# Identification Systems
Lecture 13

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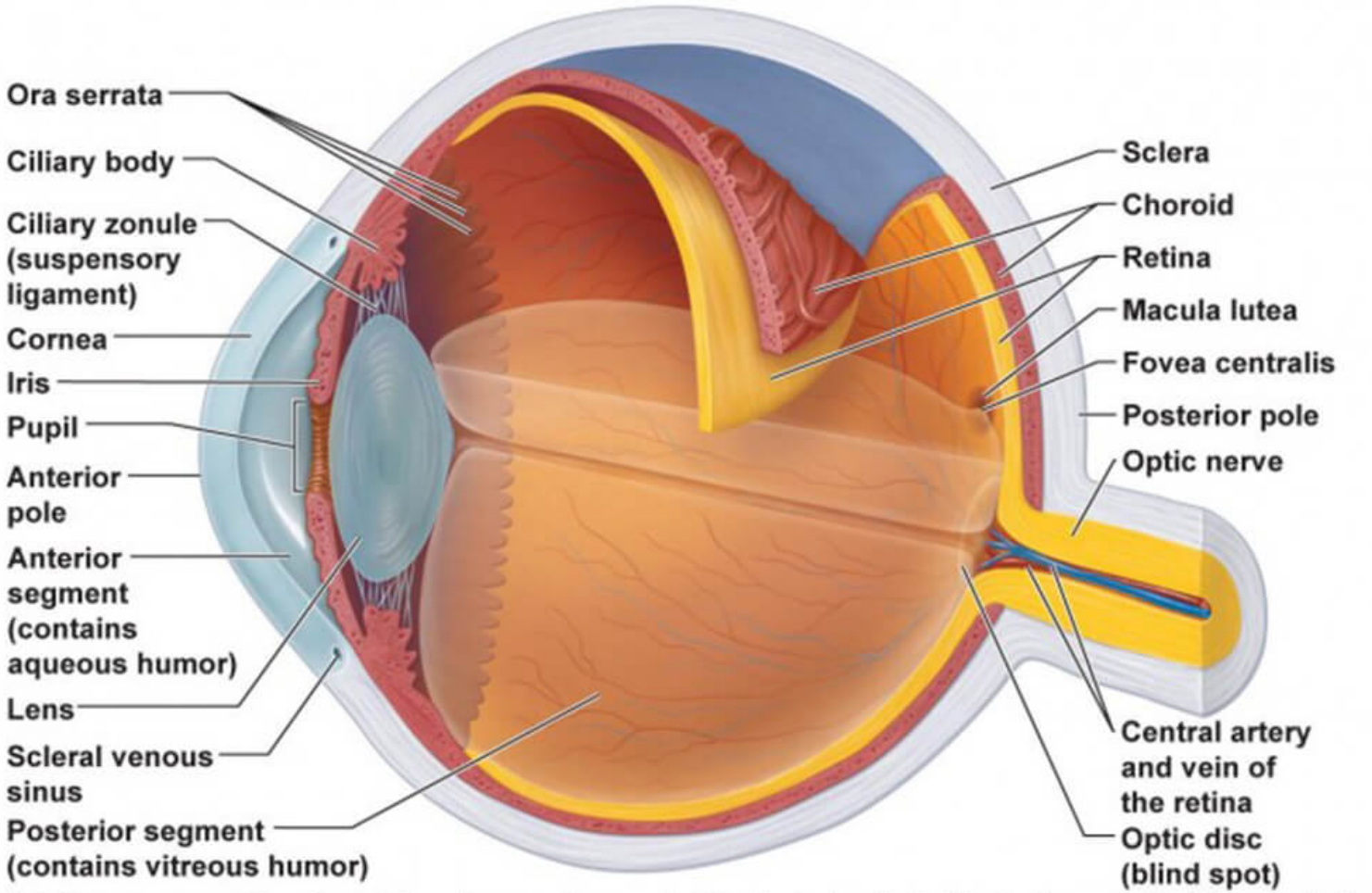
# Structure of the eye




**(a) Diagrammatic view.** The vitreous humor is illustrated only in the bottom part of the eyeball.

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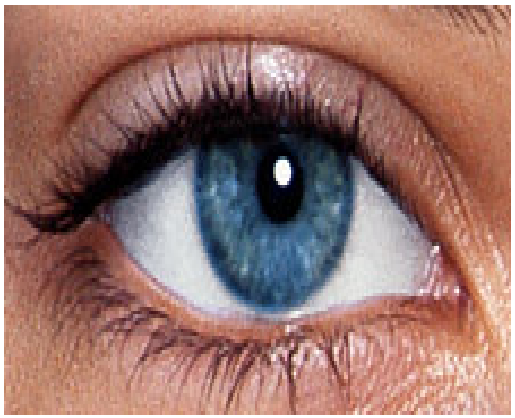
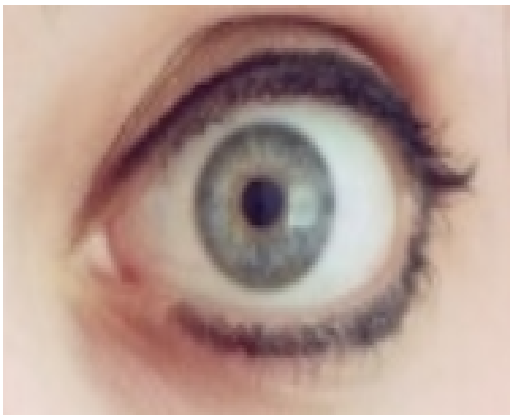
# Various eye photos

