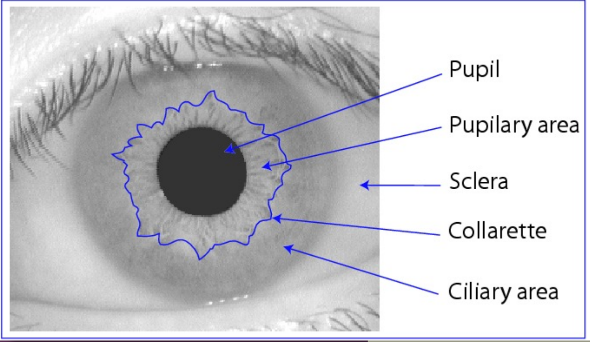


Iris Recognition

Arun Ross

Professor

Michigan State University

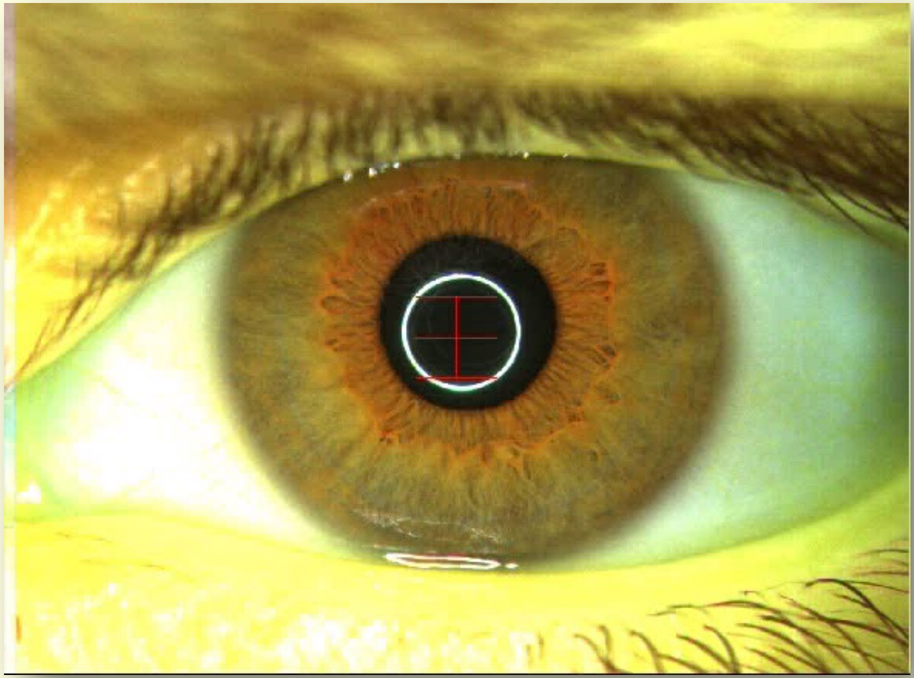
rossarun@cse.msu.edu

http://iprobe.cse.msu.edu

Ocular Biometrics

- The eye and its immediate surroundings
- Consists of iris, sclera, eyelids, eyelashes, eyebrow, skin texture, etc.

Color Iris



- Iris is the annular region of the eye bounded by the pupil and the sclera

- Visual texture of the iris stabilizes during the first two years of life and carries distinctive information useful for recognition

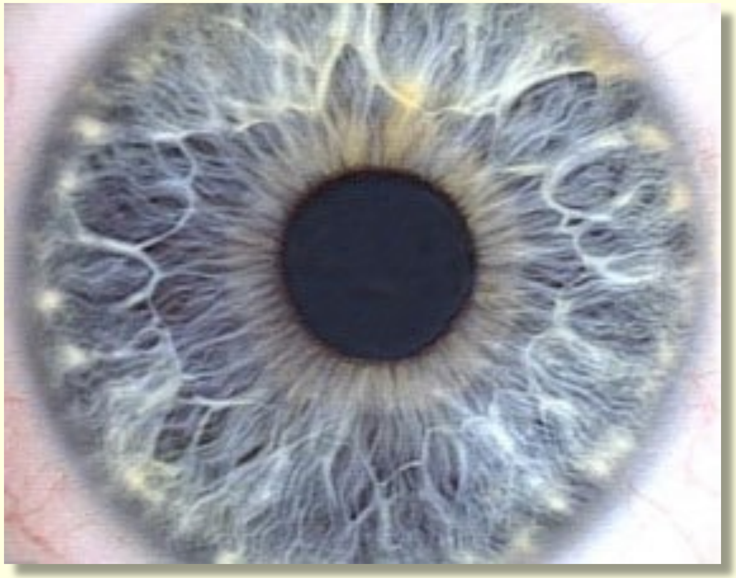
- Each iris is believed to be unique; even irides of identical twins have been observed to be different

Iris Texture

The iris exhibits a very rich texture consisting of "pectinate ligaments adhering into a tangled mesh revealing striations, ciliary processes, crypts, rings, furrows, a corona, sometimes freckles, vasculature, and other features"

- *John Daugman*

http://www.cl.cam.ac.uk/~jgd1000/sampleiris2.jpg

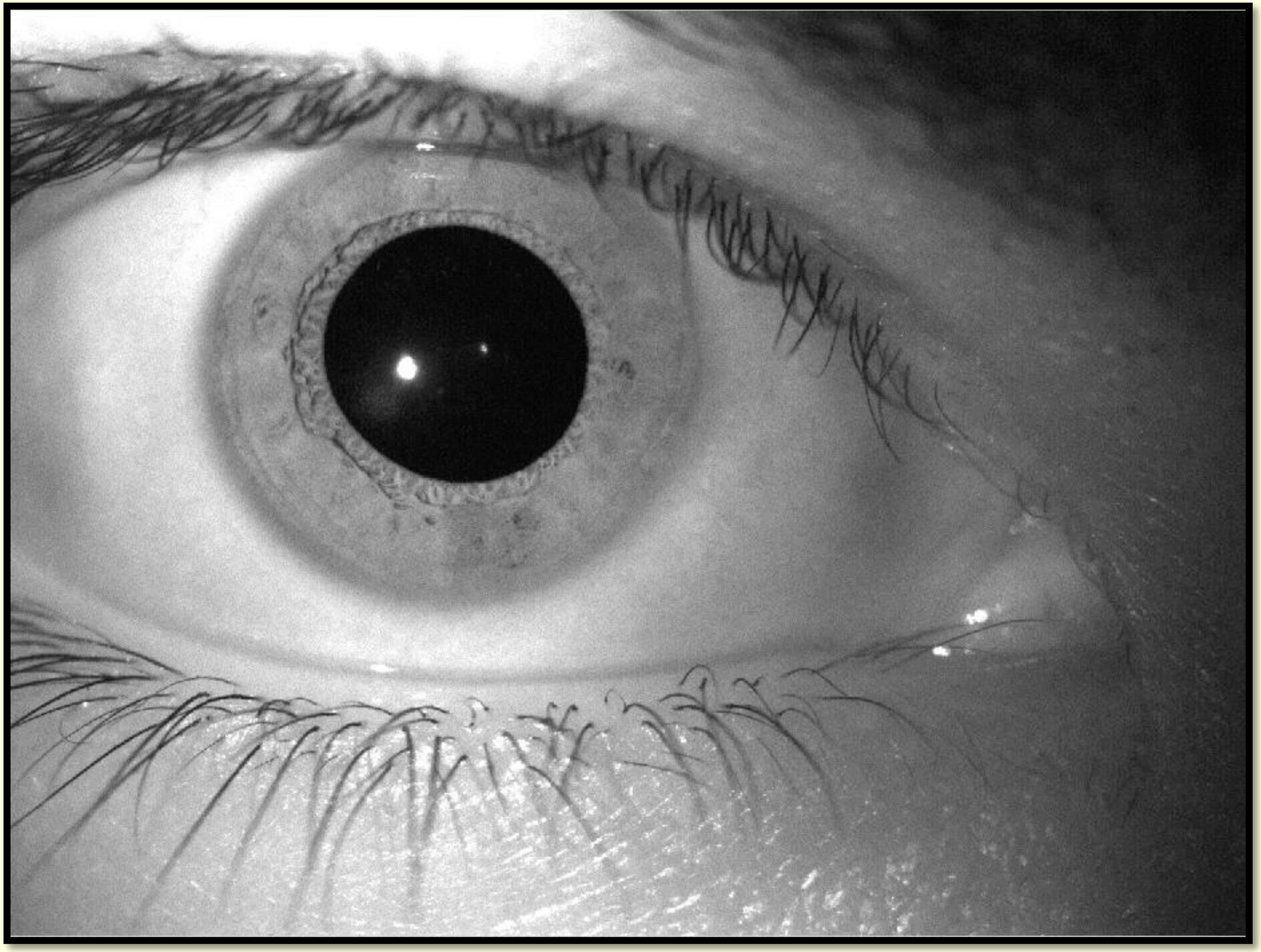


http://www.cl.cam.ac.uk/~jgd1000/sampleiris.jpg

Primary Function of the Iris

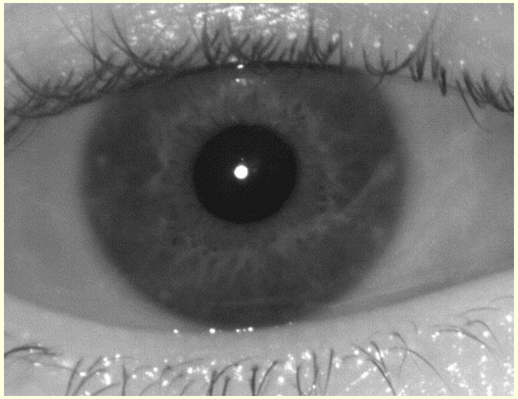
- The primary function of the iris is to regulate the amount of light entering the eye by dilating or contracting a small opening in it called the pupil
- The iris contracts the pupil when the ambient illumination is high and dilates it when the illumination is low

Impact of Light

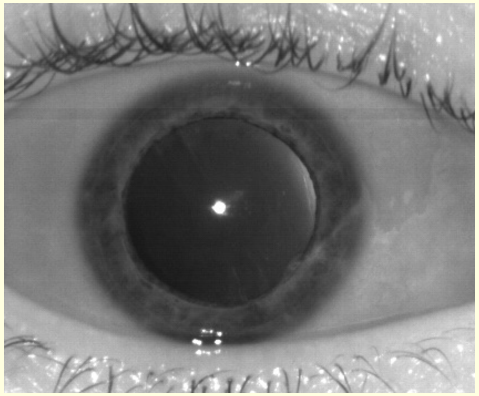


Impact of Dilation Drugs

Before



After



Hamming distance between iris codes (log-Gabor + rubber sheet): 0.40

Threshold = 0.32

Hamming Distance = 0 → **Perfect Match**
Hamming Distance = 0.5 → **Poor match**

- Pupil dilation drugs (mydriatic agents) may be used by an adversary to mask their identity from an iris recognition system

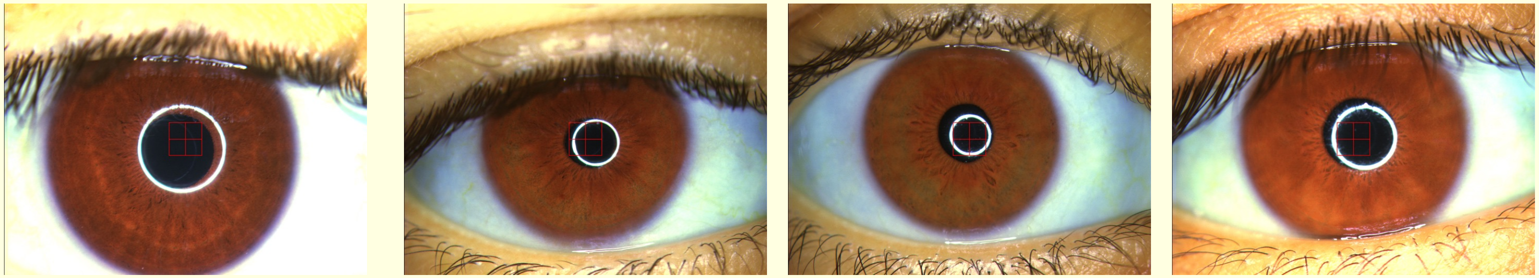
- FNMR increases when matching iris images with large differences in pupil size

