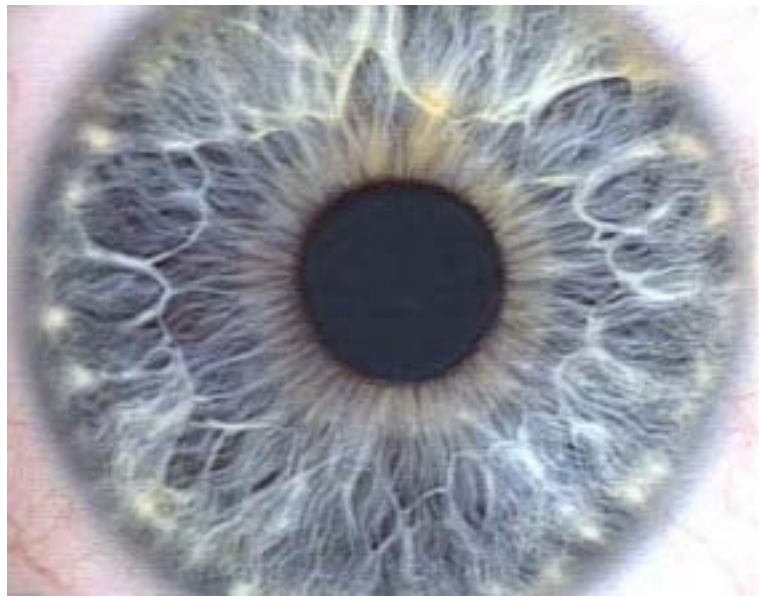
# A Quick Overview of Biometrics



- Speaker Recognition
- Dynamic Signature
- Fingerprints
- **Iris**
- Retina
- Face
- Others
- Multimodal Biometrics



- **Generalities**
- Iridology
- Properties of the iris
- Applications
- Iris sensing
- Iris features
- Iris matching
- Performance evaluation
- Identification

# Identifiable biometric characteristics



- **Biological traces**
  - DNA (DeoxyriboNucleic Acid), blood, saliva,etc.
- **Biological (physiological) characteristics**
  - **fingerprints**, **eye irises** and retinas, hand palms and geometry, and facial geometry
- **Behavioral characteristics**
  - **dynamic signature**, gait, keystroke dynamics, lip motion
- **Combined**
  - **voice**