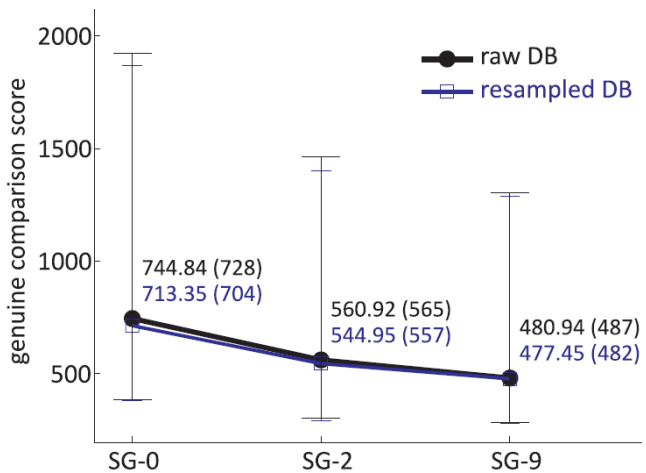



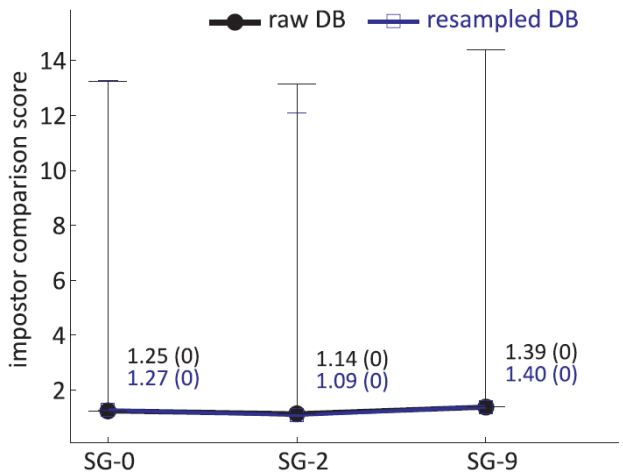

# Motivation and history

- Eye may be source of strong and weak biometric modalities.
- The methods of recognition range from requiring full, time-consuming user cooperation to measuring an unaware user.
- Iris forms between 2nd and 8th month of gestation and retains most of its features with age.
- Retina forms during gestation and is highly stable throughout the aging process.
- Aside from color, iris features are epigenic, hence even monozygotic twins differ.
- Retina posses high number of unique data points, creating identification vector with collision percentage similar to DNA and fingerprinting.
- Slow degradation of the features with age does not prevent from proper identification.
- Iris-based recognition may be used also postmortem.

