Biometric System

Biometric Traits
- Properties
  - Universability
  - Uniqueness
  - Permanence
  - Measurability
  - Acceptability
- Strong
  - Iris
  - Fingerprint
- Weak
  - Hair color

Multibiometric systems
- Various possibilities
  - Multiple sensors
  - Multiple biometric traits
  - Multiple probes
  - Multiple algorithms
  - Multiple instances
- The merging of multiple traits can occur at different points
  - Sensor level fusion
  - Feature level fusion
  - Score level fusion
    - Majority voting — Abstract
    - **Borda count** — Rank
    - Normalization — Measure
  - Decision level fusion
    - Logical AND or OR
    - Majority voting

Fingerprint recognition
- Fingerprint classification
  - **Macro singularity**
    - Arches
    - Loops — In Henry classification divided in left loops and right loops
    - Spirals
  - **Micro singluarity (minutiae)**
    - End points
    - Bifurcations
    - Delta
  - **Third level features** — Pores along crests
  - Randotypical but with some similarities between twins
  - Created by FBI — AFIS: Automatic Fingerprint Identification System
- Fingerprint capture
  - Two steps — Offline — Fingerprint on paper with a special ink; Called **latent fingerprints**
  - Online — Digital sensor
  - Common issues
    - Alignement
    - Skin conditions
    - Variable finger pressure
    - Too much movement
    - Partiality of latent fingerprint
- Four aspects
  - Global pattern evaluation
  - Quality of the fingerprint, evaluate the minutiae
  - At least 12 minutiae should match — Evaluate the quantity
  - Matching details that need to be interconnected
- Three main type of matching
  - **Correlation based** — The two images are overlayed and a calculation is made of the correlation of the various pixels
    - High computational cost
    - Sensitive to nonlinear transformations
  - **Ridge features based**
    - Orientation, frequence and shape of the ridges
    - Poorly discriminative
    - Used for low quality images
  - **Minutiae based**
    - Minutiae are extracted and used as points in a bi-dimensional space
    - Look for a possible alignment that maximizes the number of matches between minutiae
- Segmentation — Separate the background from the fingerprint
- Matching
  - **Macro features**
    - **Ridge flow**
      - Directional map
      - Grid based approach
    - **Ridge density** — Density map
    - **Poincaré index**
      - To extract singularities
      - Can have one of this values
        - 0: no singularities
        - 180: loop
        - -180: delta
        - 360: spiral
      - Represents the total rotation of the vectors of a certain curve
  - **Micro features**
    - Three steps required
      - 1. Image binarization
      - 2. Ridge flattening — To one pixel
      - 3. Minutiae localization — Using crossing-number analysis
        - 1: termination
        - 2: internal point of a ridge line
        - 3: Bifurcation
        - >3 complex minutia
    - **Ridge count**
      - Measure the distance between two minutiae
      - The number of ridge between a minutia and another
  - Hybrid Approach
    - Extracting minutiae helps to find the best possible alignment between probe and template
    - Use a bank of Gabor Filters for feature extraction
  - Fake fingerprints
    - Silicone or gelatin
    - Liveness detection to detect them

Iris Recognition
- Highly randotypical
- Pros
  - High discriminative power
  - Non-invasive capture
  - Non-variance over time
- Cons
  - Hardware required to capture the iris
  - Capture may be inconvenient
- Type of captures
  - Visible light
    - Light reflected from the iris generates noise and ruins the quality of the sample
    - Low illumination does not capture iris features well — Requires preprocessing
  - NIR
    - Color information is lost
    - Does not suffer from reflection problems
    - Requires specific hardware
- **Daugmann system**
  - Main phases
    - Localization — The integro-differential operator is used as a circular edge detector
    - Normalization
      - **Rubber Sheet Model**
        - Pseudo-polar mapping system
        - The difference with a classical polar mapping is that here we try to correct a possible off-center between pupil and limbus by going to use the segment between the pupil circle and the limbus circle as the radius, then taking a finite number of points along this
      - Important because it allows us to work on a linear plane where each iris takes the same size
    - Feature extraction (encoding) — **Gabor filters** to obtain a binary image
    - Matching — Hamming distance
- **NICE**
  - Noisy Iris Challenge Evaluation
  - NICE 1 — Iris segmentation and detection and correction of noise
  - NICE 2 — Encoding and matching
- **IS_(IS)**
  - Phases
    - Segmentation
      - Posterization filter to enhance image contrast
      - Canny edge detector
      - Taubin's circle fitting algorithm to find candidate eyes
      - Omogenity score (for the pupil)
      - Separability score
    - Feature extraction — LBP + BLOB

