Organizers:

Student Grant Sponsors:

Biometrics: Progress, Problems and Prospects

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（Thanks to Wang Yunlong, SUN Zhenan, LI Qi and ZHANG Kunbo for their help in preparing this talk）

Nanjing University

Institute of Automation, Chinese Academy of Sciences

January 15, 2025

Outline

- Preamble
- Recent Progress
- Remaining Challenges
- Future Directions and Prospects
- Conclusions

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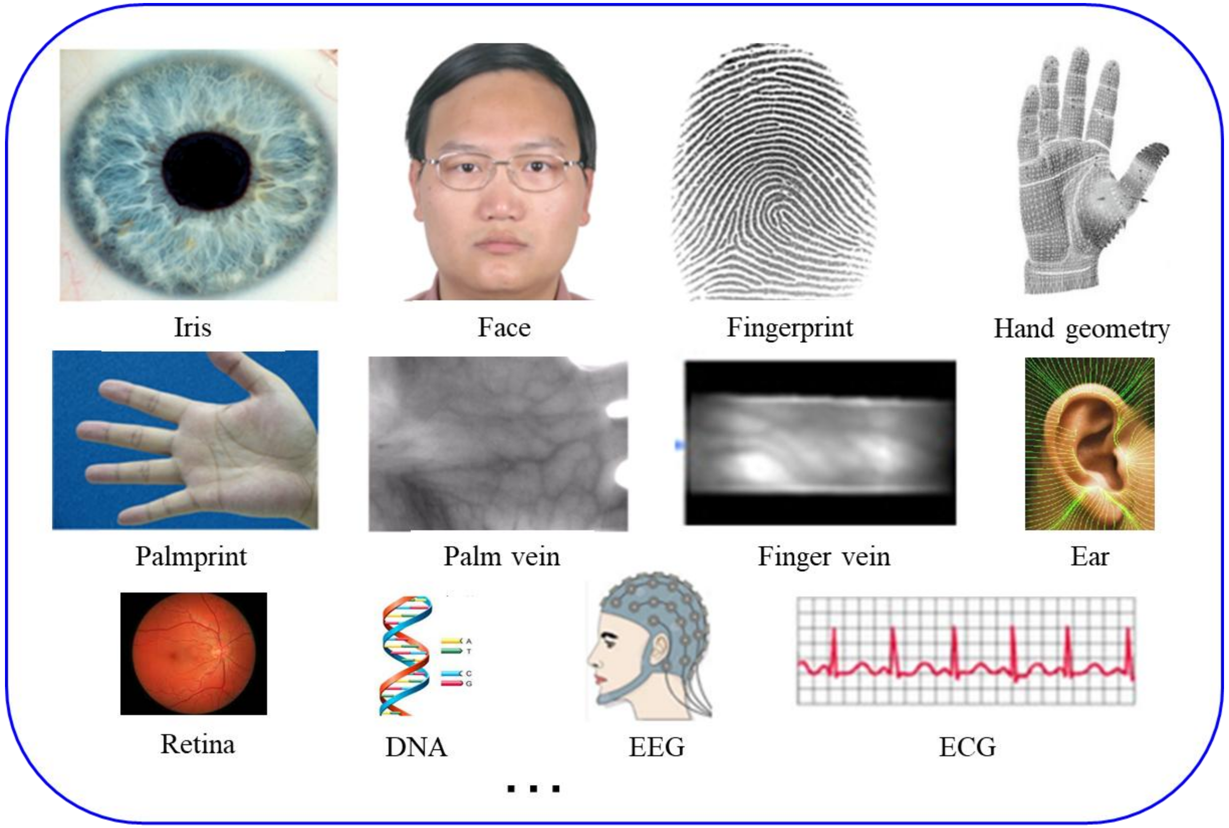
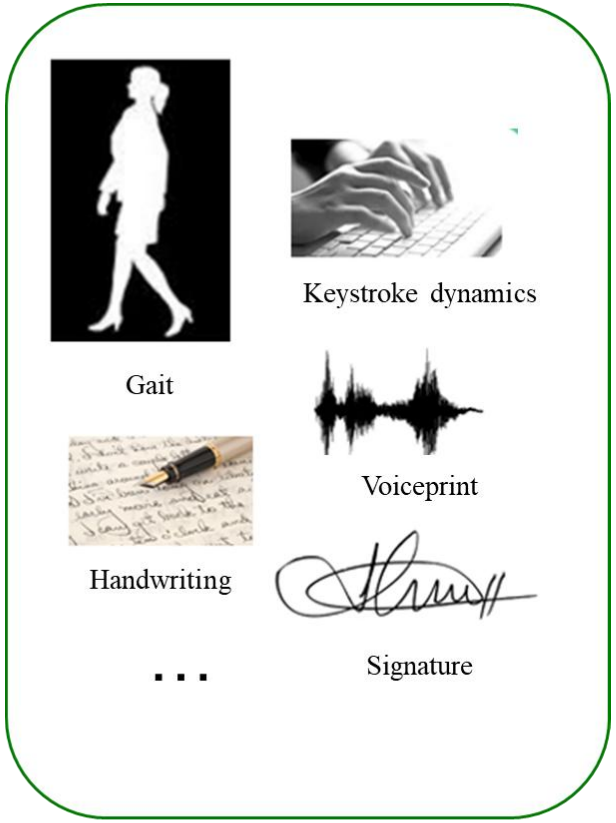
Biometrics

Automated recognition of individuals based on their behavioral and biological characteristics
[ISO/IEC 2382-37:2022]