# Motivation and history

A. Czajka, *Influence of Iris Template Aging on Recognition Reliability*



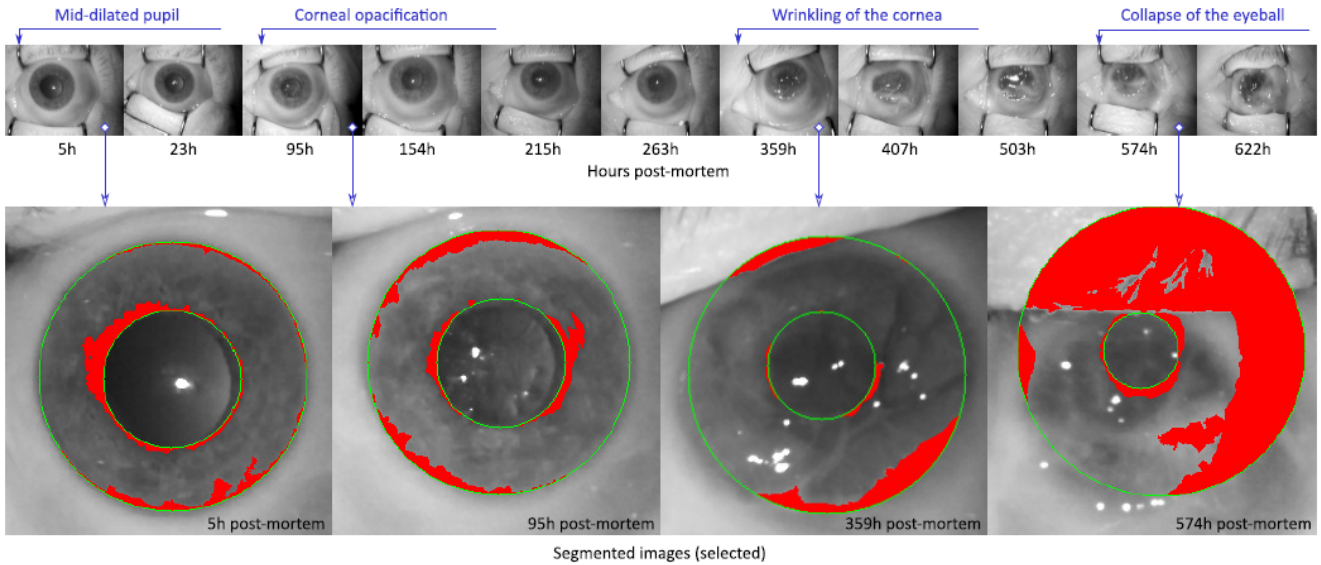
# Motivation and history

A. Czajka, *Influence of Iris Template Aging on Recognition Reliability*

| | Score group → Coding method ↓ | Same session (SG-0) | ≤ 2 years (SG-2) | From 5 to 9 years (SG-9) |
|---|---|---|---|---|
| $\|\|\xi_g\|\|$ | NT, ZG &OS for each DB | 2468 | 1588 | 2432 |
| | ML for raw DB | 2292 | 1548 | 2108 |
| | ML for re-sampled DB | 2394 | 1588 | 2346 |
| $\|\|\xi_i\|\|$ | NT, ZG &OS for each DB | 7988 | 10 186 | 33 480 |
| | ML for raw DB | 7188 | 9362 | 27 964 |
| | ML for re-sampled DB | 7690 | 9646 | 31 826 |

# Motivation and history

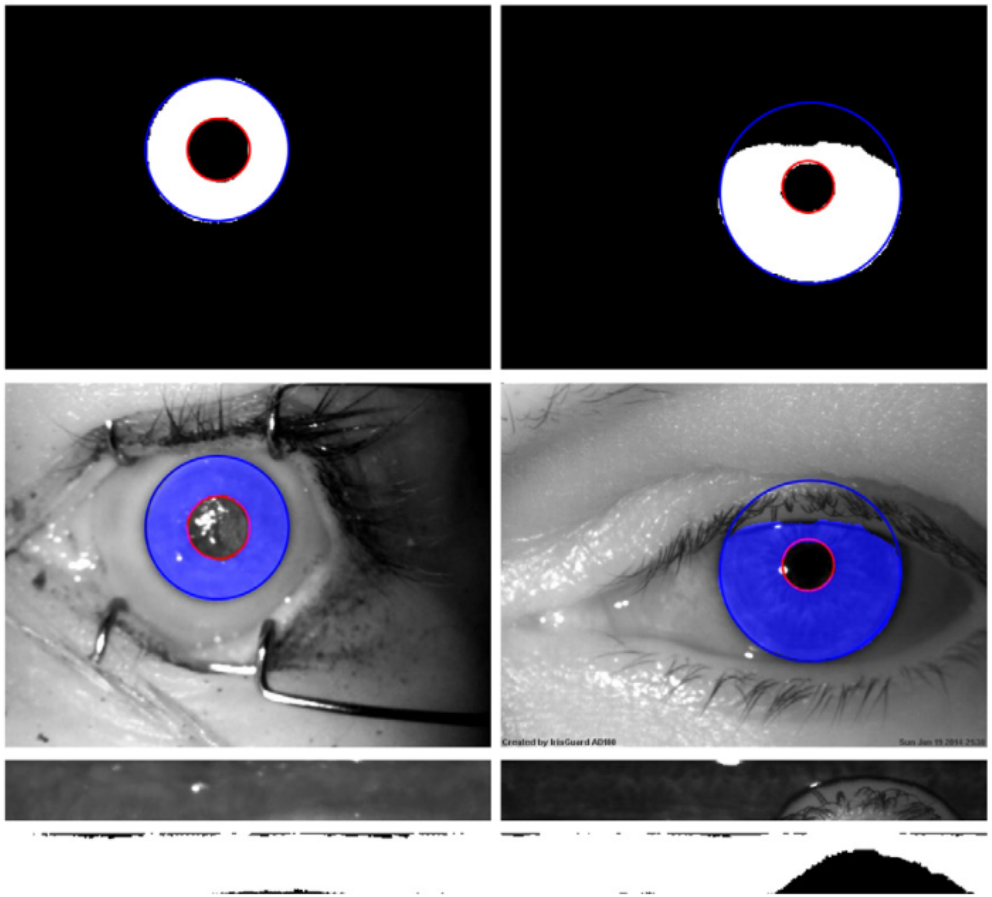
A. Czajka, *Post-mortem iris recognition*



Segmented images (selected)

