Biometrics

Lucía Montero Sanchis

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Question 1 – Leading Biometric Technology

Physiological Characteristics

01. Fingerprint

Fingerprints – 24.10.2017 2

Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal Processing (contextual filters, Local Binary Patterns (LBPs)) and Pattern Recognition (ridge-based, MCC-based, hybrid)
- Sensing and Storage (Multispectral, Finger On The Fly)
- Representation and Feature Extraction (ridge-based, hybrid)
- Models of Features for Recognition and Classification (FingerCode, Minuta Cylinder Code (MCC), Hybrid representations)
- Enrollment and Template Creation (quality control, image enhancement)
- Biometric System Errors (independent evaluation)
- Synthetic Fingerprint Generation

- Mathematical Tools for Biometric Signal Processing (Gabor filters) and Pattern Recognition (binarization, thinning, crossing number (minutiae detection))
- Sensing and Storage (optical, capacitive, ultrasonic, etc.)
- Representation and Feature Extraction (level 1, 2 (minutiae) and 3 features)
- Models of Features for Recognition and Classification (minutia coordinates and local ridge orientation, Delaunay triangulation and triangular matching)
- Enrollment and Template Creation
- Biometric System Errors

Generalities:

- Friction skin (hairless, many sweat glands...). *Biological* (physiological) characteristic. *Applications* in security and forensics. *Characteristics*: permanent (except for desease, scarring...), unique (even with same DNA).
- *Galton's details* – It suffices if 12 points are the same between two fingerprints.
- **Lights-out identification** – system requiring minimal or zero human assistance that outputs a short candidate list.
- India Universal ID System with Biometrics – *To give the poor an identity*
- **Fake finger** (spoof attack) – Gelatin, Silicone, Latex.

Sensing: Optical, capacitive, ultrasonic...

- *On-line acquisition* – Optical, Capacitive, Piezoelectric scanners. Single- or multi-finger
- *Off-line acquisition* – Thermal scanner, Inked impression, Latent fingerprint.
- Others: touchless (TBS The Surround Imager; Finger On The Fly), acquisition of derma image (internal fingerprint, more reliability).

Feature extraction: (level 1, 2 (minutiae) and 3 features)

- Minutiae: Ridge bifurcations, endings, ... (52 types)
- Core: Uppermost point on innermost ridge
- Delta: Separating point between pattern and non-pattern areas
- Pattern class: Determined by ridge flow characteristics.
- **Feature Levels**:
  - **Level 1 – singularities (core points)**: Core and delta points. Classification (left loop, right loop, whorl, arch, tented arch). Ridges (*flow* can be described with *directional map*; line density can be described with *density map*)
    - **Average Square Gradient Method**: Gradient vector lengths are squared and their angles doubled.
    - Noisy fingerprint → *Local structure* for matching is very difficult, but *global structure* is more stable.
  - **Level 2 – Minutiae (major ridge path deviations)**: Ridge ending, Bifurcation, Valley, Lake, Independent Ridge, Point, Spur, Crossover.
  - **Level 3 – Intrinsic or innate ridge formations**: Sweat pores, incipient ridges, creases...

Templates: (minutia coordinates and local ridge orientation, Delaunay triangulation and triangular matching)

- **Segmentation** (Isolate foreground from background)
- **Normalisation** (Mean 0 and variance 1, to standardise image intensity values)
- **Orientation image** (Computation of gradients over square-meshed grid)
- **Frequency image** (Ridge frequency)
- **Automatic Minutiae Detection**
  1. Binarization
  2. Thinning
  3. Crossing number (Detection of minutiae)
- **Fingerprint enhancement – Gabor filtering**: Contextual filters (characteristics change according to local context), context defined by local ridge orientation and frequency. Efficiently removes undesired noise preserving ridges and valleys.

- **Fourier Analysis** – Interpreting the spectrum; alternate representation of the signal, providing more information. Filtering and convolution become trivial.
  - Energy map
  - Frequency map
  - Orientation map
  - Fourier Domain Based Enhancement
- **Pre-alignment**:
  - Absolute pre-alignment – w.r.t. core and delta points. First align usign global structure, then use loca lstru for point-to-point matching.
  - Relative pre-alignment – superimposing singularities, correlating orientation images, correlating ridge features.
- **Match Score Generation**
- **Triangular matching** – Delaunay triangulation creates a set of triangles such that triangles don't contain any other minutiae points.

Matching (comparison):

- **Fingerprint Matching**:
  - *Correlation-based* – Correlation between pixels computed for different alignments. Non-linear distortion and missalignments makes the correlation very difficult. Direct application of 2D correlation is very expensive computationally.
  - *Minutiae-based* – Find the alignment that results in maximum number of minutiae pairings. Minutia Cylinder Code (MCC). Time consuming.
    - MCC is computationally fast, easy bit-based implementation, invariant to rotation and translation.
  - *Ridge feature-based* – size and shape of fingerprint, number type and position of singularities, sweat pores, local orientation and frequency, ridge shape... FingerCode. **Gabor filter responses**.
    - *Texture-based Representation* – Ridge pattern in fingerprint is seen as an oriented texture pattern with fixed dominant spatial frequency and orientation in a local neighborhood.
    - *Local texture patterns – Local Binary Patterns LBPs*
  - **Hybrid**
- **Intra-variability** – Variations in impressions of one same finger. Overlap, displacement, rotation, non-linear distortion (because finger is 3D), pressure, skin condition, noise, *feature extraction errors.*
  - *Feature extraction errors*: Aggresive enhancement, low-quality images...
- **Local Clarity Score (LCS)** – computes the block wise clarity of ridge and valleys by applying linear regression to determine a gray-level threshold, classifying pixels as ridge or valley.
  - Minutiae + Local Correlation
  - Minutiae + Local Binary Pattern (LBP) Histogram

02. Face (2D and 3D)

Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal Processing (2D DCT, Local Texture Patterns (LTPs)) and Pattern Recognition (Linear Subspace Analysis - Principal Component Analysis (PCA), Singular Value Decomposition (SVD))
- Sensing and Storage (photo-camera, video-camera, etc.)
- Representation and Feature Extraction (geometric and appearance (local and global features) based)
- Models of Features for Recognition and Classification (GMM, histograms of LTPs, PCA)
- Enrollment and Template Creation
- Biometric System Errors

Analysis, Modeling and Interpretation of Biometric Data

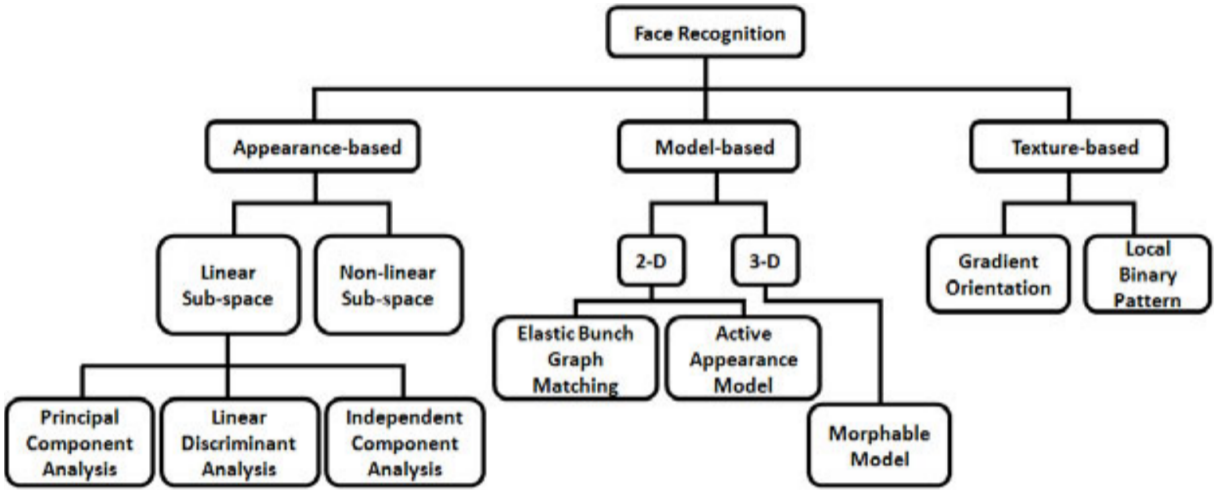
- Mathematical Tools for Biometric Signal Processing (3D Processing) and Pattern Recognition (Linear Discriminant Analysis (LDA), Graph Matching, Morphable Fitting)
- Sensing and Storage (3D Sensing)
- Representation and Feature Extraction (Fisherfaces, 2D Face Bunch Graph, 3D Shape and Texture Features)
- Models of Features for Recognition and Classification (LDA, Elastic Graph Matching, 3D Morphable Model)

Generalities:

- Three levels of details:
  1. General face geometry, global skin color – <30 *interpupilary distance* (IPD)
  2. Localized face information – 30-75 IPD
  3. Unstructured micro level features: scars, freckles, moles, skin discoloration
- Complications: Facial expression, point of view, illumination, inter-class similarity, automatic face detection, appearance changes (quick, slow).
- Advantages: Low-cost, non-contact, non-intrusive, overt (user aware) or covert (user unaware), legacy databases, socially and culturally accepted, always acquires.
- Proprietary algorithms to generate templates → not-interoperable templates (interoperable *original* photo). *Receiving State* uses its own vendor algorithm to compare taken and stored facial images.
- **Machine Readable Travel Document** (**MRTD**)
- ICAO standard: 300 dpi (112 kB); not cropped or cropped from chin to crown.
- Process:
  1. Face Detection
  2. Face Normalization
  3. Feature Extraction
  4. Classification

Sensing:

- **Imaging challenges**:
  - **Acquisition geometry** – Necessary face detection; in-plane (1 degree of freedom) and in-depth (2 degrees of freedom) rotation; scale.
  - **Imaging conditions** – Lighting, intrinsic camera characteristics (automatic white balancing, gain control, noise reduction). *Perfect conditions*: uniform background and lightning, acceptable quality.
  - **Compression artifacts** – Image degradations due to compression for transmission/storage. JPEG and MPEG often used but not designed to preserve human face.
- **Detection** (what faces have in common, tell face from non-faces); *Localization* (find position of one existing face); **Face recognition** (what differentiates two faces)
- Overlapped detections are merged if 60% overlap.
- *Detection* and *Recognition* **approaches**:
  - **Feature/Geometry-based** (analytic: eyes, mouth...) – Matching feature constellations. *Rotated models* (one model for each rotation).
    Haar features: *Haar-like transform* calculates difference of intensity in neighbor regions. With low resolution images, better than purely geometrical methods. Applies Haar-like basis functions. **Viola-Jones** face detector.
  - **Appearance-based** (local and global features, analyze distributions of individual faces in face space) – Neural Networks, **PCA**, **LDA**, **HMM**, SVM, **GMM**, Graph matching.