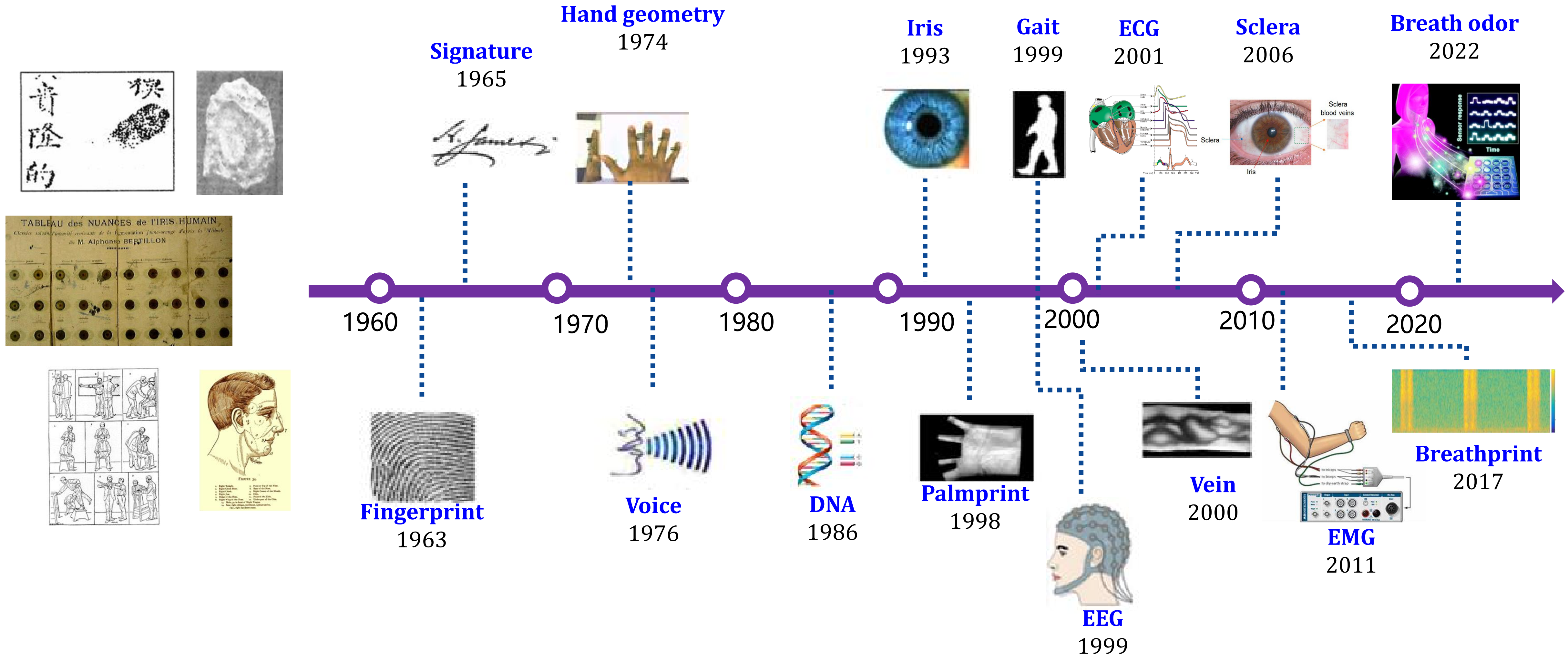


Biological Traits



Behavioral Traits

Timeline of Biometrics History

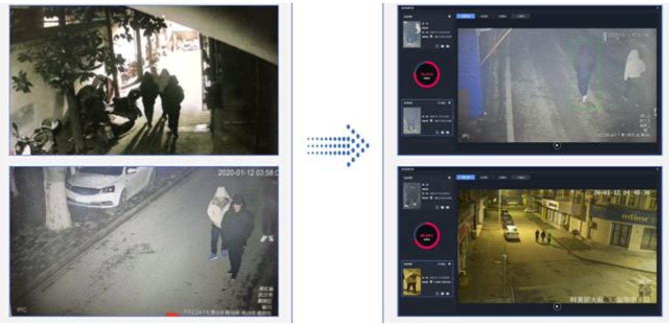


Applications of Biometrics

Fingerprint recognition for mobile authentication

Face recognition for border control

Iris recognition for coal miner identification



Gait recognition for criminal identification

Finger vein recognition for ATM authentication

Voiceprint recognition for payment

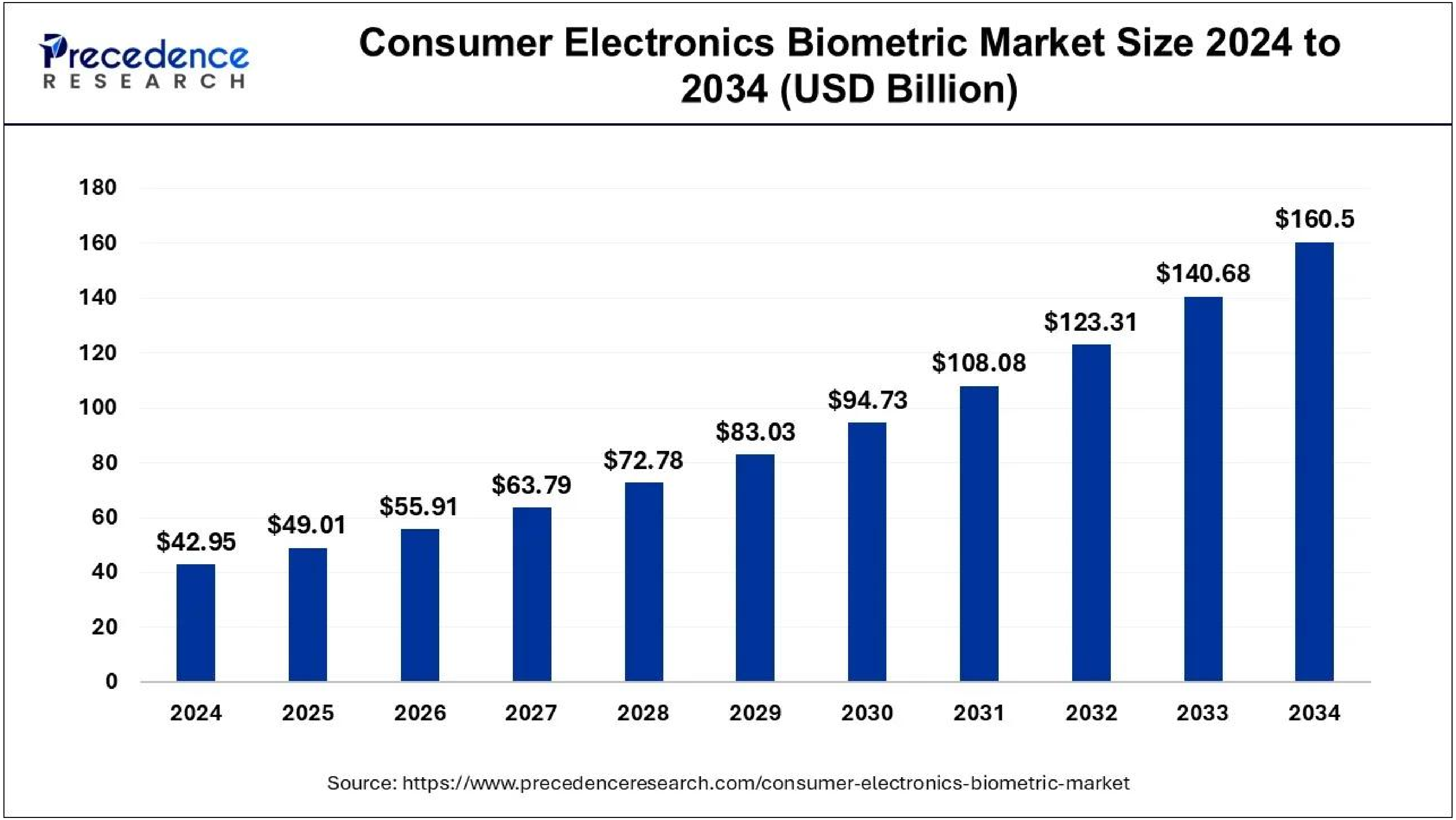
Signature verification for credit card security

Palmprint recognition for transportation

Travel without Passports

For example, on-the-move facial and iris recognition technology facilitates passport-less clearance in Changi Airport, Singapore.

Market Potential of Biometrics



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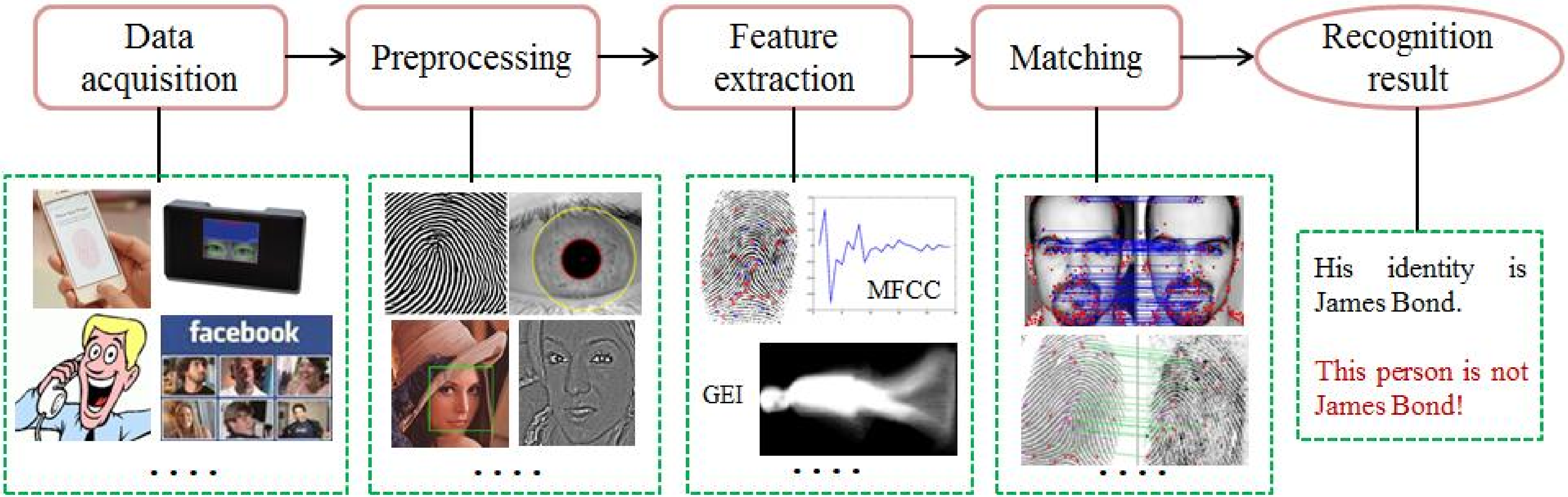
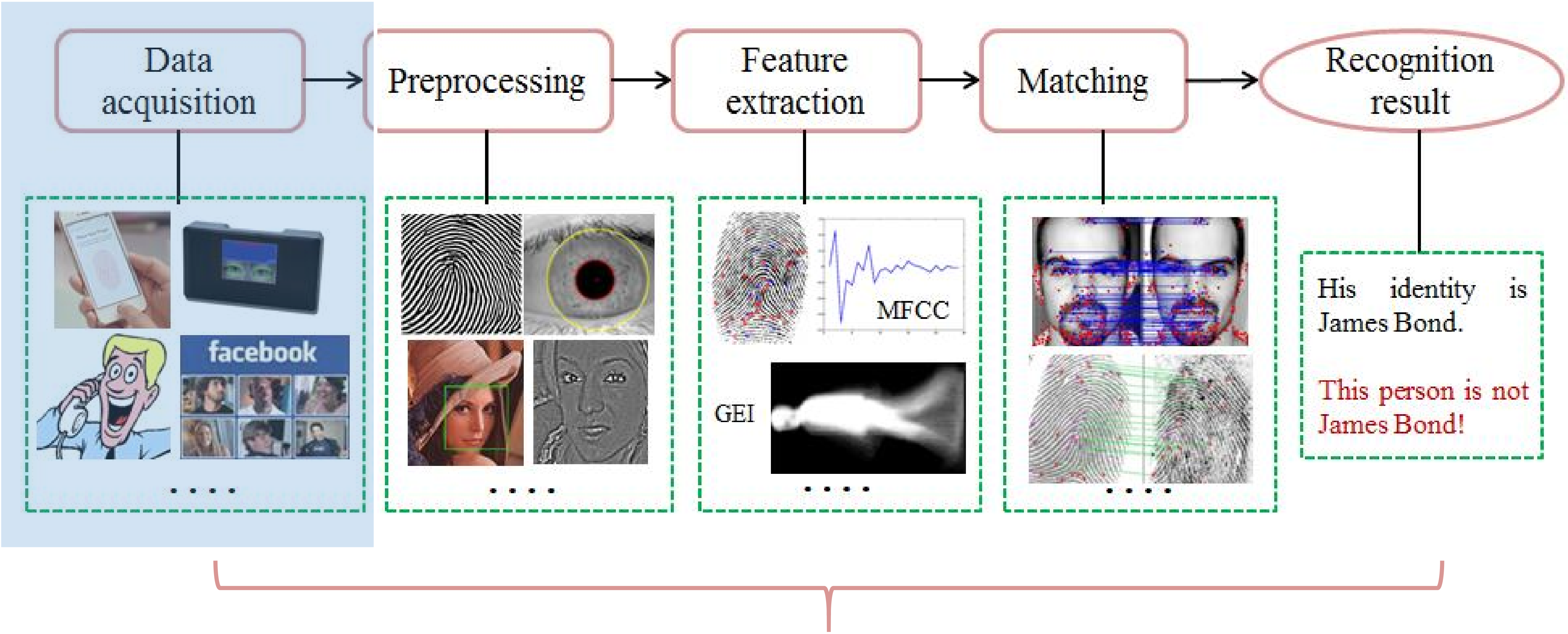
Recent Progress