# Motivation and history

M. Trokielewicz et al., *Post-mortem iris recognition with deep-learning-based image segmentation*



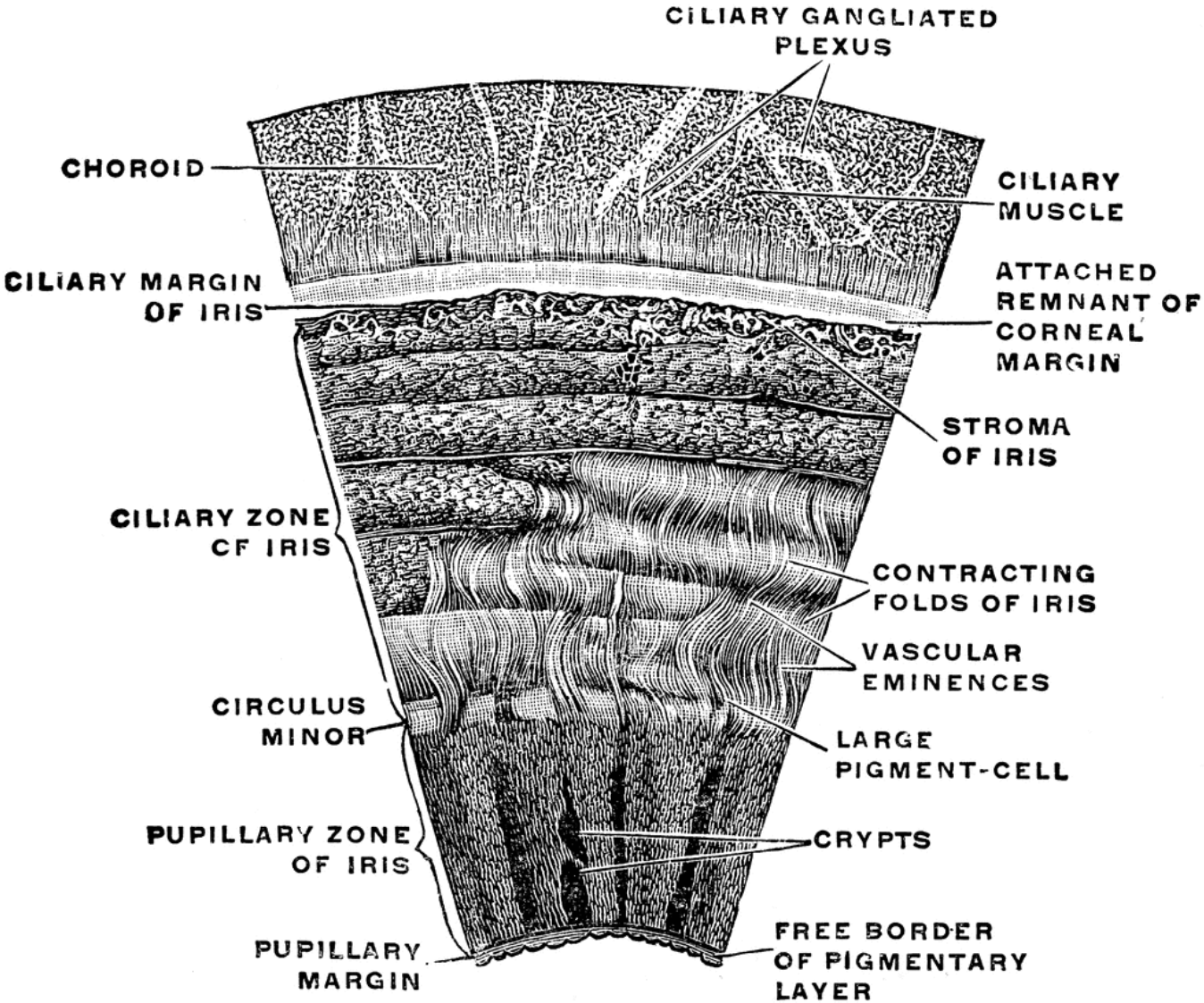
# Motivation and history

M. Trokielewicz et al., *Post-mortem iris recognition with deep-learning-based image segmentation* Relation of iris recognition EER and time passed:

| **Data subset** | **original OSIRIS** [%] | **IriCore** [%] | **proposed** [%] | number of comparisons |
|---|---|---|---|---|
| $\leq$ 10h postmortem | 16.89 | 5.37 | **0.96** | 46 360 |
| $\leq$ 24h postmortem | 18.73 | 6.31 | **1.36** | 61 425 |
| $\leq$ 48h postmortem | 20.34 | 8.00 | **3.38** | 88 831 |
| $\leq$ 60h postmortem | 23.69 | 10.46 | **7.18** | 178 503 |
| $\leq$ 110h postmortem | 24.72 | 14.36 | **10.36** | 296 065 |
| $\leq$ 160h postmortem | 28.68 | 17.79 | **15.02** | 405 450 |
| $\leq$ 210h postmortem | 29.94 | 20.77 | **17.60** | 476 776 |
| $\leq$ 369h postmortem | 33.59 | 25.38 | **21.95** | 597 871 |
| disease data | 8.90 | 3.97 | **2.55** | 152 076 |