# Popular biometric characteristics (modalities)





Fingerprint



Face



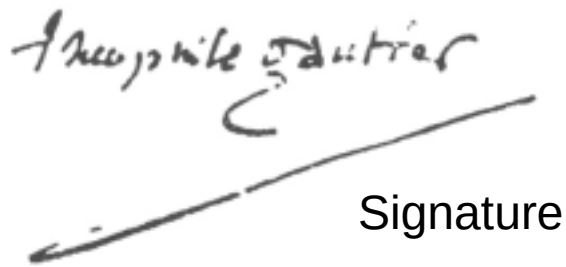
Iris



Retina



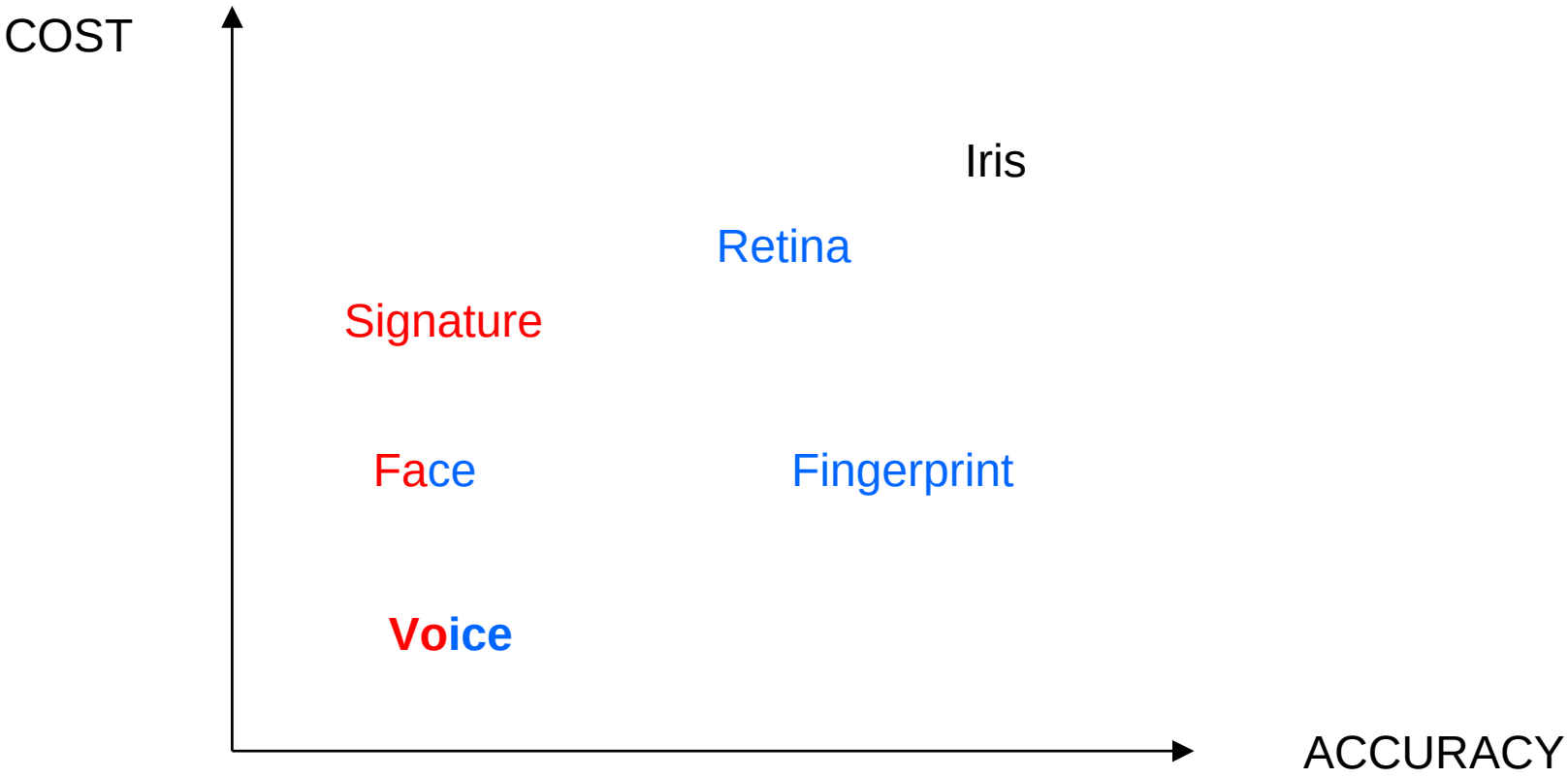
Voice



Signature

# Comparison of biometric techniques

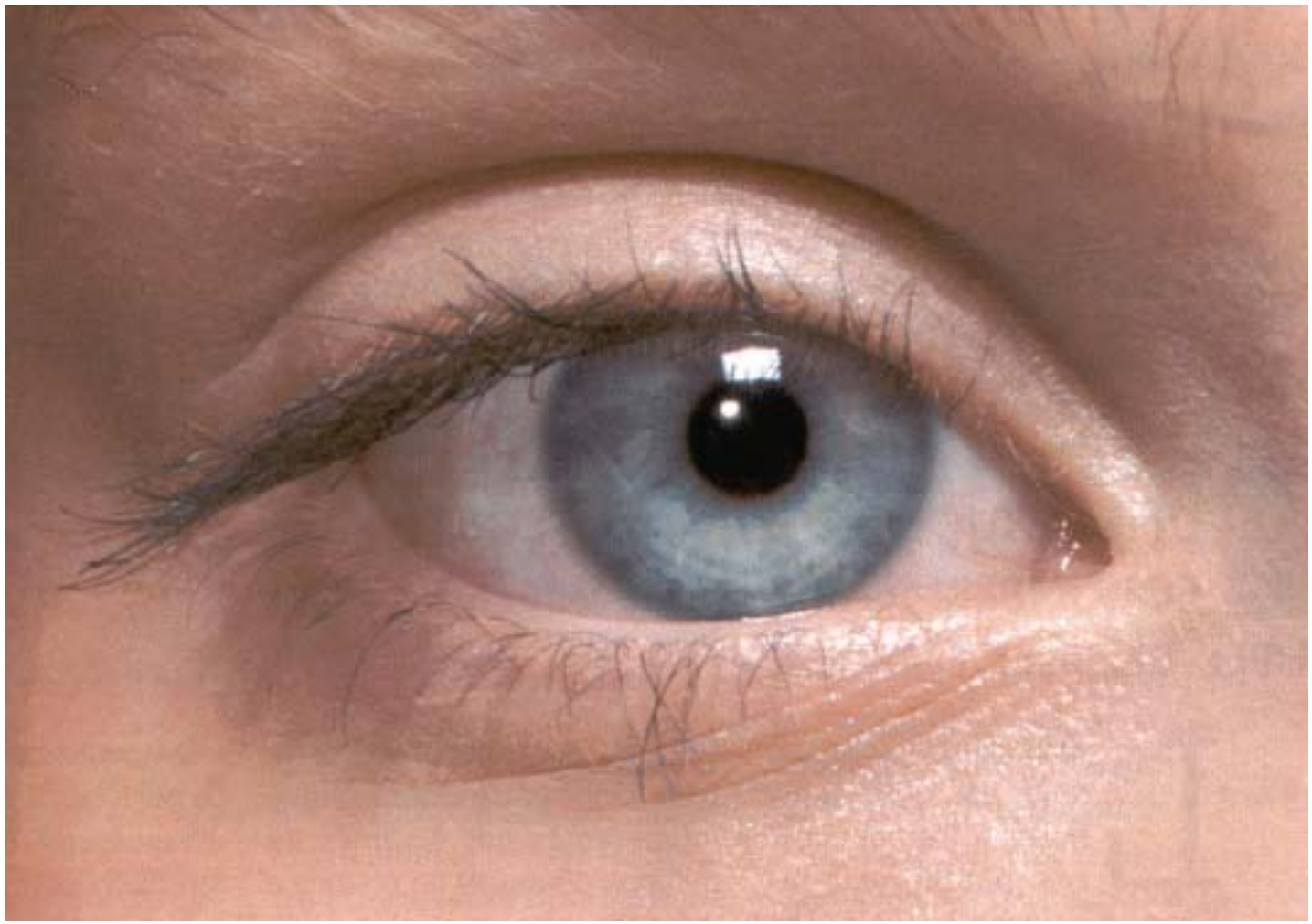





Randomnes and complexity are the keys to uniqueness

# Eye





***« … sometimes from her eyes I did receive fair speechless messages… »***

**The Merchant of Venice, Act I, Scene 1,**

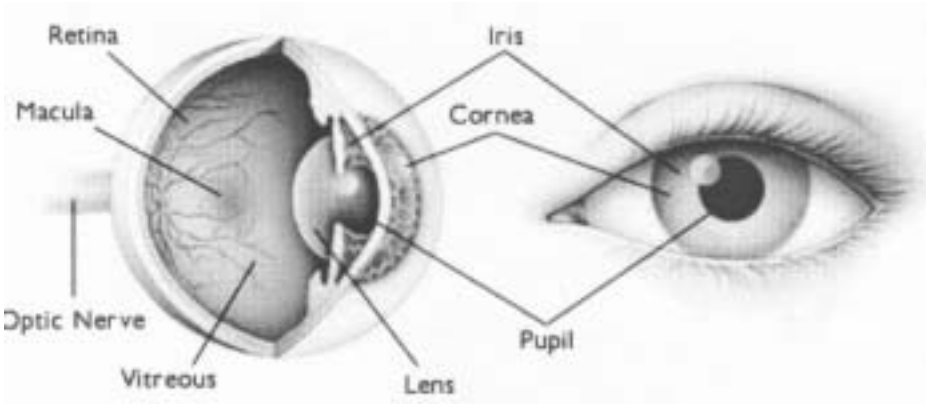
# Iris

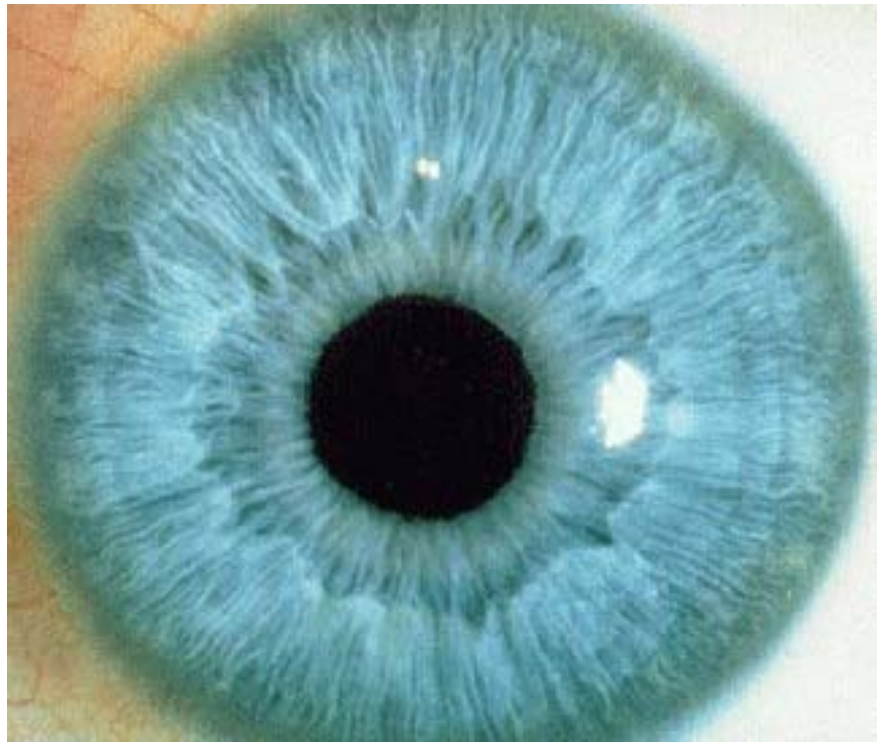




# Iris



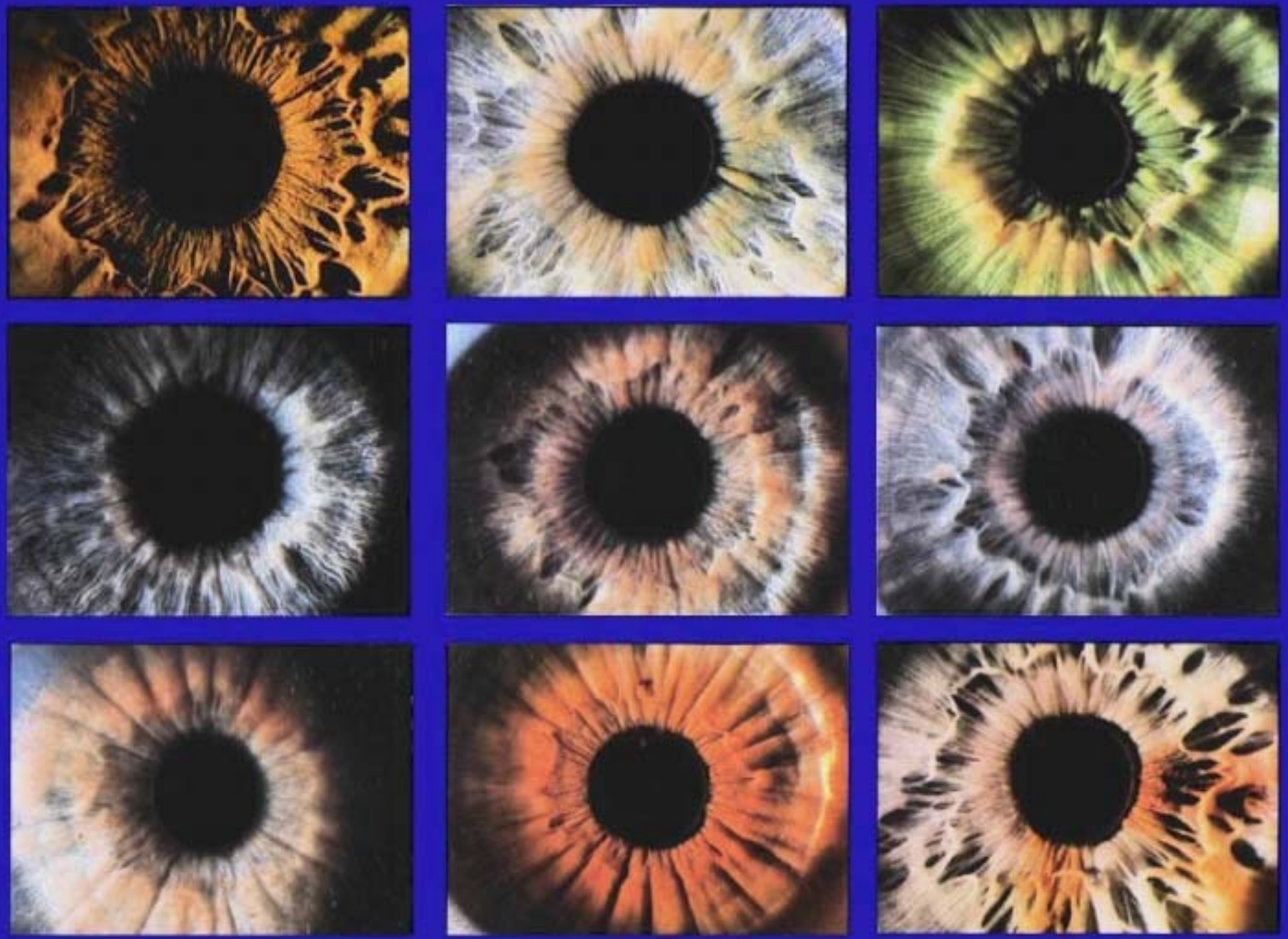


The iris begins to form in the third month of gestation and the structures creating its pattern are largely complete by the eighth month.

Pigment accretion can continue into the the first postnatal years. Iris colour is determined mainly by the density of melanin pigment. Blue irises result from an absence of pigment.

Distinctive features: arching ligaments, furrows, ridges, crypts, rings, corona, freckles, etc.



# Iris Recognition

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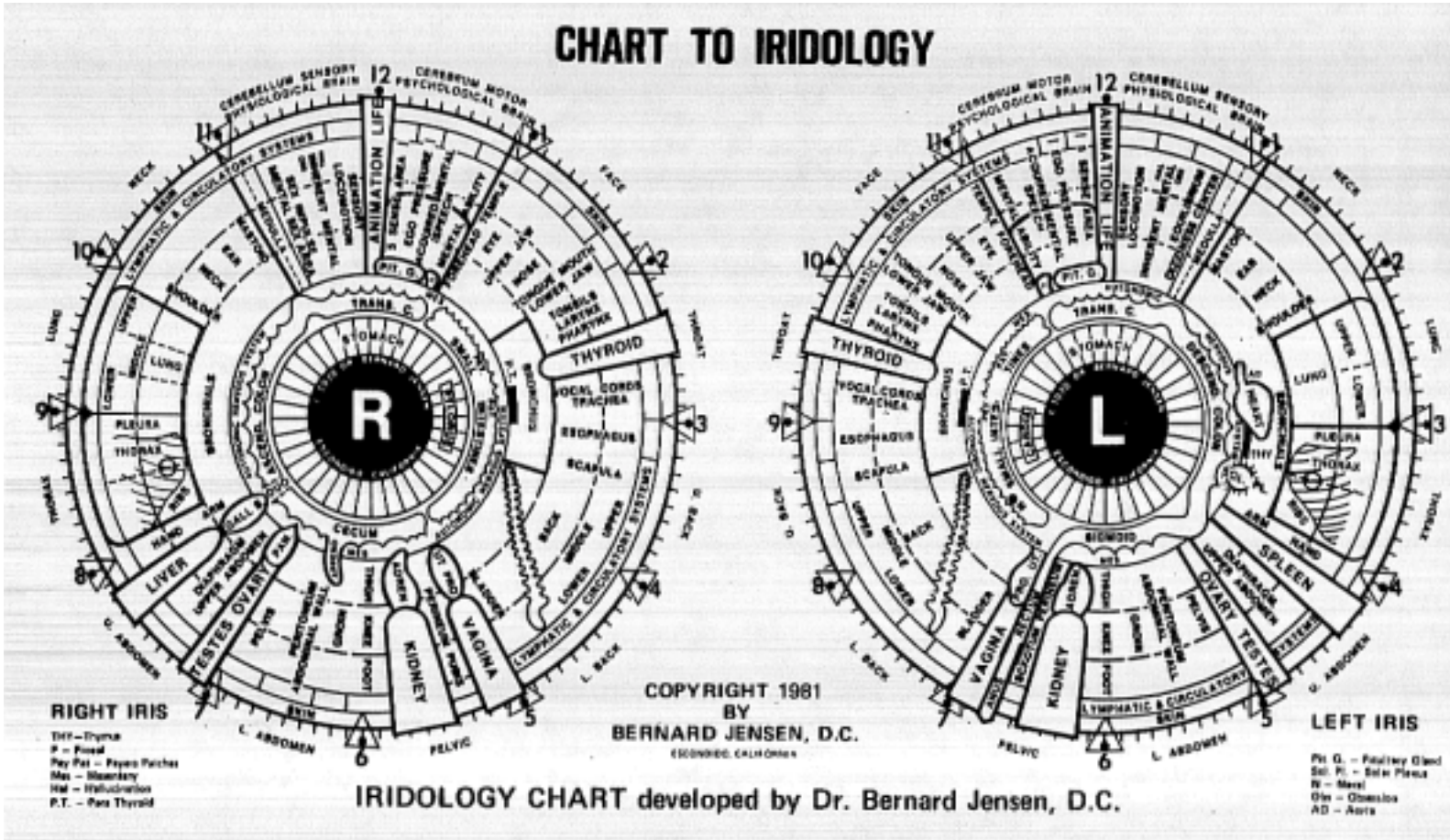
# Iridology



- There is a popular belief in systematic changes in the iris pattern, reflecting the state of health of each of the organs in the body, one's mood or personality, and revealing one's future
- Iridology resembles palm-reading and is popular in parts of Europe and in California
- **All scientific tests dismiss iridology as a medical fraud**
  - Berggren, L. (1985), “Iridology: A critical review”, *Acta Ophthalmologica*, 63(1): 1-8

# Iridology





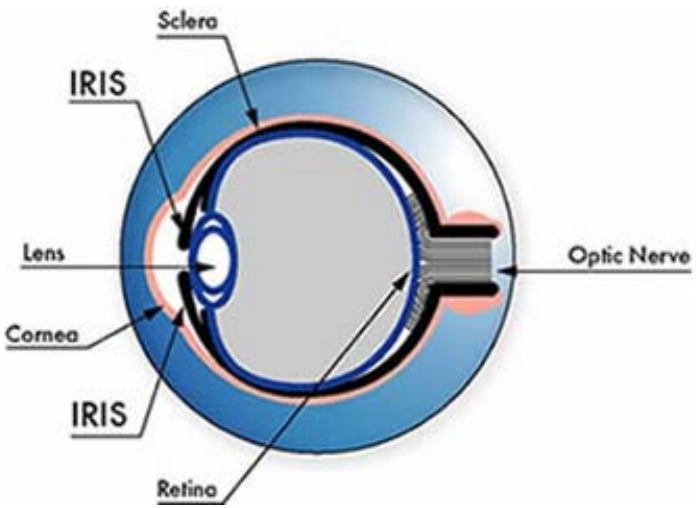

“Throughout the ages, the eyes have been known as the windows to the soul, and modern behavioral research is proving this adage to be true. If you look closely at the iris of the eye, you will notice small, dark dots, light streaks or rounded openings in the fibers. These characteristics provide the key to unlocking the mysteries of the personality” (Rayid International).

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# Properties of the Iris

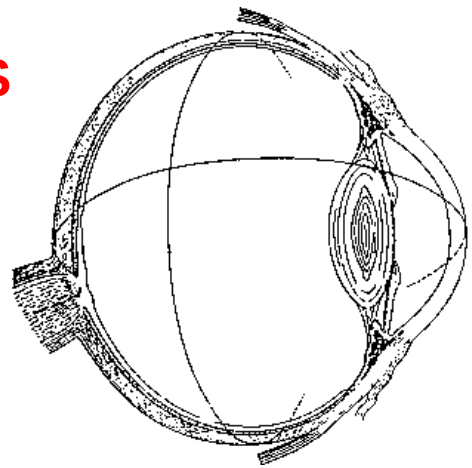


- Highly protected, internal organ of the eye
- Externally visible, from arm's length distance
- Random pattern of great complexity and uniqueness
- Pattern is epigenetic (not genetically determined)
- Stable through life, except possibly pigmentation





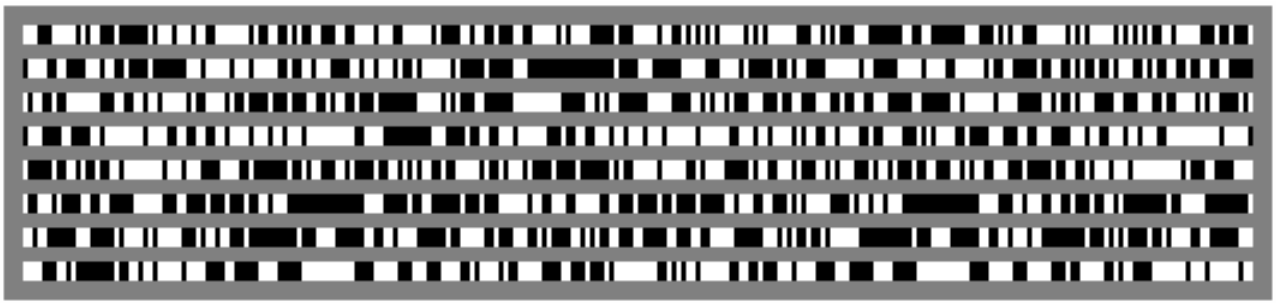




# Advantages of the Iris as a Biometric Identifier



- Changing pupil size can confirm it is a real iris
- Iris patterns possess a high degree of randomness and uniqueness set by combinatorial complexity
- Encoding and matching are reliable and fast



Iris Code

# Difficulties with the Iris in Biometric Recognition

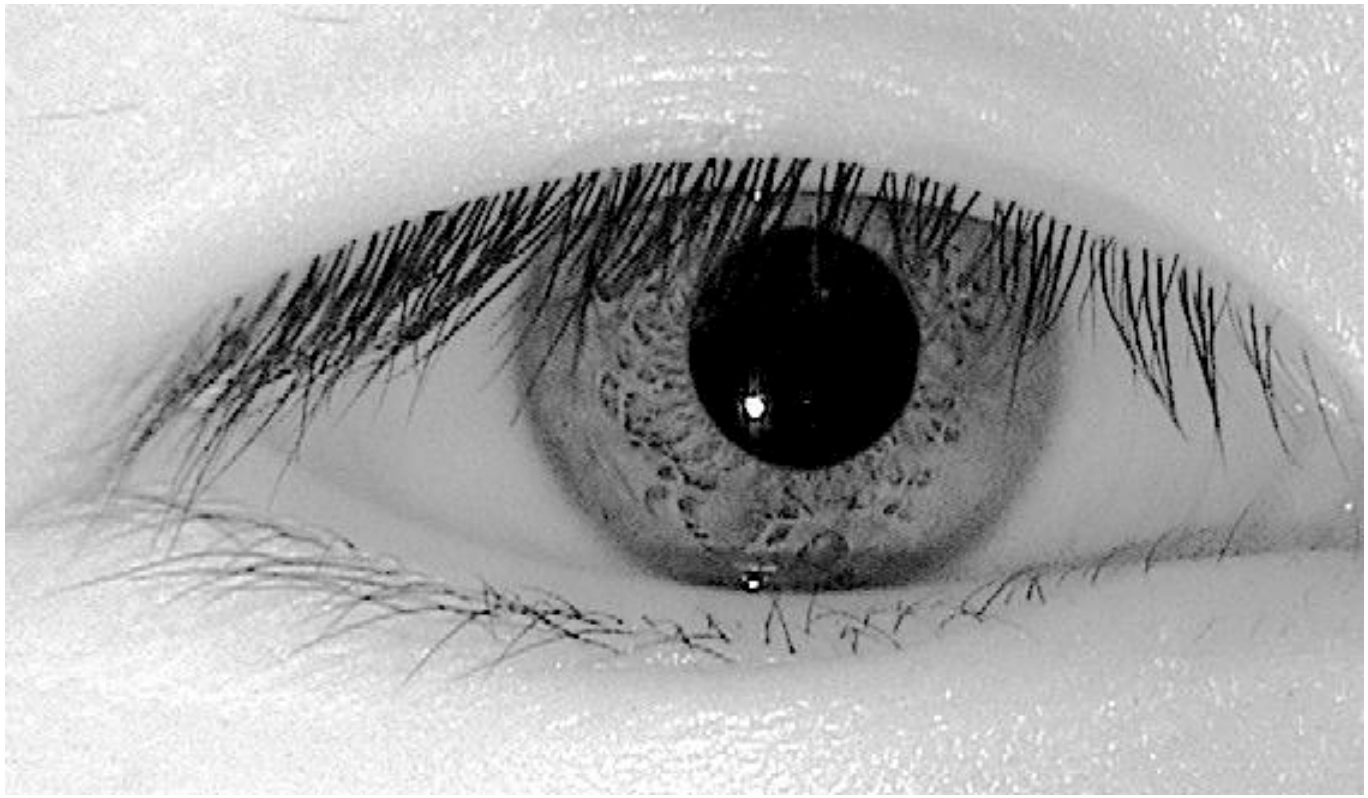


- Small target (1 cm) to acquire from (1 m) distance
- Moving target
- Located behind a curved, wet, reflecting surface
- Curvature of the cornea causes wide-angle reflections
- Obscured by lashes, lenses, reflecting eyeglasses
- Partially occluded by eyelids, often drooping
- Some ethnic groups show less than half of each iris
- Iris deforms non-elastically as pupil changes size
- Illumination should not be visible or bright



