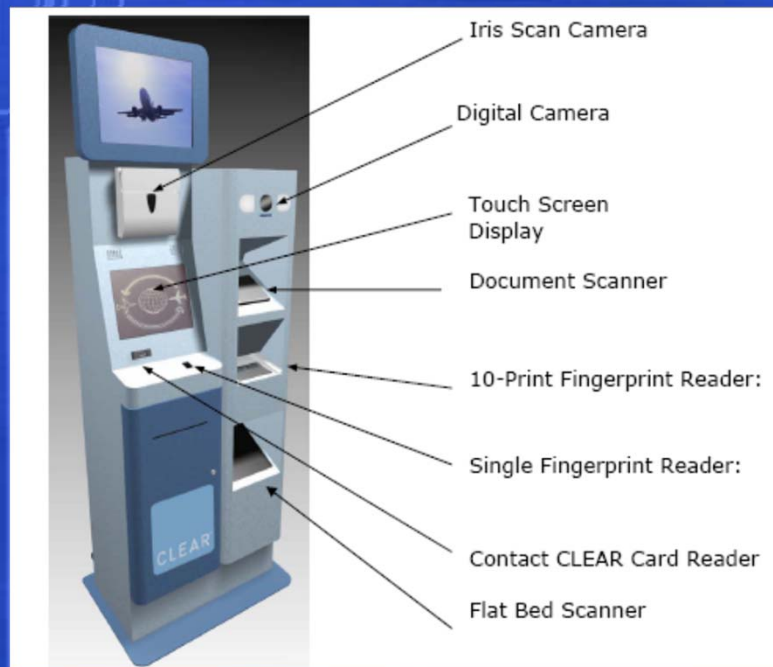
● Iris recognition for forensic applications



Iris recognition

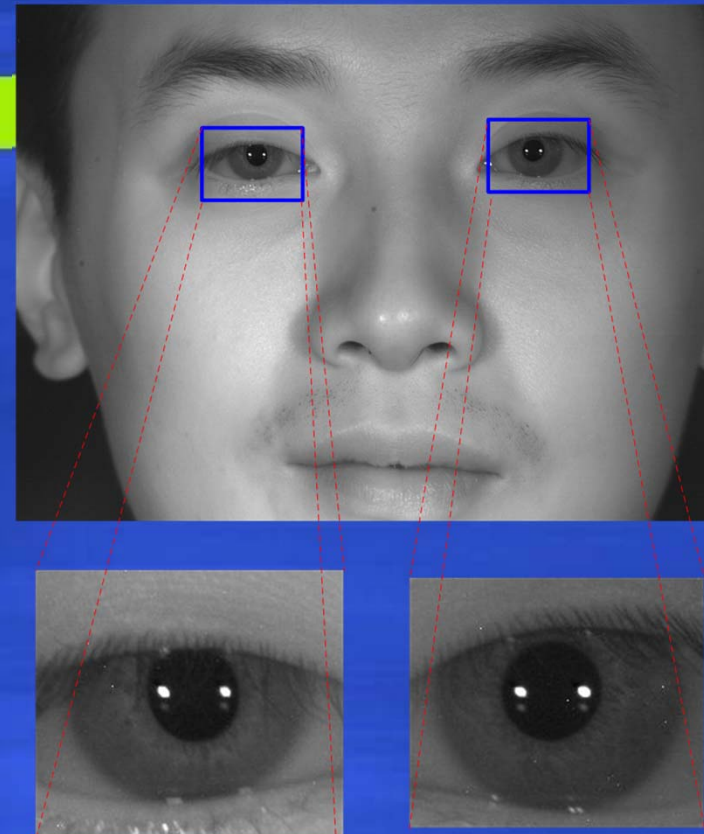


Multi-modal biometrics



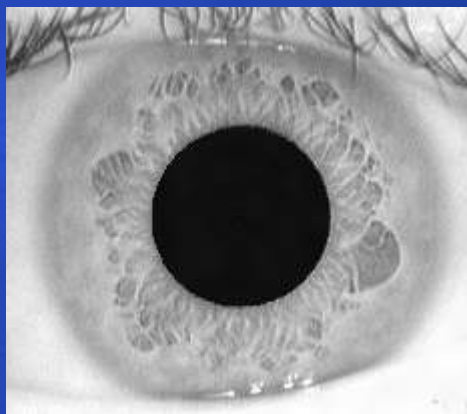
Iris/face/fingerprint

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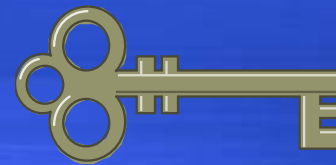
**Iris/face/skinprint from
one single image**

● Iris biometrics for information security



1011100101100101010111

.....