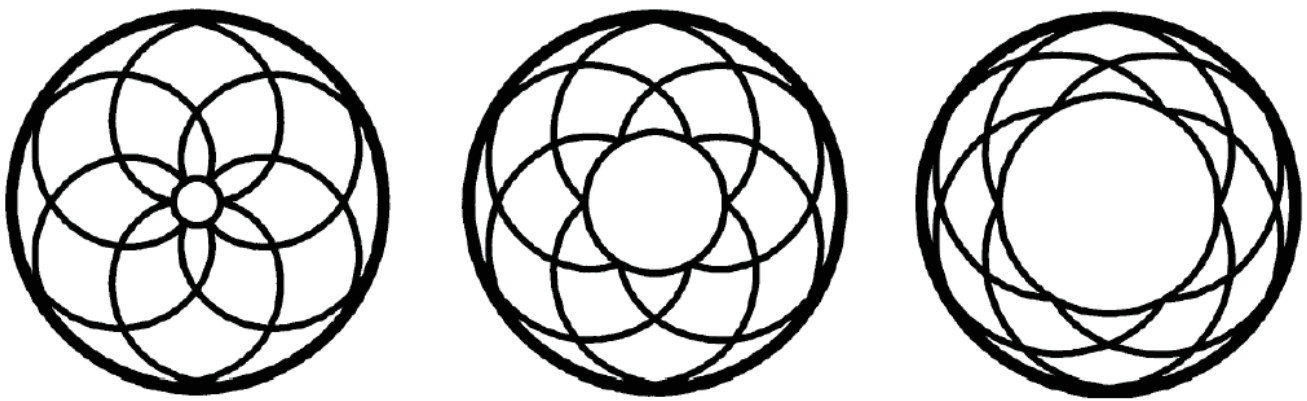
# Iris identification

## Iris structure:



# Iris identification

**Iris constriction patterns** H.J. Wyatt, *A minimum-wear-and-tear meshwork for the iris*



# Iris identification

- A. Safir, L. Flom (1987) register US patent for iris-based identification.
- J. Daugman – 2D Gabor filtering for iris coding and prototype of a working recognition system (1992)
  the iris code generation method receives a patent (1994), the iris recognition method achieves high accuracy leading to further interest.
- IriScan 2100 becomes commercially available (1996).
- Safir and Flom's patent expired in 2005.
- First smartphones with eye recognition appear in late 2014, replacing or complementing fingerprint scanner.
- Since 2016 every 'flagship' smartphone includes iris-scan recognition.

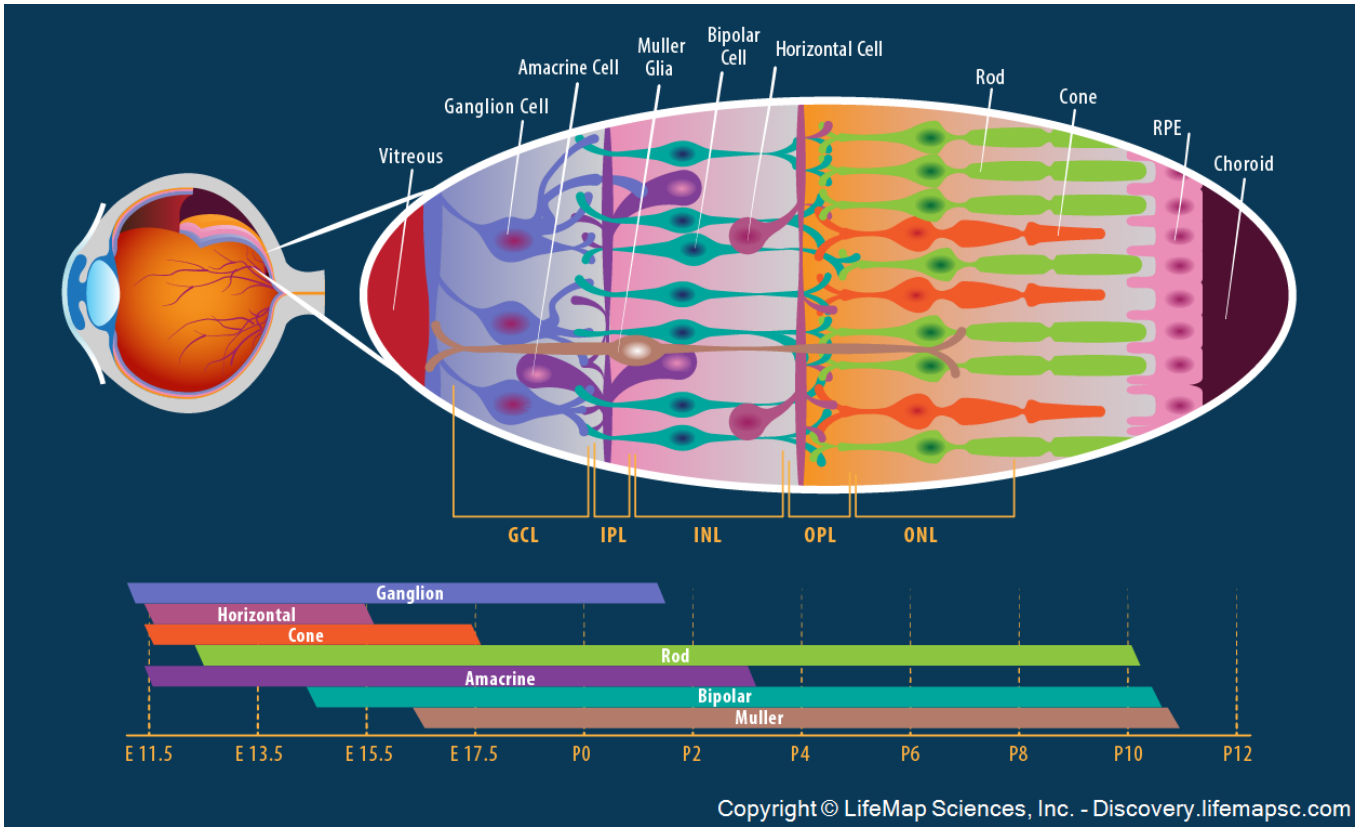
# Iris identification

**Issues:**

- Problem with exposure and depth of field.
- User cooperation and distance to the sensor.
- Image quality, occlusions (e.g., eyelids, eyelashes) and diseases (e.g., Waardenburg syndrome) may reduce the number of features.
- Reflections, iris constriction and dilation, surface warping, nonlinear deformations or off-the-point gaze.
- Different wavelengths of illuminating light or number and location of illuminants.