# Infrared Images

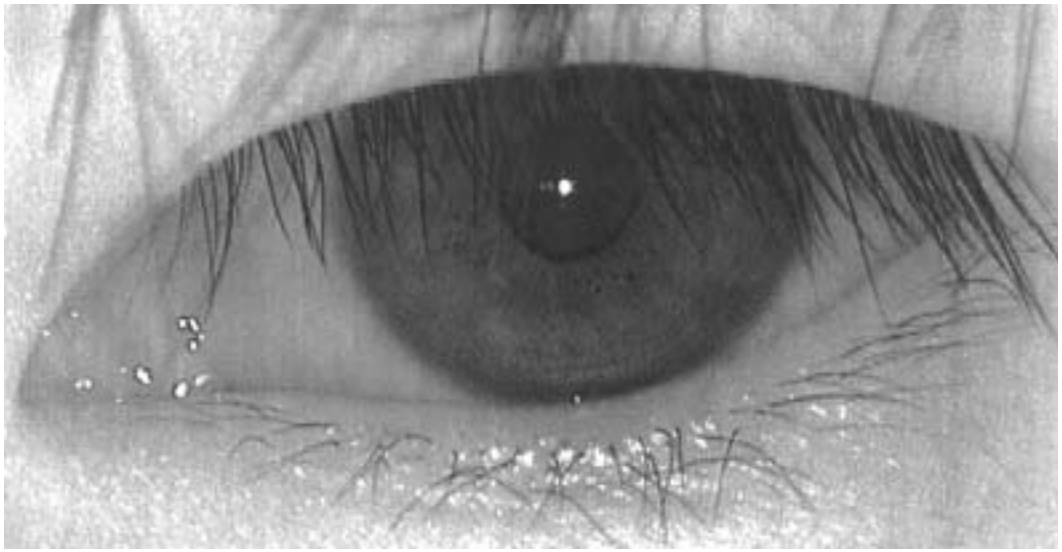


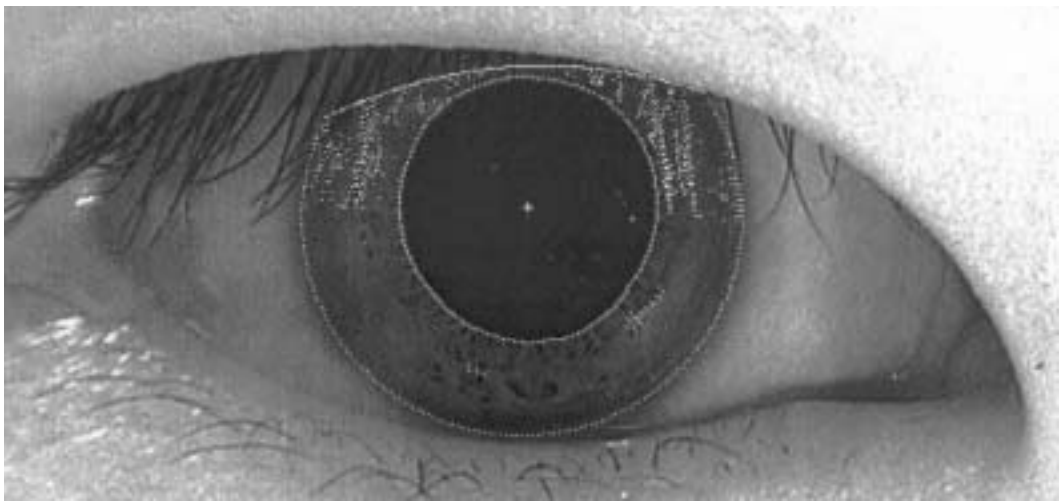


In infrared light, even dark brown eyes show rich iris texture

# Eyelashes





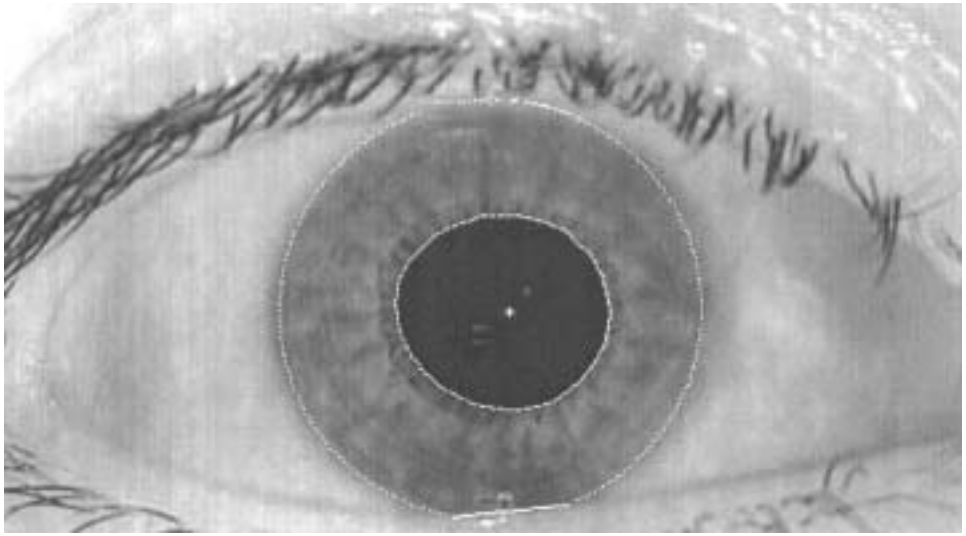


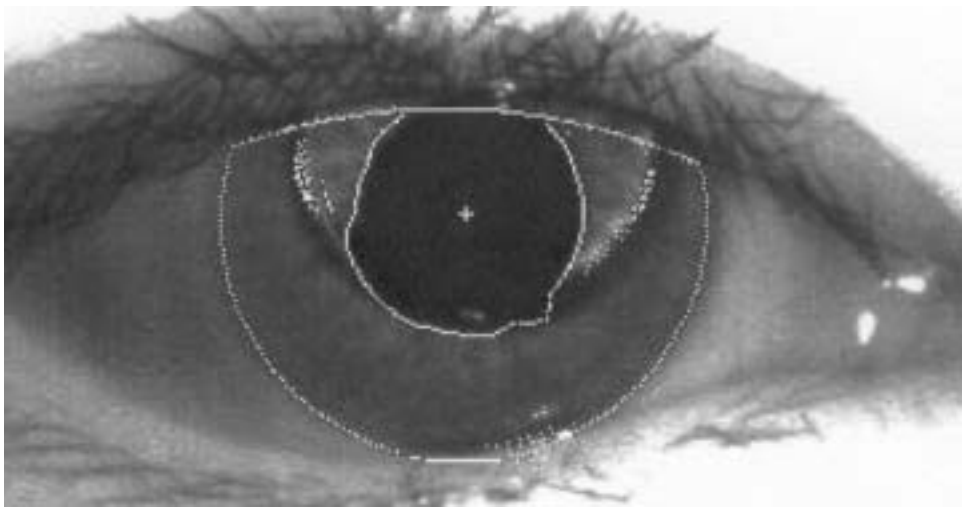
- Often the iris

  is covered by eyelashes
- They must be detected (shown in white) and excluded from IrisCode.

# Pupils and coordinate system



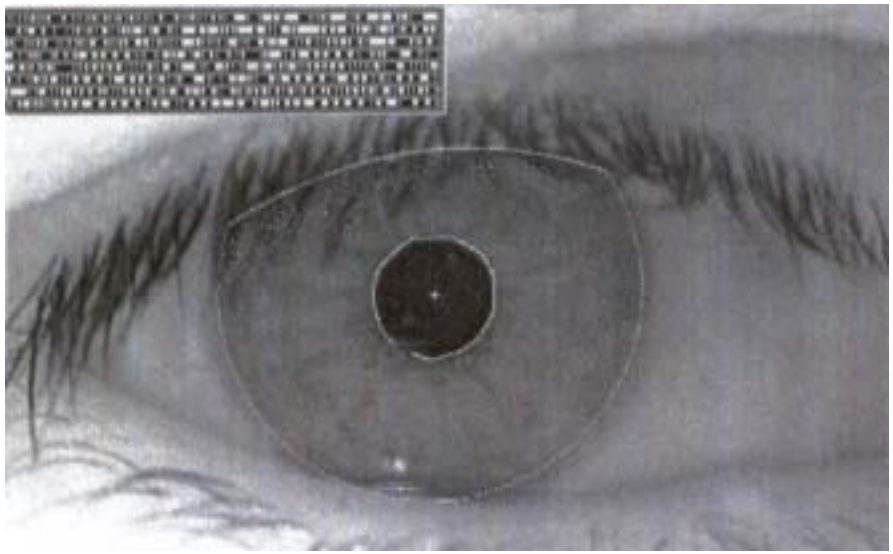


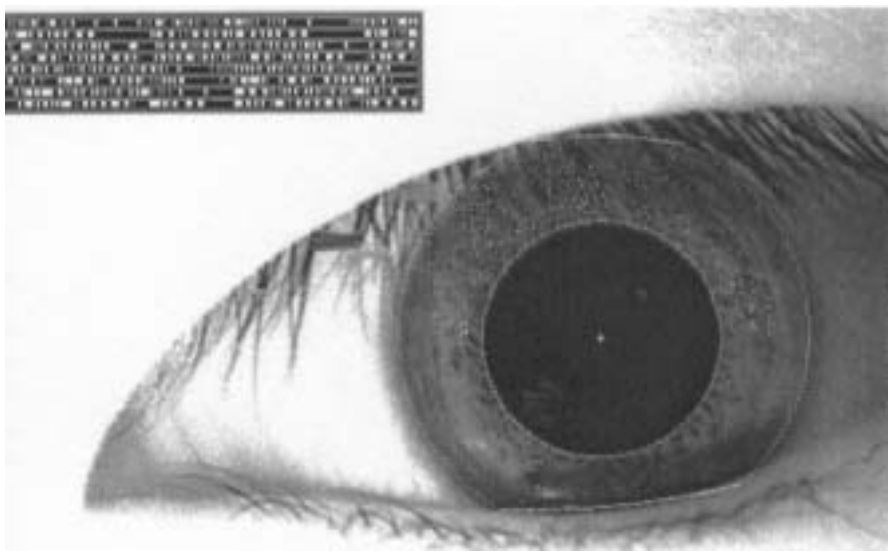


- Pupils are often very non-round
- The coordinate system must create a distorted, non-concentric, doubly-dimensionless iris mapping

# Iris mapping



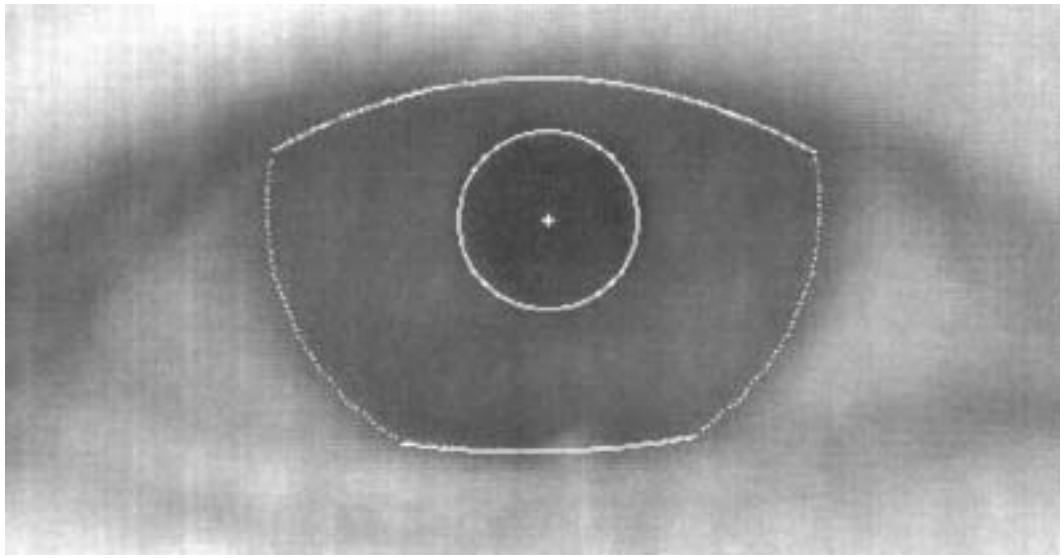




- The iris mapping has to be invariant to shift, distance, magnification, and pupillary dilation

# Defocusing

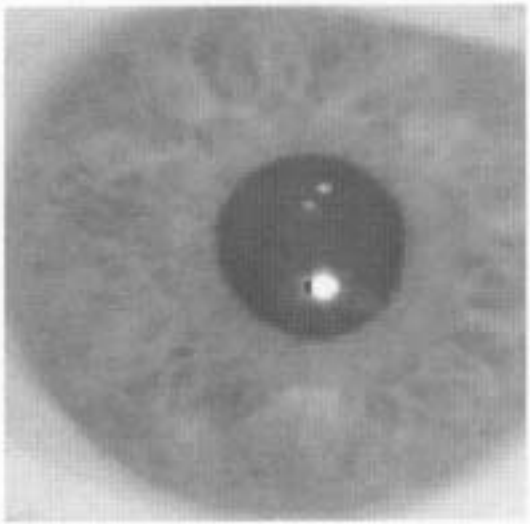




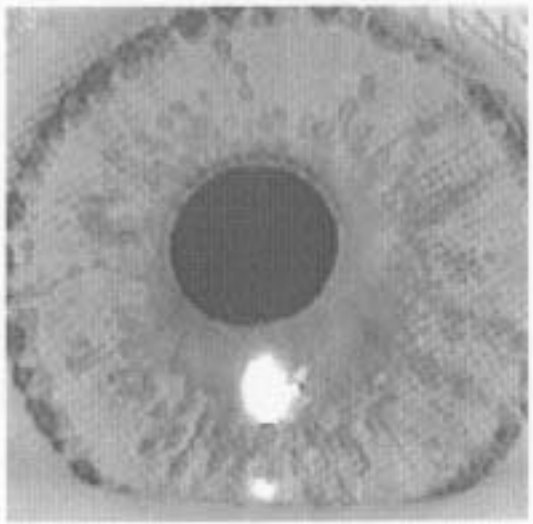
Badly defocused eyes get random IrisCodes, set by noise