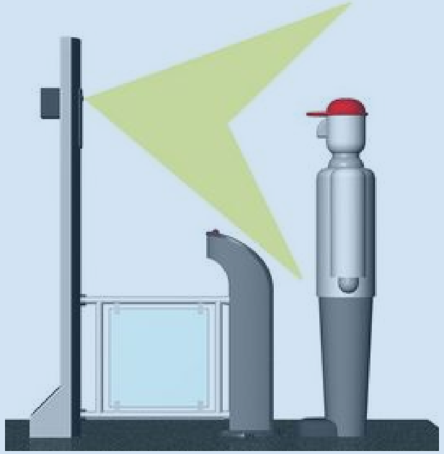
- ✓ Security and privacy
- ✓ Fairness
- ✓ Explainability

Recent Progress

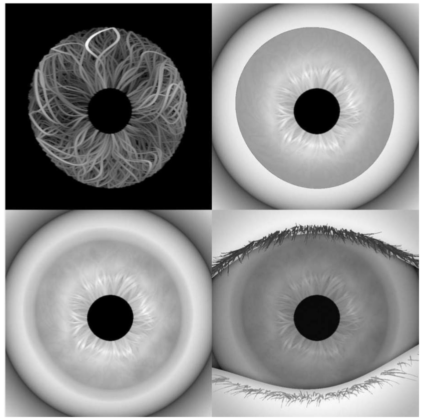


- ✓ Security and privacy
- ✓ Fairness
- ✓ Explainability

Biometric Data Acquisition



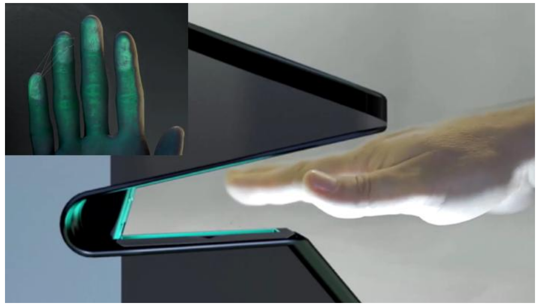
Data acquisition using biometric sensors