# Retina identification

## Retina structure:



# Retina identification

**Retina vein pattern:**

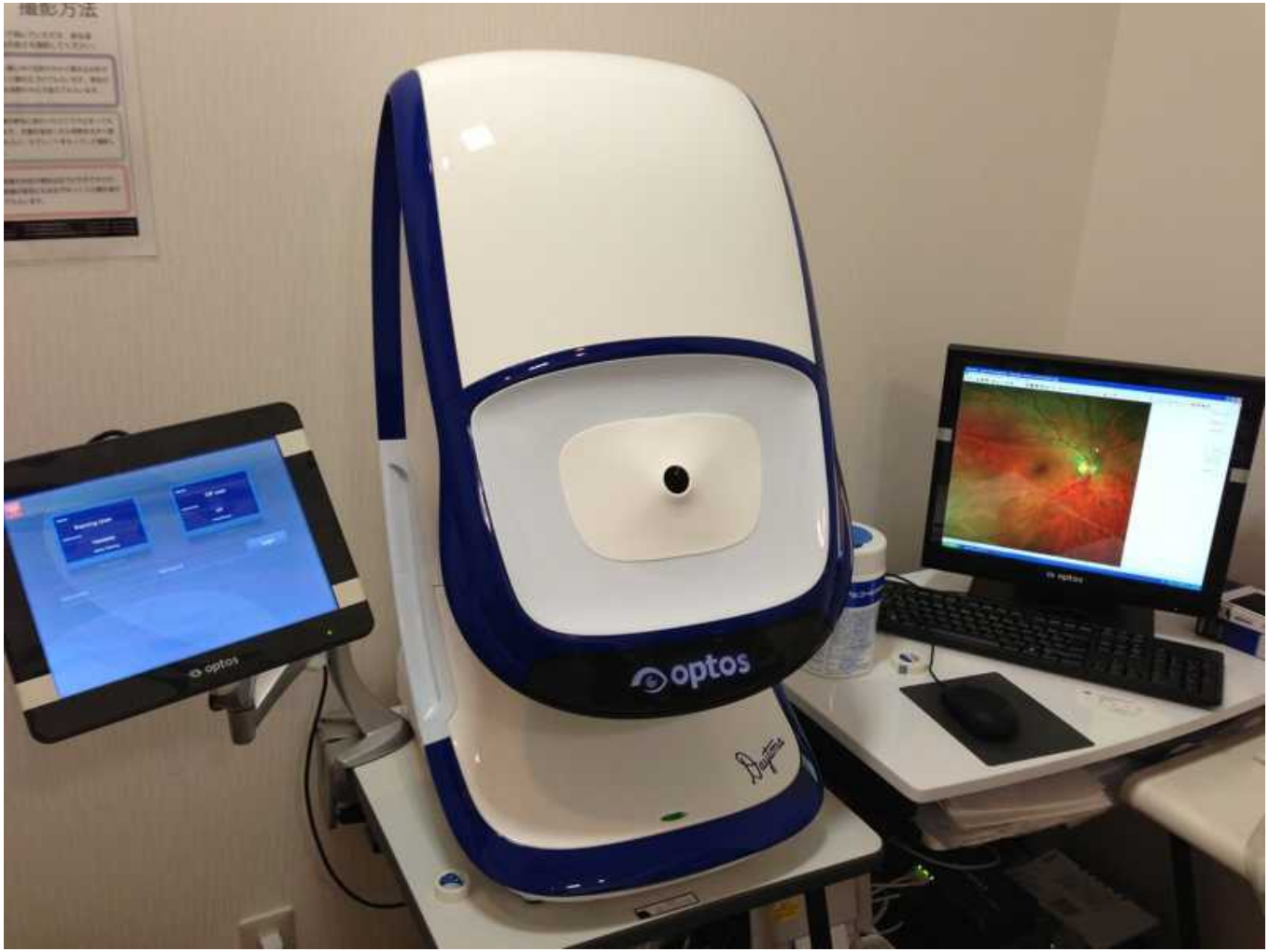


# Retina identification

- Similar to iris, first ideas in 1930s.
- In 1950s retina pattern has been shown to be unique (even for monozygotic twins).
- In 1990s first commercially available systems are made.
- Sample acquisition is intrusive, requiring the subject to be still, look directly into the device and being shone directly with IR light. The process may require several attempts to collect a viable sample.
- The lack of the cooperation, distance from the sensor or bad lighting (including caused by small pupils) may result in decreased accuracy (with FRR bias).
- Still used by US agencies, including DoD and prisoner identity verification.

# Retina identification

**Sample acquisition:**



# Retina identification

**Acquisition and identification:**

- Subject places their eye into the scanner.
- The Retina is illuminated by IR light in 360° cone around the tissue. Raw images are taken during this lighing (may take from several seconds to several minutes) so the subject has to remain still and look directly into the beam.
- Between 5 and 20 raw images are collected and passed to preprocessing and feature extraction.
- Preprocessing includes green channel extraction, noise removal, enhancement and segmentation of the blood vessels with Gabor filtering.
- Up to 400 data points determined by the vein pattern are extracted from the retina image.
- The relative location of the points and bifurcations are stored in the template (can be under 100bytes).
- During the verification and anchor is set to Fovea centralis and the samples are realigned w.r.t. the axis of the eyeball. The distances are compared using $L_2$ norm or k-NN.