# Fake Iris





Natural Iris



Fake Iris printed on a contact lens



2D Fourier spectrum of natural Iris



2D Fourier spectrum of fake Iris

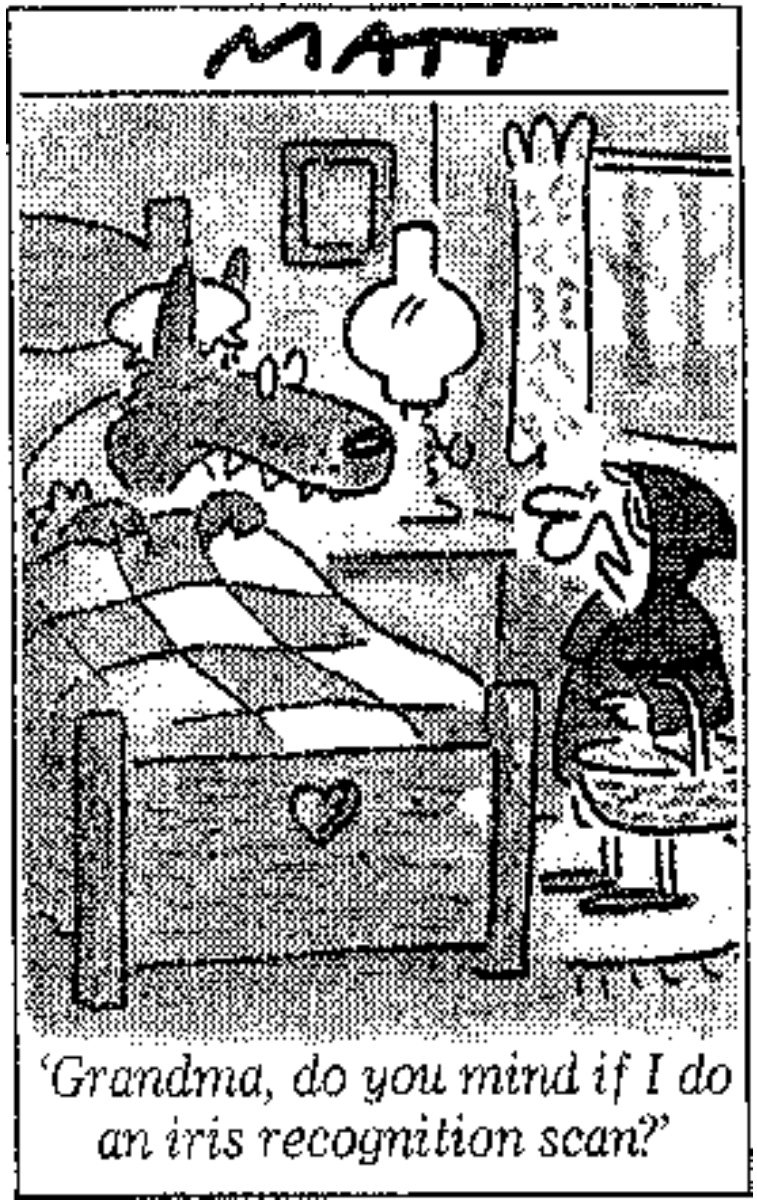
- The printing process adds a characteristic signature of periodicity to the 2D Fourier power spectrum
- Periodicity is represented as the radial coordinate of the Fourier plane, and direction corresponds to angle

# Iris Recognition

- Generalities
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# Red Riding Hood application





# Some Current and Future Applications



- computer login: the iris as a living password
- national border controls: the iris as a living passport
- telephone call charging without cash, cards, or PIN numbers
- secure access to bank cash machine accounts
- ticket-less, document-free, air travel
- premises access control (home, office, laboratory, etc)
- driving licenses, and other personal certificates
- entitlements and benefits authentication
- forensics; birth certificates; tracing missing or wanted persons
- credit-card authentication
- automobile ignition and unlocking; anti-theft devices
- anti-terrorism (e.g. security screening at airports)
- secure financial transactions (electronic commerce, banking)
- Internet security; control of access to privileged information
- "Biometric-Key Cryptography" for encrypting/decrypting messages
- any existing use of keys, cards, PINs, or passwords

# How Iris Recognition is Used at Airports



- 'Iris as Passport': Expedited immigration clearance for arriving passengers
  - Amsterdam Schiphol, Frankfurt, 10 UK airport terminals and 8 Canadian airports in 2004
- Expedited processing and check-in of departing passengers
  - Tokyo Narita (1'000 frequent travellers)
- Airline crew facility access and expedited security clearance
  - Charlotte Douglas (1'200 transactions per day)
- Airport employee access to tarmac and other restricted areas (80 access control points)
  - New York JFK, Amsterdam Schiphol (72'000 airport employees)
- 'WatchList' screening of all arriving passengers (505'000 expellees in WatchList
  - 7 airports

# United Arab Emirates (UAE)






- The largest national deployment of iris recognition to date
- IrisGuard™ distributed ‘Iris Farm’ architecture




Entry access control, wall mounted:
Panasonic ET300



LG IrisAccess 3000

# United Arab Emirates (UAE) Border Control



- Passengers arriving at all 17 air, land, and sea ports of entry into UAE today must look into an iris camera
- About 7’000 persons each day take this test; 2,557,000 so far
- Each person is compared against a central ‘Watch List’ of 505’000 expelled foreigners’ IrisCodes
- Each such exhaustive search of IrisCodes takes about 1 s
- 7’000 x 505’000 IrisCodes = 3.5 billion iris comparisons per day
- Approximately 300 billion iris comparisons performed in this programme to date
- 17’927 matches to the ‘Watch List’ of expellees have been found
- UAE Ministry of Interior says no matches have been disputed; all confirmed ultimately with other records. False Match Rate = 0.

# Schiphol Airport (The Netherlands)





Iris recognition in lieu of passport inspection

# Takhtabaig (Afganistan)

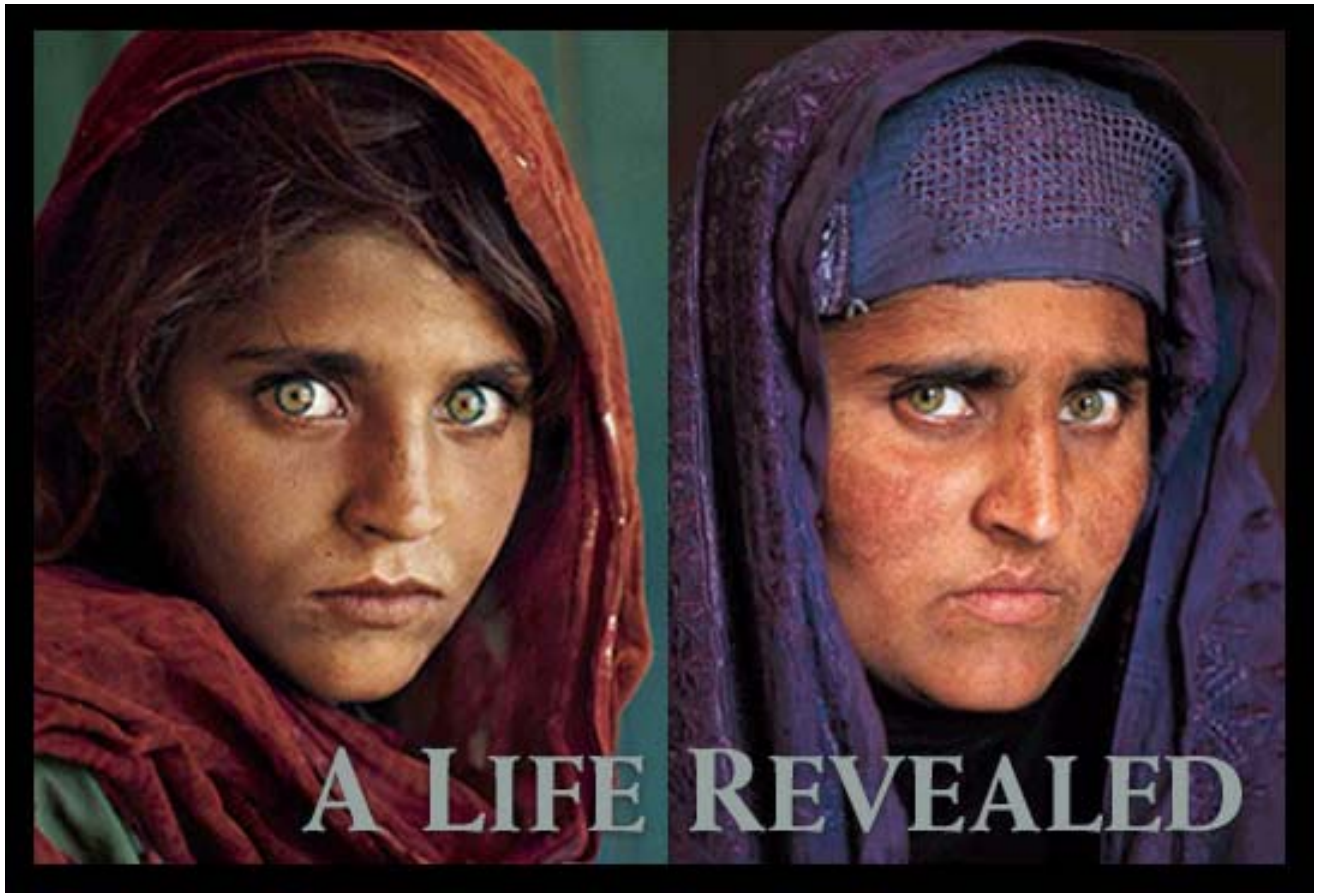




Takhtabaig Voluntary Repatriation Centre, Pakistan-Afghan border. United Nations (UN) cash grants for returnees are administered by Iris identification

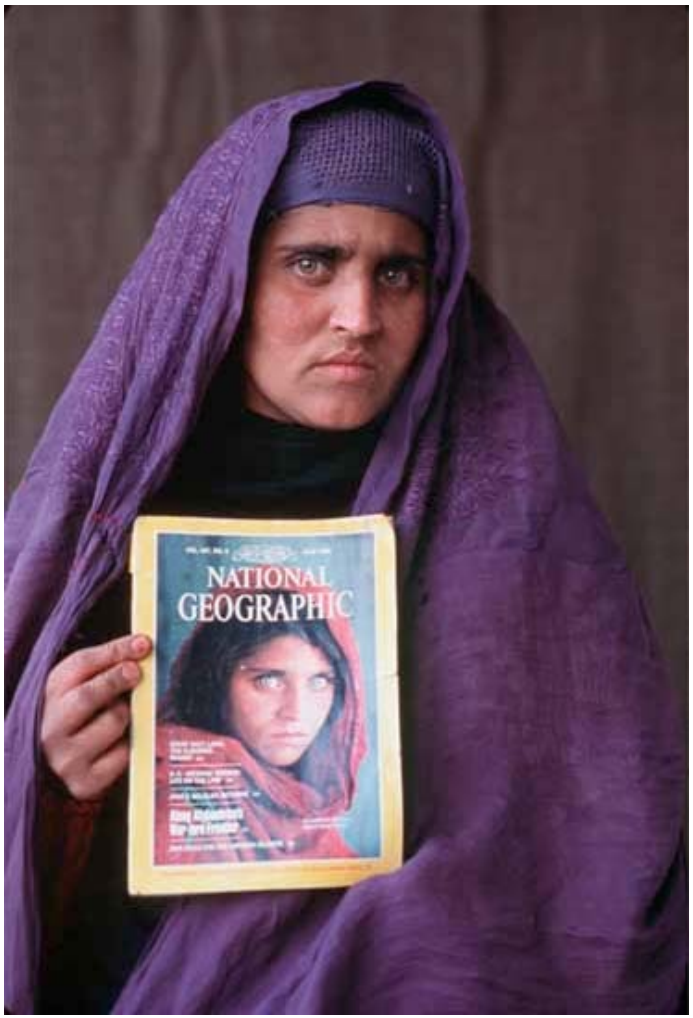
# National Geographic, 1984 and 2002





# National Geographic, 1984 and 2002

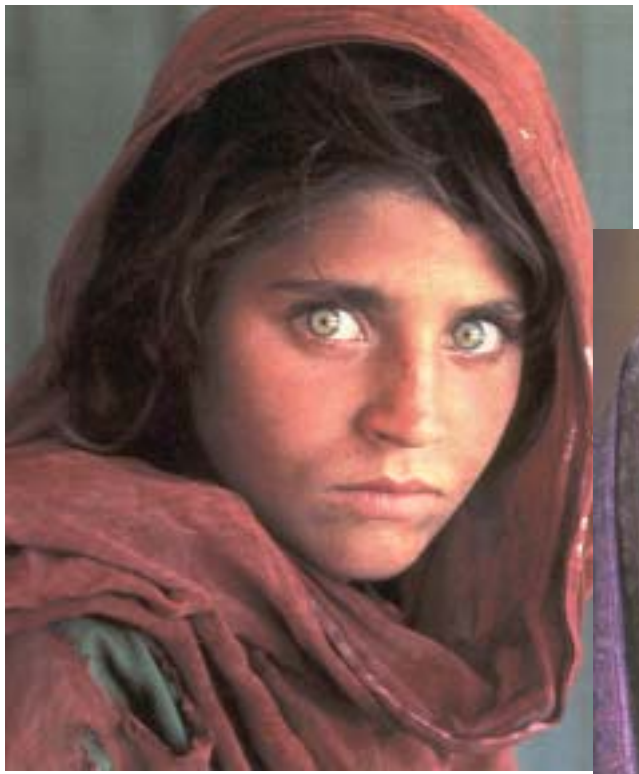


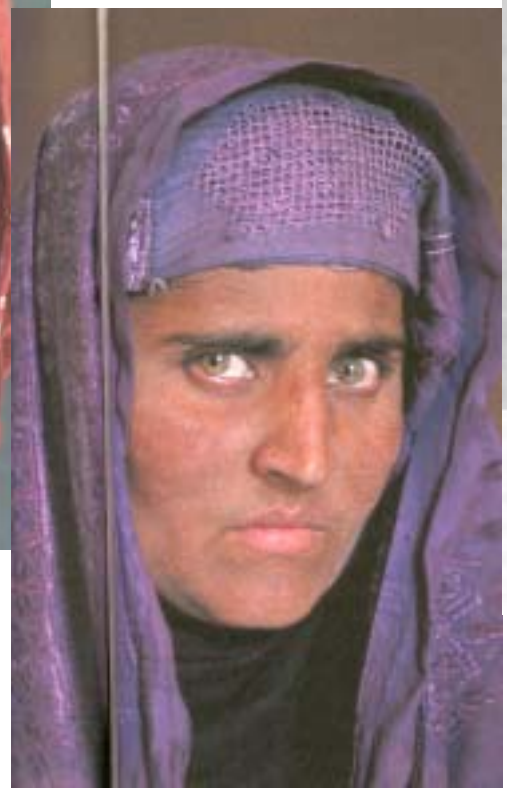



- The remarkable story of Sharbat Gula, first photographed in 1984 aged 12 in a refugee camp in Pakistan by National Geographic (NG) photographer Steve McCurry, and traced 18 years later to a remote part of Afghanistan where she was again photographed by McCurry.
- So the NG turned to the inventor of automatic iris recognition, John Daugman at the University of Cambridge.
- The numbers Daugman got left no question in his mind that the haunted eyes of the young Afghan refugee and the eyes of the adult Sharbat Gula belong to the same person

# National Geographic, 1984 and 2002







> Pour confirmer qu'il s'agit bien de la même femme sur les deux photos, à savoir Sharbat Gula, John Daugman est parti d'agrandissements du cliché de 1984 (en haut)...