Feature extraction:

- **Appearance-based** Face Recognition:
  - *Local* Features (segment image and get several feature vectors):
    - **2D-DCT** based (Discrete Cosine Transform): Divide in m u by v blocks, obtain for each $n = uv$ DCT coefficients $\Rightarrow$ m vectors of length n, each vector a row of matrix $M^{m,n}$. Coefficients are ordered in zig-zag pattern.
      Then **GMM**: 2D-DCT features for training; score = log-likelihood(2DDCT | model)
    - Local Texture Patterns:
      - Local Binary Patterns **LBPs**:

$$\mathrm{LPB}_{P,R} = \sum_{p=0}^{P-1} s(g_p - g_c)2^p$$

with g_c the gray value of the center pixel (x_c, y_c); g_p the gray values of P equally spaced pixels on a circle of radius R; s a thresholding function s.t. $s = 1$ if $x \geq 0$, else 0.
Histogram intersection measure: $H(p,q) = \frac{\sum_i \min(p_i, q_i)}{1/2 \cdot (\sum_i q_i + \sum_i p_i)}$

· Local Ternary Patterns **LTPs**: One ternary code can be expressed as two binary codes (one is sustracted from the other). Ternary Codes use -1, 0 and 1 (instead of 1 and 0 only)

- *Global* Features (Holistic approach, obtain one single feature vector):
  - Principal Component Analysis **PCA**
  - Linear Discriminant Analysis **LDA**
- **2D Model: Elastic Bunch Graph Matching** (*relational approach*, requires ≥ 2 images)
  - Estimates a model of the relationship. Each face is represented by a set of feature vectors positioned on the nodes of a coarse

    what is coarse?

    2D grid.
  - Each feature vector is a set of responses of 2D Gabor wavelets (different orientation and scale)
  - *Comparing faces*: By matching and adapting the grid of the test image to the grid of the reference. Both grids have same number of nodes
  - Elasticity of grid allows for expression and view point changes adapting
  - Quality of match evaluated with distance function
  - Approach:
    1. Split global transformation into set of local transformations
    2. Avoid over-flexibility
    3. Embed system with probabilistic framework of a 2D HMM
- **3D Morphable Model** (*Face-On-The-Fly*)
  - Based on surface matching. Pose-normalization required.
  - Face geometry reconstructed in sub-millimeters (real ground-based measurement capturing x-y-z axes)
  - Feature extraction based on underlying cranial structure (unique, permanent)
  - Compact biometric template extracted. Possible RT face analysis, feature extraction and matching
  - Robustness to changes in pose, lighting, makeup, and spoofing with photo.
  - Face-On-The-Fly:
    1. Face detection and tracking
    2. 3D pose and shape estimation
    3. Frontal view synthetis
    4. Matching algorithm

Quality measures and Face Aging:

- Quality of samples and metadata quality
- Illumination, brightness, contrast, focus, resolution, background, rotation, glasses...
- How to deal with *age*: Performance improved by updating in time a decision threshold. Databases for investigation of age progression.

Iris – 31.10.2017 2

Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal Processing (Complex Gabor Wavelets (CGW)) and Pattern Recognition (Hamming Distance, Binomial Distribution, circular edge detection)
- Sensing and Storage (Proprietary camera systems)
- Representation and Feature Extraction (from Cartesian to polar system, phase quantization from CGW or DFT)
- Models of Features for Recognition and Classification (IrisCode and Hamming distance based)
- Enrollment and Template Creation
- Biometric System Errors (Very low identification errors)
- Large Scale Iris Identification Systems (IrisGuard)

Generalities:

- Biological. Distinctive features: arching ligaments, furrows, ridges, crypts, rings, corona, freckles, etc. Random pattern, mostly stable through life.
- **Epigenetic** (not genetically determined, as opposed to *genotypic*).
- eBorders in the United Arab States.
- **Modules**:
  1. **Acquisition** – Get 2D image with *monochromatic CCD camera* sensitive to *NIR* (Near InfrarRed: 700-900 nm) light spectrum.
     Infrared light is preferred because it's more reflected by melanin than visible light, thus more iris texture is visible. Illumination is ANSI and Cenelec Certified safe to use. Pigmentation variations in iris are due to melanin density and are invisible in the NIR.
  2. **Segmentation** – *Localize iris* in eye image
     Edge Detection and Hough Transform – The operator is a circular edge detector, can be used to detect the iris as well as the eyelid boundaries.
  3. **Normalization** – Geometric normalization from *Cartesian* to *polar* coordinates (r, θ) with $r \in [0, 1]$ and $\theta \in [0, 2\pi]$
     This compensates pupil dilation and iris size inconsistencies but not rotational inconsistencies (this is accounted for during *matching* by shifting the iris templates in the θ direction until templates are aligned)
  4. **Encoding** – Feature extraction to produce a binary code. Invariant to pupil dilation and iris size. It's reliable and false. False Match Rate very small.
     2048 bits (256 bytes) are extracted from iris image and an equal number of masking bits to signify whether any region should be ignored in the demodulation code.
     The information extracted from the iris is described in terms of *phase* $\Rightarrow$ *insensitive* to contrast, camera gain, and illumination level (unlike correlation methods).
     Correlations within an iris (local structure is self-predicting). All IrisCode bits are equally likely to be 0 or 1 $\Rightarrow$ IrisCode have *maximum entropy* bitwise.
  5. **Comparison** – How closely the produced code matches the encoded features in the database. Fractional Hamming Distance (HD, fraction of bits that disagree – 10% for same eye, 45% for different)
     $$HD_{\text{raw}} = \frac{||(\text{code}_A \oplus \text{code}_B) \wedge \text{mask}_A \wedge \text{mask}_B||}{||\text{mask}_A \wedge \text{mask}_B||}$$

- Iris Code bit comparisons are Bernoulli Trials – *binomial distribution*: $f(x) = \frac{N!}{m!(N-m)!}p^m(1-p)^{N-m}$

- If *less iris visible* then decision criterion becomes *more demanding*: $HD_{\text{crit}} = 0.32 - 0.01 \cdot \log_{10} N$
- Score re-normalisation to compensate for number of bits compared: $HD_{\text{norm}} = 0.5 - (0.5 - HD_{\text{raw}})\sqrt{n/911}$
- Fewer (more) than 911 bits penalizes (improves) Hamming Distance. 1152 bits corresponds to 100% visibility of each iris.
- Extremely fast when computed in parallel (1M IrisCodes per second with 3 Gb)

Sensing:

- Techniques for improving user interface:
  - Use extremely high resolution CCD

    que es CCD?
  - Well-designed optical system to improve DOF (Depth of Field)
  - Cold mirror for user to adjust his eye
  - Auto-focus
  - Active pan/tilt camera optics
  - Facial feature detection and tracking for guiding
  - Distance sensor or image content based distance estimation
  - Dual-eye iris camera

Matching (comparison):

- **Hamming Distance** – Iris Codes are matched using a XOR to find bits at which they differ. AND is used to ensure that the compared bits are uncorrupted.
- **Liveness detection** – Photonic and *spectrographic* countermeasures (tissue, fat, blood and melanin pigment spectra; *red eye* effect) and *behavioral* countermeasures.
- *Contact Lenses* and *Large difference in dilation* result in few more False Rejections.

04. Periocular, Retina, Ear

Periocular:

- Includes eyes, eyebrows, nose bridge and facial skin. **Method**:
  1. Eye detection
  2. Normalization (illumination normalization; histogram normalization)
  3. Feature extraction
  4. Verification:
     - Component based with per-component alignment (crop components and compare component per component)
     - Holistic with global alignment (compare entire)

Retina:

- **Generalities**:
  - Eyes have unique **vascular patterns**. The retinal vascular pattern is the most **stable** physical feature because of its **internal** location (near optic nerve), thus protected from variations (except eye diseases or severe head trauma)
  - The retina receives light and converts it into neural signals. It's *transparent to infrared light*. Vessels of the choroid reflect most of useful information to recognize individuals.
  - **Fovea** – Blood vessel-free reddish spot at the center of the macula
- *Scanning and technologies*:
  - **Retina Scan** (EyeKey) – Infrared camera (*retinascope*) detects return light.
  - **Representation** of retina: Contrast data in the scanned domain. Matching compares contrast arrays (e.g. with correlation methods), not affected by cataracts or glasses. Steps:
    1. Image acquisition
    2. **Circular bar code** (after locating blood vessels, vessel thickness and angulation are translated into a summary pattern)
    3. Pattern matching
  - Retinal Technologies – Patented aspheric lens
- **Advantages**: Highly accurate, stable, difficult to spoof
- **Disadvantages**: Difficult to use, user discomfort, limited applications, expensive, medical assumptions

Ear:

- **Techniques**:
  - **Geometric measurements**: *Iannarelli System*. Anthropometric technique based on 12 ear measurements. Requires exact alignment and normalization. Features stored along with sex and race.
  - **Image filtering**
    - *Force field transformation*: Force proportional to pixel intensity. Direction (arrows) and magnitude (intensity). It's scale invariant and removes the noise.
    - *Local binary patterns (LBPs)*
  - **Subspace analysis (PCA, LDA...)**
  - **Elastic bunch graph matching**
  - **3D**
- **Challenges**: Ear occlusion; Earprint identification (ear trace)

05. Hand Geometry (shape)

Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal Processing (Hand shape and its measures, e.g., radial distance function) and Pattern Recognition (PCA, LDA, LBP)
- Sensing and Storage (Visible and NIR light cameras)
- Representation and Feature Extraction (Region of interest (ROI), Hand contour, Eigenpalm, Eigenfingers, Skeleton patterns (ridges and minutiae), Fisher-veins, Radon transform, Complex matched filtering, Local texture patterns)
- Models of Features for Recognition and Classification (PCA, LDA, Skeleton comparisons, LBP histograms)
- Enrollment and Template Creation
- Biometric System Errors

Generalities:

- Biological (physiological). Typical visible images of the hand are (a) palmar, (b) lateral, (c) dorsal.
- Hand is unique: Finger length, width, thickness, curvatures and relative locations. Bone structure is constant after growth period.
- Only the silhouette of the hand is recorded. *Orthographic scanning* (two distinct images, one from the top and one from the side)
- Inexpensive, robust to environmental changes, non-intrusive. Low accuracy, changes during childhood, difficult for some users (arthritis, missing fingers, large hands)

Sensing:

	Pros	**Cons**
Pegged	Predefined axis to measure features	Pegs may deform shape
Non-Pegged	More robust than Pegged to different placements	Difficult to locate axis to measure features

- *Enrolment*: Two snapshots of the hand are taken and averaged
- *Matching*: Newly sensed feature vector is compared (euclidean distance) with stored feature vector
- **Pegged** – Feature extraction involves computing widths and lengths of fingers and palm at various locations (16 features)
- **Non-Pegged** – Wrist reference, radial distance function (from wrist reference)