# Retina vs Iris

- Retina recognition requires highly specialized scanner and is an invasive procedure that requires full user cooperation. Iris can be sampled both from distance on unaware user and, for increased quality, in lab environment in IR lighting.
- Retina requires a proper setup, and collecting data from the inside of the eye, yet when collected, there is (almost) no circumvention, whereas iris may be read from distance with no setup, as the features are visible from distance, yet this happens with loss of accuracy and increasing the circumvention potential. For stable, accurate reads a set up is needed.
- Both can be used for high security applications. Cheaper iris recognition systems may be used also on smaller scale for personal or in-office use.
- Both modalities are stabilized in early stage and preserve the features with age (diseases and age deteriorates the samples).
- Population-based exclusion rates are similar for both modalities.
- Iris has high acceptability rate, rising even further with device-unlocking; retina remains fairly acceptable.

# Sensors




IriScan2100




MIS100



L1 Sensor

# Sensors




AOptix Insight

# Standards

- ISO standards for image capturing: ISO/IEC 19794-6, ISO/IEC 29794-6
- High-security identification recommendations: lack of glasses and contact lenses, pupil-centered image of at least 640x480 px with at least 120 lines of iris diameter, usable iris area has to be at least 70%, 8-bit gray with at least 6b significance
- Raw images stored with tiff or png bitmaps, compressed – using jpeg with at least 80% quality.
- Safety standard IEC 60825-1 allowing exposure not greater than 10% of the exposure level that causes severe eye damage in at least 50% of the population.

# Preprocessing

- Green channel filtering.
- Removing sensor noise (smoothing, spectral filtering).
- Removing reflections (morphological operations, blurring).
- Contrast enhancement, histogram equalization (CLAHE), lighting equalization (e.g., retinex), gamma correction.
- Image intensity detrending (subtracting the best fitted plane in 3D interpretation).
- Gabor transform.

# Segmentation

- We assume that the pupil and the iris are circular or elliptic (this can be relaxed).
- The centers of both circles do not overlap.
- We assume that after the preprocessing the lighting is uniform.
- We assume that the occlusions are not significant (mostly caused by the eyelids and eyelashes).
- We approximate the eyelids as a polynomial, parabolic curve or a spline.
- Eyelashes are filtered out using intensity, energy filter, texture or region growing on one of the features.
- We need to localize ROI between two lines: inner (between the iris and the pupil) and outer (between sclera and the iris).

# Segmentation

Segmentation methods include:

- Circular Hough Transform
- Gabor filtering and Otsu thresholding
- Region growing
- Edge detection
- Active contour
- Integro-Differentional operator :
  $\max_{r,x_0,y_0} \left| G(r) * \frac{\delta}{\delta r} \oint_{r,x_0,y_0} \frac{I(x,y)}{2\pi r} ds \right|$, where $I$ denote the image and $G(\cdot)$ is a smoothing function.
- Elliptic approximation

# Segmentation

Elliptic approximation:

- identification of the preliminary region of interest,
- image intensity detrending (subtracting the best fitted plane),
- a multi-level (e.g., 3) segmentation with the Otsu algorithm, followed by binarization with respect to the first threshold,
- morphological processing with calculating image complement, opening and filling,
- image opening and calculation of boundaries,
- calculation of the convex hull,
- least-squares fitting of a circle and eliminating the outliers,
- least-square fitting of an ellipse, with optional corrections with active contour.

# Extraction

- The aim is to eliminate the scale and propose an universal method (robust against occlusions).
- We rescale the 'ring' ROI to the width of 1.
- We transform the image into polar coordinates. E.g., starting at 0 radius (inner boundry) at 6 o'clock, we move counter-clockwise in order to transform the circular image into a line in (angle, radius) plane.
- We ignore the lines that are significantly occluded.
- We obtain a series of intensity values in (angle, radius) plane – 1D signals.
- We smooth out the signals in a selected manner, e.g.:
  - Use 2D Gabor filters (in the angular and radial axis), and encode the signal phase as a sign of real and imaginary part of Jacobian (Daugman).
  - We filter the signals using second derivative of the smoothing functions (e.g., Laplacian of Gaussian). Then we can encode the signal as a binary number using zero-crossings, depending on the sign of the function value (Boles).