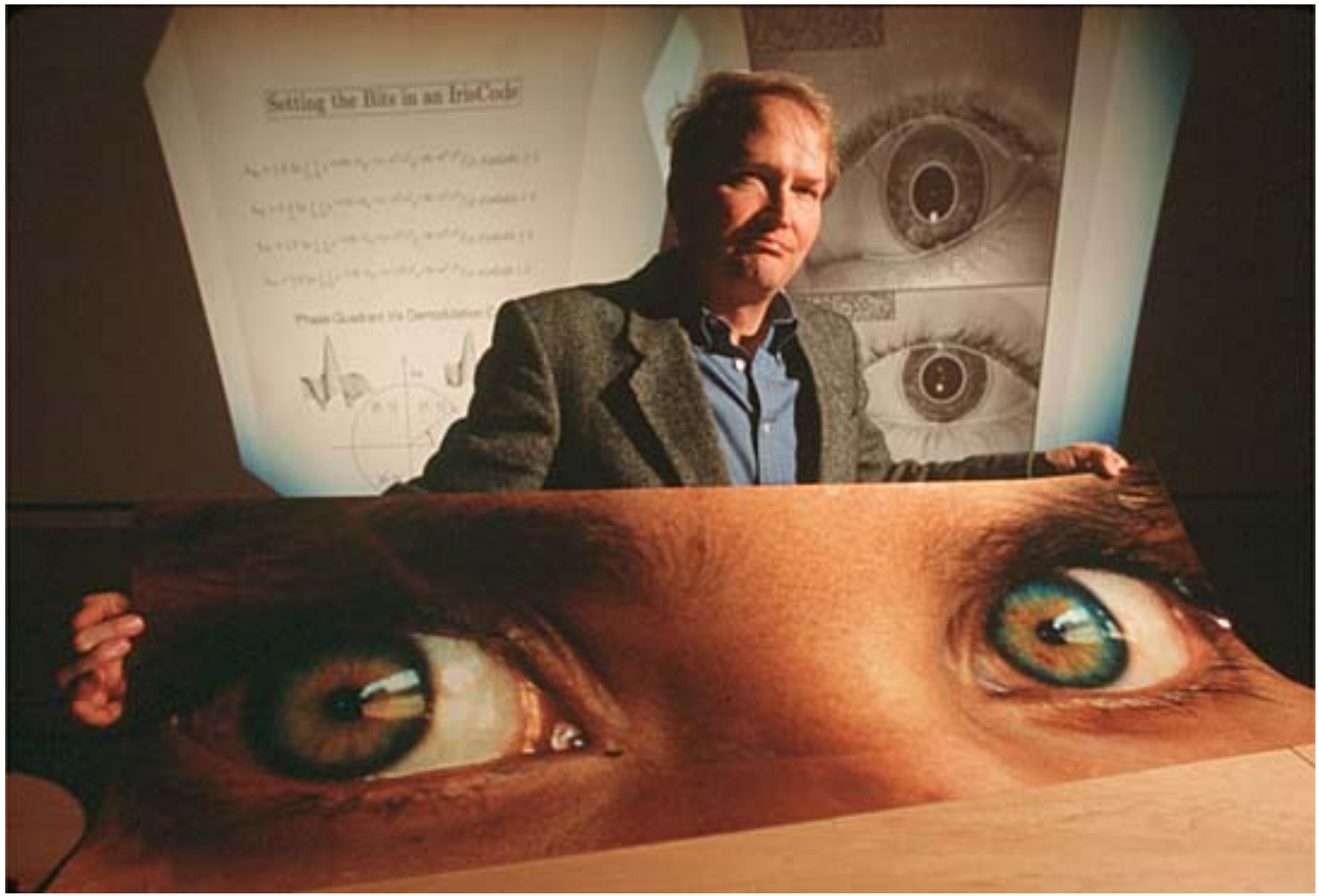


>...et de celui de 2002 (en bas) pour calculer l'IrisCode des deux yeux de l'Afghane aux deux époques différentes. La comparaison de ces codes apporta la preuve qui manquait.



# John Daugman and the eyes of Sharbat Gula





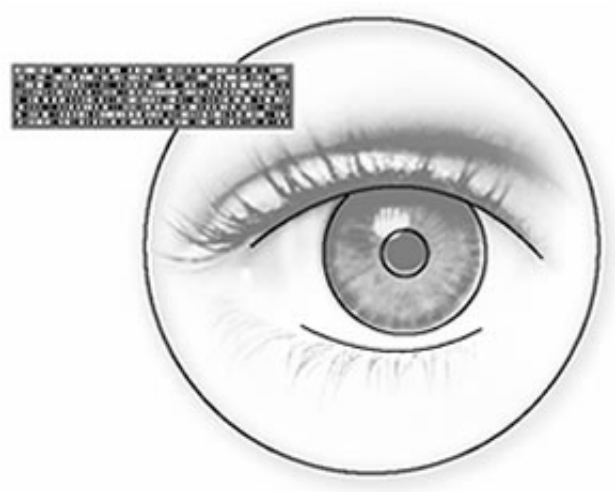

**Core Technology Patent:** *"Biometric Personal Identification System Based on Iris Analysis"*, U.S. Patent No. 5 291 560 issued March 1, 1994 (J. Daugman)

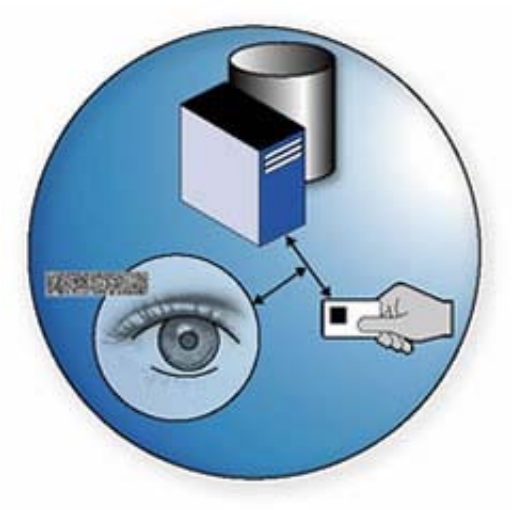
- Generalities
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# Iris Recognition











# Image Acquisition



- To capture the rich details of iris patterns, an imaging system should resolve a minimum of 70 pixels in iris radius (typical 100-140 pixels)
- Monochrome CCD cameras (480 x 640) have been used because near infrared (NIR) illumination in the 700nm – 900nm band was required for imaging to be invisible to humans. In NIR wavelength, even darkly pigmented irises reveal reach and complex features.
- Wide-angle camera is necessary for coarse localization of eyes in faces and to steer the optics of a narrow angle camera, which acquires higher resolution images of eyes.



# The iris recognition process (300 MHz)

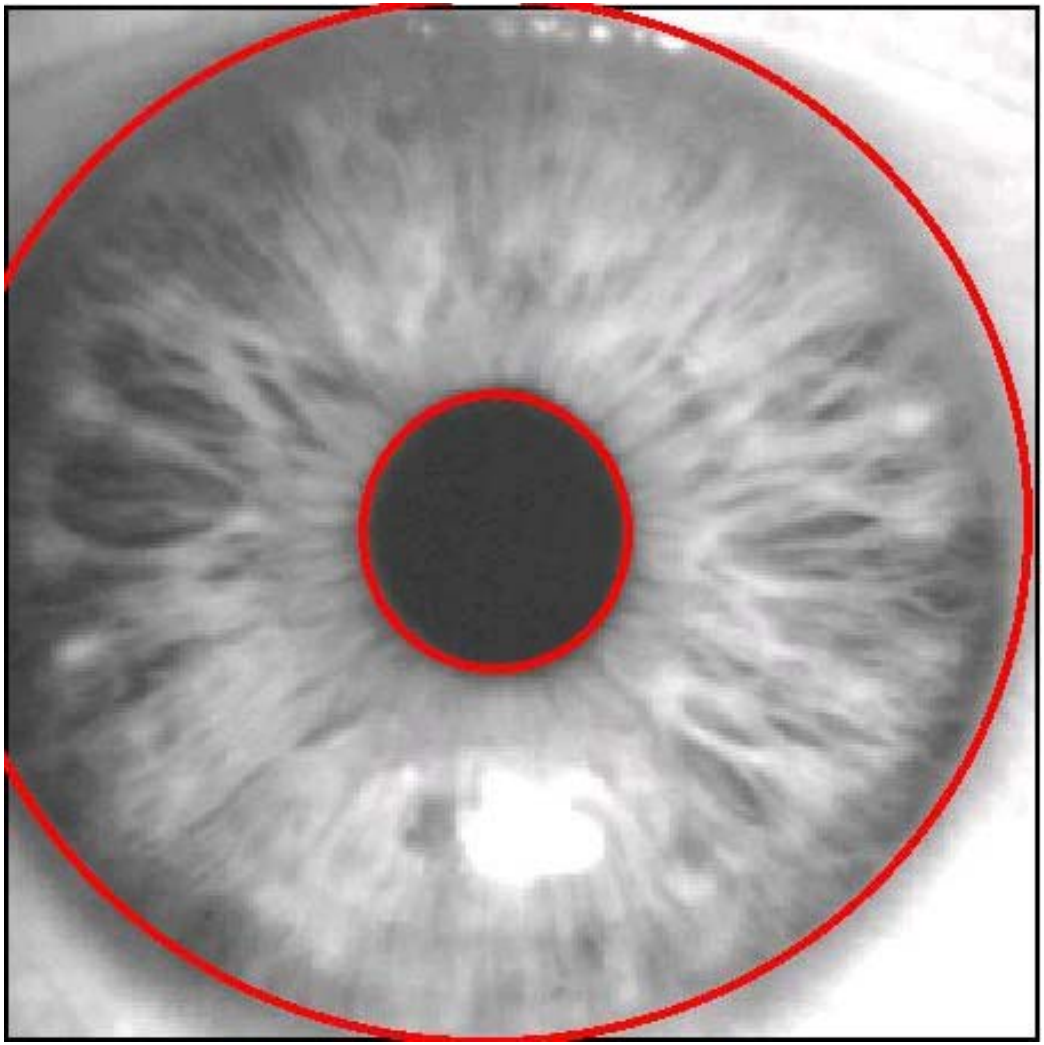





| Operation | Execution time |
|---|---|
| Assessing image focus | 15 ms |
| Scrubbing specular reflections | 56 ms |
| Localizing the eye and iris | 90 ms |
| Fitting the pupillary boundary | 12 ms |
| Detecting and fitting both the eyelids | 93 ms |
| Removing eyelashes and contact lens artifacts | 78 ms |
| Demodulation and IrisCode creation | 102 ms |
| XOR comparison of any two IrisCodes | 10 µs |

# Localizing Iris

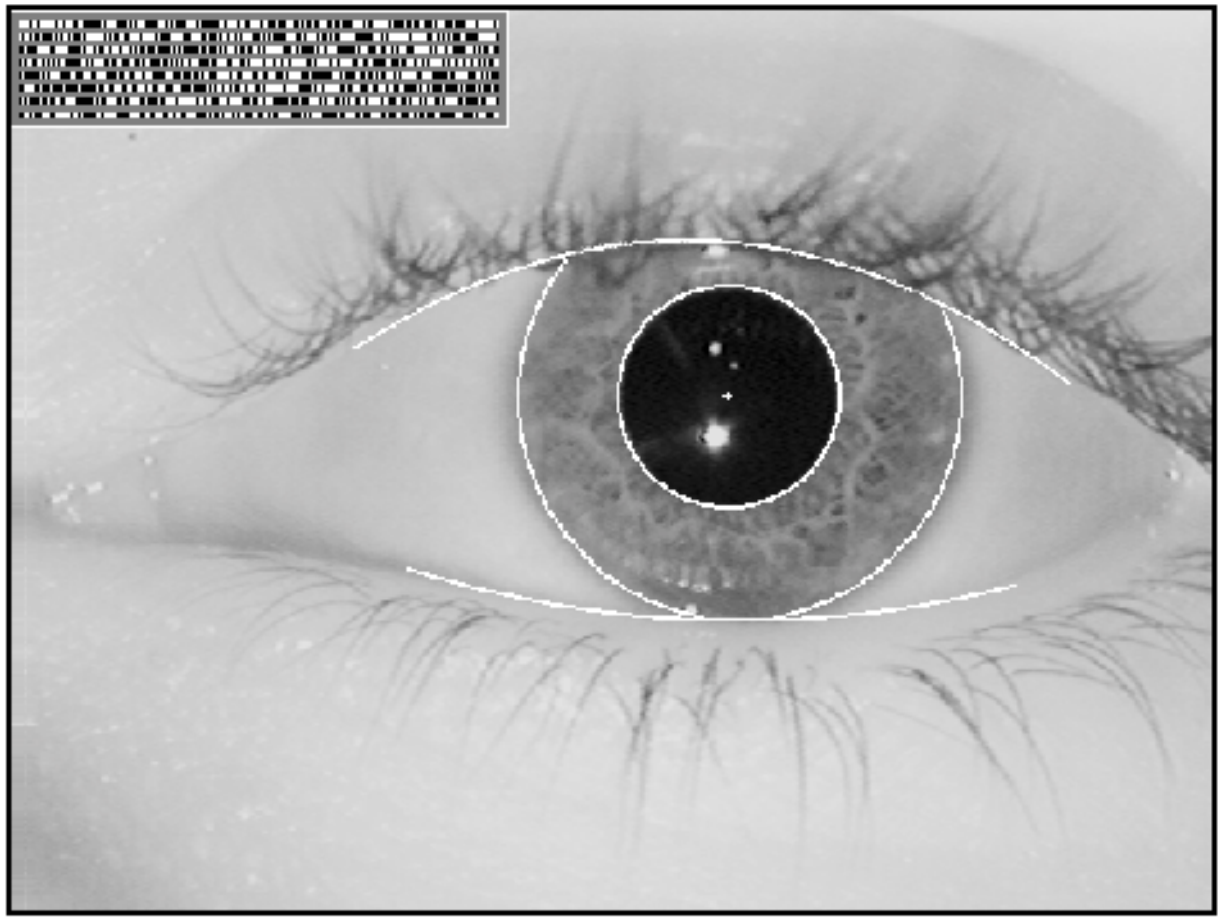




- First, it is necessary to localize precisely the inner and outer boundaries of the iris, and to detect and exclude eyelids if they intrude
- These detection operations are accomplished by an integro-differential operator, which behaves as a circular edge detector, blurred at a scale set by σ, that searches iteratively for a maximum contour integral derivative at successively finer scales through the three parameter space of center coordinates and radius $(x_0, y_0, r)$