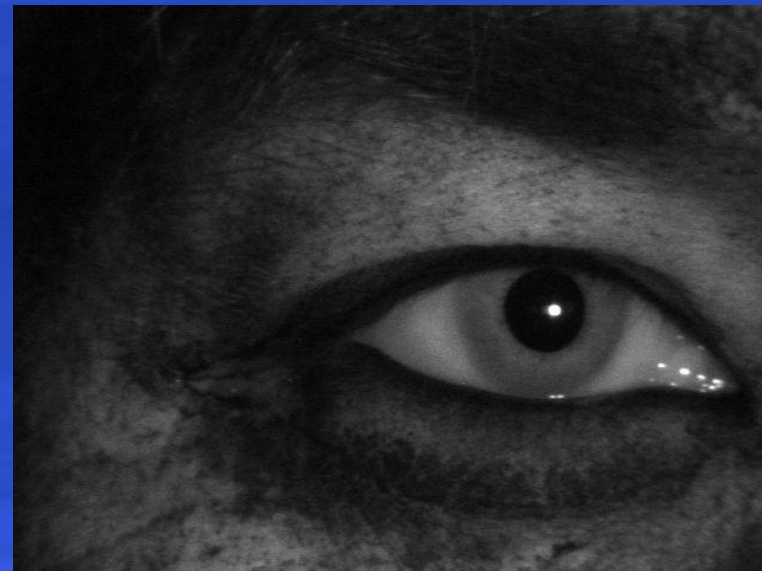
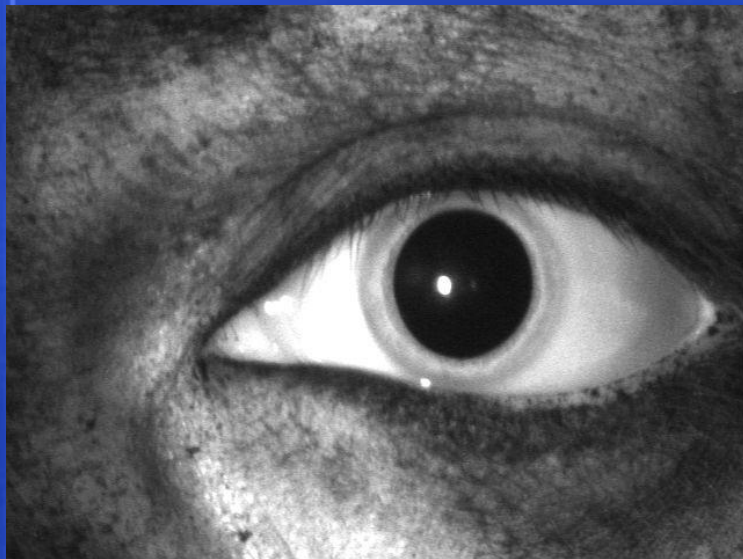
Biometric key



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Watermarking, Information hiding, IP protection, ...