I. Tomeo-Reyes, A. Ross, V. Chandran, "Investigating the Impact of Drug Induced Pupil Dilation on Automated Iris Recognition," BTAS 2016

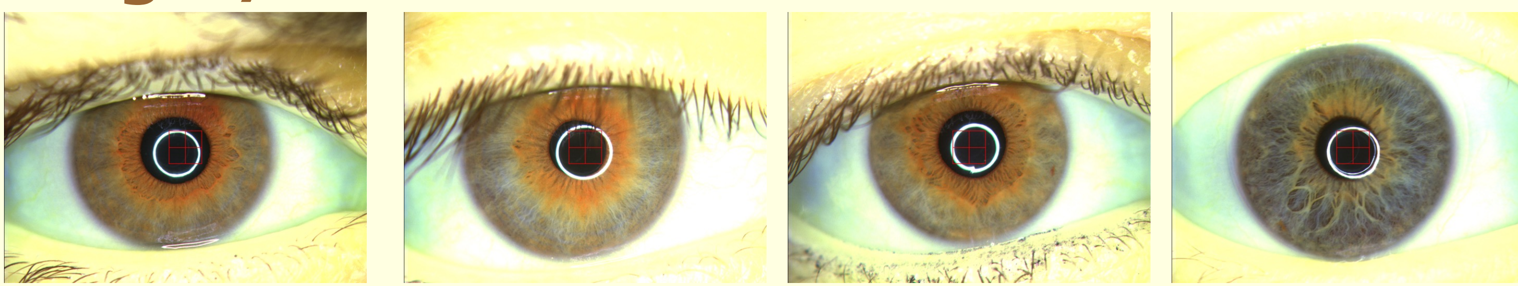
Variations in Iris Color

Brown Dark~Light

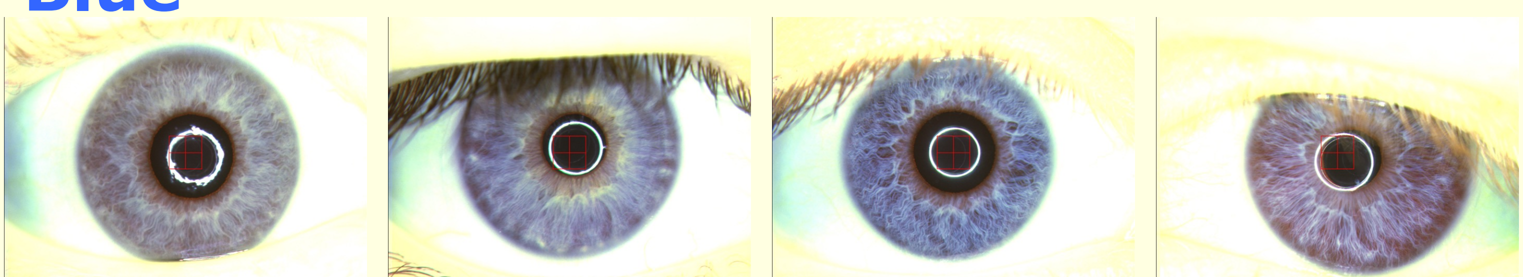
Orig Image dimension: 1300 x 1040



Light/Brown Green



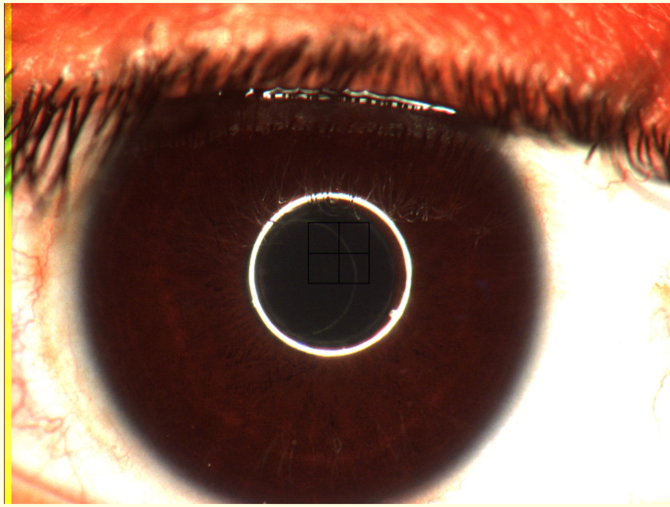
Blue

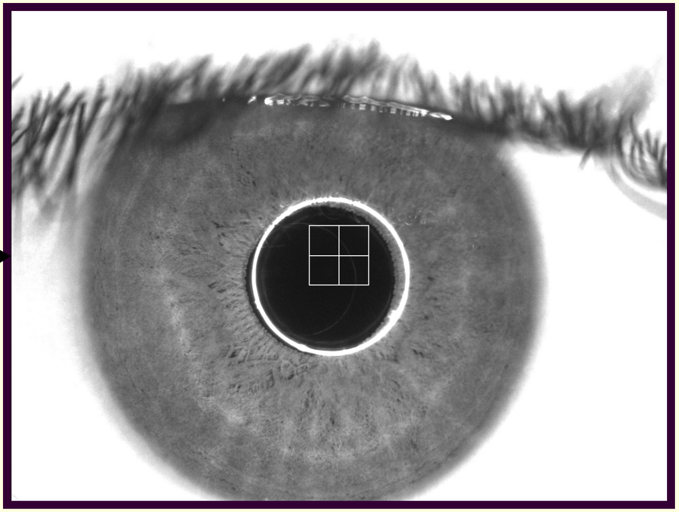


Dark-colored Iris

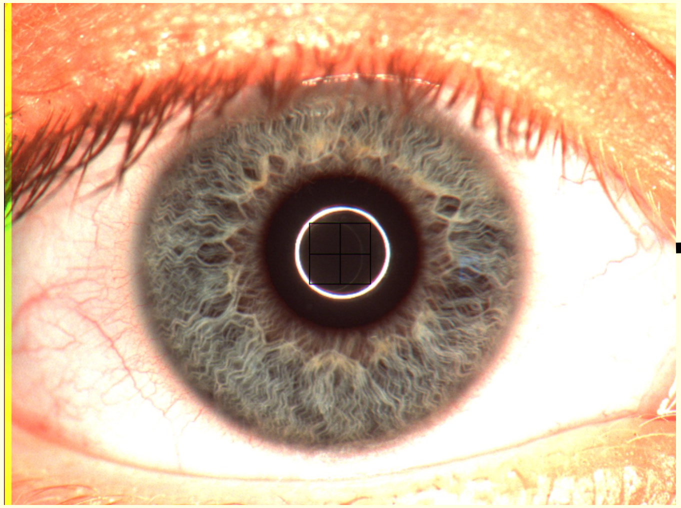
COLOR IMAGE | NIR IMAGE

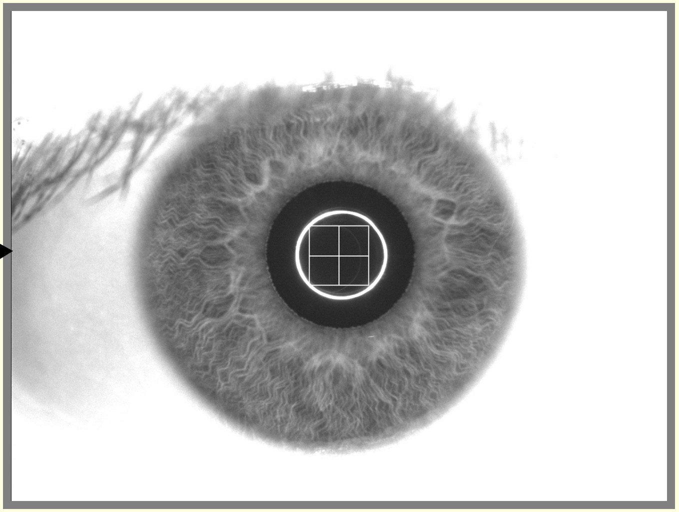
DARK IRIS





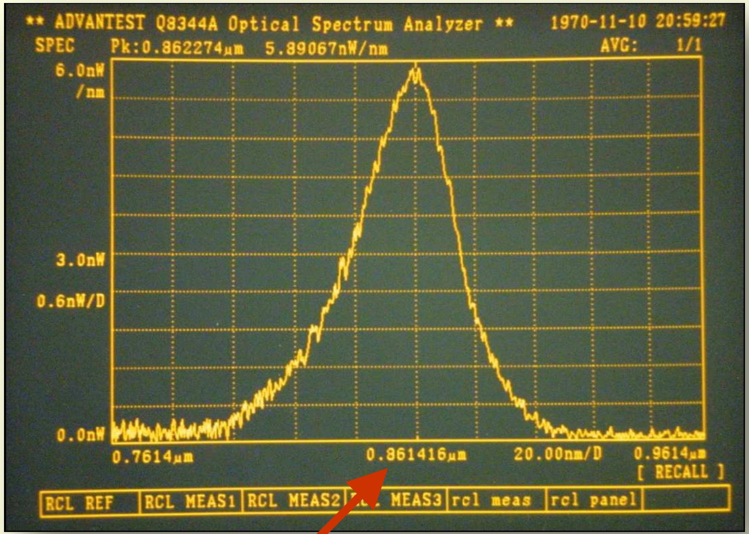
LIGHT IRIS



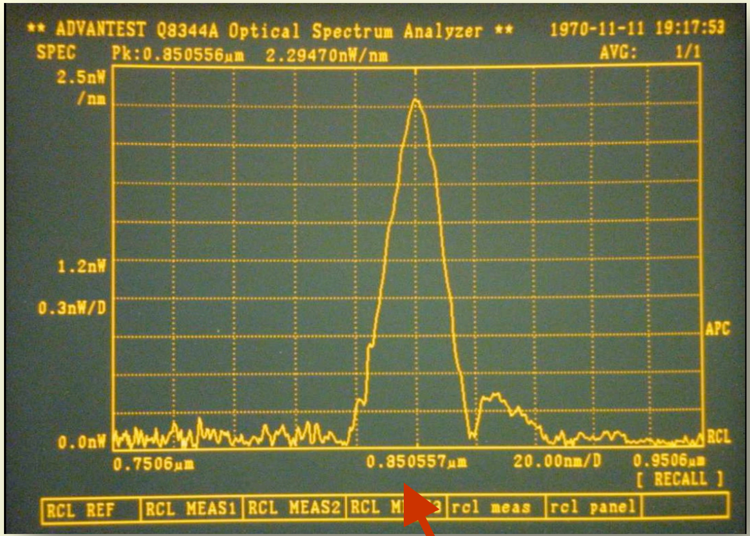


Spectrum Analyzer: NIR spectra

Panasonic Authenticam



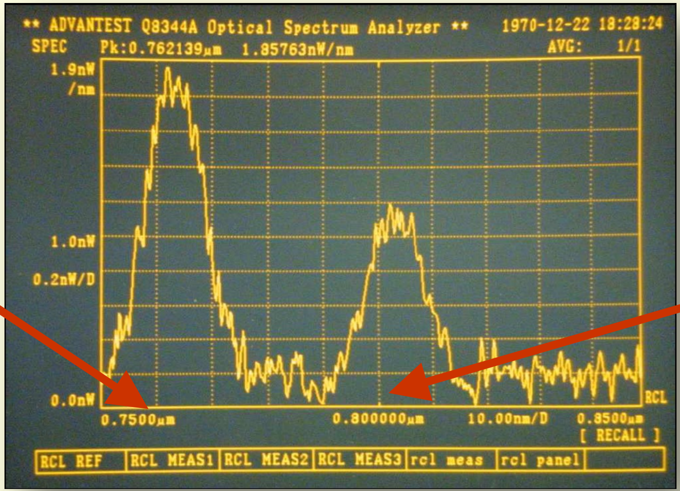
Oki IrisPass



861 nm

850 nm

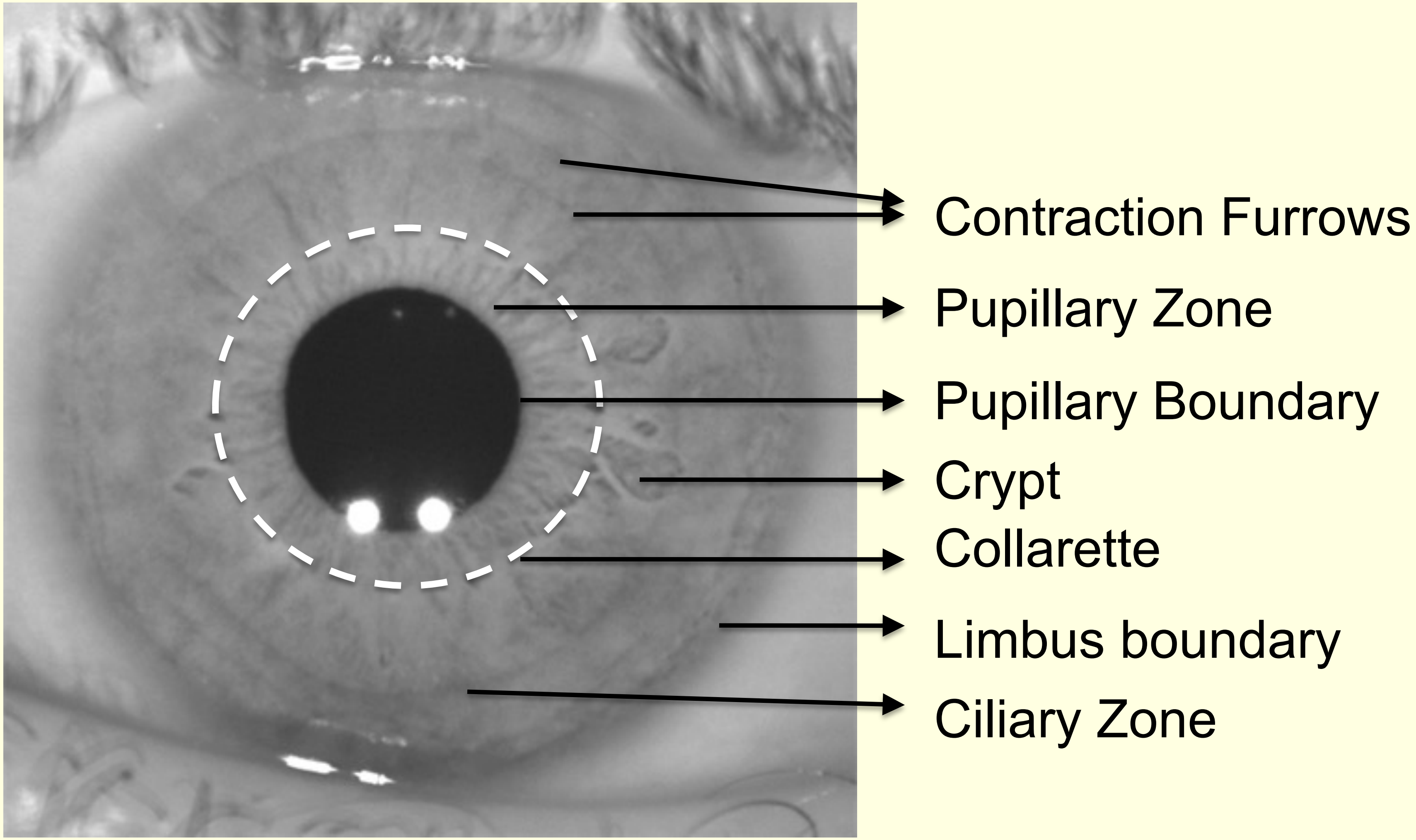
LG Iris Access

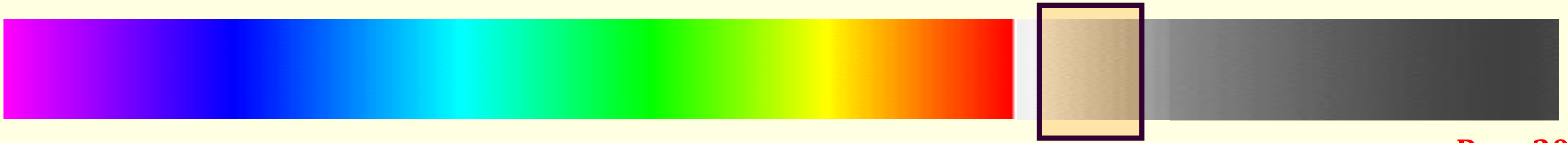


750 nm

800 nm

Anatomy of the Iris





Ross 2022

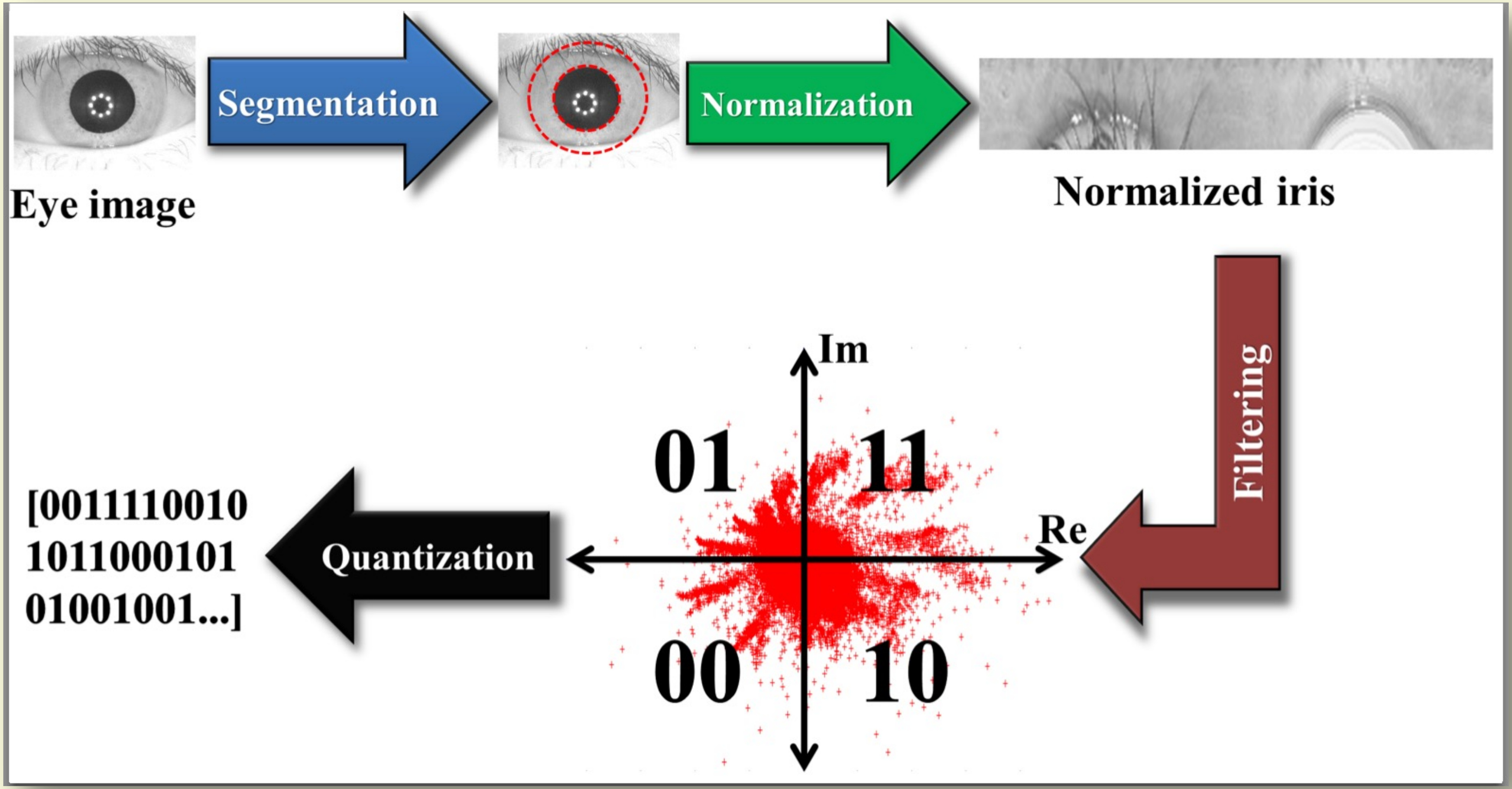
Why NIR – Near Infrared - Optics?

- Dark-colored Iris: The textural details of dark-colored irides (majority of the world population) are more evident in the NIR channel than in the red, green, or blue channels