# Localizing the iris boundaries by integro-differential operators





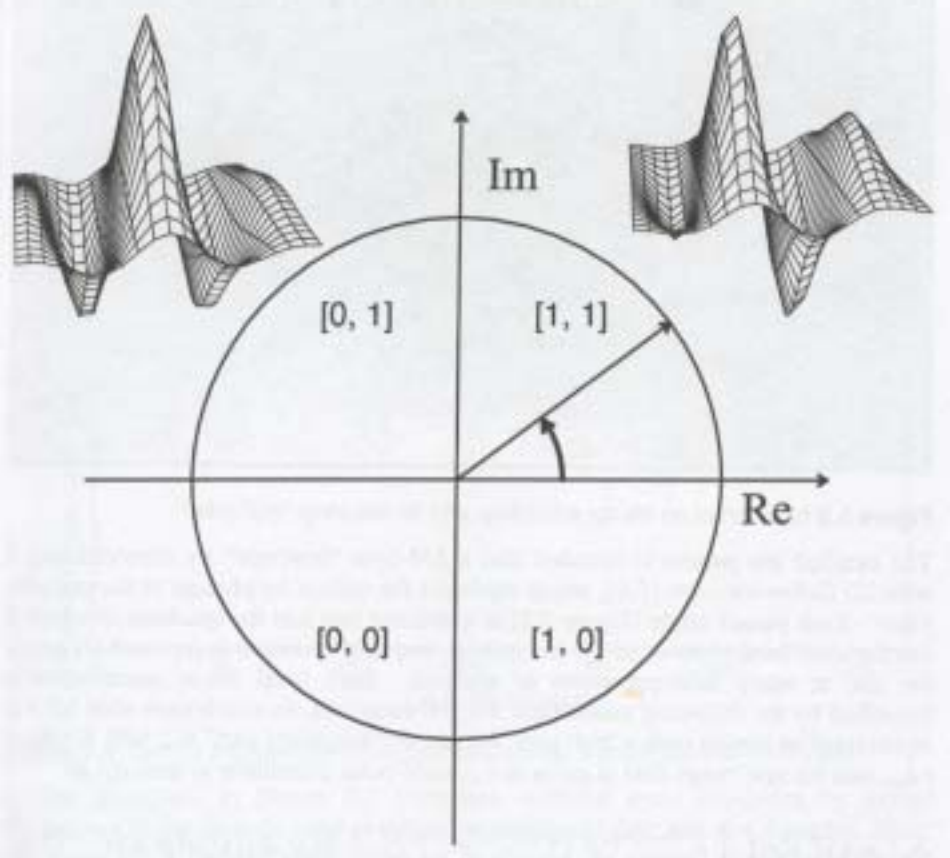
$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r,x_0,y_0} \frac{I(x,y)}{2\pi r} ds \right|$$

Localizing iris boundaries by differential operators

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# Iris Feature Encoding






- Doubly–dimensionless coordinate system is defined which maps the tissue in a manner that is invariant to changes in pupillary constriction and overall iris image size, and hence also invariant to camera zoom factor and distance to the eye
- The detailed iris pattern is encoded into a 256-byte « IrisCode » by demodulating it with 2D Gabor wavelets, which represent the texture by phasors in the complex plane
- Each phasor angle is quantized into just a quadrant in which it lies for each local element of the iris pattern at many different scales

# 2D Gabor wavelets



- ‘Phase Modulation’:

$$\phi(x,y) = \tan^{-1}\left(\frac{\mathrm{Im}\{\Psi(x,y) * I(x,y)\}}{\mathrm{Re}\{\Psi(x,y) * I(x,y)\}}\right)$$

- Complex-valued 2D Gabor Wavelet:

$$\Psi(x,y) = e^{-\pi[(x-x_0)^2/\alpha^2+(y-y_0)^2/\beta]} \cdot e^{-2\pi i[u_0(x-x_0)+v_0(y-y_0)]}$$

where:

$(x_0, y_0)$ - wavelet position

$(\alpha, \beta)$ - effective width and length

$(u_0, v_0)$ - modulation wave-vector

$\omega_0 = \sqrt{u_0^2 + v_0^2}$ - spatial frequency

$\theta_0 = \arctan(v_0 / u_0)$ - direction (orientation)

# Setting the Bits in an IrisCode

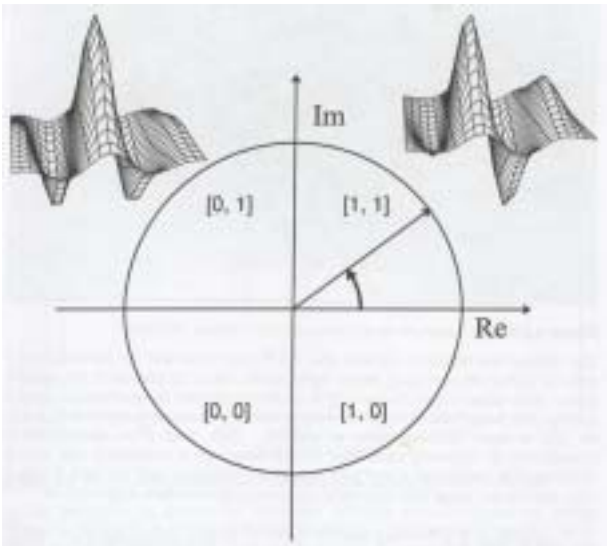


$$h_{Re} = 1 \text{ if } \mathrm{Re} \int_\rho \int_\phi e^{-i\omega(\theta_0-\phi)} e^{-(r_0-\rho)^2/\alpha^2} e^{-(\theta_0-\phi)^2/\beta^2} I(\rho,\phi)\rho d\rho d\phi \geq 0$$

$$h_{Re} = 0 \text{ if } \mathrm{Re} \int_\rho \int_\phi e^{-i\omega(\theta_0-\phi)} e^{-(r_0-\rho)^2/\alpha^2} e^{-(\theta_0-\phi)^2/\beta^2} I(\rho,\phi)\rho d\rho d\phi < 0$$

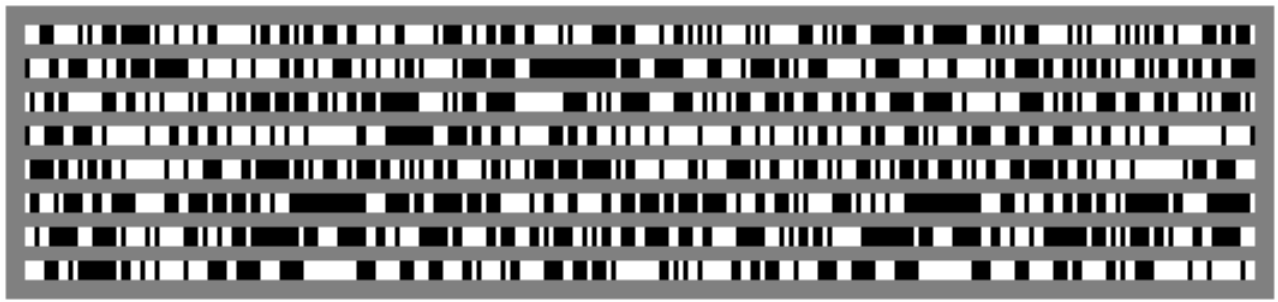
$$h_{Im} = 1 \text{ if } \mathrm{Im} \int_\rho \int_\phi e^{-i\omega(\theta_0-\phi)} e^{-(r_0-\rho)^2/\alpha^2} e^{-(\theta_0-\phi)^2/\beta^2} I(\rho,\phi)\rho d\rho d\phi \geq 0$$

$$h_{Im} = 0 \text{ if } \mathrm{Im} \int_\rho \int_\phi e^{-i\omega(\theta_0-\phi)} e^{-(r_0-\rho)^2/\alpha^2} e^{-(\theta_0-\phi)^2/\beta^2} I(\rho,\phi)\rho d\rho d\phi < 0$$



# IrisCode



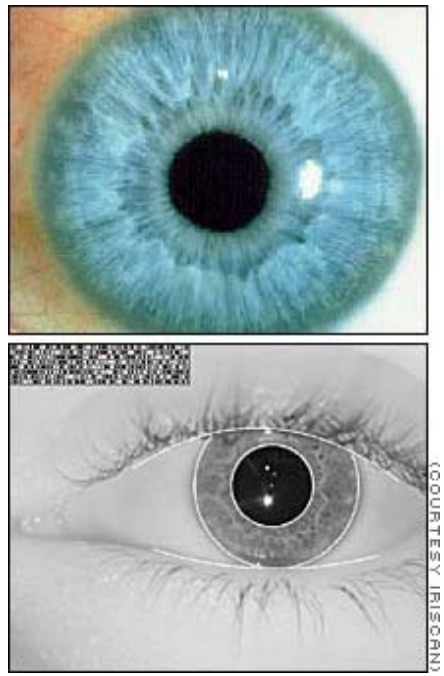


- Altogether 2’048 such phase bits (256 bytes) are computed for each iris.
- An equal number of masking bits are also computed to signify whether any region is obscured by eyelids, contains any eyelash occlusions, specular reflections, boundary artifacts or hard contact lenses, or poor signal-to-noise ratio and thus should be ignored in the demodulation code as artefact.

# Properties of the IrisCode

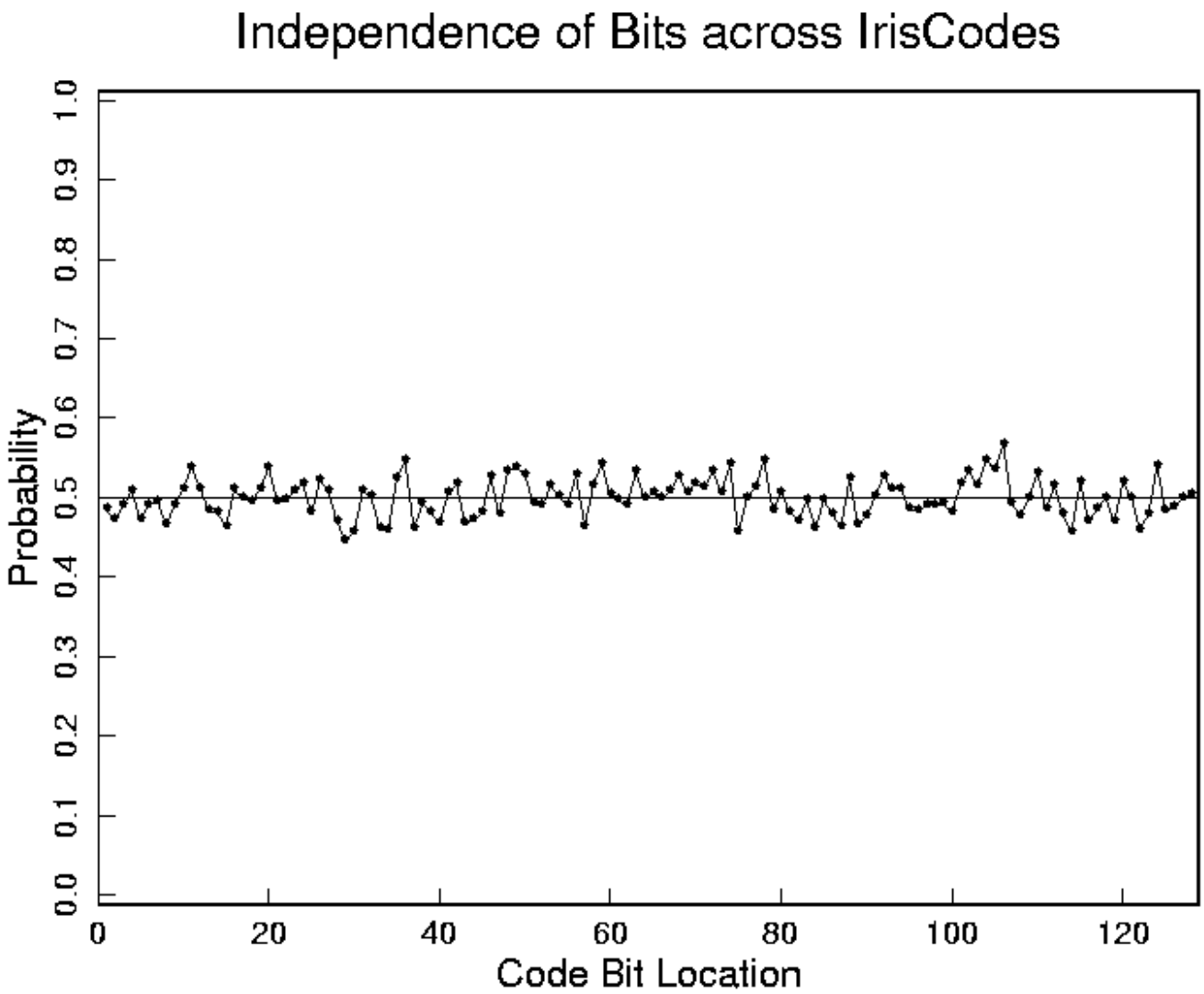


- The **iris coding** is performed in a doubly-dimensionless polar coordinate system that is invariant to the size of the iris (and hence invariant to the imaging distance and the optical magnification factor), and also invariant to the dilation diameter of the pupil within the iris
- The demodulating wavelets are parameterized with four degrees-of-freedom: size, orientation, and two positional coordinates. They span several octaves in size, in order to extract iris structure at many different scales of analysis
- Because the information extracted from the iris is inherently described in terms of phase, it is insensitive to contrast, camera gain, and illumination level (unlike correlation methods)
- The phase description is very compact, requiring only 256 bytes to represent each iris pattern, plus 256 control bytes that exclude artifacts such as eyelashes or reflections or data that is unstable or weak



# Independence of bits across IrisCodes





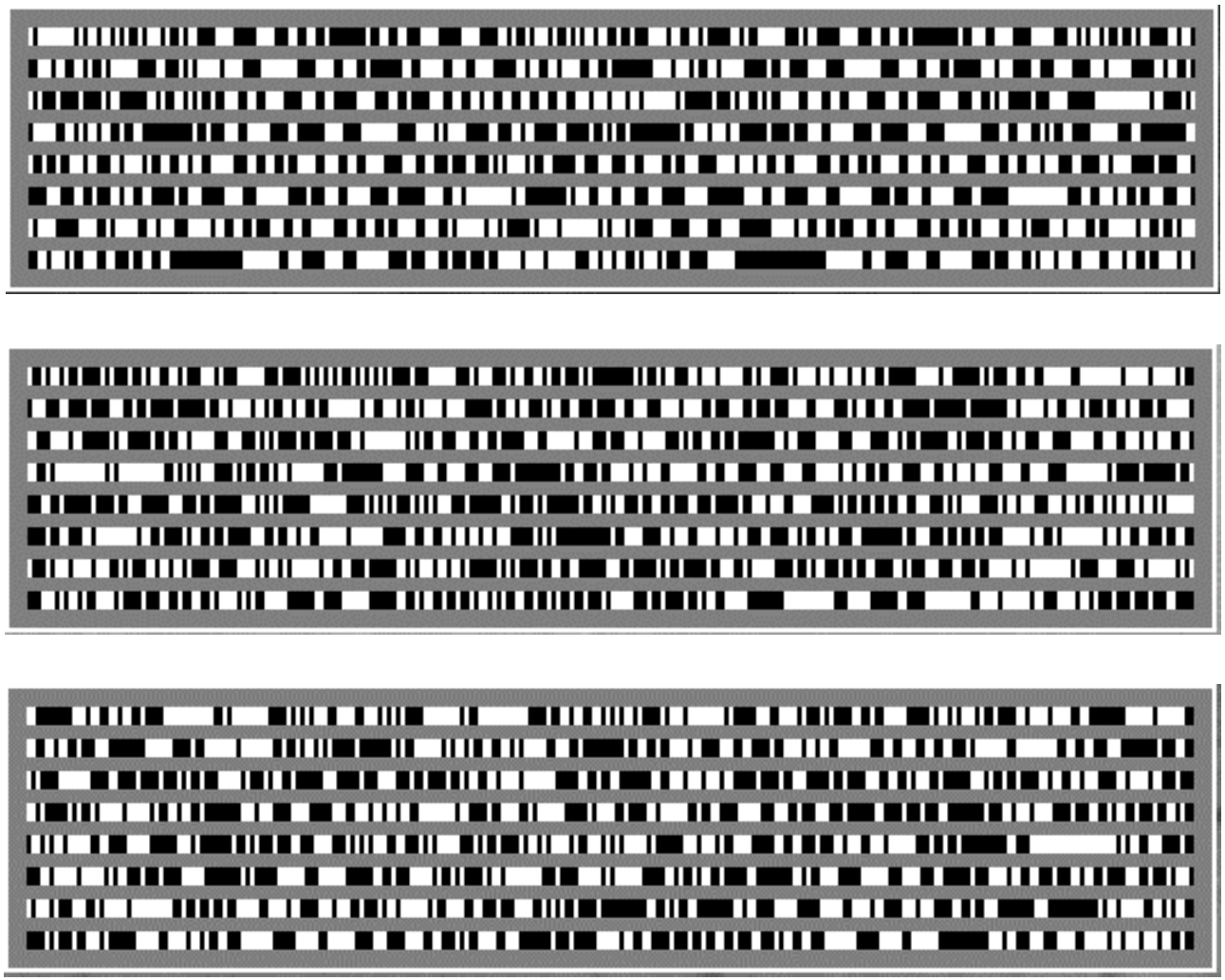
# Independence of bits across IrisCodes



- It is important to establish and to measure the amount of independent variation both within an iris and between different irises
- There are correlations within an iris because local structure is self-predicting; for example, furrows tend to propagate themselves radially. Such self correlations limit the number of degrees of freedom within irises.
- The flat probability distribution suggests that no systematic correlations exist between different irises
- The fact that this distribution hovers near 0.5 indicates that all IrisCode bits are equally likely to be 0 or 1
- This property makes IrisCodes "maximum entropy" codes in a bit-wise sense