Data generation using GAI methods

Biometric Sensor Design

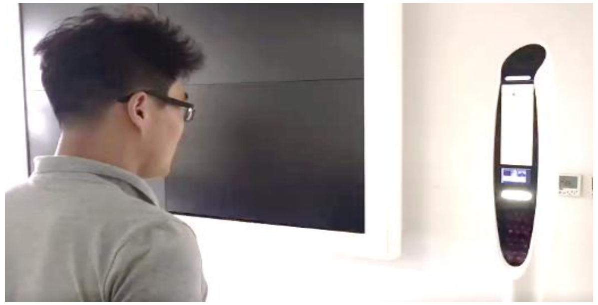
More user-friendly sensor



Touchless 3D fingerprint recognition

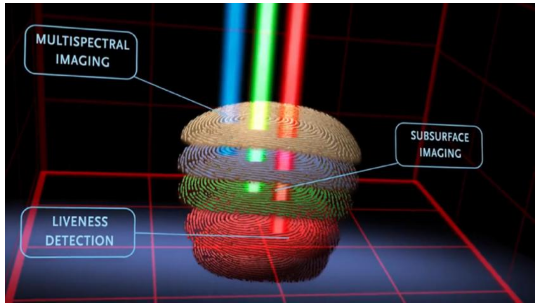
Far-field voiceprint recognition

Noncontact palm vein Recognition

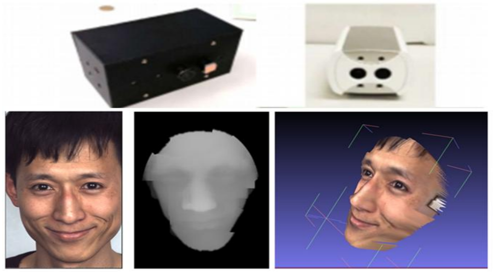


Iris recognition at a distance

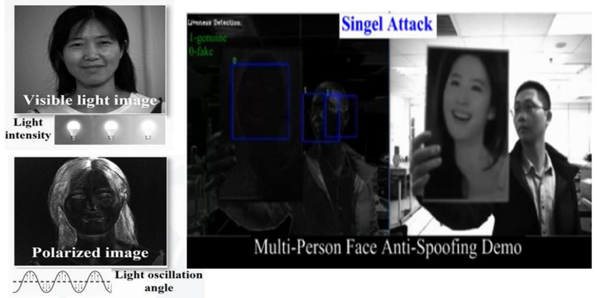
Higher dimensional information



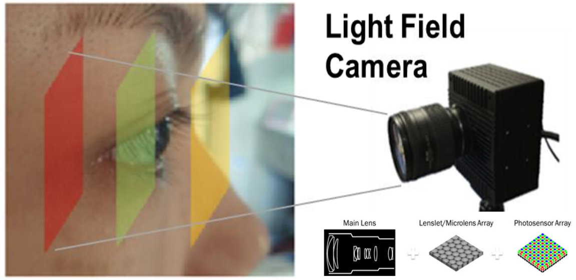
Multispectral imaging for fingerprint



ToF camera for 3D face recognition



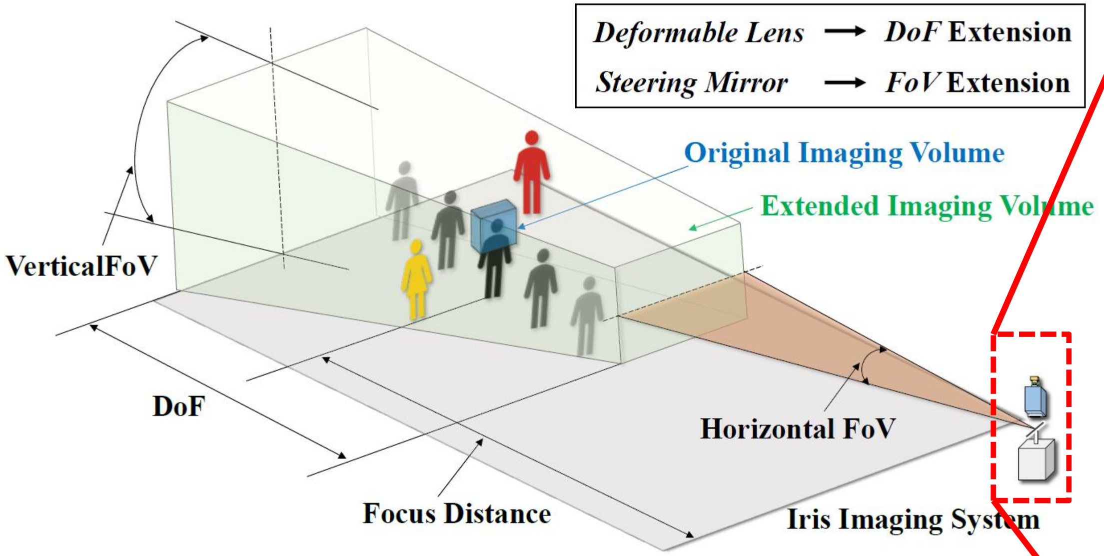
Polarized face camera for anti-spoofing



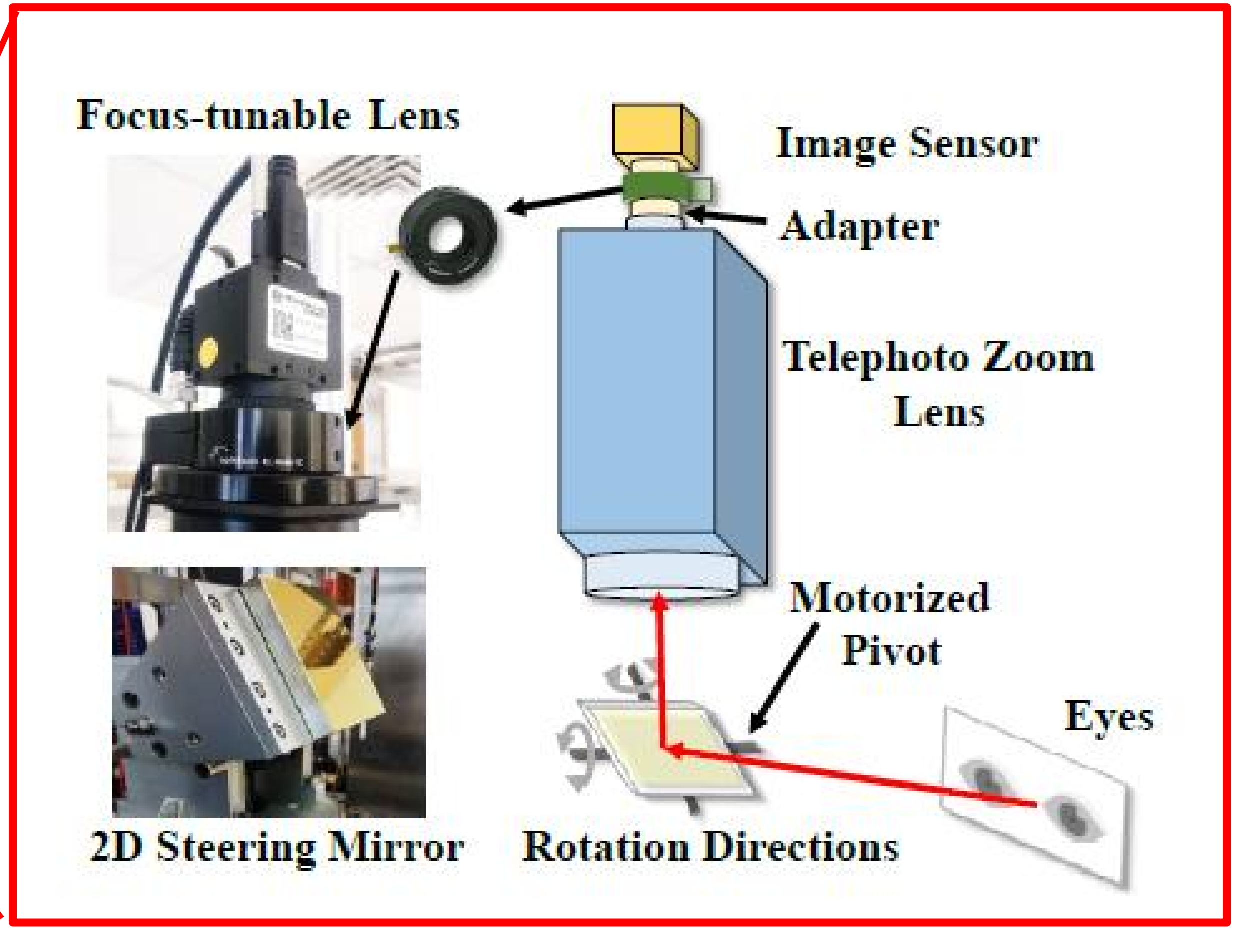
Mircolens-based light field camera

Our Journey in Iris Camera Development

Iris Imaging With Expanded Capture Volume

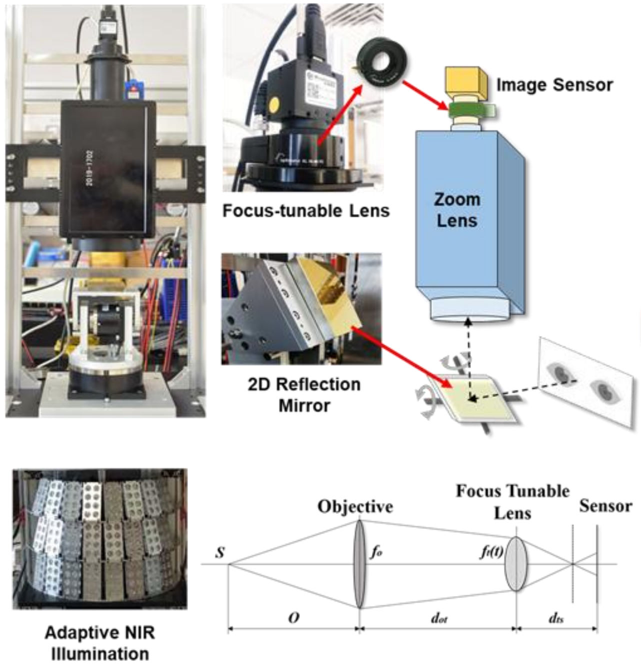


Combining a two-axis beam steering mirror and focus-tunable lens integrated with a telephoto zoom lens

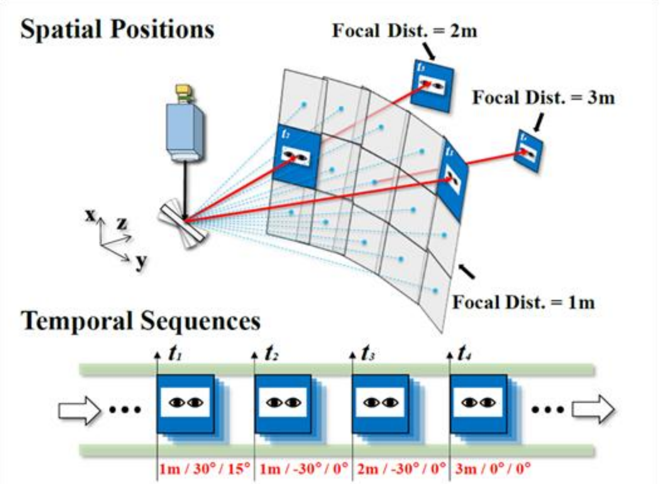


Zhang K, Shen Z, Wang Y, et al. All-in-focus iris camera with a great capture volume[C]//IEEE International Joint Conference on Biometrics (*IJCB*), 2020. (**IJCB 2020 Google Best Paper Award Runner-Up**)

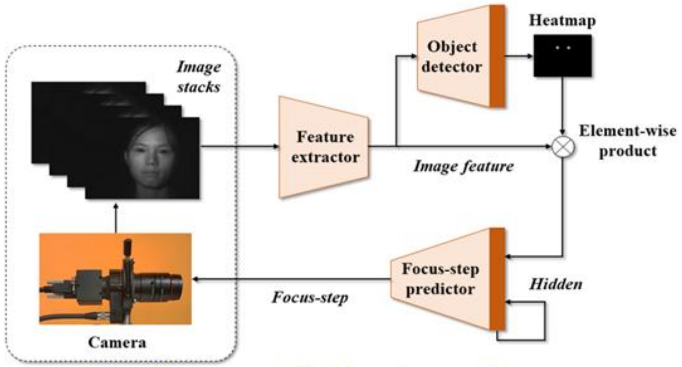
CASIA Long-range (10m) Iris Prototype



Focus-tunable liquid lens and 2D steering mirror

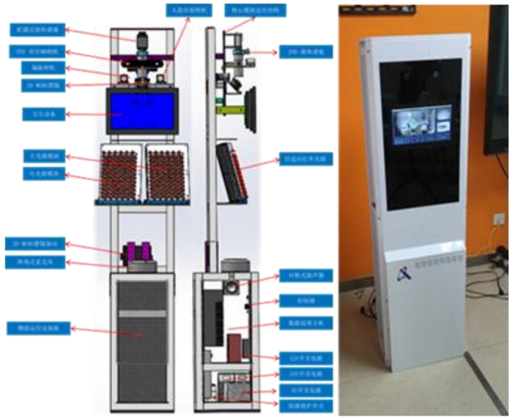


Spatiotemporal Multiplexing Imaging



End-to-end Iris Autofocus

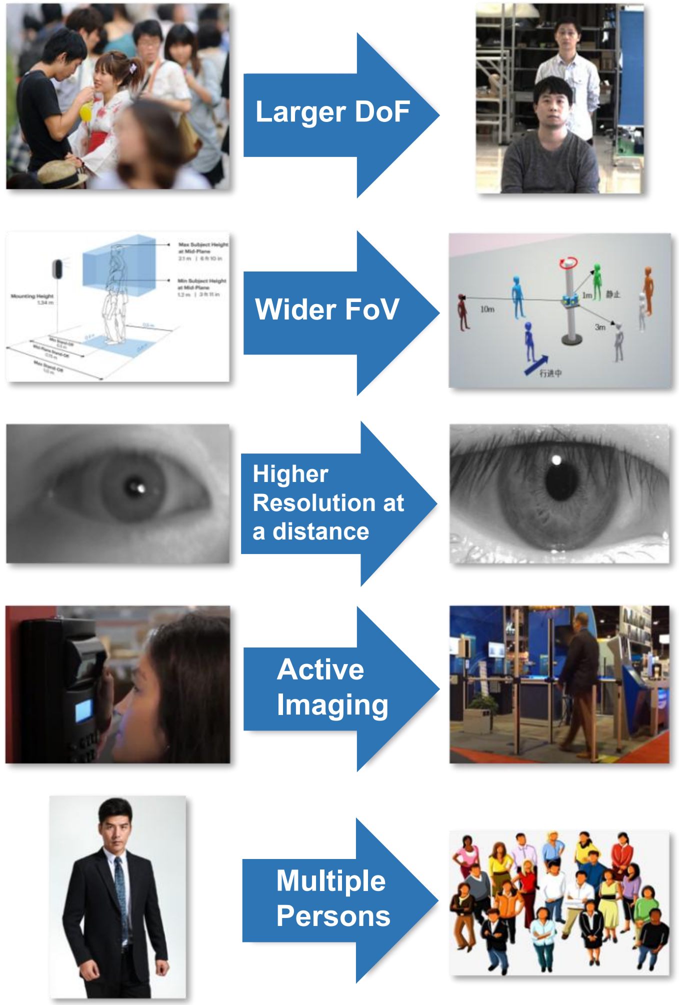
Prototype I



Prototype II

[1] Zhang K, Shen Z, Wang Y, et al. All-in-focus iris camera with a great capture volume[C]//IEEE International Joint Conference on Biometrics (***IJCB***), 2020.
[2] Wang L, Zhang K, Wang Y, et al. An end-to-end autofocus camera for iris on the move[C]//IEEE International Joint Conference on Biometrics (***IJCB***), 2021.