- Non-intrusive: NIR light cannot be perceived by the human eye. This ensures that the image acquisition process is non-intrusive, even when the eye is required to be in close proximity to the sensor and the NIR light source

Structure of Iris

- The posterior layer at the back, which is two cells thick, contains heavily pigmented epithelial cells, making it impenetrable to light
- The muscle layer above it consists of the sphincter (circle-like) and dilator (spoke-like) muscles that contract and dilate the pupil
- The stromal layer, located above the muscles, is made up of collagenous connective tissue (arranged in an arch-like configuration) and blood vessels (arranged along the radial direction)
- The anterior border layer is the foremost layer and has an increased density of chromatophores (i.e., pigment containing cells) compared to the stromal layer

Iris Recognition Modules



Applications: Past and Present

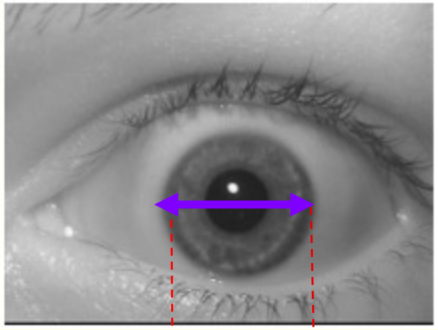
- Aadhaar Program - India
- National ID Program – Indonesia
- National Population Register ("RENAPO") - Mexico
- CAC Program - US Department of Defense
- Privium Program - Schiphol Airport, Netherlands
- Border Control System – UAE
- NEXUS and CANPASS program – Canada

Coal Mine in China

Iris Image Acquisition

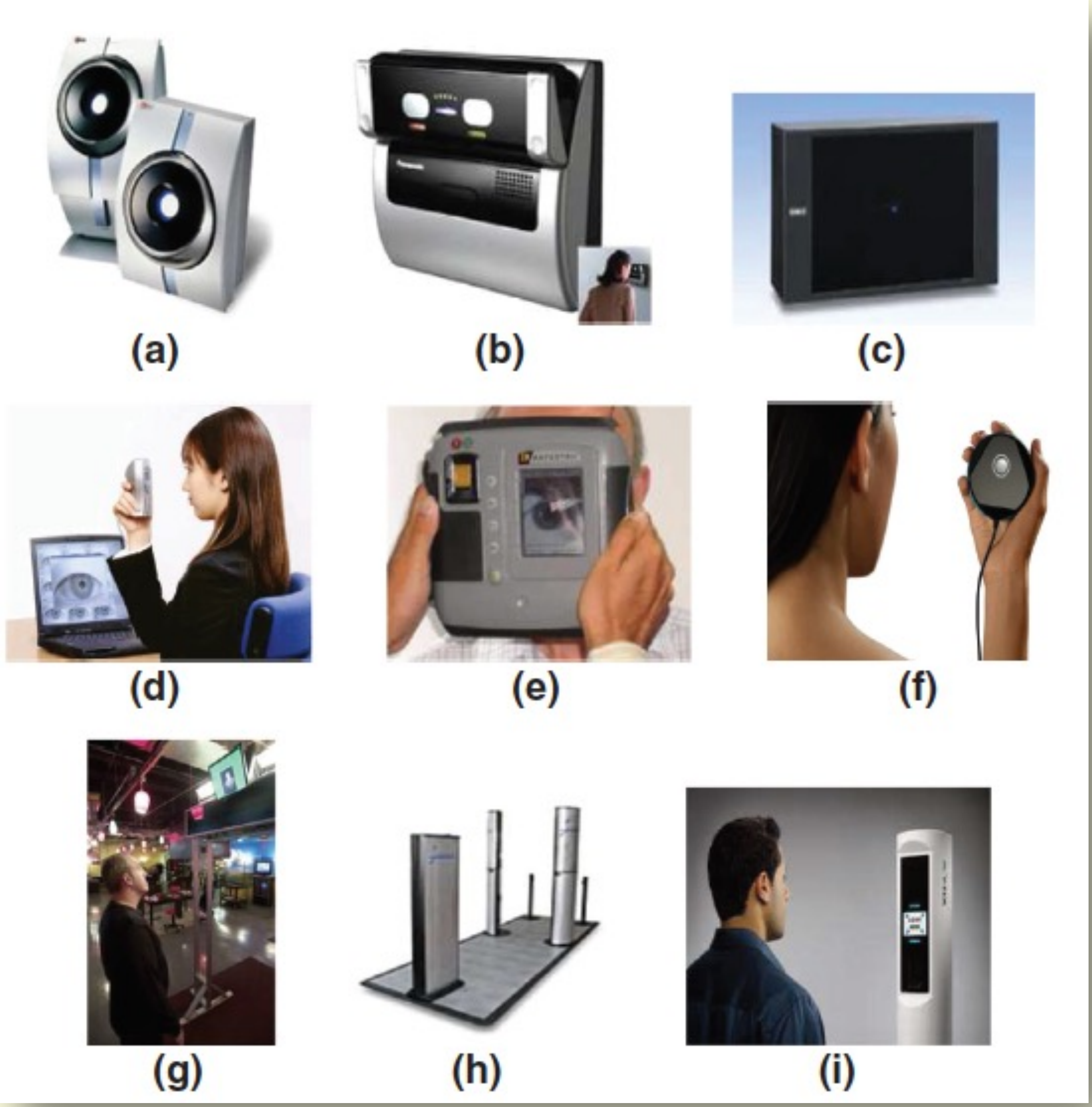
Sequence of Iris Images Captured from Subject