06. Palmprint and Palm Veins

Palmprint:

- **Sensing**
  - Regions: interdigital, thenar and hypothenar
  - Major creases: distal transverse crease (heart), proximal transverse crease (head), radial transverse crease (life)
  - Palmprint: Ridges, minutiae and pores
  - Preprocessing: Global thresholding; Contour-following algorithm; Reference points

- **Region of Interest (ROI)** – Subimages of regions of interest: Little-finger, Ring-finger, Middle-finger, Index-finger, Thumb, Palm,
- **Palm and finger strips features**
  - Eigenfingers and eigenpalm features (PCA)
  - High recognition accuracy for some fingers (esp. middle and ring, not for thumb)
  - Palm: >98% recognition for >70 features. Local minutiae extraction and MCC.
  - Quality definitions: Local clarity score; Ridge valley uniformity; Orientation certainty level; Orientation flow; Frequency domain analysis; Radial power spectrum; Gabor filters (several variants)

Palm Veins:

- **Properties, sensing and imaging**
  - Cross section through the skin. Thick, hairless skin
  - Veins less numerous but more distinct in dorsal imaging than palm imaging
  - Near-Infra-Red (NIR) sensing
  - **Imaging**:
    - Light reflection method – Near-infrarred light (LED) reflected (in not-vein?); Image sensor (CCD cam)
    - Light transmission method – Near-infrarred light (LED) goes through (vein?); Image sensor (CCD cam)
  - Vascular patterns not apparent under visual light. Infra-red light causes veins (hemoglobin) to appear black
  - Images depend on temperature
- **Hand-vein recognition** – Invariant, can be used together with fingerprints, can be used for left and right hands...
  - **Skeletonization**: (a) Original far infrared image of the back of the hand, (b) Extraction of the region of interest, (c) Image enhancement of the region of interest, (d) Extraction of the vein lines, (e) Skeletonization of the vein lines
    Minutiae-like approach: Cross- and end-points detection. Can be done by:
    - Crossing number (counting *pixel neighbors*)
    - Convolution Based Minutiae Extraction: Convolving skeleton image with a single bi-dimensional filter G and two look up tables Te and Tb (sets of filter response values for endpoints and bifurcations, respectively)
  - **Principal Component Analysis (PCA)** and **Linear Discriminant Analysis (LDA)** (Fisher-veins)
  - **Radon Transform**
  - **Complex Matched Filtering**
  - **Local Texture Patterns**
    - Local Binary Patterns (LBPs)
      - Region of Interest (ROI): Find hand contour; Find reference points between fingers (determine left or right hand); Draw a square based on reference points; Re-scale to average size
      - Pre-processing, to enhance veins. Methods: Adaptive Histogram Equalization, Morphological Background Removal, Directional Filter Enhancement
      - Code (texture micro-pattern) computer per pixel (Gray-level difference encoded)
    - Local Derivative Patterns (LDPs)

Behavioral Characteristics

07. Voice (02, 03)

Speaker Recognition – 3.10.2017

Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal Processing (STFT, Cepstrum) and Pattern Recognition (DTW, VQ, GMM, HMM, Bayes' Theorem)
- Sensing and Storage (Microphone, Bandwidth, Sampling, Quantization)
- Representation and Feature Extraction (Spectral envelope, MFCC)
- Models of Features for Recognition and Classification (DTW, GMM, VQ, HMM, EHMM)
- Enrollment and Template Creation (DTW and VQ templates,HMM, GMM (ML, EM, Score Normalization, UBM))
- Biometric System Errors (FMR, FNMR, FAR, FRR, DET and ROC Curves, EER, FTA, FTE, Identification Errors)
- Speaker Recognition Systems (Conventional SV, SV with Verbal Information Verification, Text-prompted Speaker Recognition)

Generalities:

- **Voice biometric** combines physiological and behavioral characteristics. Useful for remote-access transactions over telecommunication networks. Voice is subject to many sources of variability.
- **Disambiguation** – Voice recognition can refer to *Speaker recognition* (who is speaking) or *Speech recognition* (what is being said).
- **Perceptual Cues**: *High-level* (learned behaviors – Semantic, Dialogic, Idiolectal that depend on status, education, place of birth) vs *Low-level* (physical characteristics – Spectral, Prosodic, Phonetic that depend on anatomical structure)

Sensing:

- **Microphones** (e.g. in smartphones)
- **Speech signal** is real, continuous, non-stationary, 4-dimensional (4D), has finite energy. It's complex and variable over time. Sometimes periodic (pseudo-periodic) for voiced sounds; Sometimes random for fricative sounds; Sometimes impulsive in explosive phases of occlusive sounds.
- **Bandwidth** – Frequency Band of Telephone Speech: 300 Hz – 3.4 kHz
- **Coding Bands**:
  - Hi-Fi: 20 Hz – 20 kHz (sampling frequency 44.1 kHz)
  - Wideband: 50 Hz – 7 kHz (sampling frequency 16 kHz)
  - Narrow band: 300 Hz – 3.4 kHz (sampling frequency 8 kHz)
- **Sampling** and Uniform **Quantization**:

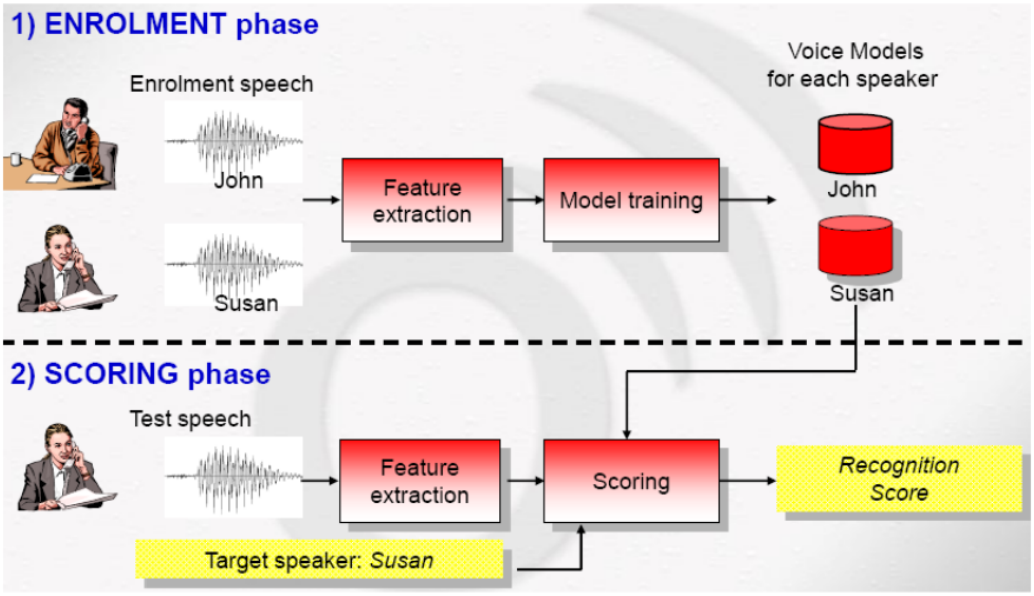


Figure 1: Enrolment and Scoring in Speaker Recognition

Feature extraction: Spectral envelope, MFCC

this??

- **Mel-Frequency Cepstral Coefficients (MFCCs)**: Mel-Frequency Cepstrum (MFC) is a representation of spectral energy of a sound on the mel scale, and is made up by the MFCCs (coefficients). In an MFC the frequency bands approximates the human auditory system's response – better representation of sound.
  - GMMs are used to capture the distribution of MFCCs in the feature space.
  - We enroll a speaker by adapting the UBM using the speaker's input.
  - Are obtained through FFT (Short-term transform), Logarithm, Deconvolution source/tract (cepstre). The acoustic vector consists of cepstrum, delta-cepstrum and delta-delta-cepstrum
  - **Short-Term Feature Extraction**:

    Window, frame, feature vector (acoustic vector)
  - **Short-term Processing**:

    window N, frame M, window and frame duration definitions
  - **Short-term DFT**
  - **Spectral envelope**

    (+spectrogram)
  - **Real Cepstrum**
  - **Dynamic features**
- Recent research on supervectors and i-vectors.

Templates:

- **Template** is a compact, electronic representation of a biometric sample that is created at the time of enrollment and stored in the system database for future reference and comparison. The process of creating a template and storing it in the database is called *enrollment*.
- **Speech Modalities**:

- *Text-dependent*: System knows text spoken (e.g. find fixed phrase, prompted phrase). Used for strong control over user input. Improved system performance.
- *Text-independent*: Not know text spoken (e.g. conversation). Less control over user input. More flexible and more difficult.

- **Vector Quantization**

explain VQ

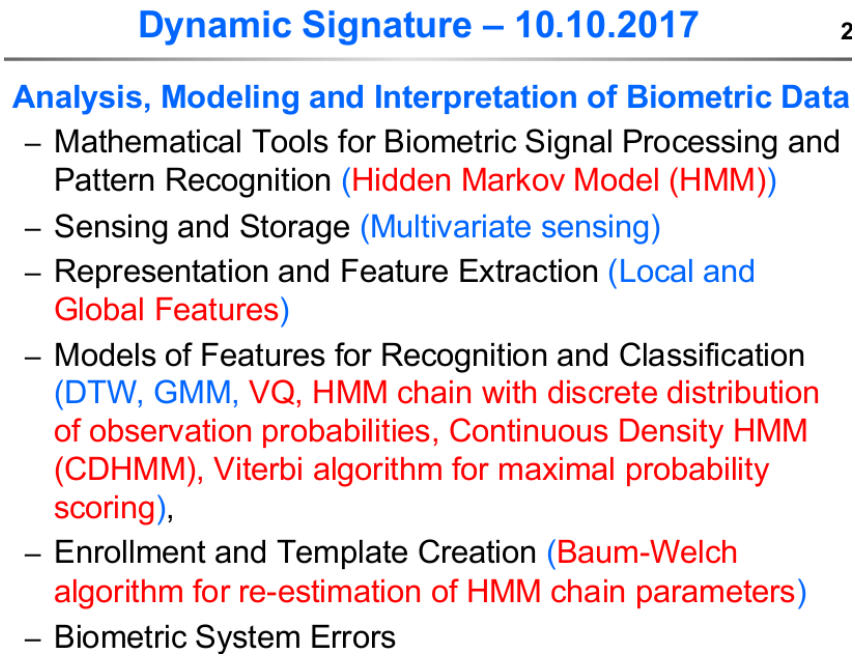
	Deterministic	**Statistical**
Text-dependent	Dynamic Time Warping (DTW)	Hidden Markov Model (HMM)
Text-independent	Vector Quantization (VQ)	Gaussian Mixture Model (GMM)

Table 1: *Templates and Models* in Speaker Recognition

Matching (comparison):

- **Comparative analysis** is a comparison between two biometrics, typically a tested sample and an enrollment (reference) template or model. The output of the comparison is a distance or score.
- **Speaker Recognition Systems**:
  - *Conventional Speaker Verification System*
    Enrollment:
    GMM training → Speaker-dependent GMM → Database
  - *SV with Verbal Information Verification*
    Automatic enrollment:
    Verbal Information Verification ⇒ Save for training → Verified pass-phrases for training → HMM training → Speaker-dependent HMM → Database
  - *Text-prompted Speaker Recognition*: Uses **speaker-specific phoneme models** as basic acoustic units. New prompted sentence every time – can't cheat with pre-recordings.
- **Prerequisites for good performance in Speaker Recognition**: Speakers must not disguise their voices; Recording conditions and signal processing techniques are known or controlled; Speech recorded in conditions similar to those of the test signal is available; Reference values for similarity measures established in similar conditions as the test signal; Decision thresholds calibrated according to reference values depending on the application.