# Examples of IrisCodes





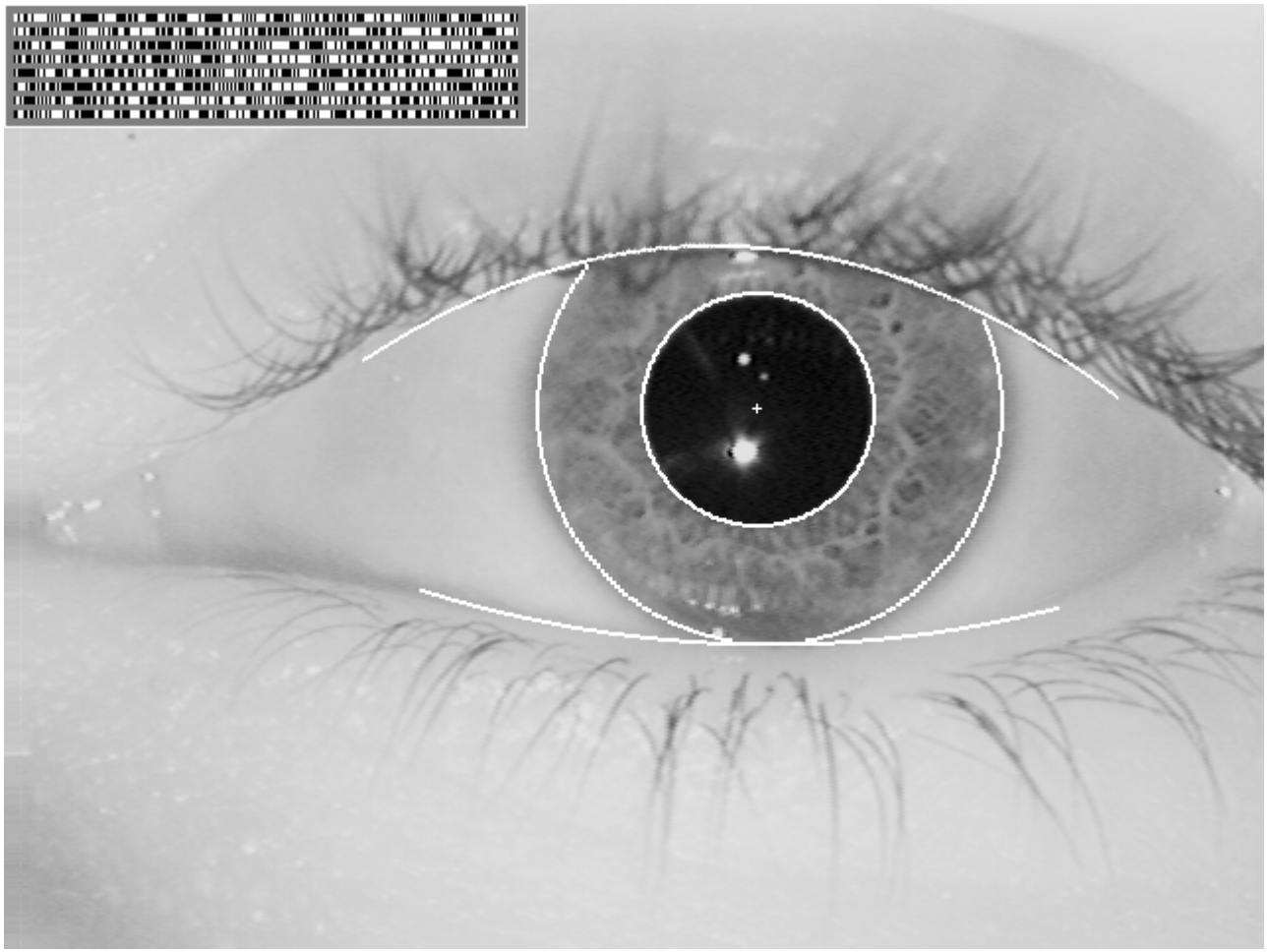
# Iris Recognition



- Generalities
- Iridology
- Properties of the iris
- Applications
- Iris sensing
- Iris features (IrisCode)
- **Iris matching**
- Performance evaluation
- Identification

# Comparison





- Different eyes' IrisCodes are compared by vector Exclusive-OR'ing them in order to detect the fraction of their bits that disagree.

# Hamming Distance



- Using a Boolean XOR similarity metric on the phasor bit strings generates similarity scores among different IrisCodes that are binomially-distributed and that therefore have tails that attenuate extremely rapidly
- The XOR operator detects disagreement between any corresponding pair of bits, while the AND operator ensures that the compared bits are both deemed to have been uncorrupted by eyelashes, eyelids, specular reflections, or other noise. **0 would represent a perfect match**
- The norms (|| ||) of the resultant XOR'ed phase bit vectors and of the AND'ed mask vectors are then measured in order to compute a fractional Hamming Distance (HD) as the measure of the dissimilarity between any two irises, whose two phase code bit vectors are denoted {*codeA, codeB*} and whose mask bit vectors are denoted {*maskA, maskB*}:

$$\text{Hamming Distance} = \frac{\left\| (\text{code A} \otimes \text{code B}) \cap \text{mask A} \cap \text{mask B} \right\|}{\left\| \text{mask A} \cap \text{mask B} \right\|}$$

# Hamming Distance



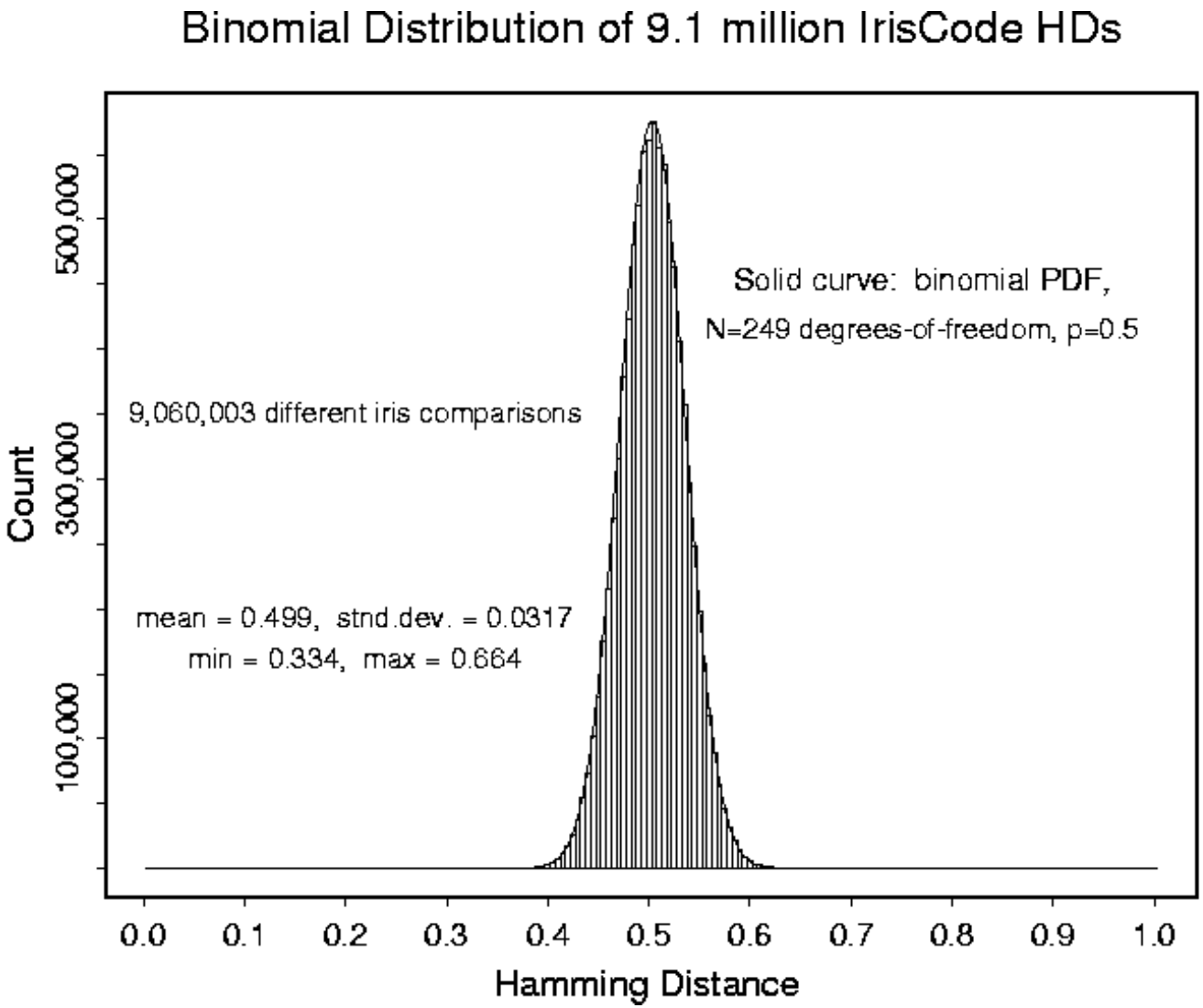
- The Boolean operators XOR and AND are applied in vector form to binary strings of length up to the word length of the CPU, as a single machine instruction. Thus for example on an ordinary 32-bit machine, any two integers between 0 and 4 billion can be XOR'ed in a single machine instruction to generate a third such integer, each of whose bits in a binary expansion is the XOR of the corresponding pair of bits of the original two integers

- This implementation of the Hamming Distance computation in parallel 32-bit chunks enables extremely rapid comparisons of IrisCodes when searching through a large database to find a match

- On a single 300 MHz CPU, such exhaustive searches are performed at a rate of about 100,000 irises per second. On a single 3 GHz server, one million IrisCodes can be compared in about 1 second

# Distribution of Hamming Distances among Unrelated IrisCodes





# Distribution of Hamming Distances among Unrelated IrisCodes



- For each pair comparison, the percentage of their IrisCode bits that disagreed was computed and tallied as a fraction
- Because of the zero-mean property of the wavelet demodulators one would expect on average 50% of the bits between two different IrisCodes to agree by chance. The mean is 0.499.
- The standard deviation of this distribution, 0.0317, reveals the effective number of independent bits (binary degrees of freedom) when IrisCodes are compared
- For IrisCodes, the distribution corresponds to that for the fraction of "heads" that one would get in runs of 249 tosses of a fair coin. This is a binomial distribution with 249 degrees of freedom, with parameters p=q=0.5 and N=249 Bernoulli trials (coin tosses). The solid curve in the above histogram is a plot of such a binomial probability distribution
- This property makes it extremely improbable that two different IrisCodes might happen to agree just by chance in, say, more than 2/3rds of their bits (making a Hamming Distance below 0.33 in the above plot).

# Why False Match Probability does not Accumulate in Large Database Searches



- Because the binomial tail of the distribution generated when different irises are compared attenuates so rapidly, very small adjustments in the decision threshold allow truly huge databases to be searched without suffering False Matches
- The rate of attenuation is such that each reduction in the decision threshold by 1 percentage point in Hamming Distance (-0.01) causes a nearly 10-fold further reduction in False Match probability
- Since very small reductions in the decision threshold have such dramatic effects on the False Match probability, it is possible to accommodate extremely large search databases -- even the sizes of national populations -- by making just modest reductions in the Hamming Distance decision criterion. This is the reason why the United Arab Emirates deployment can perform 3 Billion iris comparisons every day without getting False Matches