Quality assessment is done to select the 'best' image



$\sim 100 - 200\ pixels$

Iris Sensors



(a) LG IrisAccess
(b) Panasonic BM-ET
(c) Oki IrisPass-M series

(d) Oki IrisPass-H series
(e) DataStrip Easy Verify
(f) Eyelock Myris

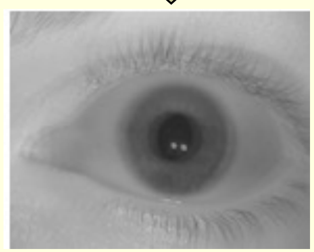
(g) Hoyos Hbox
(h) Sarnoff Iris On the Move
(i) AOptix Insight

Need for Quality Assessment

Factors negatively affecting an iris image:

occlusion

motion blur



defocus

non-uniform illumination

poor resolution

Quality Assessment Techniques

- Examination of sharpness of the portion between pupil and iris from the image
- Computation of energy of the image from high spatial frequencies using Fourier analysis
- Quantifying the energy from 2D wavelets at local concentric iris bands

Iris Segmentation

- Definition: determining the pixels in an iris image that correspond to the iris
- Challenges
  - Iris texture is stochastic and irregular, precluding appearance-based algorithms
  - Limbus and pupillary boundaries may not be sharp
  - Eyelids and eyelashes may create irregular boundaries or be detected as spurious edges

Integro-Differential Operator (IDO)

- Assumptions
  - Limbus and pupillary boundaries are circular
  - The magnitude of the limbus and pupillary boundary edge pixels is stronger than any other circular edge in the image

Integro-Differential Operator (IDO)

Differential in radial direction

Radius and Circle Center

Convolution

Pixel Intensity

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

Radial Gaussian Filter of scale σ

Integral over circle perimeter

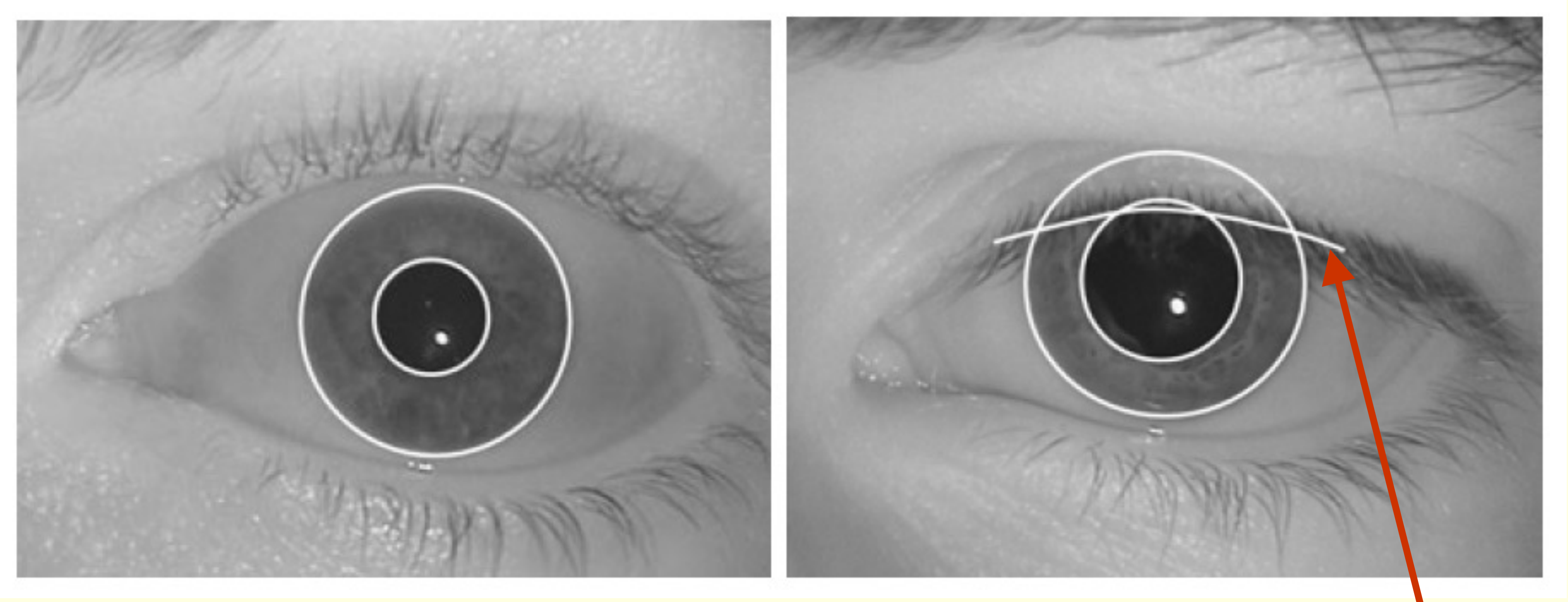
Integro-Differential Operator (IDO)

Integro-Differential Operator (IDO)

- Summary
  - **Radial Gaussian filter**: convolved across image to smooth out crypts, furrows, etc.
  - **Circular Integral**: gradients are summed across a candidate circle’s boundary
  - Circle with max gradient sum is assumed the pupillary boundary
  - Circle with next highest gradient across vertical edges is assumed limbus boundary

Integro-Differential Operator (IDO)

- Example Segmentation



Eyebrow found through post-processing

Geodesic Active Contours (GAC)

- Assumptions
  - Limbus boundary may not be circular (e.g. due to occlusions)
  - Geodesic active contours can be used to evolve a non-circular limbus boundary approximation

Geodesic Active Contours (GAC)

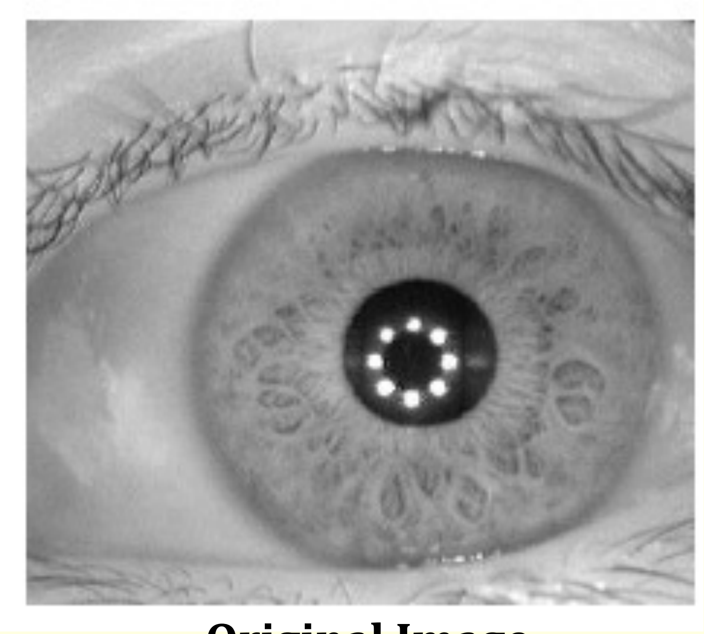
- Summary
  - Initial contour is placed just outside pupillary boundary
  - Image gradients used to create a "stopping function" image as a stopping condition
  - Contour is evolved outward using an update function until it reaches stopping condition
  - Contour may split at local minima and later remerge, preventing strong edges in iris texture from stopping the GAC evolution

Geodesic Active Contours (GAC)

- Stopping Function

$$K(x,y) = \frac{1}{1 + \left(\frac{\|\nabla(G(x,y) \star I(x,y))\|}{k}\right)^{\alpha}}$$

α , k = constants



Original Image

Stopping Function

Geodesic Active Contours (GAC)

- GAC Update Function

Stopping function

Smoothness Level

$$\psi_t = -K(c + \varepsilon\kappa)\|\nabla\psi\| + \nabla\psi . \nabla K$$

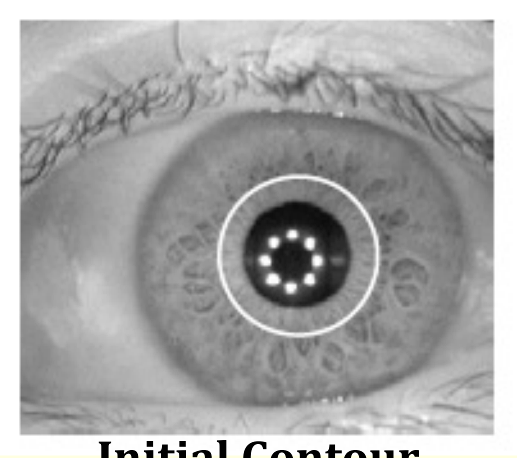
Evolution velocity

Function measuring distance to curve at iteration *t*

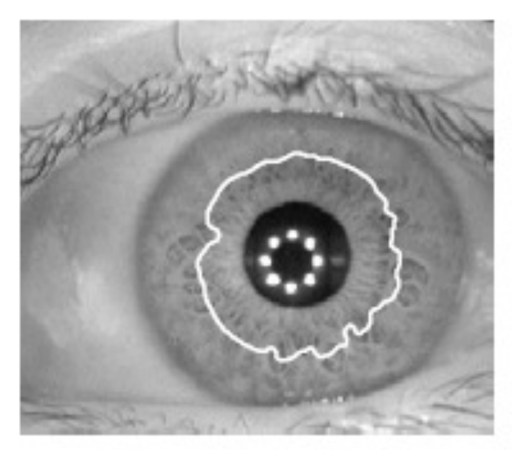
Curvature Measure

Geodesic Active Contours (GAC)