● Application specific problems



Iris images of coal miners

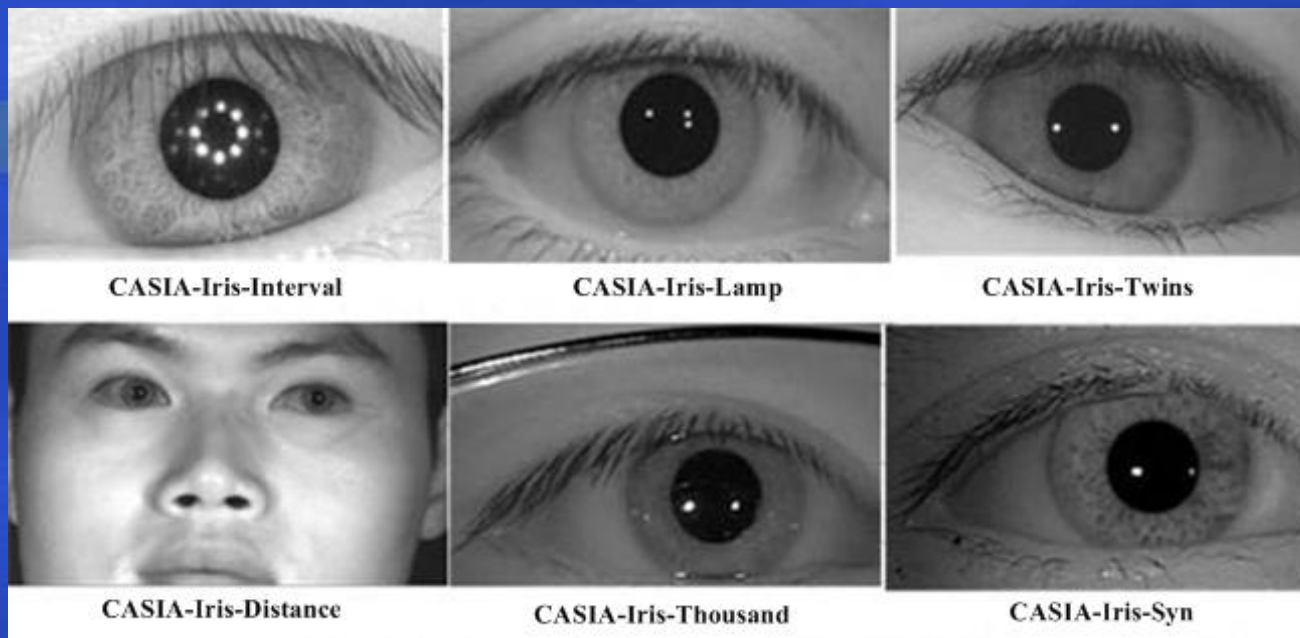


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Outline of Talk

- 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



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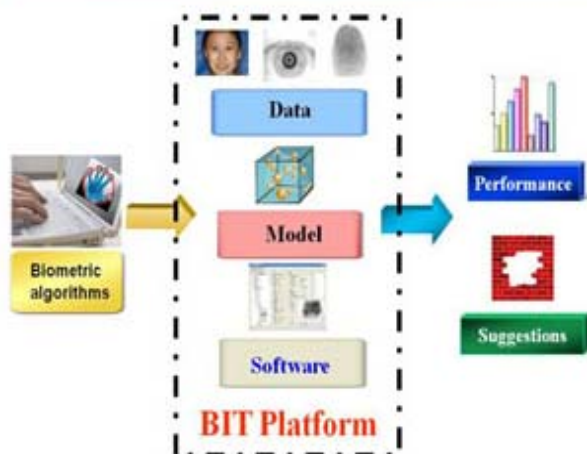
BIT: A website for biometric database sharing and algorithm evaluation ([Http://biometrics.idealtest.org](http://biometrics.idealtest.org))



Biometrics Ideal Test

[Home](#) [Register](#) [Login](#) [Help](#) [About us](#)

Introduction



Biometrics Ideal Test (or BIT for short) is a website for biometric database sharing and algorithm evaluation. Our mission is to facilitate biometrics research and development by providing quality public services to biometric researchers. You are welcome to register an account in BIT so that you can download publicly available iris, face, fingerprint, palmprint, multi-spectral palm and handwriting ... [more](#)

User

E-mail:
Password:
Validation code:



[Login](#)

Forget your password? [Reset](#)

No account? [Register](#)