CASIA Long-range (10m) Iris Prototype



Small DoF	Narrow FoV	Single
20cm	<10° (no PTZ)	person

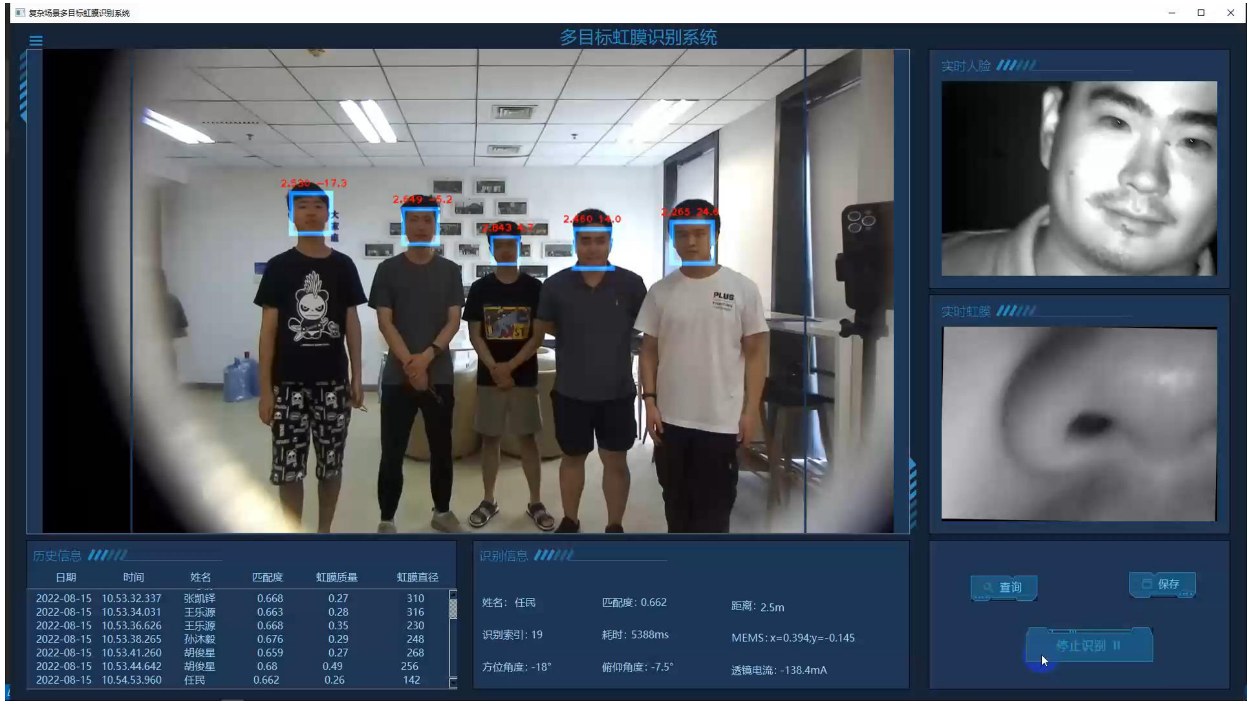
→

Large DoF	Wide FoV	Multiple
3.9 m@5m	360°	(≥3)

Model	Distance	Performance	Person	User cooperation
IOM, Sarnoff	2.4-3 m	0.2m x 0.4 m x 0.1 m, two cameras, 0.5 s/person	1	Standstill, walk (1m/s@5m)
Eagle-Eyes, Retica	3-6 m	3 m x 2 m x 3 m, double cameras	1	Standstill
CASIA	2.4-3 m	0.15 m x 0.15 m x 0.1 m, PTZ camera	1	Standstill
CMU	12 m	0.97 m x 0.73 m @1 m	1	Standstill, walk (0.6m/s)
SRI	25 m	0.305 m x 0.405 m@25 m, long focal zoom lens, O.D. 254 mm	1	Standstill
iCAM D1000, Iris ID	0.5-1 m	0.2 m x 0.5 m x 0.5 m, vertical moving camera (50 mm)	1	Standstill
S200P, Iristar	1-1.2 m	Height 1.3-1.95 m, DoF 30 cm, 2 s recognition	1	Standstill
Versa F Max, Irisian	0.8-2 m	Height 1.2-2 m, PTZ camera, 1 s eye tracking, 3 s recognition	1	Standstill
Ours	**1–10 m**	**Height 0.8-2 m, 360° , single camera**	**≥3**	**Standstill, walk (1m/s@1-10 m)**

CASIA Long-range (10m) Iris Prototype

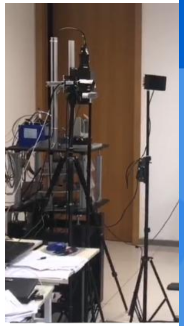
Prototype II



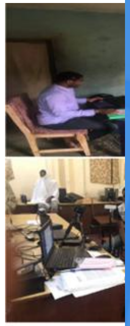
Iris recognition process of multiple persons

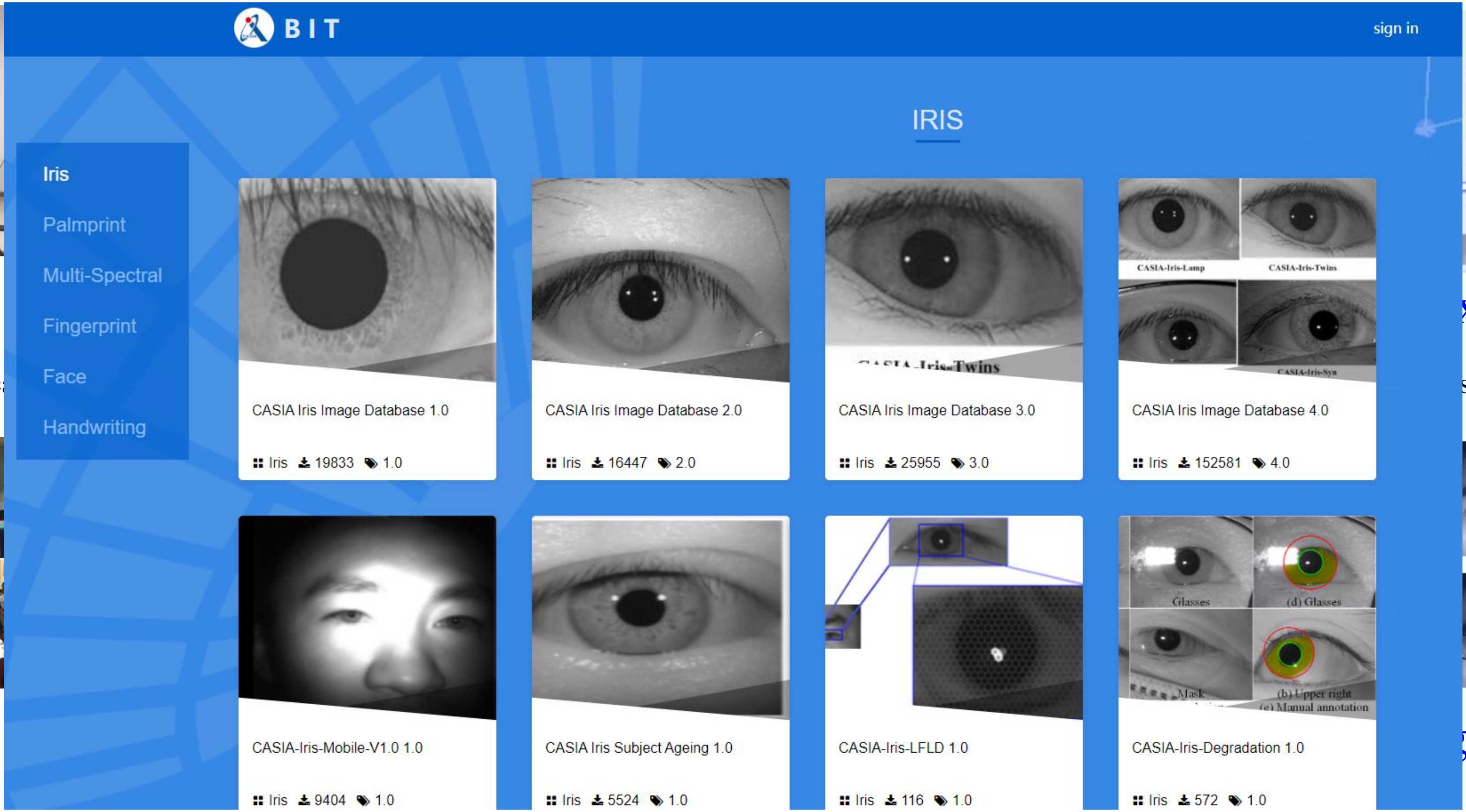
CASIA Iris Image Database V5.0-pre

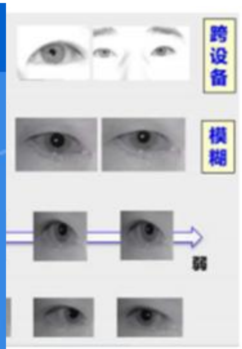
BIT website: http://www.idealtest.org/



Large-sc







x

ss-sensor

(c)

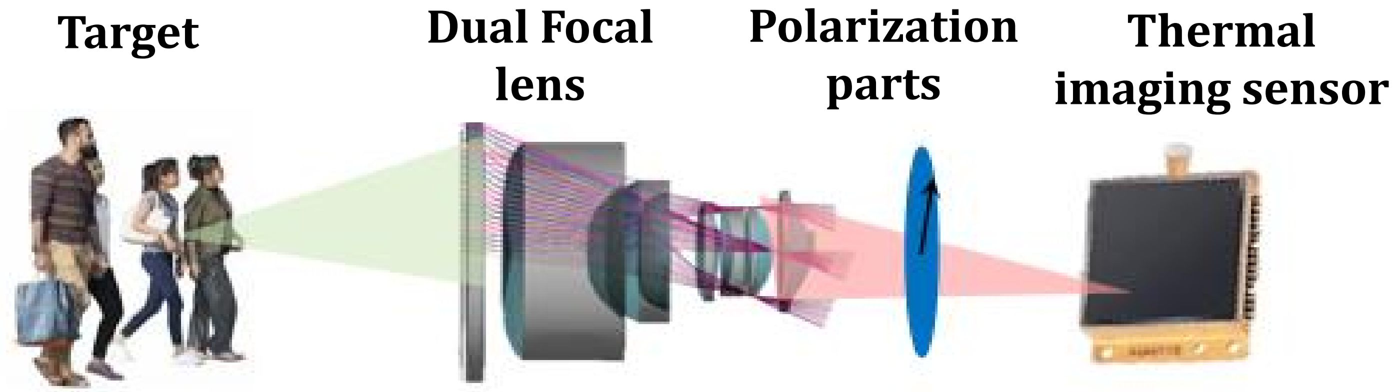
hput

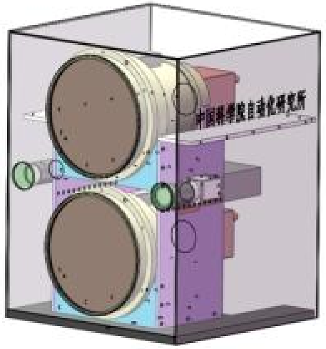
Collected in Nigeria, over 1K African subjects, various eye state