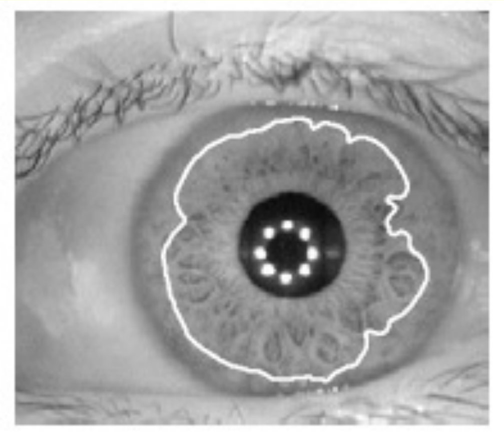
- Example Segmentation



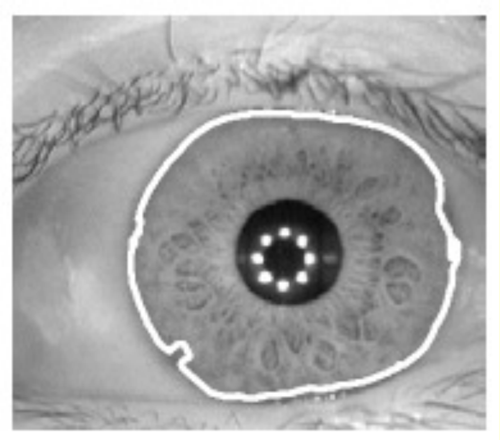
Initial Contour



Iteration 600

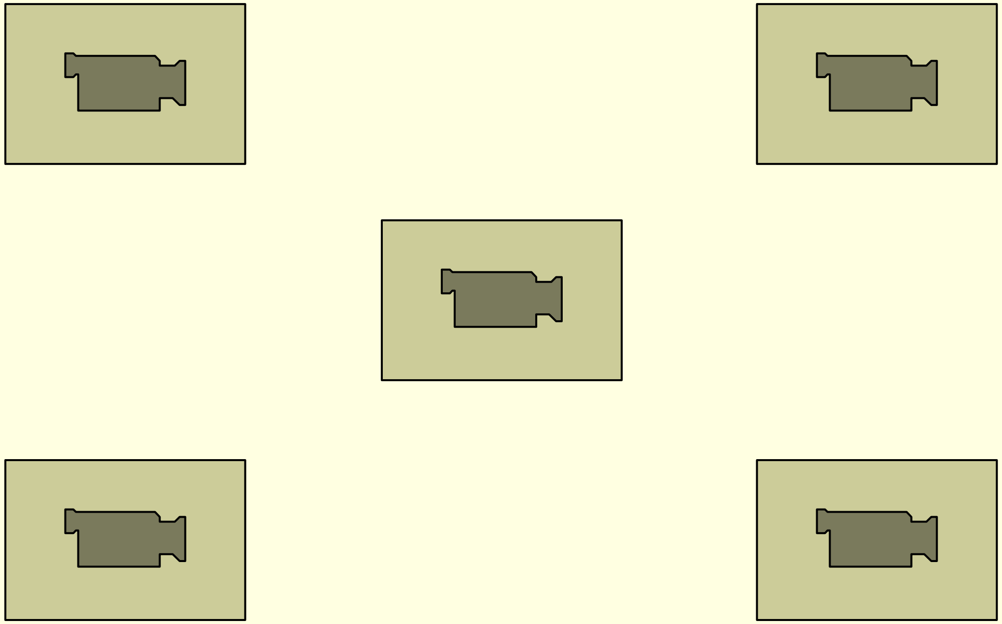


Iteration 1400



Iteration 1800

GAC: Example

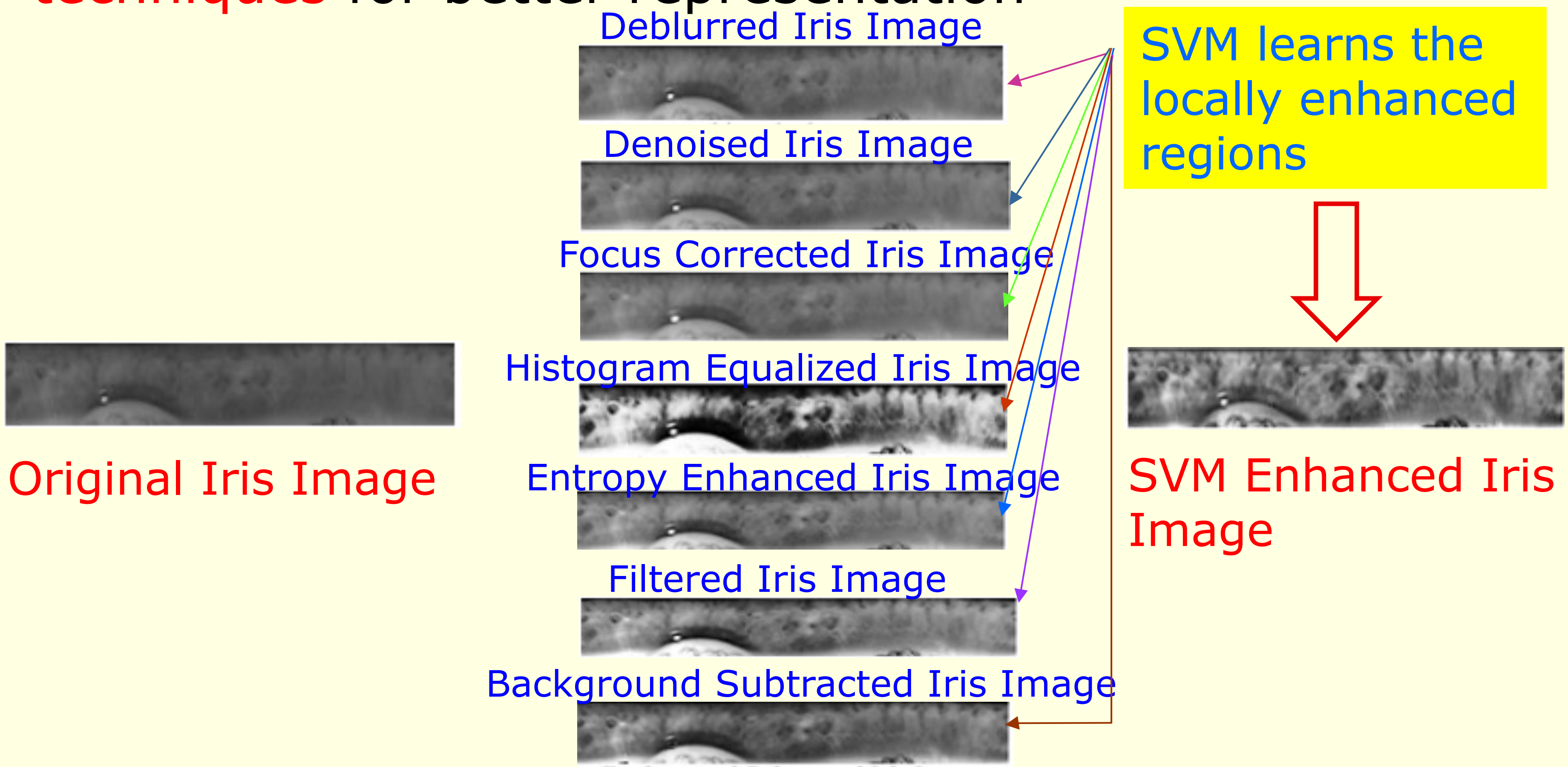


S. Shah and A. Ross, "Iris Segmentation Using Geodesic Active Contours," IEEE Transactions on Information Forensics and Security (TIFS), Vol. 4, Issue 4, pp. 824-836, December 2009.

Iris Image Enhancement

Vatsa et al, "Improving iris recognition performance using segmentation, quality enhancement, match score fusion, and indexing," TSMC 2008

Normalized iris images may undergo enhancement techniques for better representation

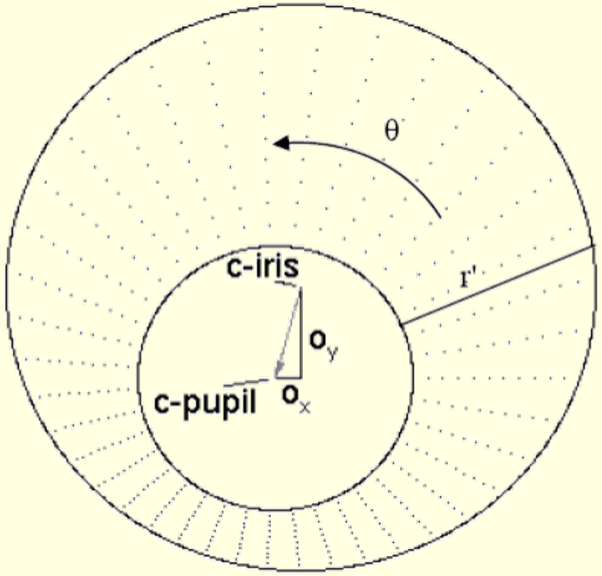


Iris Normalization

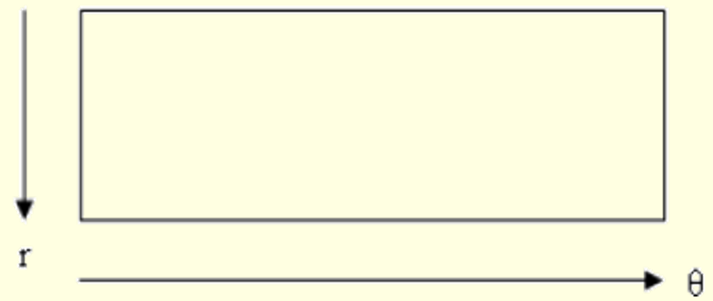
- Challenge with Iris
  - Size of iris and pupil varies greatly (e.g. dilation/contraction of pupil and distance to sensor)
- Solution
  - "Normalize" the iris by unwrapping it into a rectangular region

Iris Normalization

- Daugman's rubber sheet model used to account for variations in iris size caused by
  - dilation and constriction of pupil
  - distance from the camera during image acquisition



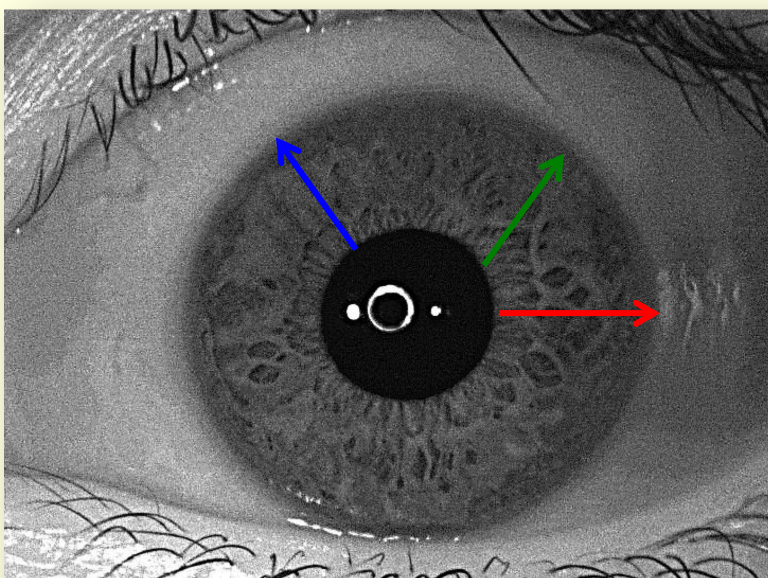
Cartesian Coordinates



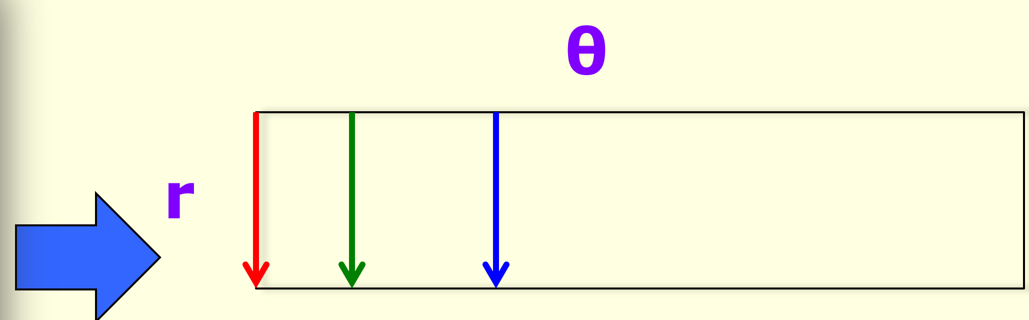
Pseudo Polar Coordinates

Linear Sampling

- The normalization process employs a sampling process: linear sampling of pixels from the pupillary boundary to the limbic boundary



Cartesian Coordinates



Pseudo Polar Coordinates

Iris Normalization

- Daugman's Rubber Sheet model

Horizontal Polar Coordinate

Radius

Axis Angle

$$x(r,\theta) = (1-r)x_p(\theta) + rx_l(\theta),$$

$$y(r,\theta) = (1-r)y_p(\theta) + ry_l(\theta),$$

Coordinates of a Limbus Boundary Point

Vertical Polar Coordinate

Coordinates of a Pupillary Boundary Point

Iris Encoding

- Definition: extracting a feature vector from the normalized iris
- Summary:
  - The normalized iris image is subjected to filtering
  - The phasor response of the filtered image is examined
  - Two bits are assigned to the pixel based on the sign of the real and the sign of the imaginary components of the phasor response
  - Resulting feature vector is called the iris code