# Matching binary codes

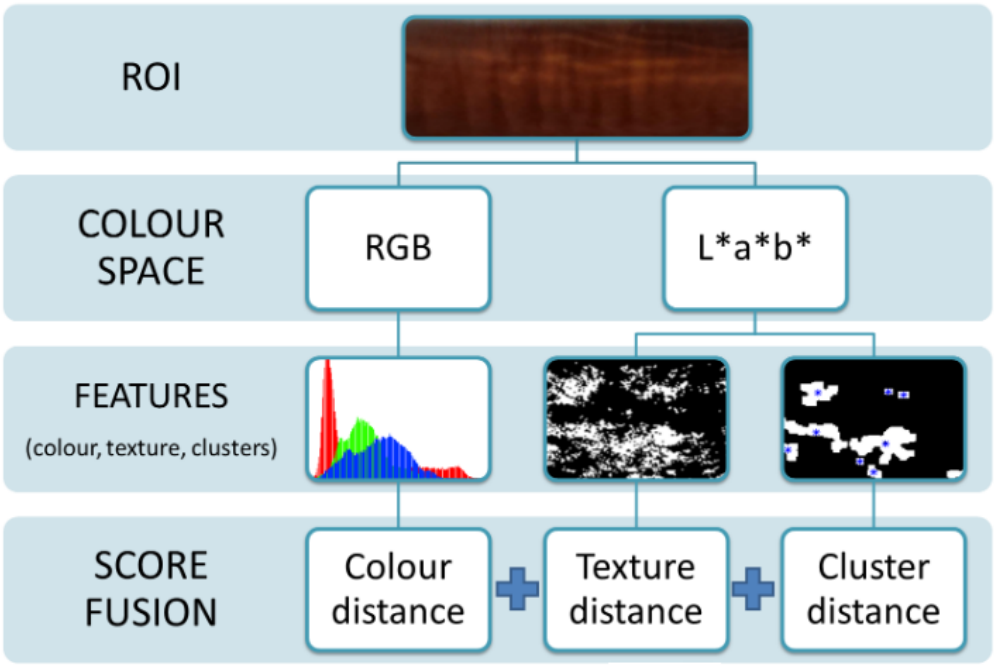
- Normalized Hamming distance: $H = \frac{\|(C_1 \otimes C_2) \cap M_1 \cap M_2\|}{\|M_1 \cap M_2\|}$ and adjusting for the rotation, i.e. we check all the cyclic shifts of the sample $C_2$, we assume that the sample with the lowest Hamming distance is the proper match (a threshold may apply, for Daugman $\tau = \frac{1}{3}$).
- Daugman showed that the left and right eye of a person have uncorrelated codes and that impostor scores have binomial distribution. Due to lack of correlation and characteristic pattern of the iris, the genuine and impostor samples are well separated.
- We can model the impostor scores by calculating standard deviation $\sigma = \sqrt{\frac{p(1-p)}{N}}$, where $N$ denotes the number of degrees of freedom.
- We may estimate the degrees of freedom required for $\hat{p} = 0.50001$, $\hat{\sigma} = 0.00316$ – $\hat{N} = 25000$, for $\hat{p} = 0.501$, $\hat{\sigma^2} = 0.001$ – $\hat{N} = 250$
- $\hat{N}$ divided by the ROI area gives discrimination entropy.

# Recognition on mobiles

Ch. Galdi, J.-L. Dugelay, *FIRE: Fast Iris REcognition on mobile phones by combining colour and texture features.*

- Presents low resources identification method under visible light.
- Solution based on a highly parallel algorithm submitted to Mobile Iris CHallenge Evaluation II.
- LAB and RBG color spaces are analyzed as well as cluster distance.
- EER oscillates around 0.33.
- For 2x Xeon 2.27GHz (6 cores) with 32 GB RAM a single sample comparison took under 0.1s using MATLAB implementation.

# Recognition on mobiles



# Recognition on mobiles

- Iris images are split into blocks and compared on block-to-block manner by measuring the distance between the histograms.
- Texture descriptor $dim_{\mathrm{box}}(S) = \lim_{\epsilon \to 0} \frac{\log N(\epsilon)}{\log \frac{1}{\epsilon}}$, where $N(\epsilon)$ is the number of boxes of side length $\epsilon$ needed to cover $S$. The image was analyzed after division into layers.
- Cluster descriptors under two color spaces LAB and RGB were used with single-color-clusters' features including centroid coordinates, orientation and eccentricity

# Recognition on mobiles

Multiple distances are investigated

Euclidean – $d_E(H,K) = \sqrt{\sum_i (h_i - k_i)^2}$

Chi-square – $d_{\chi^2}(H,K) = \sum_i \frac{(h_i - m_i)^2}{m_i}$, where $m_i = \frac{h_i + k_i}{2}$

Histogram intersection – $d_\cap(H,K) = 1 - \sum_i \frac{\min(h_i, k_i)}{\sum_i k_i}$

Match distance – $d_M(H,K) = \sum_i \left|\hat{h}_i - \hat{k}_i\right|$, where $\hat{h}$, $\hat{k}$ are cumulative histograms

Kolmogorov-Smirnov – $d_{KS}(H,K) = \max_i \left|\hat{h}_i - \hat{k}_i\right|$, where $\hat{h}$, $\hat{k}$ are cumulative histograms

# Recognition on mobiles

**Table 1. Colour distance performance evaluation.**

| Technique | RR | AUC | EER |
|---|---|---|---|
| Euclidean distance | 0.12 | 0.55 | 0.48 |
| Chi-square statistics | 0.10 | 0.59 | 0.44 |
| Histogram intersection | 0.10 | 0.61 | 0.41 |
| Match distance | 0.13 | 0.63 | 0.40 |
| Kolmogorov-Smirnov dist. | 0.10 | 0.65 | 0.40 |

# Further reading


- J.B. Mazumdar, S.R. Nirmala, RETINA BASED BIOMETRIC AUTHENTICATION SYSTEM: A REVIEW
- J. Daugman, How Iris Recognition Works
- G. Santos et al., Fusing iris and periocular information for cross-sensor recognition
- A. Czajka, K.W. Bowyer, Presentation Attack Detection for Iris Recognition: An Assessment of the State-of-the-Art
- N. Othman et al., OSIRIS: An open source iris recognition software
- K. Nguyen et al., Long range iris recognition: A survey
- S. Umer et al., A novel cancelable iris recognition system based on feature learning techniques
- L. Shuai et al., Statistical Cognitive Learning and Security Output Protocol for Multi-State Iris Recognition