Ear Recognition
- Ear structure
  - **Helix**: the external border
  - **Anti-Helix**: internal borders
  - **Earlobe**
  - **Intratragical notch**: the point between the lobe and the ear hole
- Pros and cons
  - Pros
    - Passive trait
    - Age resistant
    - Not covered usually
    - High resolution not needed
    - Not affected by expression variation
  - Cons — Affected to illumination and pose variations
- Ear localization
  - 3 main ways
    - **Key-points localization**
      - Neural Networks — Different ways to extract them
      - To obtain a rectangle containing the ear that wil be normalized
    - **Object detection** — E.g. Viola-Jones
    - **Distance capture**
      - Using a distance measure with the image
      - The ear will contain the components with the minor distance
- Feature extraction and recognition
  - Multiple Approaches
    - 2D
      - Iannarelli
        - Helix is used as a starting point for 4 segments
        - 12 measurements
        - Feature vector contains gender, etnicity and the 12 measurements
      - Voronoi
      - Force fields — Based on physical properties where each pixel is consider an "attractor"
      - Jet
      - SIFT
    - 3D
      - Depth
      - Curvature of the components of the ear
      - Thermal camera
        - Pros
          - Easy to locate the ear
          - Robust to occlusions
        - Cons
          - Not robust to movements
          - Low resolution
          - High cost

Spoofing and camouflage
- Spoofing involves deceiving a biometric system by assuming an identity that does not belong to us
- The purpose of camouflage is to avoid being recognized by the system
- Spoofing can be classified in two types
  - At capture time — Direct
  - In the following steps — Indirect
- Face spoofing
  - **Print attack**
    - Different between a genuine face and a print
      - Color differences
      - Differences in light reflections
      - Texture differences
    - In all these cases LBP can be a solution
    - Other type of solutions are
      - Involuntary face movements
      - In general all the liveness detection features
  - **Video** — LBP is a solution
  - **Face mask** — Light reflection on the skin
- Metrics
  - **Spoofing FAR**
  - **False Living Rate**
  - **False Fake Rate**

Face Recognition
- 2D face recognition
  - Feature extractors
    - **LBP: Local Binary Pattern**
      - Operator that works pixel by pixel
      - To extract informations about the textures
      - First version
        - Consider a 3x3 grid of pixels
        - Assign a binary value of all the pixels
          - If the value is greater than the center pixel 1
          - Otherwise 0
        - To obtain a binary string — Then assigned to the central pixel
      - Then generalized
        - Number of close point is a parameter
        - Same for the distance ray
      - **Uniform patterns**
        - Contains at most 2 transitions 0->1 or 1->0
        - Represent essential informations
        - To reduce the dimensionality
      - To obtain a feature vector
        - 1. The image is divided in sub-windows k*k
        - 2. For each sub-window compute the histogram (a pattern for each bin)
        - 3. The final vector is obtained concatenating the k^2 histograms
    - **Gabor Filter**
      - Using
        - Filters
        - Transformations
        - Operators
      - Linear filter used in edge detection
      - Gaussian kernel modulated by a sinusoidal plane wave
      - In images or complex tasks a single filter is not enough — **Bank of filters**
        - To extract a feature vector
        - With big images this creates really big feature vectors — Two possible solutions
          - Apply the filter on a subset of pixels — Some informations would be lost
          - Apply the filter to all pixels, then select only the points with peak values — Alignment problem
    - **EBGM: Elastic Bunch Graph Matching**
      - Collection of graphs — One for each pose
      - Vertices are weighted by the distance between nodes
      - Nodes contains a set of results from different Gabor Filters
        - 5 frequencies
        - 8 orientations
        - Stored in a structure called **Jet** — Located in important spots such as nose, eyes and mouth
  - Classification of 2D face recognition systems
    - Based on face appearance
      - PCA
      - LDA
      - Neural Networks
      - Issues
        - Gives to each pixel the same importance
        - Requires a big correlation from train and test data
        - On large variations of PIE, they are not performant
    - Based on local features
      - EBGM
      - LBP
      - Robust to position variance
      - Computationally fast
      - Issues
        - A-priori choice of points where the features are extracted
        - Lack of discriminative power
    - Based on graphs
      - Each face is associated with a graph
      - Each node corresponds to some discriminative points of the face
      - They are excellent from the point of view of position variation and illumination
      - Issues
        - Slow train
        - Slow test
    - Based on thermographic images
      - Excellent with regard to lighting variations
      - Require expensive hardware
      - Issues
        - Temperature can change based on the subject condition
        - Sensitive to movements
- 3D face recognition
  - Allows you to overcome A-PIE problems and disguises by impostors
  - Higher complexity
    - To capture data
    - To handle data
  - Two possible representations
    - 2.5D — 2D image with capture distance information
    - 3D
      - Points connected in the space (using triangulation) to create a **3D mesh**
      - Different capture methods
        - Stereoscopic camera
        - Light pattern scanner
        - Laser scanner
      - Preprocessing to solve
        - Noise
        - Presence of holes
        - Decentralization
  - From 2D images to 3D
    - Using shading properties
    - Using **morphing**
      - A 3D reference model is created
      - The model is then modified to model the face
      - **Morphable models**
    - From a 3D model it is possible to
      - Adjust the pose
      - Compute the **normal map** to compare it to other normal maps
- Face recognition evaluation
  - Usual metrics (FAR, FRR, CMS) provides a marginal evaluation of the performance of the system
  - It is important to consider the variations (not only A-PIE)
  - The dataset can influence the results
  - **FERET** is a popular dataset used as a benchmark for face recognition