Iris Encoding

- Filtering Equation

Normalized Iris Image

Wave frequency

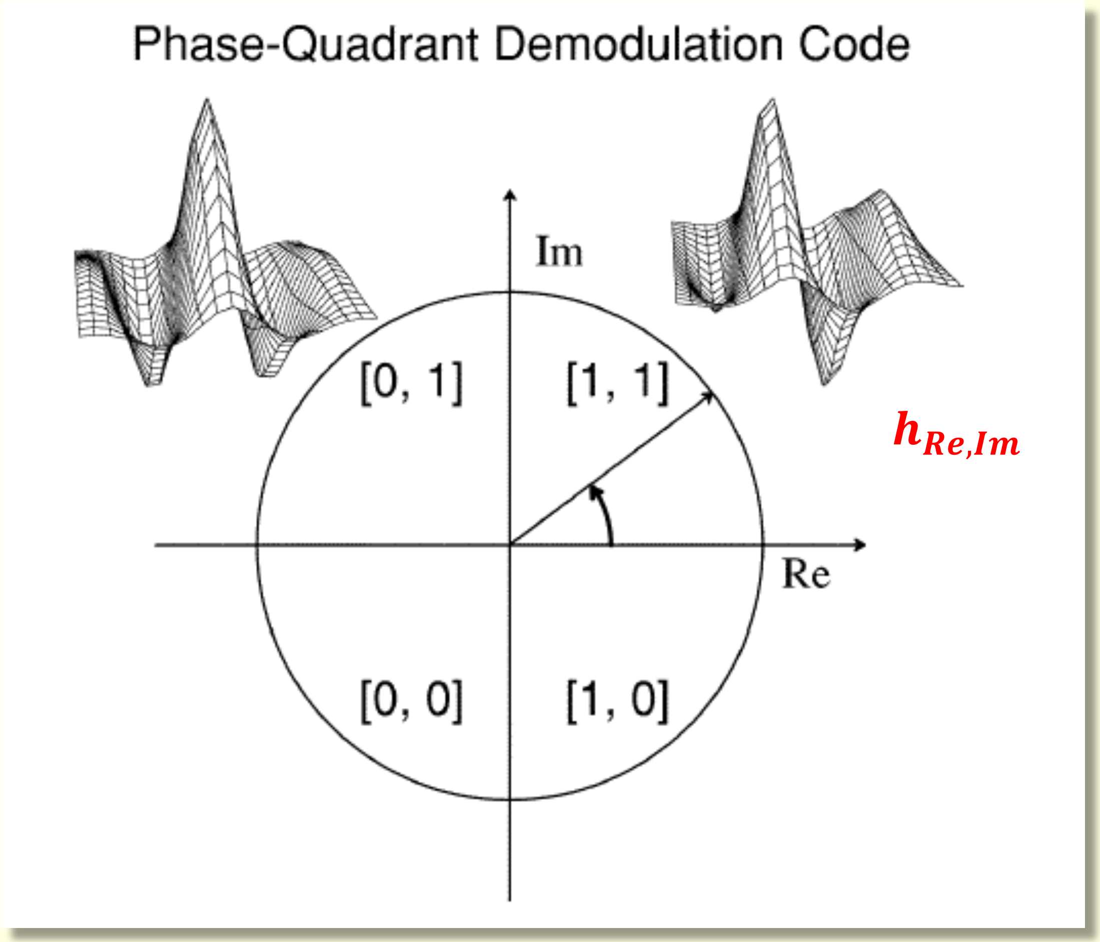
(α, β) = effective width & length

$$h_{Re,Im} = sign_{Re,Im} \int_{\rho} \int_{\phi} I(\rho, \phi) e^{-i\omega(\theta_0 - \phi)} e^{-(r_0 - \rho)^2/\alpha^2} e^{-(\theta_0 - \phi)^2/\beta^2} \rho d\rho d\phi,$$

(r_0, θ_0) = center frequency of wavelet

Iris Encoding

- Assigning the bits



$h_{Re,Im}$

Iris Matching

- Summary
  - Match two iris codes using normalized **Hamming Distance** (HD)
  - Use **masks** to account for occlusions
    - Mask has value ”0” for non-iris pixels
    - Mask has value “1” for iris pixels

Iris Matching

- Normalized Hamming Distance (HD)

XOR AND

$$HD = \frac{\| (IrisCodeA \oplus IrisCodeB) \cap MaskA \cap MaskB \|}{\| MaskA \cap MaskB \|}$$

XOR

A	B	A ⊕ B
0	0	0
0	1	1
1	0	1
1	1	0

AND

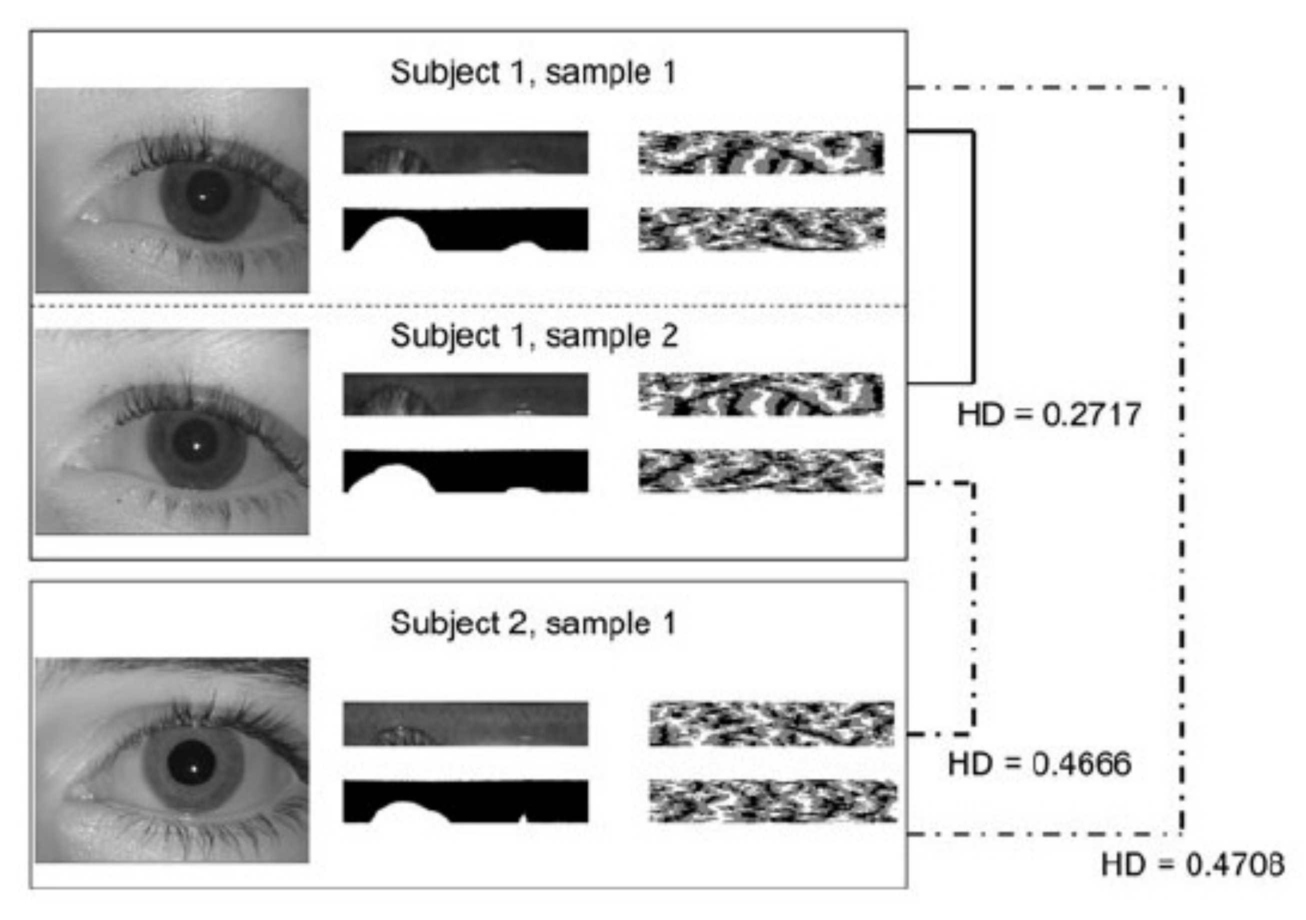
A	B	A ∩ B
0	0	0
0	1	0
1	0	0
1	1	1

Numerator: Counting the number of bits that are different corresponding to the iris-only pixels (the mask excludes non-iris pixels)