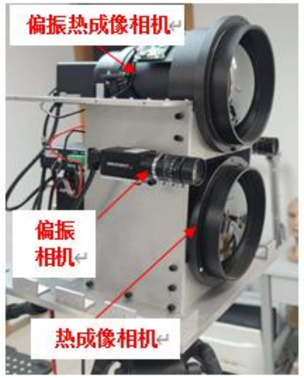
Iris image sequences, moving subjects, glasses on and off

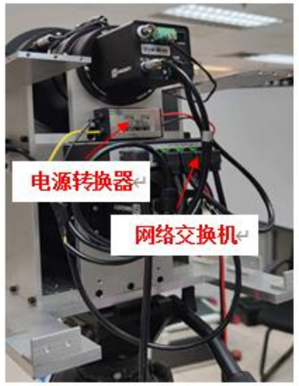
CASIA Thermal and Polarization Integrated Imaging Device

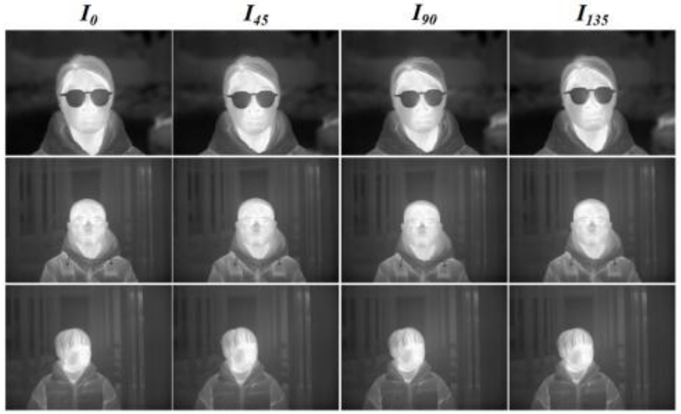
We integrate infrared thermography and polarization imaging technologies to construct a multimodal biometric imaging device specifically designed for ultra-long-range low-illumination scenarios.



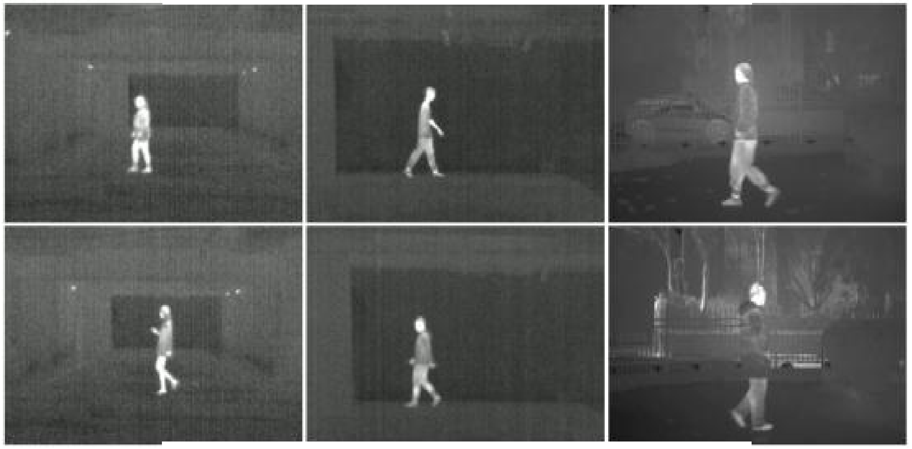






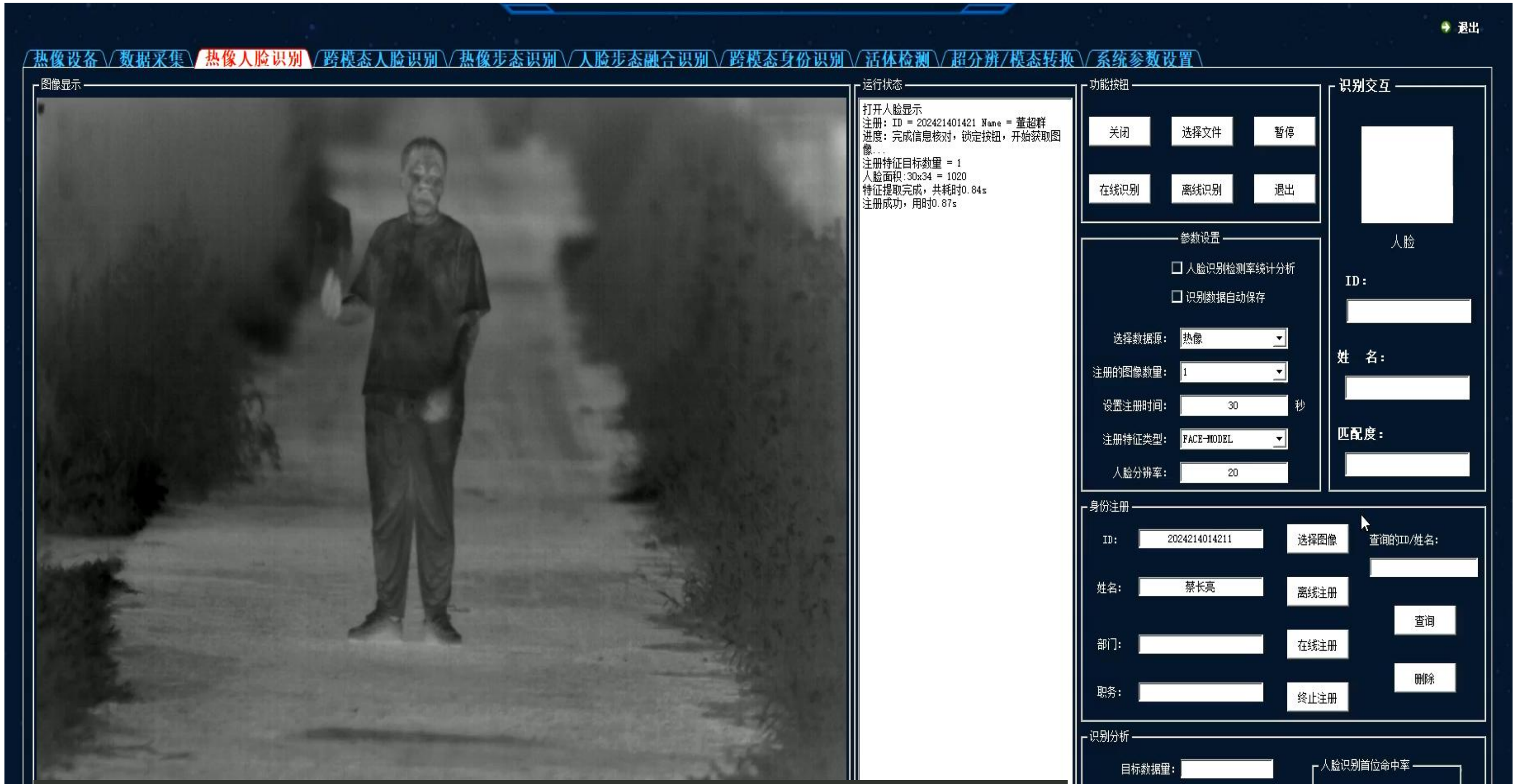


Captured Face Instances



Captured Gait Sequences

CASIA Thermal and Polarization Integrated Imaging Device

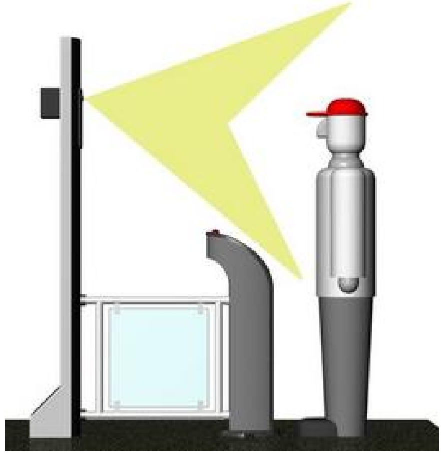


500m Continuous Recognition in Low-illumination outdoor scenes

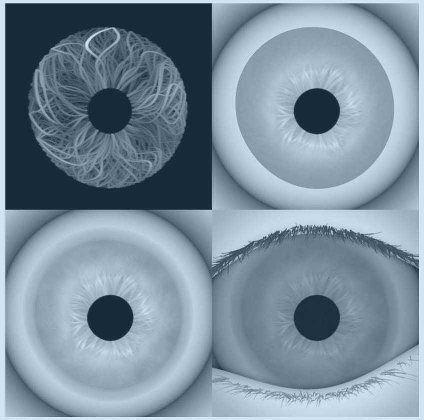
Highlights

- ＞500 meters multi-modal biometric (e.g., face and gait) data acquisition and continuous recognition
- Extremely low-illumination outdoor scenarios
- Active imaging, requiring no cooperation from targets
- High frame rate (50fps)