08. Dynamic Signature



Generalities:

- *Behavioral* characteristic. Combines *knowledge* and *biometric*. Not *permanent* (invariant over time). Currently can be digitalized and is in ID cards.
- **Applications**: Signature forensics, Signature authentication, Signature surveillance, Digital Rights Management, Biometric cryptosystems.
- **Off-line** or **Static** – scanned from paper documents, written conventionally.
- **On-line** or **Dynamic** – written with electronic device. Dynamic information (pen tip location through time) usually available at high resolution, even if pen not in contact with paper.

Sensing: Multivariate sensing

- Tablets, smartphones, IKEA's and Sunrise's SignPad, UPS and SwissPost...

Feature extraction:

- **Basic (Local) Features:**
  1. X, Y coordinates
  2. Velocity
  3. Acceleration
  4. Pen azimuth (0 - 359 deg)
  5. Pen altitude (0 - 90 deg)
  6. Pressure
  7. First and second derivatives of feature
- **Global features (more than 150)**
  - Signature length, height, weight
  - Total signature time
  - Total pen-down and pen-up time
  - Avg., max. and min. velocity
- Pre-processing: Smoothing; Segmentation (determine beginning and end); Initial point alignment.

- Forgery: Zero-effort; Home-improved (based on static image); Over-the-shoulder (observe signing); Professional (skilled individuals). Over-the-shoulder + Home-improved combo is called *skilled*.

Templates

- *Models of Features for Recognition and Classification* are DTW, GMM, HMM chain with discrete distribution of observation probabilities, Continuous Density HMM (CDHMM), Viterbi algorithm for maximal probability scoring)
- *Enrolment and Template Creation*: Baum-Welch algorithm for re-estimation of HMM chain parameters.

Matching (comparison):

- DET curves to compare different GMMs, HMM...
- Resistant to imposters, non-invasive, can be changed by users, fast and intuitive enrolment, fast verification, independent of native language user.
- Inconsistent signatures increase error rates, limited applications, for good accuracy a 5D pen is needed (costly), some people can't sign.

09. Gait, Typing Rhythm

Gait: How people walk

- **Generalities**: Walking is similar for all humans. Non-contact. Uses sequences. Applications: security/surveillance, medicine, forensics. Hard to disguise and perceivable at distance.
- **Features**: Width of silhouette; vertical and horizontal projections; angular representation; PCA and LDA.
- **Feature extraction**: Recognition includes *dynamic* (motion) and *static* (body shape) features.
  1. Global *motion* and *shape*
  2. Gait *period* and *phase*
  3. Gait model initialisation
     - Extended pendular thigh-model based on angles
     - Forced oscillator/bilateral symmetry/phase coupling
  4. Local contour deformation
- **Matching**: DTW and HMM

Typing Rhythm (keystroke dynamics):

- **Generalities**: Way a user types on a keyboard, identity verification is based on how you type. Behavioral, transparent and natural. Can be used on smartphones. Typing pattern may be unique because it's based on neuro-physiological factors (similar to dynamic signature)
  Narrow range of applications, need to account for typing errors. Minimal training, no additional hardware.
- **Features**:
  - **Latencies** between succesive keystrokes
  - **Duration** of each keystroke
  - Overall typing speed
  - Especially consistent features for known regularly-typed strings (e.g. username and password)
- **Trigraph features**: 3 consecutively typed keys. *Duration*: (time between first and third key). Feature vector in trigraphs are sorted in ascending duration order.
- **Trigraph matching**: *Degree of disorder* (sum of absolute changes in position between two sorted arrays, normalized to have a value in [0,1])

- **Password hardening** – Text password + Typing pattern
  More security, but also high false rejects (e.g. change of keyboard).

Biological Traces

10. DNA

Generalities:

- *Biological traces*
- DNA **unique** to every individual, only shared by **identical twins**. Can be obtained from many sources. Does not change during life, but can be damaged by chemical and physical events and by random mutations.
- Invasive collection of samples. Money and time expensive. Privacy concerns?
- Requires **tangible** physical sample and matching is not done in real-time. Currently not completely automated.
- *Biological background*: All cells of an organism contain same DNA content. A **chromosome** is the visible state of genetic material. Humans have 23 pairs of chromosomes. Genes are made of **DeoxyriboNucleic Acid** (DNA).
  DNA: Double helix is the natural form in which DNA is found within nucleus of the cells. DNA is a polymer (long string of simple repeating units). Repeating units are called **nucleotides** (four types: **A**denine, **C**ytosine, **G**uanine, **T**hymine). The complete DNA molecule consists of two of these strands of the four bases.
- Components:
  - Nucleotides
  - Hydrogen bonds (electrostatic connection): A-T; C-G

Concepts:

- Most DNA is the same accross people, but some varies: **Short Tandem Repeats (STRs)** in non-coding sequences.
- **Polymerase Chain Reaction (PCR)** – Method of amplifying a specific region of the genome (from 1 to over 1 Billion copies)
  - **Locus** – region of the genome being examined

    ??
  - **Allele** – State of the genetic variation being examined. STRs is the nb. of repeat units, SNPs is the base sequence at the site.
  - Chromosomes are **paired**: Homozygous (Heterozygous) – Alleles identical (differ) on each chromosome
  - **Process**:
    1. DNA molecule with target sequence is heated to denature it
    2. When the mixture cools, primers bond to the single stranded DNA
    3. dNTPs and DNA polymerase are added to synthesize two new strands of DNA
    4. Process is repeated, many copies can be produced in a short time
- **Short Tandem Repeats (STRs)** – Length Variation
  These repeat regions usually bounded by specific *restriction enzyme* sites ⇒ possible to cut out segment of chromosome
- **Single Nucleotide Polymorphisms (SNPs)** – Sequence Variation; insertions/deletions

- **Capillary Electrophoresis** – Separates the fragments by drawing them towars a positively charged pole. Shortest fragments move faster, therefore their order reflects their size. Laser light activates the fluorescent tags as the fragments pass a detection window, producing a color readout that is translated into a sequence.

  ddNTP? Locus? watch a video on this whole thing? :/

DNA Analysis steps:

1. Collection: Blood, saliva, semen, urine, hair, teeth, bone, tissue
2. Specimen Storage
3. Extraction
4. Quantitation
5. Genotyping
6. Interpretation of results
7. Database (storage and searching)

Applications: Forensics, Paternity testing, Historical investigations, Missing persons investigations, Mass disasters

Synthetic Biometric Data Generation

11. Synthesis of Fingerprints

Synthetic Fingerprint Generation: To automatically create large databases of fingerprints, allowing to train, test, optimize and compare algorithms. Collecting fingerprints is expensive (money and time) and problematic (privacy legislation).

1. Select → Obtain:
   (a) shape parameters → **fingerprint shape**
   (b) class and singularities → **directional map** model
   (c) average density (and singularities) → **density map** model
2. **Ridge pattern** generation, to obtain **master** fingreprint
   - Gabor filters iteratively applied to an initially white image, enriched with a few random points. Orientation and frequency of the filters are locally adjusted according to directional and density maps.
   - As a result, realistic minutiae appear at random positions.
3. Add **variability** data:
   (a) Determine contact region and erosion/dilation (low-pressure or dry/high-pressure or wet)
   (b) Skin deformation
   (c) Noise and rendering
   (d) Translation and rotation
   (e) Generate background

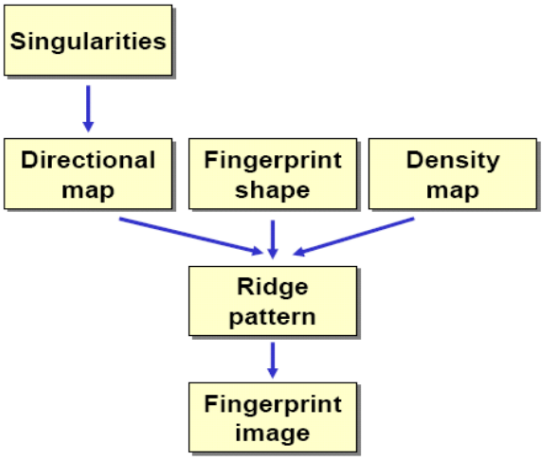


Figure 2: Synthetic Fingerprint Generation

Multimodal Biometrics

12. Multimodal Biometrics

Multimodal Biometrics – 5.12.2017 2

Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal and Pattern Recognition (multimodal and multiclassifier fusion (classification and combination))
- Sensing and Storage (Sensor level fusion (mosaicing))
- Representation and Feature Extraction (Feature level fusion, heterogeneous feature vectors, early integration)
- Models of Features for Recognition and Classification (fusion and normalization, late integration, matching score level fusion (classification and combination), decision level fusion)
- Enrollment and Template Creation
- Biometric System Errors

Generalities:

- *Desired characteristics*: Universality; Uniqueness; Permanence; Collectability; Performance (achievable recognition accuracy, resources required, operating environment); Acceptability; Circumvention (how easily can it be spoofed?)
- Every biometric characteristic has some limitations ⇒ *Solution*: *Multimodal Biometrics*
- **Multimodality** (combine evidence from multiple traits)
  - High cost; Longer verification time
  - Permit choice of biometric; Increase population coverage, reduce failure to enroll; Enhance performance; Improve resilience to spoofing

Classification of biometrics:

- **Unimodal** (*most restrictive*) – subset of a unibiometric system that uses a single instance (snapshot), a single representation and a single matcher for recognition
- **Unibiometric** – uses a single biometric identifier
- **Multi-biometric** – uses more than one independent biometric identifier (e.g. fingerprint and face)

- **Multimodal** (*most general*) – superset of a multi-biometric system that may use more than one correlated biometric measurement (e.g. multiple impressions of a finger)

What to integrate?:

- **Multiple sensors** for same biometric (e.g. optical and solid-state sensors for fingerprints)
- **Multiple biometrics (traits)** – Each sensor senses a different biometric. Improves system accuracy and matching speed
- **Multiple samples** of same biometric, e.g. multiple impressions of the same finger
- **Multiple instances**: e.g. fingerprints from two or more fingers.
- **Multiple representations** and matching algorithms for the same biometric – combines different approaches to feature extraction and matching of single biometric.