Denominator: Counting the number of iris-only pixels in both the images

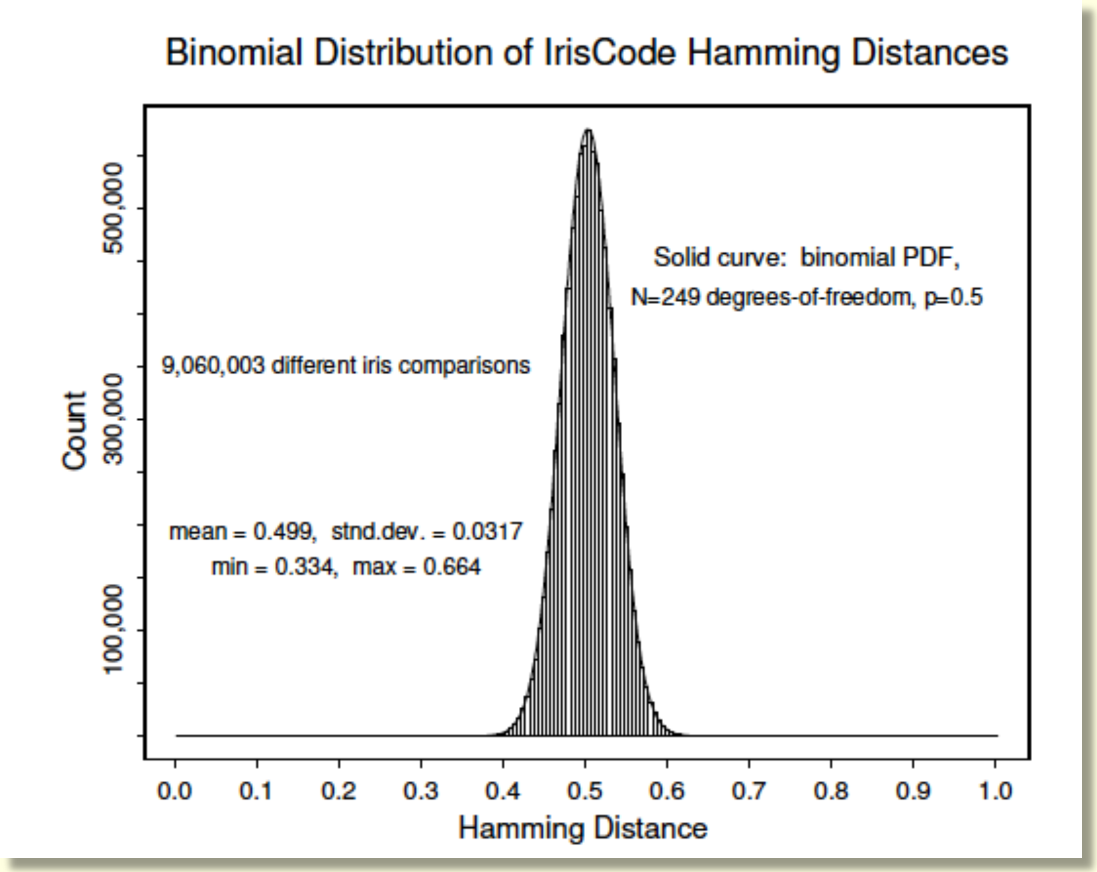
Iris Matching

- Example



Making a Decision

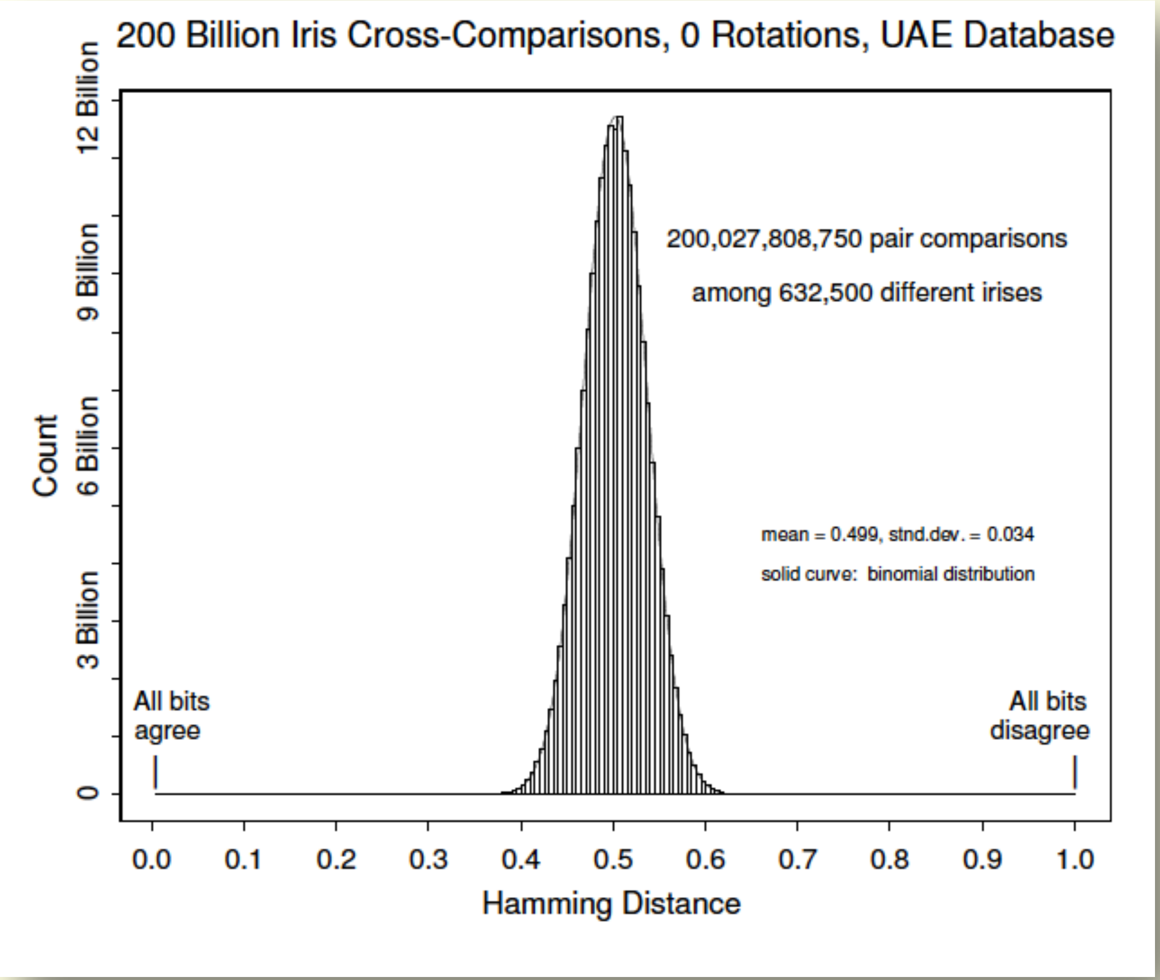
- If HD is below a threshold, say that the two iris codes came from the same individual



- 4,258 different iris images, including 10 each of one subset of 70 eyes.
- The total number of unique pairings between different eye images whose HDs could be computed was 9,060,003

J. Daugman, "How Iris Recognition Works," TCSVT 2004

Statistical Independence Test



http://www.cl.cam.ac.uk/~jgd1000/UAEsummary.pdf

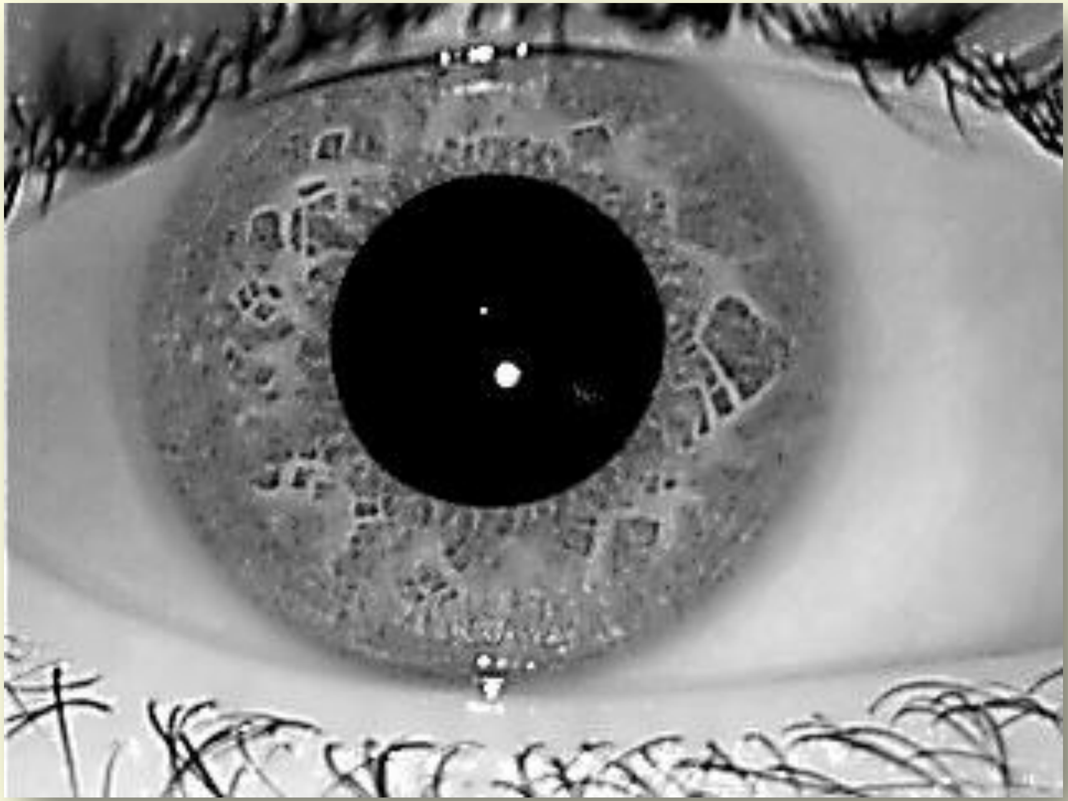
IREX IX: Iris Matching Results

	One-eye	**Two-eyes**
1:1 Matcher	FNMR = 0.016 @10^{-4} FMR+	FNMR = 0.0054 @10^{-4} FMR*
1:N Matcher	FNIR = 0.024 @ 10^{-4} FPIR+	FNIR = 0.007 @ 10^{-4} FPIR+

* NEC 5
+ NEC 6

- NEC Matcher gave the best results
- Number of enrolled identities = 160K

What *else* is revealed in an iris image?



- **Viewing the iris as a textural entity rather than just a binary code**

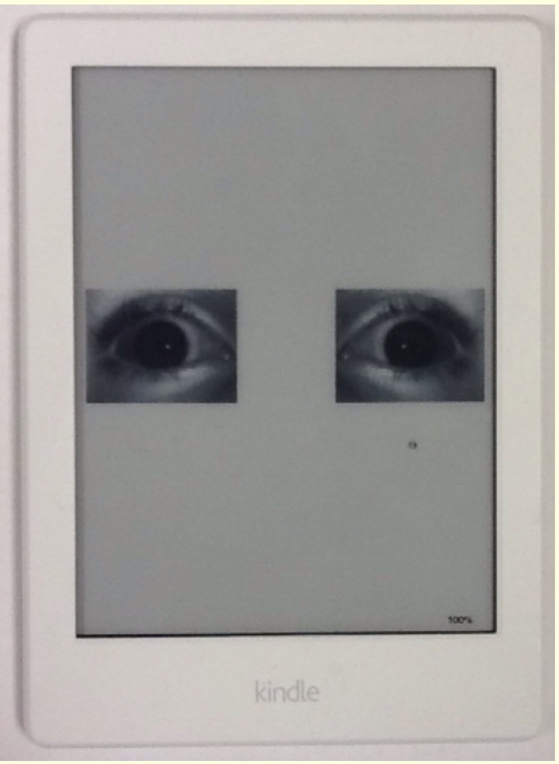
Levels of Information

- Biographical:
  Age, Gender, Race
- Anatomical:
  Distribution of crypts, Wolfflin nodules, pigmentation spots
- Environmental:
  Sensor, Illumination wavelength, Indoor/Outdoor
- Pathological:
  Stromal Atrophy
- Other:
  Pupil dilation level, Contact Lens

Not all information can be reliably extracted

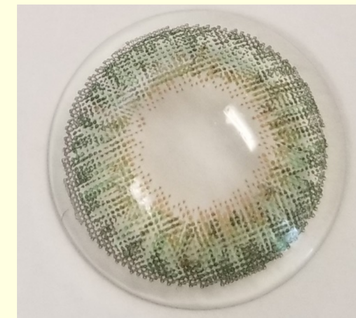
But information can be aggregated

Presentation Attacks

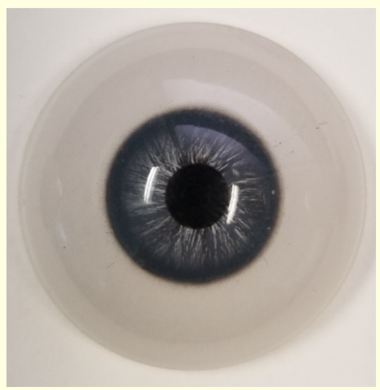


Display

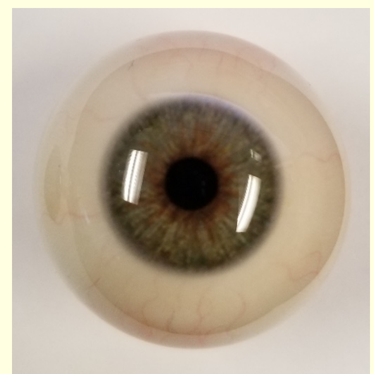
Prints



Cosmetic contact



Glass

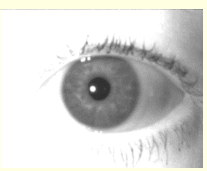


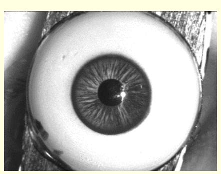
Prosthetic

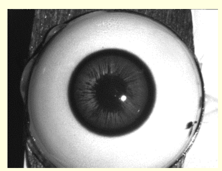
Plastic fake eye

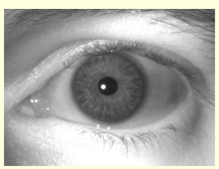
Sample Images (JHU-APL, GCT#3)

- A total of 3,315 iris images were collected from 1,315 subjects
- There are 2,963 bonafide and 352 PA images
- Collected PAs are VanDyke eyes and cosmetic contact lens