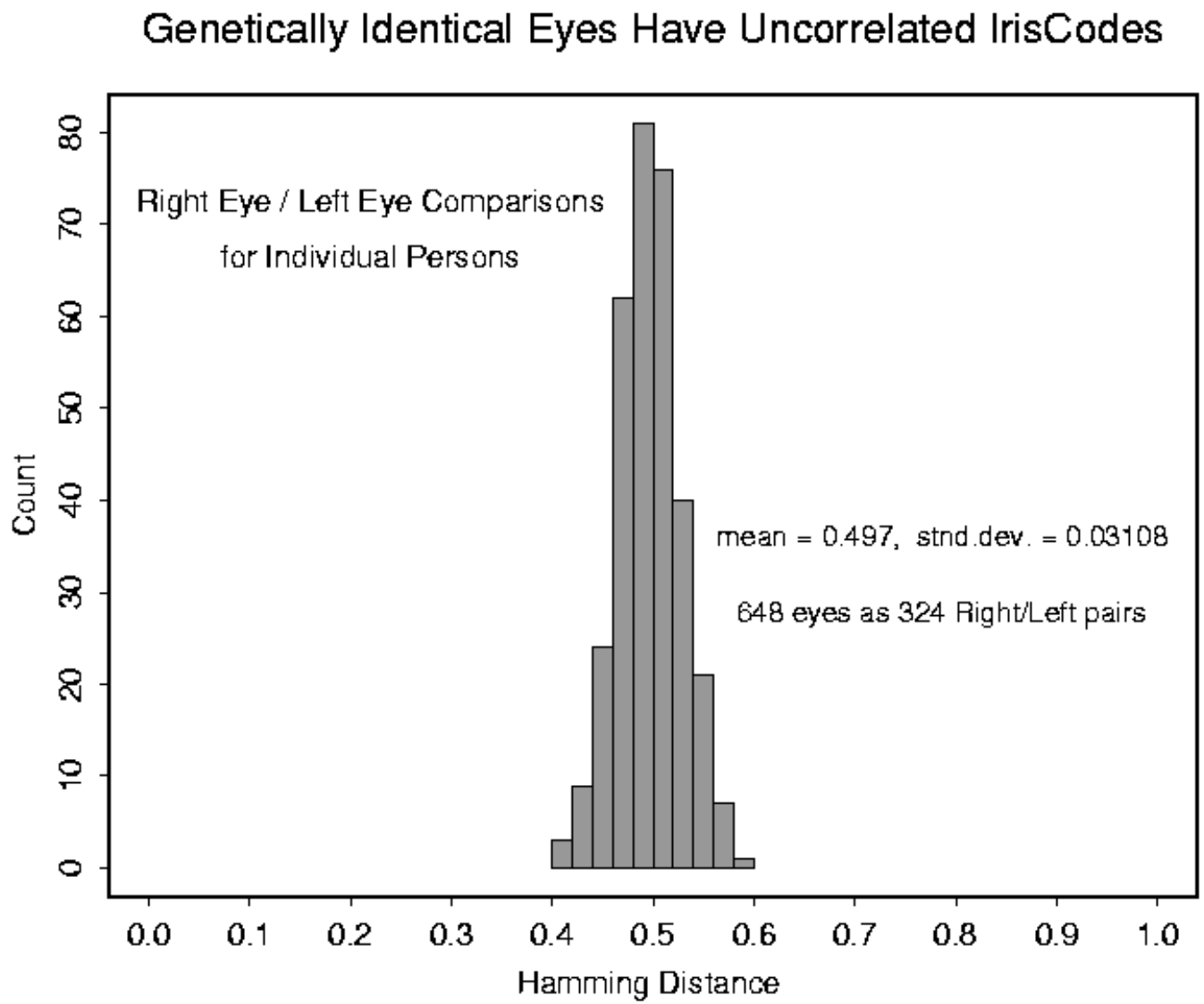
# Why False Match Probability does not Accumulate in Large Database Searches



| Decision Threshold | Odds of False Match |
|---|---|
| 0.33 | 1 in 4 million |
| 0.32 | 1 in 26 million |
| 0.31 | 1 in 185 million |
| 0.30 | 1 in 1.5 billion |
| 0.29 | 1 in 13 billion |

# Comparisons Between Genetically Identical Iris Patterns





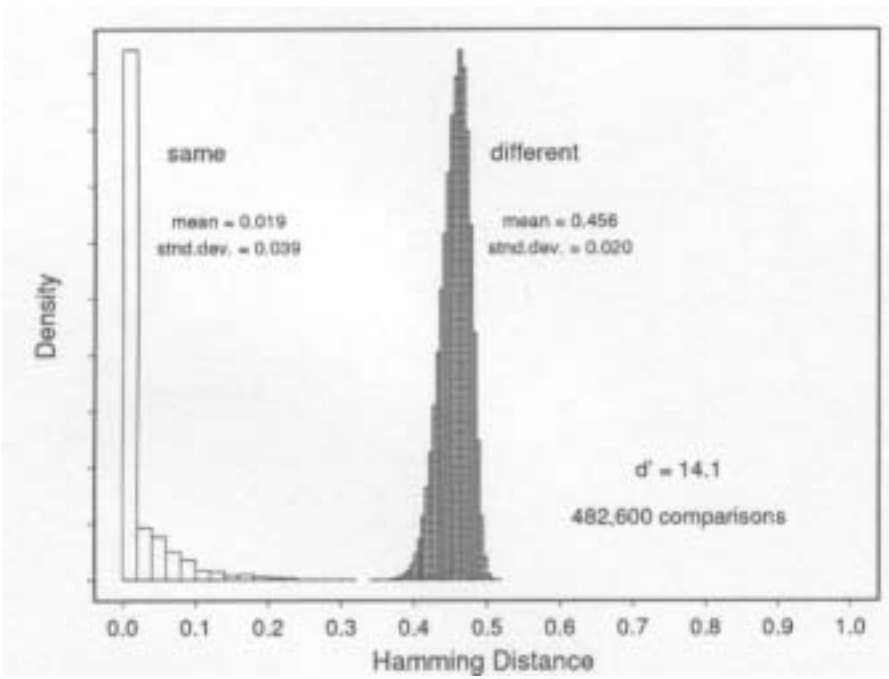
# Comparisons Between Genetically Identical Iris Patterns

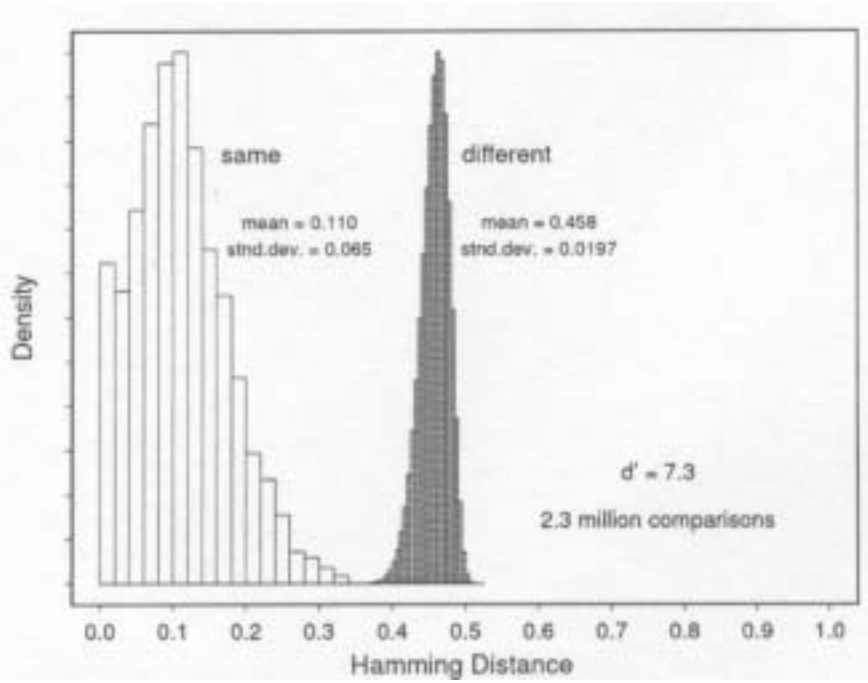


- A convenient source of genetically identical irises are the right and left pair from any given person
- Such pairs have the same genetic relationship as the four irises of two identical twins, or indeed in the probable future, the 2N irises of N human clones
- Eye colour of course has high genetic penetrance, as does the overall statistical quality of the iris texture, but the textural details are uncorrelated and independent even in genetically identical pairs
- The mean Hamming Distance between genetically identical irises is 0.497 with standard deviation 0.031, which is statistically indistinguishable from comparisons between 9.1 million pairings of genetically unrelated irises
- This shows that the detailed phase structure extracted from irises by the phasor demodulation process is purely epigenetic, so performance is not limited (as it is for face recognition, DNA, and some other biometrics) by the birth rate of identical twins or by the existence of partial genetic relationships.

# Statistical Recognition Principle





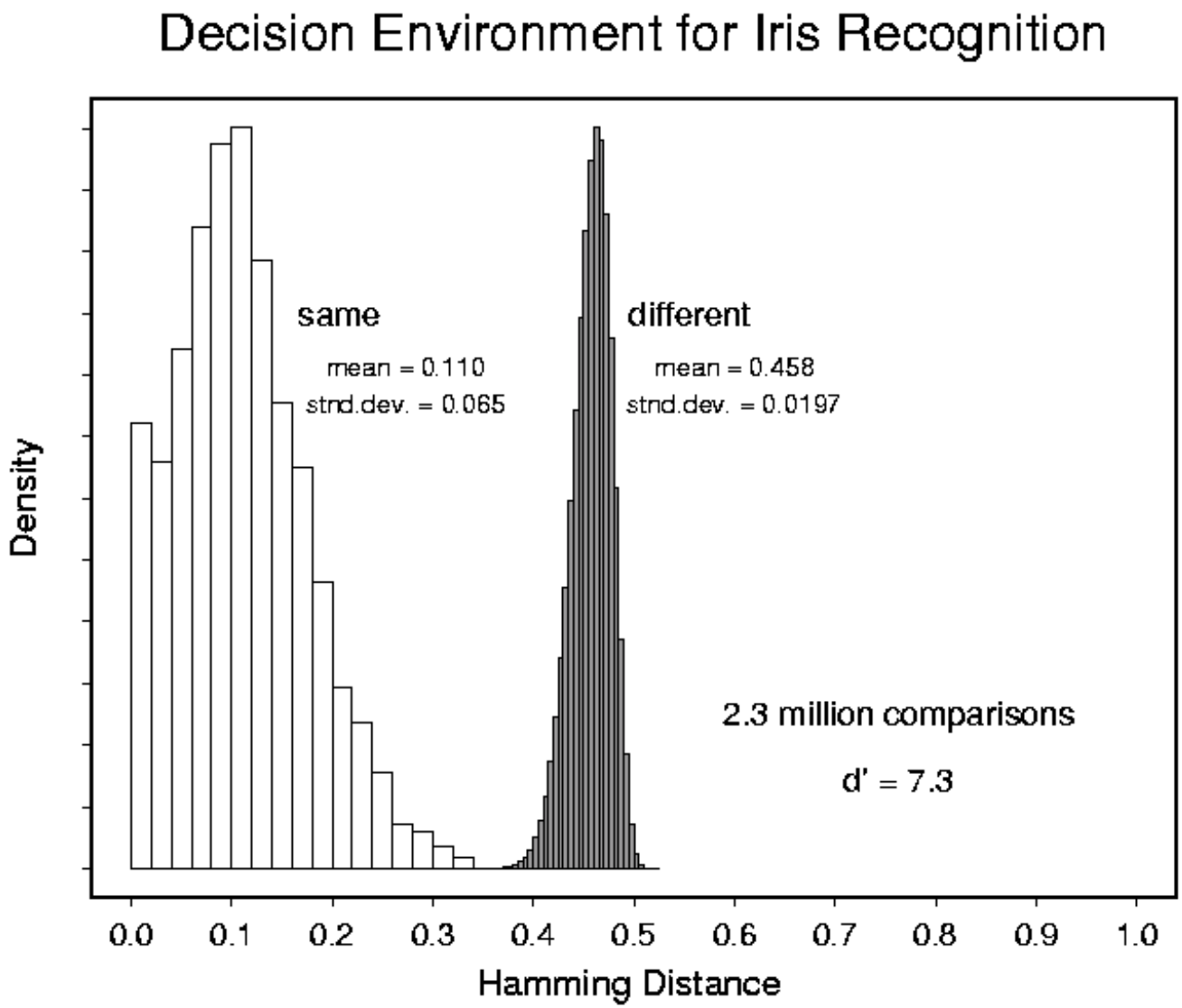

Ideal imaging

Non-ideal imaging

The overall « decidability » of the task of recognizing persons by their iris patterns is revealed by comparing the Hamming Distance distributions for same versus different irises.

# Decision Environment





# Decision Environment



- In the particular case of iris recognition, the similarity measure is a Hamming Distance: the fraction of bits in two IrisCodes that disagree
- The distribution on the left in the graph shows the results when different images of the same eye are compared; typically about 10% of the bits may differ
- But when IrisCodes from different eyes are compared, with rotations to look for and retain the best match (lowest HD), the distribution on the right is the result: the fraction of disagreeing bits is very tightly packed around 45%
- Because of the narrowness of this right-hand distribution, it is possible to make identification decisions with astronomic levels of confidence.
- For example, the odds of two different irises agreeing just by chance in more than 75% of their IrisCode bits (i.e. having a Hamming Distance of 0.25 or lower) is only one in 10-to-the-14th power
- These extremely low probabilities of getting a False Match enable the iris recognition algorithms to search through extremely large databases, even of a national or planetary (10-to-the-10th) scale, without confusing one IrisCode for another despite so many error opportunities

# Effect of the 'Amount of Iris Visible'



- If eyelids occlude much of the iris, fewer IrisCode bits are available for comparison with other IrisCodes
- Decision criterion then becomes correspondigly more demanding
- Renormalization is based on equal-confidence contours for binomial combinatorics, whatever the number of bits compared
  - Adaptation of decision criterion by database search size N, to avoid accumulation of probability of a False Match

$$HD_{crit} = 0.32 - 0.01 \cdot \log_{10}(N)$$

  - Renormalization of raw Hamming Distance $HD_{raw}$ by the number of IrisCode bits n actually compared

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

# Effect of the 'Amount of Iris Visible'



All of the matches in this table are equivalently decisive:

| *number of bits compared* | *approximate percent of iris visible* | *maximum acceptable fraction of bits disagreeing* |
|---|---|---|
| 200 | 17% | 0.14 |
| 300 | 26% | 0.20 |
| 400 | 35% | 0.24 |
| 500 | 43% | 0.27 |
| 600 | 52% | 0.29 |
| 700 | 61% | 0.31 |
| 800 | 69% | 0.32 |
| 911 | 79% | 0.33 |
| 1000 | 87% | 0.34 |
| 1152 | 100% | 0.35 |

*Notes: two critical points are included in this Table. Fewer than 911 bits compared penalize Hamming Distance, whereas more than 911 bits improve it. The comparison of as many as 1152 bits between two IrisCodes normally corresponds to 100% visibility of each iris.*

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# Permutation of Bytes to Defeat Replay Attacks



- ‘You can’t get a new iris; what if a hacker steals a copy of your IrisCodes?’
- IrisCode matching algorithm is indifferent to byte order
- $256!=10^{507}$ possible permutations of IrisCode bytes
- Intractable permutation space: stolen IrisCodes become useless
- Can make a new IrisCode permutation every day (or minute)
- Application-specific IrisCode templates
- Device-specific, session-specific IrisCode templates
- Permutation keys may be generated by a trusted server
- Still need to test the ‘liveness’ of a presenting iris

# Iris Recognition



- Strengths
  - It has the potential for exceptionally high levels of accuracy
  - It is capable of reliable identification as well as verification
  - It maintains stability of characteristic over a lifetime
- Weaknesses
  - Acquisition of the image requires moderate training and attentiveness
  - It has a propensity for false rejection
  - A proprietary acquisition device is necessary for deployment
  - There is some user discomfort with eye-based technology

# Advantages



- Iris is currently claimed and perhaps widely believed to be the most accurate biometric, especially when it comes to FA rates. Iris has very few False Accepts (the important security aspect). Therefore iris might be a good biometric for pure identification applications
- Given that the iris sample acquisition process is solved using unobtrusive and distant cameras, the sensing of the biometric is without physical contact and without too much inconvenience
- Iris has received little negative press and may therefore be more readily accepted. The fact that there is no criminal association helps
- The dominant commercial vendors claim that iris does not involve high training costs.

# Disadvantages



- There are few legacy databases. Though iris may be a good biometric for identification, large-scale deployment is impeded by lack of installed base.
- Since the iris is small, sampling the iris pattern requires much user cooperation or complex, expensive input devices
- The performance of iris authentication may be impaired by glasses, sunglasses, and contact lenses; subjects may have to remove them
- The iris biometric, in general, is not left as evidence on the scene of crime; no trace left
- Some people are missing one or both eyes, while others do not have the motor control necessary to reliably enroll in such a system