Integration strategies:

- **Integration architecture** – Combination of classifiers:
  - Parallel
    - Early integration (*Feature* extraction)
    - Late integration (*Matching Score* or *Decision*)
  - Serial
  - Hierarchical
- **Levels of fusion**:
  - **Before matching** (*often not possible*):
    - **Data/Sensor Level** (combine raw sensor outputs) – Mosaicing for fingerprints, 2-3D faces
    - **Feature Level** (combine extracted features)
  - **After matching**:
    - Dynamic Classifier Selection
    - **Classifier Fusion**:
      - **Score Level** (combine matching scores, *most popular*, *Classification* or *Combination* approaches possible)
      - **Rank Level** – Consolidates the ranks associated with every subject. Highest rank (best rank assigned to an individual by any of the classifiers); Borda count (number of identities whose ranks are worse than the individual's rank)
      - **Decision Level** (combine identity decisions, *least informative*). Possible schemes: AND, OR, majority voting
        Support Vector Machines find the hyperplane that gives the largest minimum distance to the training samples
- **Fusion strategy**
  - *Quality based*: Multi-classifier Stacking (1 signal, several features sets extracted), Multi-biometrics Stacking (several signals)
  - *Fusion after normalization* (Score normalization, weighted sum, decimal scaling, Z score, double sigmoid function...)

Miscellaneous

13. Quality and Ageing in Classication of Biometric Data

Quality measures:

- **Data quality**: Quality of samples. **Metadata quality**: Information associated with samples (e.g. age)
- **Face quality measures** (*omniperception*): Reliability, illumination, brightness, contrast, focus, bits per pixel, background uniformity and brightness, spatial resolution, reflection, in-plane and in-depth rotation, presence of glasses
- Dependence between scores and quality measures grants improved class separation. Quality measures can be used together with classifier scores to take the final decision.

Face Aging:

- Age: time difference between the template (model) creation and the query image testing
- How to deal with *age*: Performance improved by updating in time a decision threshold.
- Publicly available database for investigation of age progression.

Question 2 – Other Topics

Fundamentals of Biometrics (01)

01. Identity and Biometrics

The role of Biometrics is to recognize a person by their body traits and link the body to an externally assigned identity.

Biometrics:

- *Biometrics* – automated recognition of individuals based on biological and behavioral characteristics
- *Biometry* – statistical and mathematical methods applicable to data analysis problems in the biological sciences
- *Biometric system* – automatic pattern recognition system that recognizes a person by verifying the authenticity of a specific biological and/or behavioral characteristic (biometric modality) they possess
- (forensic, judicial) *Anthropometry* – (identification of criminals by) measurement techniques of human body and its specific parts

Identity:

- *Identity* – whatever makes something the same or different.
- *Authentication* (identity verification) – process to link a physical person with a certain identity

People are identified by **three basic means**:

- Something they *have* – identity document or card, passport, birth certificate, token...
- Something they *know* – password, PIN, name, date of birth
- Something they *are* – human body

Security level of each solution:

$$\text{Know} \quad < \quad \text{Know} + \text{Have} \quad < \quad \text{Know} + \text{Are} \quad < \quad \text{Know} + \text{Have} + \text{Are}$$

Advantages of Biometric identifiers: *Security*; *Convenience*; *Audit trial*; *Avoid fraud*; *De-duplication*. Examples: automated comparison process occurs in seconds; can replace passwords (often forgotten, lost, or misappropriated); identity justification without paperwork.

Ideal biometric identifier: *Universality* (every person has it); *Uniqueness* (different for every person); *Permanence* (invariant in time); *Collectability* (measurable, practical); *Acceptability* (public has no strong objections).

Challenge of biometrics: *Scalability*, *Usability*, *Accuracy*.

Identifiable biometric characteristics: *Biological traces* (DNA, blood, saliva); *Biological (physiological) characteristics* (fingerprint, iris, retina, hand palm, hand veins, hand geometry, facial geometry); *Behavioral characteristics* (dynamic signature, gait, keystroke dynamics, lip motion); *Combined* (voice).

Comparison of biometric techniques (Cost and Accuracy):

$$\text{Cost:} \quad \text{Voice} < \text{Face} \approx \text{Fingerprint} < \text{Signature} < \text{Hand} < \text{Iris}$$

$$\text{Accuracy:} \quad \text{Voice} \approx \text{Face} \approx \text{Signature} < \text{Hand} < \text{Fingerprint} < \text{Iris}$$

02. Recognition, Verification, Identification and Authentication (01)

Recognition – used when we do not distinguish between verification, identification and authentication.

Verification – performs one-to-one comparison of a submitted biometric characteristic (sample) set against a specified stored biometric reference, and returns the comparison score and decision (deciding whether a sample belongs to a specified person) – *Is this person who he claims to be?*

Identification – performs one-to-many comparison/search to determine the identity of the user from a known set of identities – *Who is this person?*

Authentication – the user claims an identity and the system verifies whether the claim is genuine (link a person with a chosen identity).

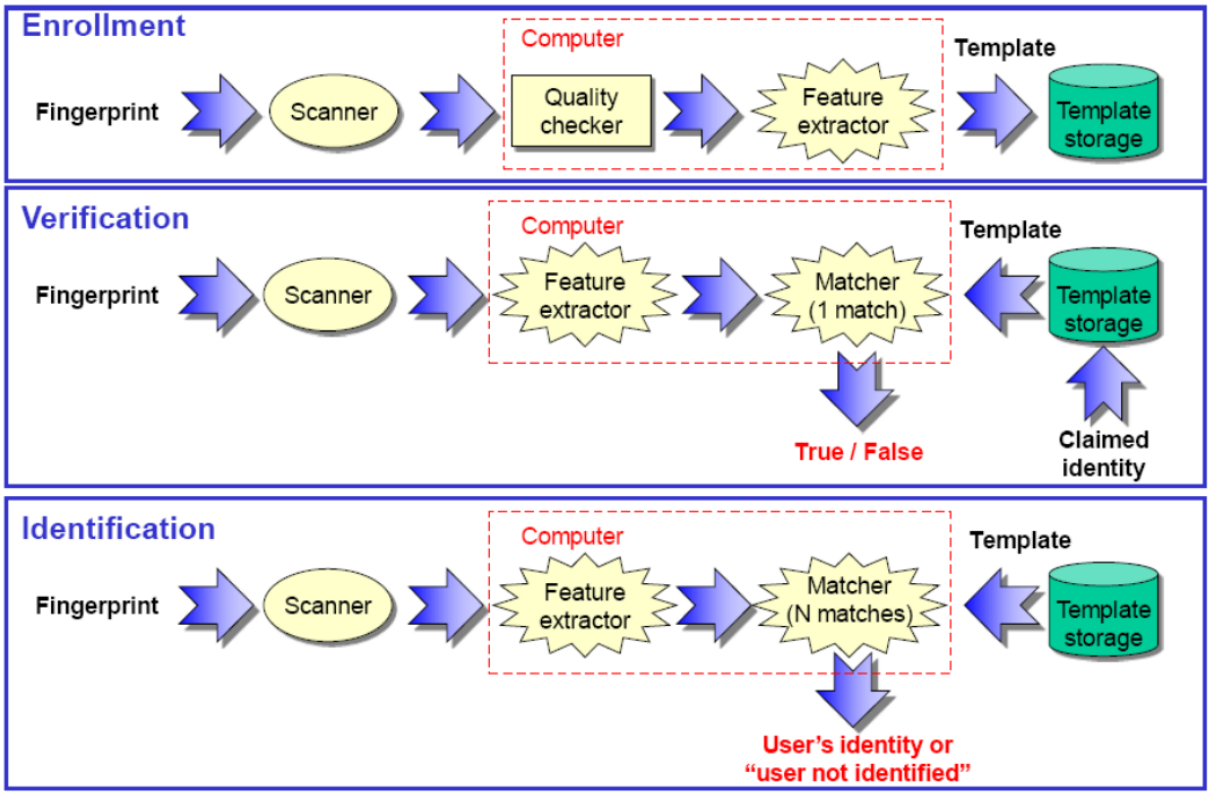


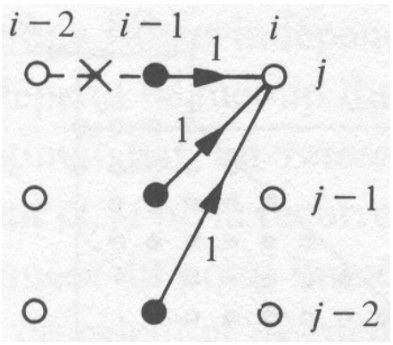
Figure 3: Enrolment, Verification and Identification

Analysis, Modeling and Interpretation of Biometric Data

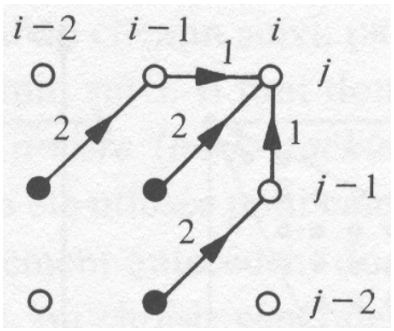
03. Mathematical Tools: Dynamic Time Warping (DTW) (02,03)

- In voice: Algorithm for measuring **dissimilarity** (distance) between two temporal sequences, which may vary in speed. Given a test word T and reference words R_1, ... R_N (all represented by sequences of feature vectors), we choose the reference word R_r with smallest distance $D(T, R_r)$.
- In voice: The recognition system is adapted to the single speaker who uttered the reference word. Limited vocabulary, without words too close phonetically. The words to be recognized are pronounced in an environment free of noise. They could be isolated in a perfect manner.
- **Non-linear time alignment**: The sequences are *warped* non-linearly in time dimension to determine a measure of their similarity independent of certain non-linear time variations.
- **Algorithm**. *Conditions*: Boundary; monotonicity; step size.
  - Recursively calculate a minimum accumulated distance for each point (i, j) taking into account some local heuristic constraints and weights.

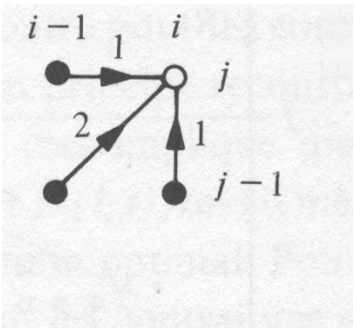
– Each grid point (i, j) is associatied with a *local distance* $d(i, j)$ and an accumulated distance $D(i, j)$.