Biometric Data Acquisition

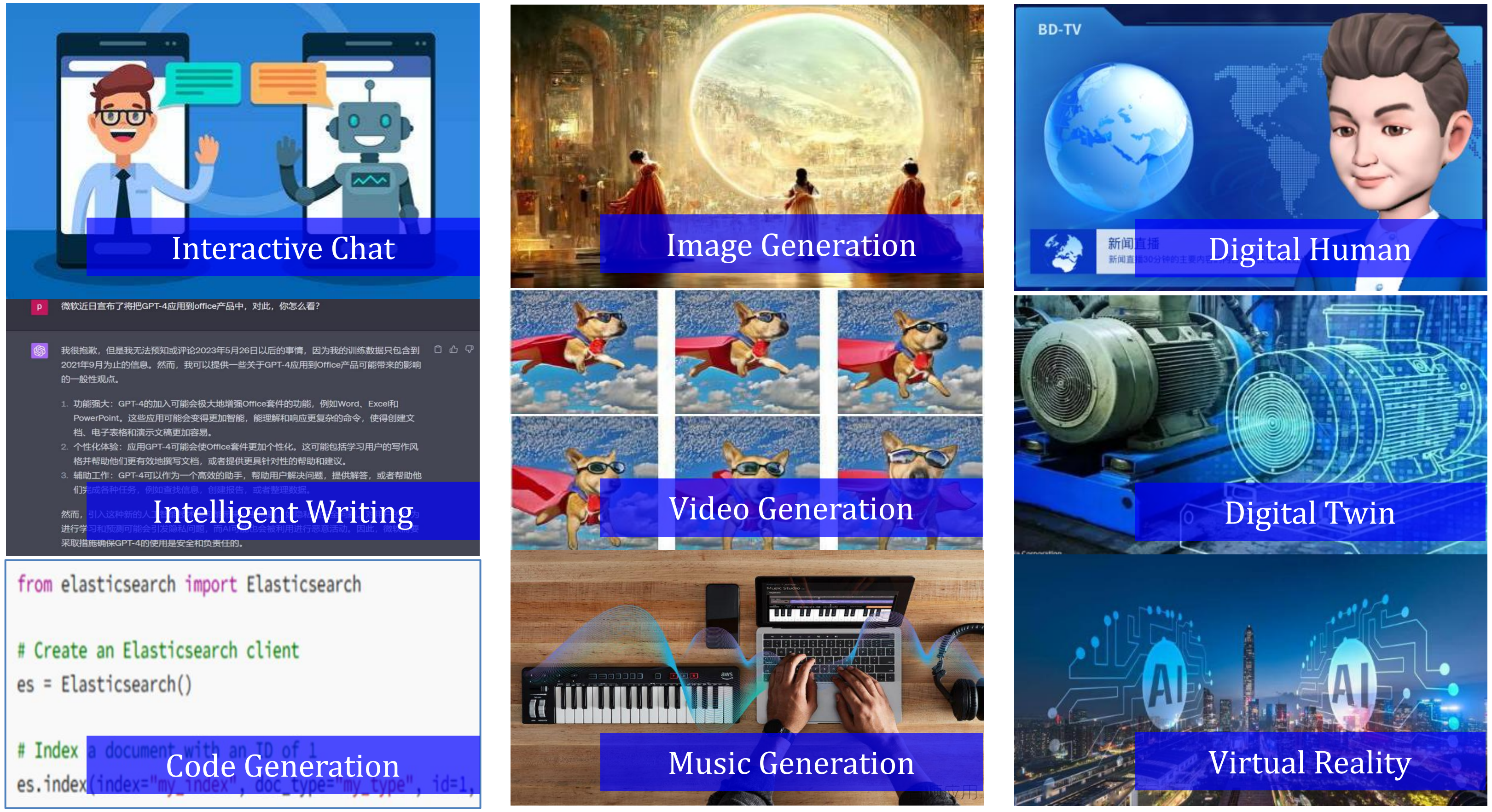


Data acquisition using biometric sensors

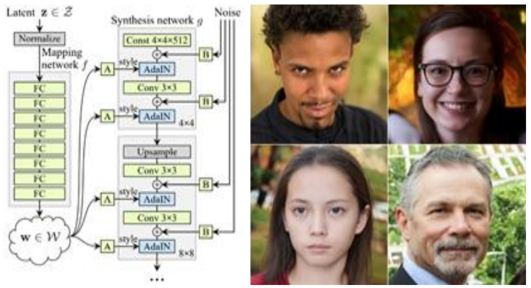


Data generation using GAI methods

Generative AI (GAI)



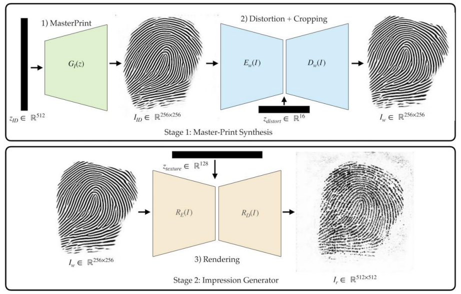
Biometric Data Generation using GAN



A style-based generator is proposed for high fidelity face generation.

Face

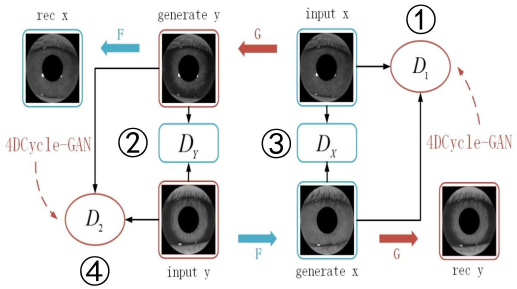
StyleGAN [Karras et al., ***CVPR'19***]



Capable of generating more realistic fingerprints. 512K fingerprints are synthesized.

Fingerprint

PrintsGAN [Engelsma et al., ***TPAMI'23***]

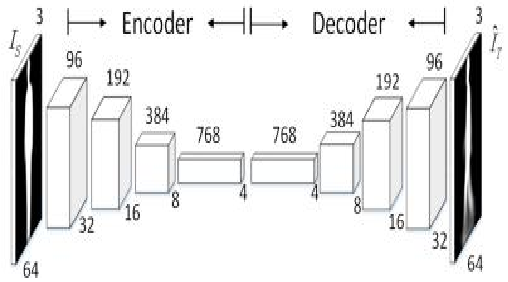


4 Discriminators

A novel 4DCycle-GAN with is proposed to synthesize fake iris images.

Iris

4DCycleGAN [Zou et al., ***ICPR'18***]

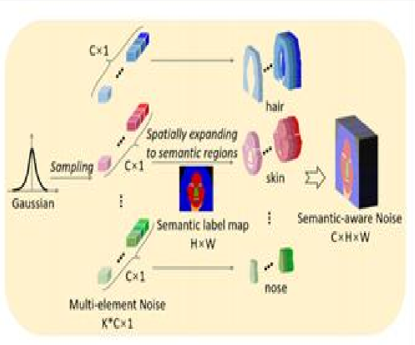


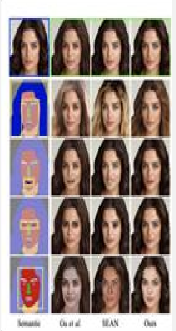
A GAN model is taken as a regressor to generate gait images.

Gait

GaitGAN [Yu et al., ***CVPR'17***]

Our Work on Face Image Generation

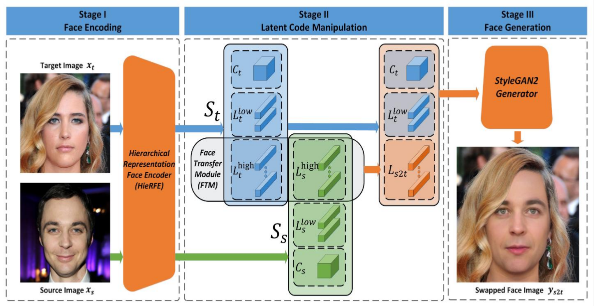




3D semantic noise is proposed for semantic portrait synthesis and manipulation.

Generation from noise

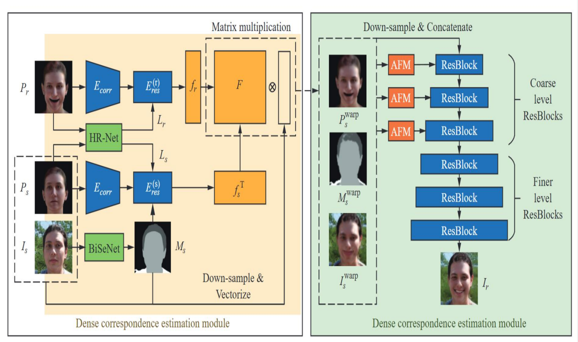
Deng et al. Semantic-aware noise driven portrait synthesis and manipulation[J]. IEEE Transactions on Multimedia (***TMM***), 2022, 25: 2799-2811



Capable of conducting one shot face swapping at megapixel level.

Face Swapping

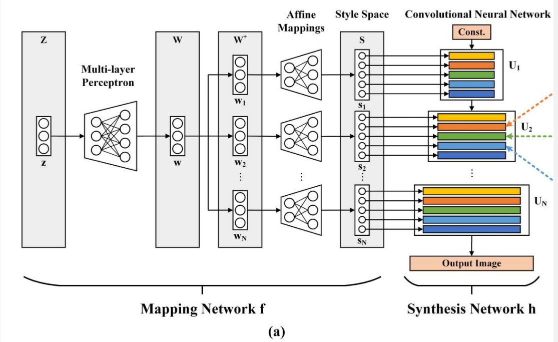
Zhu et al. One-shot face swapping on megapixels[c]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (***CVPR***),2021, 4834-4844



A 3D Morphable is used for explicit facial semantic segmentation and identity disentanglement.