Iris



- ▶ 4 databases for download
- ▶ 1 database for test
- ▶ Public results

Fingerprint



- ▶ 2 databases for download
- ▶ 1 database for test
- ▶ Public results

Face

Palmprint

Statistics

109883 visitors

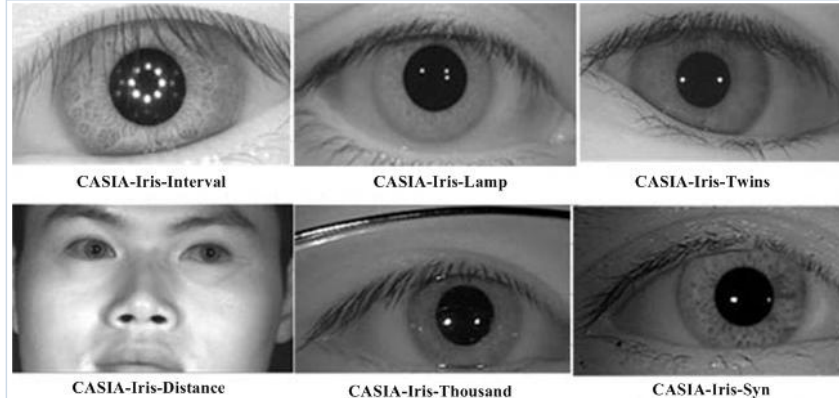
6391 registered users

0 tested algorithms

Downloadable biometrics databases

CASIA Iris Image Database Version 4.0

Download counts: 7,079



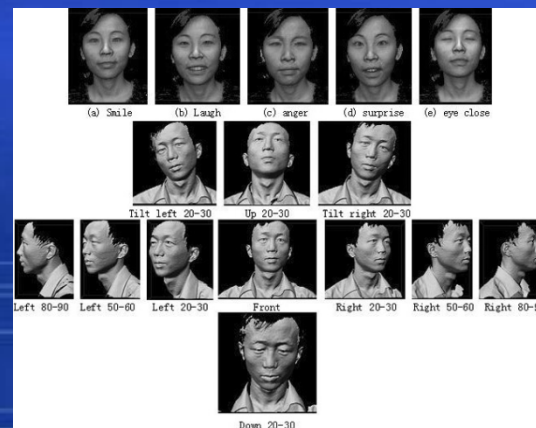
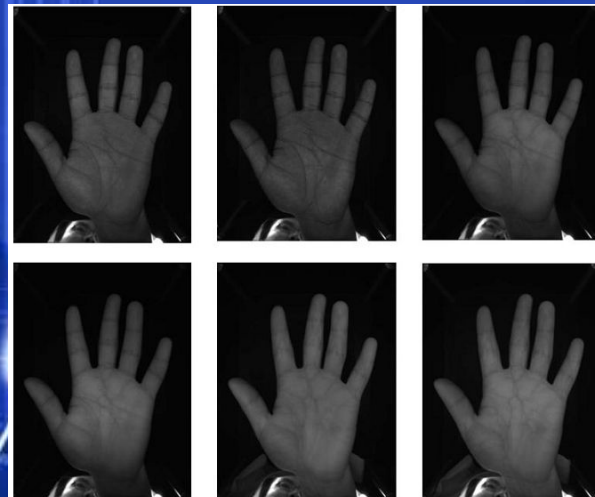
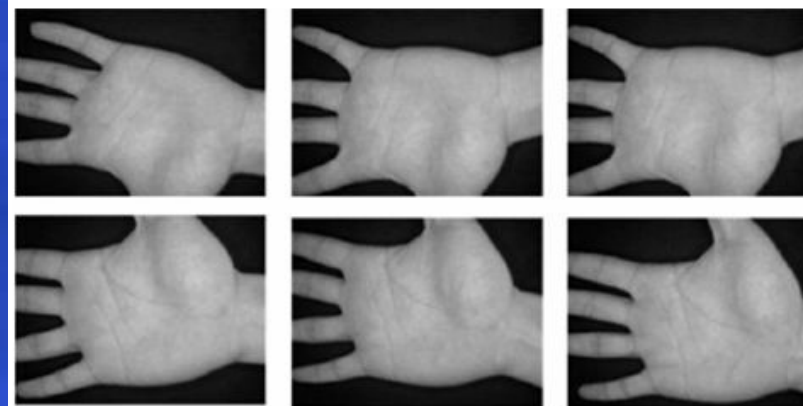
CASIA Face Image Database Version 5.0

Download counts: 1,314



CASIA Fingerprint Image Database Version 5.0

Download counts: 2,559



The farthest distance in the world is not between life and death but when I stand in front of you yet don't know that I love you.

Contrary to the claim in the literature that the affine reconstruction is possible from two images captured by a translation camera with unknown and varying parameters.

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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