(a) Local constraints (A)



(b) Local constraints (B)



(c) Local constraints (C)

– Type C constraints: Allow a path of any shape satisfying monotonicity.

– Spectral distance:

esto?

04. Mathematical Tools: Gaussian Mixture Model (GMM) (02,03)

- A Gaussian Mixture Model (GMM) is a parametric probability density function represented as a weighted sum of Gaussian component densities.
- Under the assumption that any arbitrary probability density function (PDF) can be approximated by a linear combination of uni-modal Gaussian densities, the Gaussian mixture models (GMMs) have been applied to model the distribution of a sequence of D-dimensional feature vectors.
- The sum of *mixture weights* equals 1.
- Model parameters: $\lambda = \{w_i, \mu_i, \Sigma_i\}$ (estimated with Expectation Maximization algorithm, although can also be estimated with Maximum A Posteriori estimation).
  - Expectation step: Compute a posteriori probability for component i
  - Maximization step: Maximize, guaranteeing a monotonic increase in model's likelihood.
- MAP estimation is used in speaker recognition to derive speaker model by adapting from a speaker independent universal background model (UBM), or to adapt a prior, general model.
- Decision is carried out using a likelihood test with H_0 (tested recording and speaker's model are from same source), H_1 (not H_0) and Bayes theorem (σ is the decision threshold):

$$\frac{P(T|\lambda_0)}{P(T|\lambda_1)} > \sigma$$

- Similarity domain normalization: $\log L(X) = \log p(X|S = S_c) - \log \sum_{S \in \text{Cohort}} p(X|S \neq S_c)$
- Normalization by a general/world model: A Gaussian mixture which models the parameter distribution for free-text utterances by many speakers.

05. Mathematical Tools: Hidden Markov Model (HMM) (02,03)

- HMM is a statistical Markov model in which the system being modeled is assumed to be a Markov process with unobserved (i.e. hidden) states. Is doubly probabilistic finite-state machine.
- **Ergodicity**: There is transition from any state to any other state.
- **Three Basic HMM Problems**:
  1. **Decoding** – Given the observation sequence $X = [x(1), x(2), ..., x(t), ..., x(L)]$ and the word model $W = (A, B)$, how do we choose a state sequence $Q = [q(1), q(2), ..., q(t), ..., q(L+1)]$ that is optimal in some meaningful sense sense (e.g. maximal probability)?
  2. **Evaluation** – Given the observation sequence $X = [x(1), x(2), ..., x(t), ..., x(L)]$ and a word model $W = (A, B)$, how do we (efficiently) compute $P(X|W)$ (probability of the observation sequence)?
     - The Baum-Welch algorithm (**forward**): $\alpha_j(t) = \sum_i \alpha_i(t-1) \cdot \alpha_{ij} \cdot B_{ij}(X(t))$
     - The Baum-Welch algorithm (**backward**): $\beta_i(t) = \sum_j B_{ij}(X(t+1)) \cdot \alpha_{ij} \cdot \beta_j(t+1)$
     - **Total probability**: $P(X|W) = \alpha(L, q_F) = \beta(0, q|I)$
  3. **Training** – How do we adjust the model parameters $W = (A, B, \pi)$ to maximize $P(X|W)$? Algorithm de Baum-Welch (forward-backward):
     - Calculate *all forward-backward* probabilities for all states q_i
     - Calculate posterior probability of transitions γ_{ij}, from state i to state j, conditioned on the observation sequence and the model.
     - Obtain a new estimate $a_{ij} = \gamma_{ij}(X)/\gamma_i$
     - If the value of the total probability has not improved compared to the previous iteration, the re-estimation has converged.
- Continuous Density HMM (CD-HMM) – Parametric approach: Continues probability density functions (ergodic and left-right models).
- *Viterbi Algorithm*: By induction, find the path that leads to a *Max. Likelihood* considering the best likelihood at the previous step and the transitions from it.

06. Mathematical Tools: Principal Component Analysis (PCA) – Karhunen-Loeve transformation

- *Seeks directions that are efficient for representing the data, maximize determinant of total scatter* – Find set of parameters s.t. most variability in the data is compressed in first parameters. The transformed PCA parameters are orthogonal. It diagonalizes the covariance matrix → diagonal elements are the variances of the transformed PCA parameters.
- Advantages and disadvantages:
  - *Advantages*: Completely decorrelates; packs the most variance in the fewest number of transform coefficients; minimizes MSE between reconstructed and original data; minimizes the total entropy of the data.
  - *Disadvantages*: Not fast implementation and computationally costly to get eigenvalues and eigenvectors; not a fixed transform – needs to be generated for each type of data statistic; problems for different illumination, pose, expression.
- To obtain K eigenfaces:
  1. Let X_{DM} the matrix that has features per rows (X_{DM} has been mean-centered, $X = X_0 - \mu$).
  2. Compute covariance (scatter) matrix $C_{DD} = X \cdot X^T$ (or $C_{MM} = X^T \cdot X$, if $D \gg M$)
  3. SVD: Compute eigenvectors and Eigenvalues of chosen C
  4. Choose K largest eigenvalues

5. Form W_{DK} with K columns of eigenvectors
6. Transform data/features by projecting onto face space: $X_{\text{PCA}} = W^T \cdot X$
7. Extra stuff: $E_{DD} = W^T C_{DD} W$, $E_{MM} = V^T C_{MM} V$ (both E are the same, only adding 0 to get correct dimension); $X = W \cdot E \cdot V^T$

- To recognize a face r:
  1. Subtract average face from it $r_m = r - m$
  2. Compute its projection onto the face space $x_{PCA} = W^T \cdot r_m$
  3. Compute its difference w.r.t all known faces
  4. Reconstruct the face from eigenfaces: $r_{PCA} = W \cdot x_{PCA}$
  5. Distance between the face and its reconstruction: $|r_m - r_{PCA}|_2^2$ (depending on value, r can be not a face, a new face or a known face)

07. Mathematical Tools: Linear Discriminant Analysis (LDA)

- *Seeks directions that are efficient for discrimination between the data*: maximizes ratio between determinant of *between-class scatter* and determinant of *within-class scatter*.
- Problems: Small databases; the face to classify must be in database.
- Compute Fisherfaces:
  1. Compute average of all faces (m)
  2. Compute average face of each person $x_i = 1/2 \cdot (a_i + b_i)$
  3. Substract average person face for training faces (a_i^m=a_i-x_i, b_i^m=b_i-x_i)
  4. Build **between-class scatter matrix** $S_B = \sum_i 2 \cdot |x_i - m|_2^2$
  5. Build scatter matrices $S_i = a_i^m \cdot (a_i^m)^T + b_i^m \cdot (b_i^m)^T$
  6. Build **within-class scatter matrix** $S_W = \sum_i S_i$
  7. We are seeking the matrix W maximizing the ratio between *between-class variance* and *within-class variance* is maximized:
  $$J(W) = \frac{|W^T S_B W|}{|W^T S_W W|}$$
  8. Project faces onto LDA-space: $x_{LDA} = W^T x$
- To classify a face:
  1. Project it onto LDA space
  2. Run a nearest-neighbor classifier
- **Comparison with PCA**:

LDA	**PCA**
Fisherfaces	*Eigenfaces*
Discrimination	Uncorrelated representation
Maximize *inter* to *intra* class variability	Lower dimensional space
$N^2 \Rightarrow P - 1$, P nb. classes	$N^2 \Rightarrow K$
Works with different illumination	Problems with different illumination
Same intra-class variability for all classes	Verify if it's a face

- **Combination of PCA and LDA** – First apply PCA to reduce dimensionality, then apply LDA:
$$W_{\text{Fisher}} = \arg\max_W \frac{W^T W_{\text{PCA}}^T S_B W_{\text{PCA}} W}{W^T W_{\text{PCA}}^T S_W W_{\text{PCA}} W}$$

08. Enrolment and Template Creation

⇒ Feature extraction; Modeling of features

- **Enrolment** – process of enrolling a user into a biometric system. This generally involves creating a template for the user and storing it in the database.
- **Template** – compact, electronic representation of a biometric sample that is created at the time of enrolment, and stored in the system database for future reference and comparison.
- **Comparative analysis** – comparison between two biometrics, typically a tested sample and an enrollment (reference) template or model. The output of the comparison is a distance or score.
- *Enrolment phase* – each individual provides a sample, from which features are extracted and used to create a template for said user. It may involve training a model to obtain the template or just storing the feature vectors.
  Sensor ⇒ preprocessing ⇒ feature extraction ⇒ generation and storage of template
- *Matching/testing phase* – Features are extracted from a newly provided sample (test sample), and are compared with the template features (reference templates). A score is obtained.

(See table 1 and Expectation Maximization for GMM)

09. Verification and Identification System Errors

10. Evaluation of Biometric Systems (01,03)

Non-technical aspects:

- **Users acceptance**: Ergonomics (accuracy, speed, resource requirements); Health and safety (harmless); Psychology (accepted)
- **Legal and social issues**: Privacy; Data Protection Legislation (robust); Accessibility

Technical performance testing:

- Reliability, availability and maintainability;
- Vulnerability;
- Security;
- User acceptance;
- Human factors;
- Cost/benefit;
- Privacy regulation compliance.

Types of Evaluation:

- Technology – Offline, using pre-collected samples.
  ⇒ In enrolment: same general conditions
- Scenario – Online, performance in prototype or simulated application.
  ⇒ In enrolment: modeling potential target application
- Operational – Online, performance in specific application environment and specific target population.
  ⇒ In enrolment: no control over conditions

Technology Evaluation. Mistakes are testing on training set and overtraining. Phases:

- **Phase 1 Training** – Database A is available. It is split into training and validation tests. System is trained on it.
- **Phase 2 Testing** – The sequestered data is newly made available and used to test biometric matchers. The scores obtained are used to estimate FMR and FNMR (FAR and FRR for positive authentication) as a function of threshold T.

Technical Performance Evaluation: assesses *accuracy* and *usability*. Performance, Accuracy, Enrollment and Response time, Throughtput, Scalability.