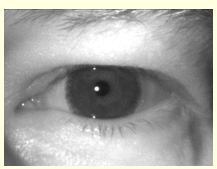

Bonafide

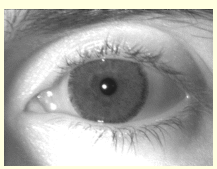

VanDyke Blue Eye

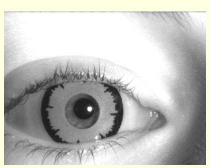

VanDyke Brown Eye

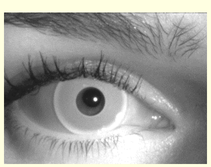

Air Optix


Air Optix


Extreme SFX

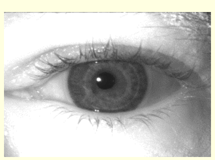

Extreme SFX

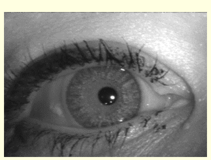

Extreme SFX


Extreme SFX


Extreme SFX

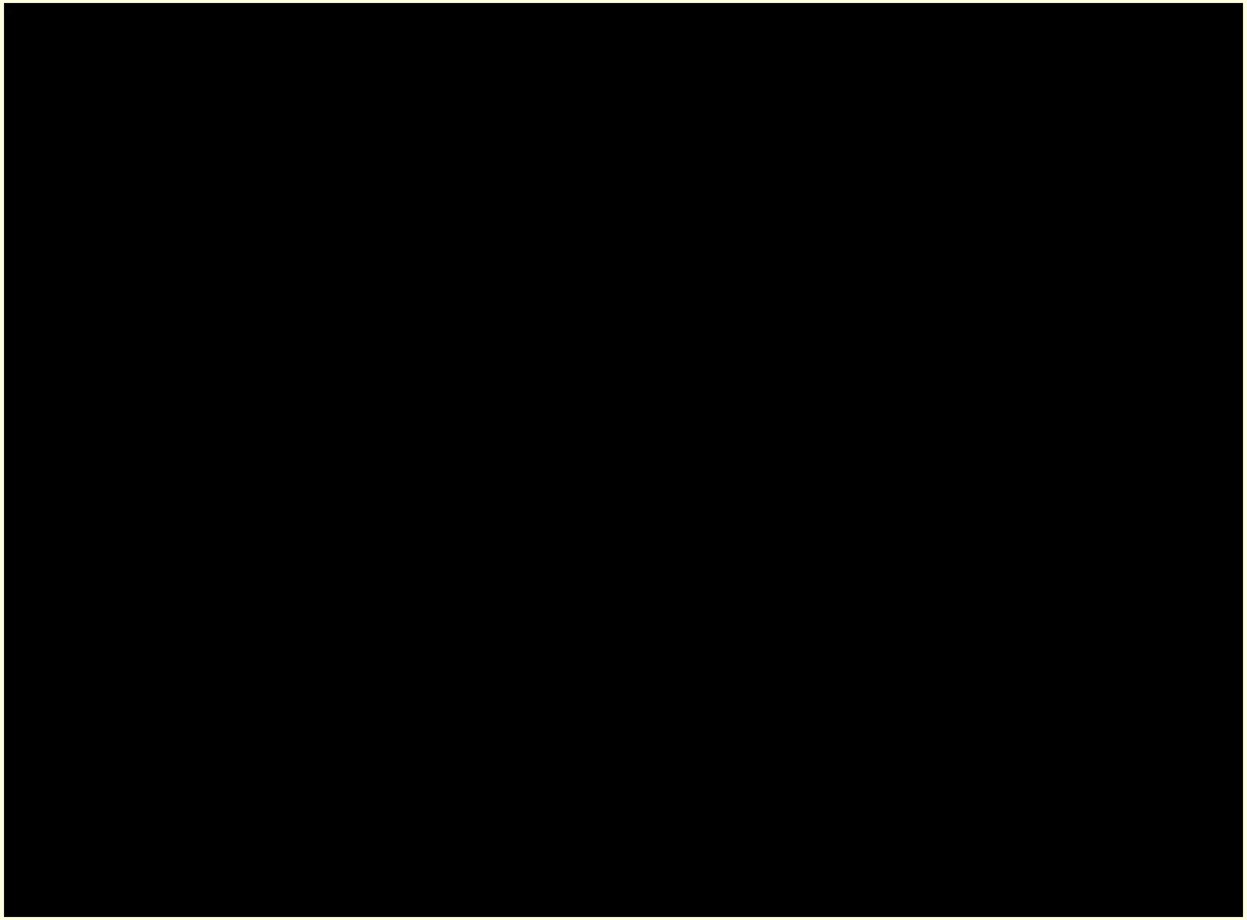

Custom


Custom


Coopervision

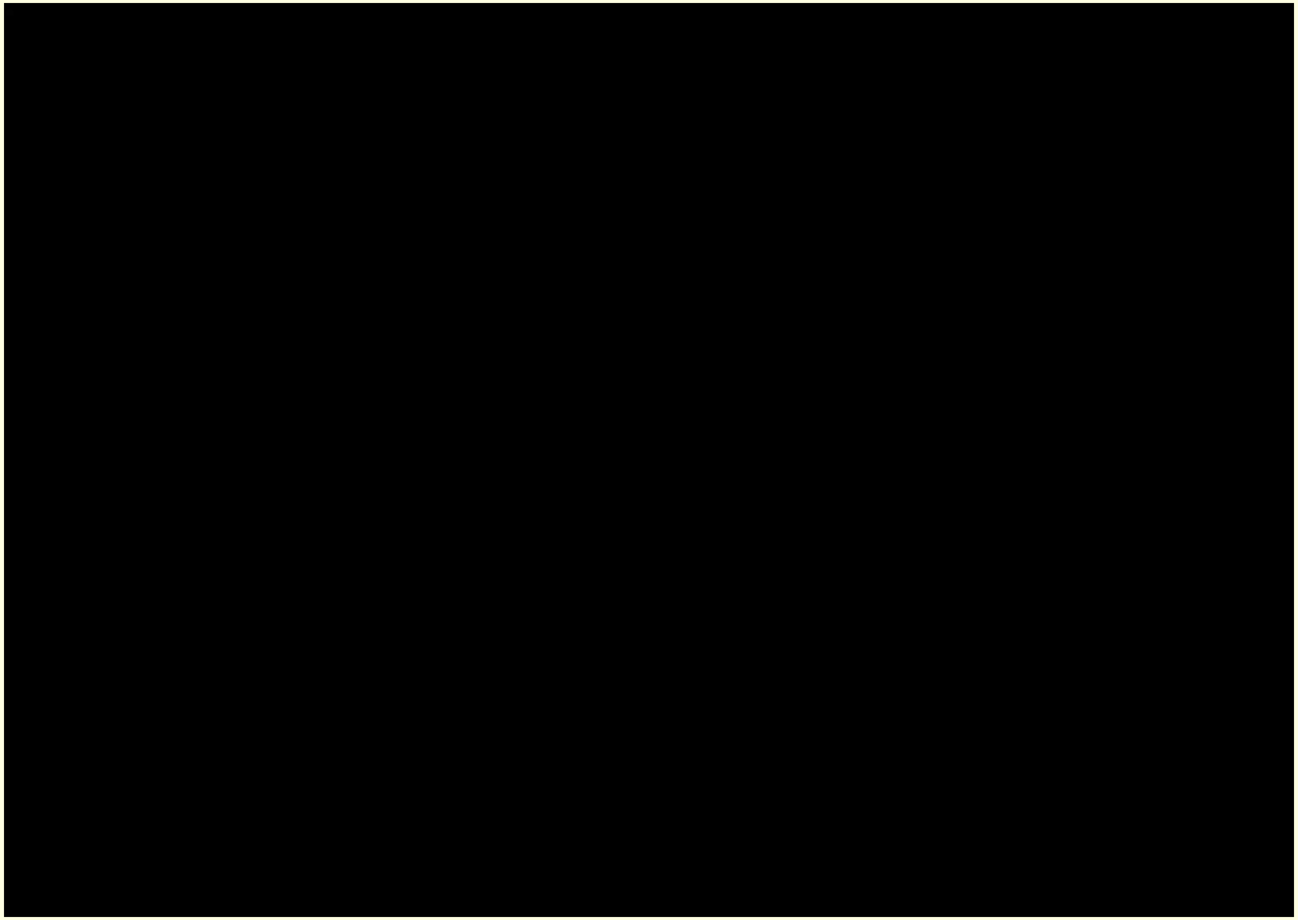
98.58% - 99.51% TDR @ 0.2% FDR

Presentation Attacks



PLASTIC EYE ATTACK

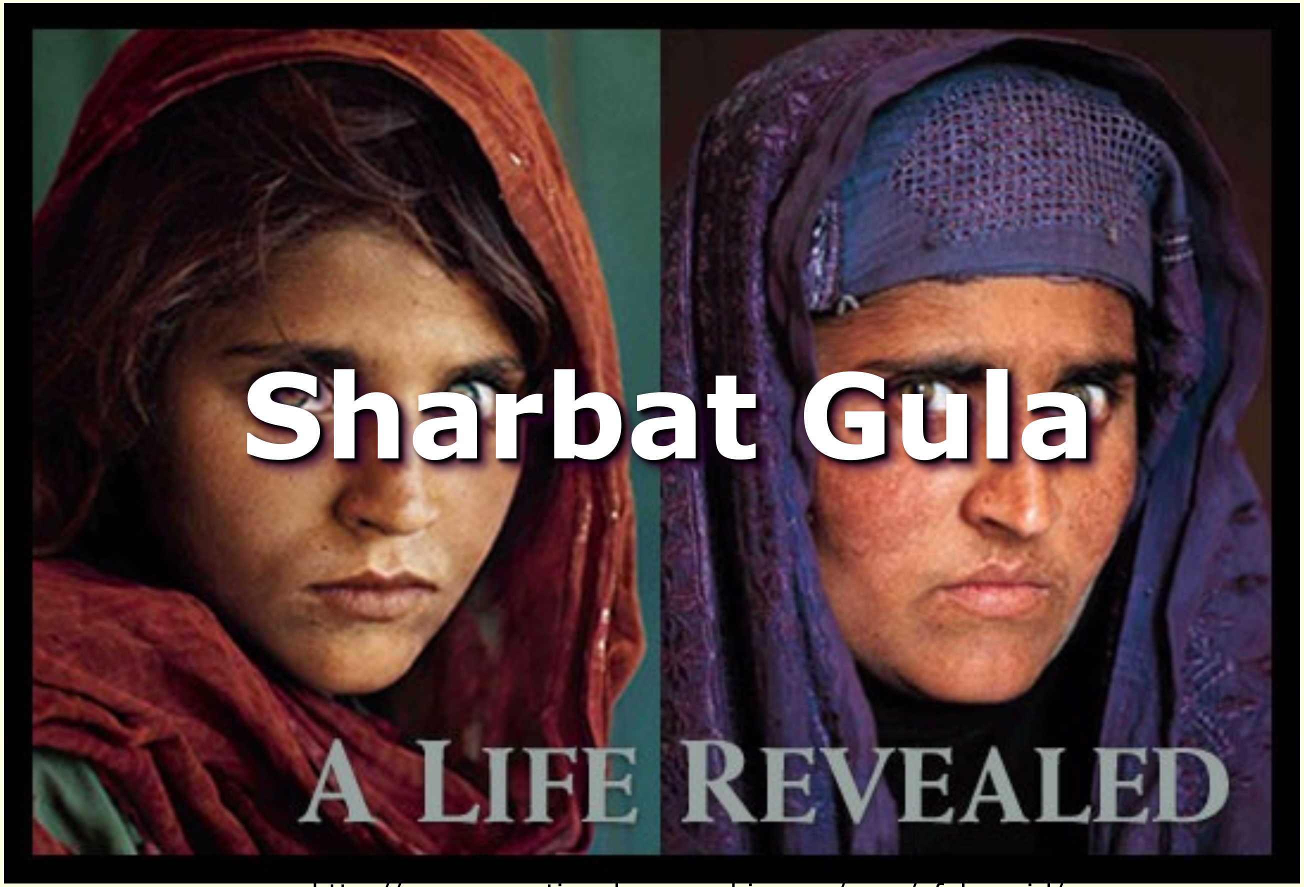
Presentation Attacks



PRINT ATTACK

Who is She?

- The Afghan girl identified via iris (and facial scar) match



http://magma.nationalgeographic.com/ngm/afghangirl/

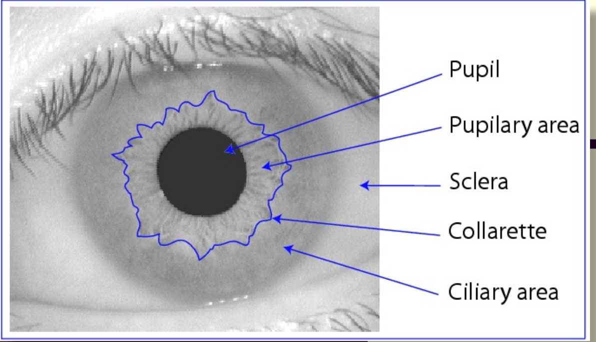
1984 and 2002

John Daugman

- “First I computed IrisCodes from both of her eyes as photographed in 1984.
- Then I computed IrisCodes from both of her eyes in the 2002 photograph.
- When I ran the search engine (the matching algorithm) on these IrisCodes, I got a Hamming Distance of 0.24 for her left eye, and 0.31 for her right eye.
- These measured Hamming Distances are so far out on the distribution tail that it is statistically almost impossible for different irises to show so little dissimilarity.
- The mathematical odds against such an event are 6 million to one for her right eye, and 10-to-the-15th-power to one for her left eye”

Summary

- Capturing an iris image often involves cooperation from the user; long-range iris recognition is area of research
- Iris data of some users may be of poor quality resulting in a failure to enroll
- Extraction of soft biometric traits from iris is possible: gender, ethnicity, etc.
- Presentation attack detection and image forensics are important application areas
- Impact of ageing is being studied: conflicting findings reported in the literature
- Post-mortem iris recognition needed in some cases
- Deep learning methods are becomingly increasingly popular



Iris Recognition

Arun Ross

Professor

Michigan State University

rossarun@cse.msu.edu

http://iprobe.cse.msu.edu