Evaluation
- Performance measures
  - Common issues
    - High intra-class variations
    - Low inter-class variations
    - Noise
    - Spoofing
  - Verification
    - Possible outcomes
      - Genuine Acceptance GA
      - False Rejection FR — Type 1 error
      - False Acceptance FA — Type 2 error
      - Genuine Rejection GR
    - Metrics
      - False Acceptance Rate FAR — FAR = |{probe of impostors accepted}| / |{probe of impostors}|
      - False Rejection Rate FRR — FRR = |{probe of rejected genuine subjects}| / |{probe of genuine sunjects}|
      - Genuine Acceptance Rate GAR — 1-FRR
      - Genuine Rejection Rate GRR — 1-FAR
      - Equal Error Rate EER — FAR=FRR
      - Detection Error Trade-off DET — FAR vs FRR
      - Receiving Operating Characteristics ROC — GAR vs FAR
  - Identification
    - Open set
      - Detection and Identification Rate DIR@K — DIR(t, k) = |{p_j: rank(p_j) <= k and d_i,j <= t and id(p_j) = id (g_i)}| / |P_G|
      - False Rejection Rate FRR — 1-DIR(t, 1)
      - False Alarm Rate FAR — FAR = |{p_j: max_i d_i,j <= t}| / |P_N|
      - Equal Error Rate EER
      - Receiving Operating Characteristic — FAR vs DIR@1
    - Closed set
      - Cumulative Match Score CMS@K — Probability of identifying a subject within rank k
      - Cumulative Match Characteristic CMC — For each k, CMS@k
      - Recognition Rate RR — CMS@1
- Dataset Organization
  - Train and Test division
  - Probe vs gallery division
  - Probe set division
  - All probe vs All Gallery
  - All vs All
- Doddington Zoo
  - **Sheep**
    - good match with themselves
    - poor match with others
  - **Goat**
    - poor match with themselves
    - FR
  - **Lamb**
    - easily impersonable
    - FA
  - **Wolf**
    - good at impersonating
    - FA
  - **Chameleon**
    - High G_k
    - High I_k
    - FA
    - low FR
  - **Phantom**
    - Low G_k
    - Low I_k
  - **Dove**
    - High G_k
    - Low I_k
  - **Worm**
    - Low G_k
    - High I_k
- Image quality
  - Average template with train set
  - Sharpness estimate — Low high frequency
  - For face recognition — **SP** distortion
- **SRR: System Response Reliability**
  - This system uses a function ϕ that measures the amount of "confusion" among possible candidates
  - Taken the list given in output by an identification step, we look in the surroundings of the result at rank 1. If the subjects at lower ranks are very close, we will have an unreliable answer, otherwise if there is a good distance we will have a reliable answer
- Template Update Policy for Aging
  - Supervised
  - Semi-supervised
- Main issues
  - A-PIE
    - Aging
    - Pose
    - Illumination
    - Expression
  - Easy to spoof
    - Makeup
    - Cosmetic surgery
    - Glasses
  - Intra-personal variations
  - Inter-personal similarity
- Main phases
  - Image capture
  - Face localization
    - Subphases
      - Localization
      - Crop
      - Normalization
    - Two approaches
      - Feature based
        - Localization of main features such as eyes, mouth
        - Verification of some properties of them
          - Skin color
          - Eyes distance
          - Eyes-nose distance
      - Image based — Machine Learning models (usually CNNs)
    - **Algorithm A**
      - 1. Searching for possible faces
        - Illumination adjustment
        - From RGB to YCbCr
        - Localization based on the skin model
          - K-Means
          - Connection of the components identified by the model
      - 2. Verification of possible faces identified — Using face features
        - Eyes
        - Nose
      - 3. Assigning a score based on the possible combinations of eyes and mouth — The triangle with the highest score is selected
      - 4. Face's edge detection with Hough
    - **Algorithm B**
      - **Haar features**
        - Machine Learning approach with positive and negative samples
        - Ada-Boosting for feature selection
        - Cascade Classifier
  - Feature extraction
  - Main problems
    - Selection of discriminative features
    - Classifier design
    - The curse of dimensionality — Dimensionality Reduction
      - PCA — Issues
        - Lack of discriminative power
        - In the presence of PIE variations, the model could use those as principal components, making them useless
      - LDA: Linear Discriminant Analysis
        - Supervised
        - Minimize intra-class distance
        - Maximize inter-class distance