- Matching errors: **FMR** and **FNMR**:
  - False Match Rate **FMR** – proportion of impostor attempt samples falsely declared to match the compared nonself template (number of impostor FMs / number of impostor attempts)
  - False Non-Match Rate **FNMR** – proportion of genuine attempt samples falsely declared not to match the template of the same characteristic from the same user submitting the sample (number of genuine FNMs / number of genuine attempts)
  - **Calculation**: Create biometric templates using training data set. Define a test set with genuine and impostor trials. Run test and group genuine and impostor scores. Choose threshold value T and calculate FMR(T) and FNMR(T).
- Decision error rates: **FAR** and **FRR**:
  - False Accept Rate **FAR** – Proportion of imposters accepted (security breaches)
    FAR=FMRx(1-FTA)
  - False Reject Rate **FRR** – Proportion of genuine users rejected (inconvenience)
    FRR=FTA+FNMRx(1-FTA)
- Data acquisition errors: **FTA** and **FTE**:
  - Failure to Acquire Rate **FTA** – Proportion that cannot be verified (does not process a certain biometric)

  - Failure to Enroll Rate **FTE** – Proportion that cannot be enrolled (system fails to complete the enrolment process, due to bad quality)

- **DET** and **ROC** curves:
  - Detection Error Tradeoff **DET** – can be computed from distributions of scores with a variable threshold. FAR vs FRR
  - Receiver Operating Characteristic **ROC** – Correct Accept Rate as function of False Accept Rate (FAR)

- **CAR** and **CRR**:
  - Convenience – Correct Accept Rate **CAR**=1-FRR
  - Security – Correct Reject Rate **CRR**=1-FAR

- **Performance measures for identification**:
  - Correct Identification Rate (**CIR**) – proportion of identification transactions by users in the system s.t. the user's identifier is among the ones returned.
  - Cumulative Match Characteristic (**CMC**) – Identification rate as function of K.

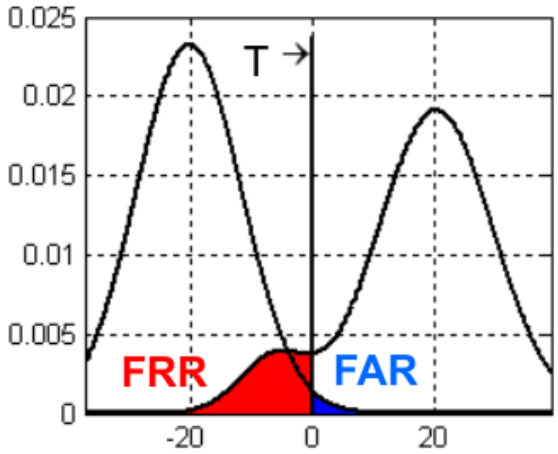


Figure 5: Threshold T, FRR and FAR

Planning the Evaluation

- What exactly is the evaluation trying to determine?
- Which is the appropriate evaluation type: technology, scenario, or operational?
- Determine information about the system – Needed to determine data collection procedures:
  - Logs transaction information
  - Saves sample images or features for each transaction
  - Returns matching scores or just accept/reject decisions
  - Image quality and matching decision thresholds for target application
  - Expected error rates
  - Factors that influence performance (Population demographics, Application, User physiology, User behaviour, User appearance, Environmental Influences, Sensor and hardware, User Interface). *Classes*:
    - Independent variables, to observe effect they may have
    - Controlled factors (experimental conditions, unchanging)
    - *Randomized* factors
    - Ignored factors (considered to have no effect), which will be ignored

- Data collection
  Test size:
  - Rule of 3 – $p \approx 3/N$ for 95% confidence level, N trials, p error rate
  - Rule of 30 – To be 90% confident that the true error rate is within ±30% of the observed error rate, there must be at least 30 errors.

  Definitions: *Corpus* (raw data samples or features); *Database* (information about those images and the volunteers who produced them)

Scenario Evaluation.

- Objectives:
  - Show attainable level of performance
  - Determine the feasibility of demonstrating satisfactory performance through testing
  - Encourage more testing to be sponsored and promote methodologies
- Results presented include: FTE and FTA, FMR and FNMR, FAR and FRR; Throughput rates of users (live) and of matching algorithm (offline); Sensitivity to environmental conditions and differences in performance over different classes of users.

Enrolment Evaluation – UKPS Biometric Enrollment Trial
Trial commissioned by the UK Passport Service in partnership with the Home Office Identity Cards Programme and the Driver and Vehicle Licensing Agency (DVLA). Eight months; involved 10,000 volunteers. Research was undertaken by Atos Origin.

Selecting a Biometric – Selecting a biometric involves not only accuracy (e.g. good looking devices outsell ugly). Biometrics Checklist:

- Background Work
- Enrolment Issues
- Technical Considerations
- Cost Issues
- User-related considerations
- Operational Issues
- System Administration Concerns

Performance of Forensic Biometrics

- Likelihood ratio (LR) summarises forensic expert's statement
- Performance evaluation of LR method can be obtained from the observed strength of evidence (LR) when H_0 is true and when H_1 is true.
- Evaluation should be carried out using a relevant population database
- Performance characteristics (e.g., Tippett plots I and II as well as Proportions Trade-Off (PTO) plot)
- Performance metrics provide a single numerical value that describes the performance in terms of e.g., accuracy, discriminating power, etc. of the LR method (e.g., probabilities of misleading evidence (PMEH_0 and PMEH_1), equal proportion probability (EPP))

Miscellaneous

11. Forensic Automatic Speaker Recognition (03)

Speaker Recognition Systems – 3.10.2017 3

Forensic Automatic Speaker Recognition (FASR) – Analysis, Modeling and Interpretation of Biometric Data

- Mathematical Tools for Biometric Signal Processing and Pattern Recognition (The odds form of Bayes' theorem)
- Models of Features for Recognition (Biometric Evidence, Models of scores variability for suspected speaker and relevant population , Bayesian Interpretation of Biometric Evidence, Strength of Evidence – Likelihood Ratio)
- Biometric System Errors (Evaluation of the Strength of Evidence – Tippett plots and Probability of Misleading Evidence, Empirical Cross-Entropy (ECE) and Log-Likelihood Cost (Cllr))

- **Forensic Biometrics** – Challenge is to automate forensic biometric methods. Applications of biometric principles and methods to the investigation of criminal activities: to demonstrate the existence of a crime and determine the author. *Forensic* means the use of science or technology in the investigation and establishment of facts or evidence in the court of law.
- **Existing systems and databases**:
  - Automatic Fingerprint Identification System (AFIS) and fingerprints databases
  - DNA sequencers and DNA databases
  - Challenge: Automatic Biometric Identification System (ABIS) and databases for voice, face...
- **Speaker Identification Integrated Project (SIIP)** – Aims to develop technology to rapidly identify suspects' voices and isolate conversations of interest in a wide range of cases (kidnapping, ransom or terrorist calls...)
- **Forensic Speaker Recognition (FSR)**:
  - **Aural-perceptual methods**: earwitnesses, line-ups
  - **Visual methods and *voiceprint?***: visual comparison of spectrograms of linguistically identical utterances (utterly misleading!)
  - **Aural-instrumental methods**: analytical acoustic approach combined with an auditory phonetic analysis
  - **Automatic methods**:
    - *Speaker verification* – not adequate
    - *Speaker identification* – not adequate
    - *Voice as biometric evidence* (How to measure biometric evidence?)
- **Automatic Speaker Recognition (ASR)**:
  - FASR $\neq$ Speaker Verification
  - H_0 (H_1) – speaker's model λ_0 and the tested recording T have same (different) source.

$$\frac{P(H_0)}{P(H_1)} \cdot \frac{P(T|H_0)}{P(T|H_1)} = \frac{P(H_0|T)}{P(H_1|T)} \qquad \frac{P(T|\lambda_0)}{P(T|\lambda_1)} > \sigma \qquad (\sigma \text{ – Decision threshold})$$

- See Table 1.
- **Forensic Automatic Speaker Recognition (FASR)**:
  - **Forensic specifity** – Role of *forensic science* is to testify to the worth of the evidence *quantitatively* (if possible). Forensic science provides *opinion* to help investigators and courts of law answer important questions. Up to the *judge/jury* to use this information in deliberations and decision.
  - **Evaluative forensic science opinion** – opinion of evidential weight, based upon case specific propositions (hypotheses) and clear conditioning information (framework of circumstances) that is provided for use as evidence in court. Is based upon the estimation of a likelihood ratio (in relation with Bayesian interpretation of evidence).
- **Bayesian Interpretation of Biometric Evidence** ($H_0 \equiv$ suspected speaker is source of the recording). Via Bayes Rule, we use the data to update prior beliefs about unknowns. See Figure 6. Freedom of: choosing evidence evaluation and its value; formulating propositions; choosing automatic speaker recognition method.

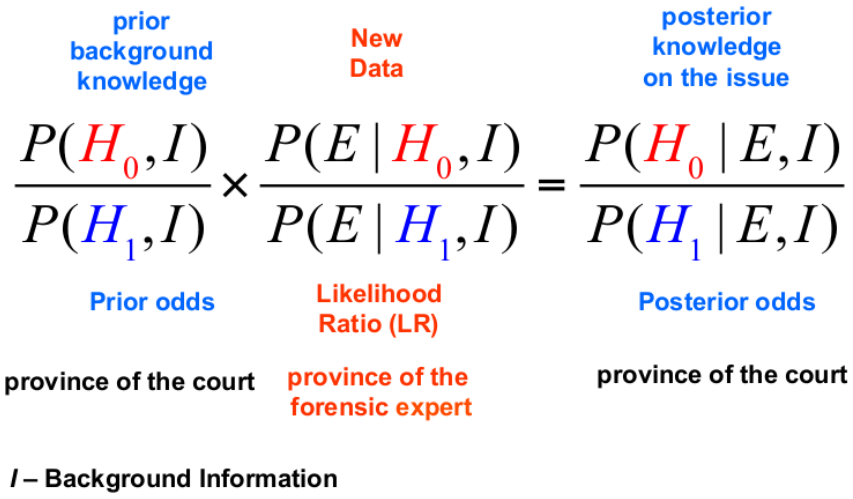


Figure 6: Odds form of Bayes' Theorem: Bayesian Interpretation of Forensic Evidence

- **Measures**:
  1. **Biometric Evidence** – Quantified degree of *similarity* between the speaker dependent features extracted from the trace and the extracted from recorded speech of a suspect (model).
     - **FASR – Univariate (Scoring) Method** – See Figure 1. The *score* is used together with the distributions of *between-sources variability* and the *within-source variability* to reach a decision.
  2. **Strength of Evidence – Likelihood Ratio** – A likelihood ratio $LR = P(E|H_0)/P(E|H_1)$ of 9.16 means that it is 9.16 times more likely to observe the score (E) given H_0 than given H_1. If $LR > 1$ then H_0, else H_1.
     - **FASR – Multivariate (direct) Method** – E is the multivariate feature representation of trace evidence.
  3. **Evaluation of the Strength of Evidence** – (similar idea to Figure 5) *Principle*: Estimation and comparison of likelihood ratios that can be obtained from same speaker and different speaker trials. H_0 true →suspected person recording and questioned recording are from same speaker.
     - Tippett plots I to obtain *Probability of Misleading Evidence (accuracy)* PMEH_0 and PMEH_1.
     - Tippett plots II to obtain EPP (Equal Proportion Probability), PD (Probabilistic Distance) of case LR_{case} to PMEH_0.

- Empirical Cross-Entropy (ECE) and Log-Likelihood Cost (CLLR)

these two?

12. Forensic Biometrics (Fingerprints, Face, DNA, Ear, Gait)

- **Fingerprints**:

$$LR = \frac{p(\text{evidence}|H_p)}{p(\text{evidence}|H_d)}$$

with H_p (suspect left the fingerprint), H_d (someone else left the fingerprint), numerator (variability of minutiae configurations due to distortion and clarity), denominator (variability between minutiae from different sources). Delaunay triangulation, MCC and Local Quality Measures (embedding quality measures), ridge quality maps are used.

- **Face**:
  - Challenges: Forensic Sketch Recognition, Facial Aging, Facial Marks, Unconstrained Facial recognition
  - De-identification: Blurring, pixelation
  - Near infra-red to Visible Light images
- **DNA**: Very used in forensics to match crime scene evidence to individuals.
  - DNA profiles from a single region (Locus); DNA lineup of the *suspects*
  - Uses: Identify a person; exclude a suspect; link suspect, victim and crime scene; link weapon to victim; link witness to scene; (dis)prove alibi; reconstruct scene; provide investigative leads.
  - *Innocence Project* – To exonerate falsely incarcerated individuals.
  - Missing persons investigation and mass disasters – Only possible method to identify remains in some cases. Time is the biggest enemy. Family members can be used to identify remains.
- **Ear**: Identify ear traces
- **Gait**: How people walk. Identification of burglars from security/surveillance camera recordings.

13. Biometric Standards

Standards and Evaluation – 5.12.2017

Standards
- Standardisation Organisations
- Biometrics Based ISO Standards
- ICAO Recommendations for Biometric Passports

Evaluation of Biometric Systems
- Technology Evaluation
- Scenario Evaluation
- Operational Evaluation
- Best Practices in Testing and Reporting Performance of Biometric Devices
- Performance of Forensic Biometrics

Why standards? For interoperability and data interchange between applications and systems. Included are: APIs, file formats, biometric templates, template protection techniques, related application/implementation profiles, methodologies for conformity.

- Interoperability
- Vendor independence
- Cost effectiveness
- Increased competition
- Reduced risk

Standardisation Bodies

- **Industry**:
  Industry Consortia: BioAPI, BC (Biometric Consortium)
- **National** Standardization Bodies:
  ANSI (American National Standards Institute), SNV (Swiss Association for Standardization)
- **International**:
  - ISO/IEC (International Organization for Standardization/International Electrotechnical Commission)
  - ICAO (International Civil Aviation Organization)
  - EU: CEN/ISSS (European Committee for Standardization (Comité Européen de Normalisation)/ Information Society Standardization System)

Biometrics Based Standards – *Subcommittee 37 (SC37) on Biometrics*

- Established by ISO/IEC Joint Technical Committee 1 (JTC 1) in June 2002
- an international venue to accelerate and harmonize formal international biometric standardization
- to ensure that future standards based systems and applications are more interoperable, scalable, reliable, usable, and secure
- **Working Groups** (WG):
  - WG 1 – Harmonized Biometric Vocabulary and Definitions (what we mean by the words)
  - **WG 2 – Biometric Technical Interfaces (how data is transferred in a biometric system)**. *BioAPI* is intended to provide a high-level generic biometric authentication model

suited for any biometric technology. Covers Enrollment, Verification, and Identification. Includes a database interface to allow a biometric service provider (BSP) to manage the identification population for optimum performance. Also provides primitives for Capturing on a client and Enrollment, Verification, and Identification on a server.
Benefits:

* Easy substitution of biometric technologies
* Use of biometric technology across multiple applications
* Easy integration of multiple biometrics using the same interface
* Rapid application development - increased competition (tend to lower costs)

– **WG 3 – Biometric Data Interchange Formats (how biometric characteristics are encoded in an interoperable way)**.
Projects:

* 19794-1 – Framework
* 19794-2 – Finger Minutiae Data
* 19794-3 – Finger Pattern Spectral Data
* 19794-4 – Finger Image Data
* 19794-5 – Face Image Data
* 19794-6 – Iris Image Data
* 19794-7 – Signature/Sign (Behavioral) Data
* 19794-8 – Finger Pattern Skeletal Data
* 19794-9 – Vascular Image Data
* 19794-10 – Hand Geometry Silhouette Data
* 19794-11 – Signature/Sign Processed Dynamic data
* 19794-12 – Face Identity Data
* 19794-13 – Voice Data
* 19794-14 – DNA Data
* 19794-15 – Hand Crease Data

Layers of standards:

* **Layer 1**: Data Formats – The Biometric Data Block (BDB). Defines formats for the digital representation of measurements of various physical characteristics. Can be *images* and/or extracted *features*.
* **Layer 2**: Meta-data – Common Biometrics Exchange File Format (CBEFF) is an emerging standard for sharing biometrics in raw signal or template form. The standard is recommended for interchange between different components of a system or across systems.
  Biometric Information Record (BIR) is an encapsulating unit for storage and transfer of BDBs and consists of BDB + Metadata. *Enrolment* is capturing biometric data into a BIR and storing it.
  Data described by CBEFF includes:
  · Security information in the form of digital signatures and data encryption
  · Identification of biometric type
  · Information about the biometric sample
  · Actual biometric data
* **Layer 3**: System integration – BioAPI
* **Layer 4**: Interworking systems – BIP

        * Societal and Legal issues
        * Vocabulary, Testing and Evaluation
    - WG 4 – Biometric Functional Architecture and Related Profiles (selecting the right options in the standards for a specific application)
    - WG 5 – Biometric Testing and Reporting (testing that systems will perform)
    - WG 6 – Cross-Jurisdictional and Societal Aspects (taking care of the legal and societal aspects)

ICAO Recommendations for Biometric Passports

- UN agency: managing civil aviation. Defining biometric requirements for travel documents
- ICAO selected biometrics as the technique to verify association between travel documents and the owner. Issues:
    - Interoperability
    - Reliability of biometric data
    - Appropriate methods of electronic storage and transmission
    - Security from tampering and for citizen privacy protection
- ICAO Recommendations:
    - Adaptation of ICAO recommendations for ePassport: Storage on ISO 14443 conform Chip; Primary biometric feature FACE (FINGER and IRIS optional)
    - Interoperability based on defined ISO standards based interfaces and data interchange formats

  ICAO Technical Reports:

    - Describe how biometrics and chip technology schould be applied in Machine Readable Travel Documents (MRTDs).
    - Provide implementation specialists with the specifications needed to achieve global interoperability in issuance and inspection

  Biometric ePassport Specifications (since 2004)

    - Contactless IC Chip
    - Logical Data Structure
    - PKI to digital sign data
    - Facial Recognition (Iris and Fingerprint optional)

14. Securing Biometric Data and Biometric Encryption

15. Biometrics in Identity Documents

16. Privacy and Legal Issues

Privacy:

- Data protection – fair practices
- Security:
  - Authentication
  - Data-integrity
  - Confidentiality
  - Access Controls
  - Non-repudiation

Legislation USA:

- USA Patriot Act – US Public Law 107-56
  - Tools for strengthening law enforcement agencies to intercept and obstruct terrorism.
  - Requires use of fingerprints to obtain criminal history background of visa applicants to the USA.
  - Study to investigate the use of biometrics (emphasis on fingerprints) for providing access to the FBI IAFIS (Integrated Automated Fingerprint Identification System) at overseas consular posts and points of entry to the USA.
- Improve Aviation Security using emerging technologies – US Public Law 107-71
- Enhanced Border Security and Visa Reform Act – US Public Law 107-173
- Paperwork Reduction Act (PRA)
- Health Insurance Portability and Accountability Act (HIPAA)

Legislation Europe: Council of Europe, *Convention for the protection of individuals with regard to automatic processing of personal data*, European Treaty Series – No. 108, Strasbourg, 28.01.1981

- **Article 1 – Object and purpose**: *Data protection.* Secure in the territory of each Party for every individual respect for his rights and fundamental freedoms, in particular his right to privacy, with regard to automatic processing of personal data relating to him.
- **Article 5 – Quality of data**: Personal data undergoing automatic processing shall be:
  - obtained and processed fairly and lawfully
  - stored for specified and legitimate purposes and not used in another way
  - adequate, relevant and not excessive in relation to the intended purposes
  - accurate and up to date
  - preserved in a form which permits identification of the data subjects for no longer than is required for the purpose for which those data are stored
- **Article 6 – Special categories of data**: Personal data revealing racial origin, political opinions, religious beliefs, health or sexual life, may not be processed automatically unless domestic law provides appropriate safeguards. The same applies to personal data relating to criminal convictions.
- **Article 7 – Data security**: Appropriate security measures for protection of personal data stored in automated data files against accidental or unauthorised destruction or accidental loss as well as against unauthorised access, alteration or dissemination.
- **Article 8 – Additional safeguards for the data subject**: Any person shall be enabled:

  - to establish the existence of an automated personal data file, its main purposes, and the identity and habitual residence of the controller of the file
  - to obtain confirmation of whether personal data relating to him are stored in the automated data file as well as communication to him of such data
  - to obtain rectification or erasure of such data if these have been processed contrary to the provisions of domestic law giving effect to the basic principles in Articles 5 and 6
  - to have a remedy if a request for confirmation or communication, rectification or erasure is not complied with
- **Directive 95/46/EC** of the European Parliament and of the Council of 24 October 1995 on the *protection of individuals with regard to the processing of personal data and on the free movement of such data*

Legislation Switzerland: The Federal Data Protection and Information Commissioner (FDPIC)

- SR 235.1 Federal Act on Data Protection (Federal Council)
- Annual reports (24th annual report 2016-2017)
- Information Sheets and Guides
- **Biometric Data in the Private Sector**: FDPIC *Some data protection considerations with regard to the use of biometric data in the private sector*
- **Swiss National Science Foundation (SNSF) projects**:
  - ABID 1: *Applying Biometrics to Identity Documents: Technological, Legal and Security Challenges and Applications*
  - ABID 2: *Applying Biometrics to Identity Documents: Investigation of security issues and elaboration of an efficient communication strategy*
  - **Partners**:
    * Ecole des sciences criminelles, UNIL
    * Speech Processing and Biometrics Group, EPFL
    * Swiss Institute of Comparative Law (Lausanne)
    * Università della Svizzera italiana – Istituto di Comunicazione Istituzionale e Formativa
- **Swiss Biometric Passport** (17 May 2009) Swiss voters approved of the new electronic passport and a central fingerprint register. One of the closest results in recent Swiss history.