Face Reenactment

Liu et al. One-shot face reenactment with dense correspondence estimation[J]. Machine Intelligence Research (***MIR***), 2024, 21:941-953



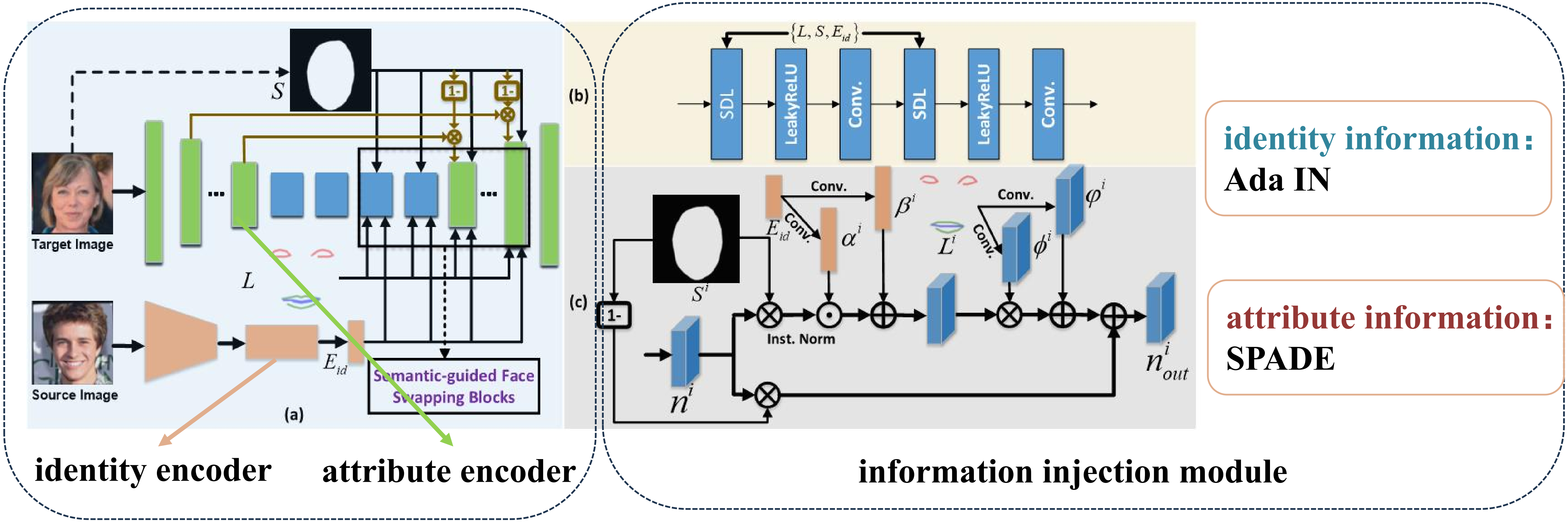
Spatially disentangled manipulation of high-resolution images with a pre-trained StyleGAN generator.

Facial Attribute Manipulation

Liu et al. Towards spatially disentangled manipulation of face images with pre-trained stylegans [J]. IEEE Transactions on Circuits and Systems for Video Technology (***TCSVT***), 2023, 33: 1725-1739

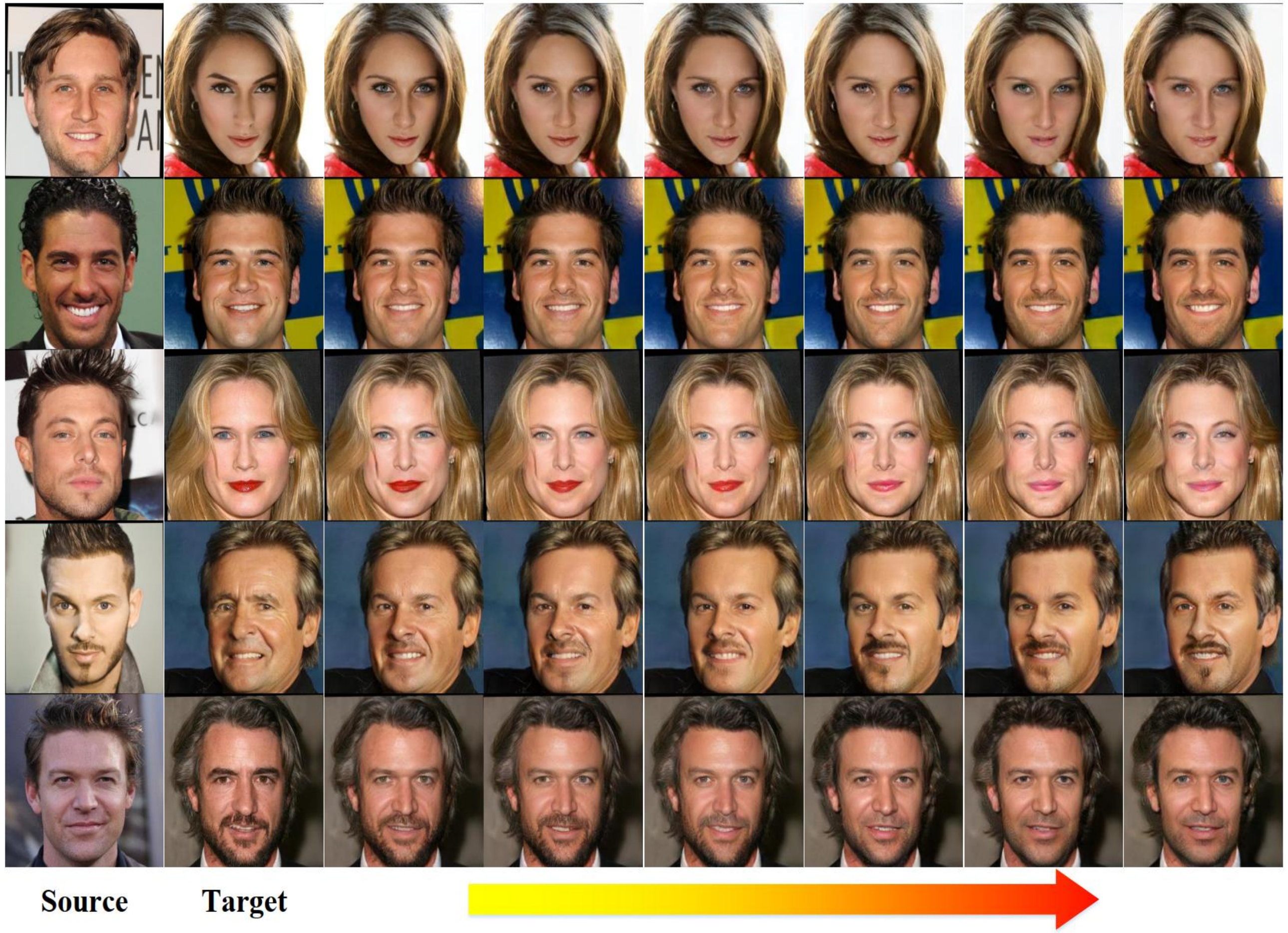
Disentangled Representation for Face Swapping

We designed identity and attribute encoders to separate facial features and embedded semantic information into the generator, enabling efficient and accurate progressive face swapping with low computational cost.



Li Q, Wang W, Sun Z et al. Learning disentangled representation for one-shot face swapping[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence (***TPAMI***), 2024 , 46: 8348-8364.

Disentangled Representation for Face Swapping

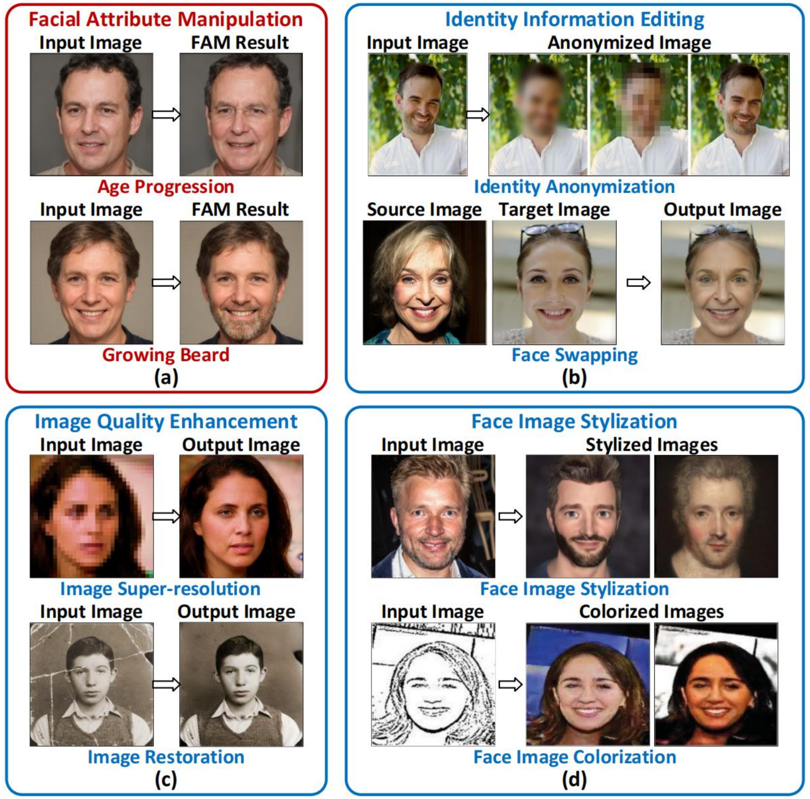


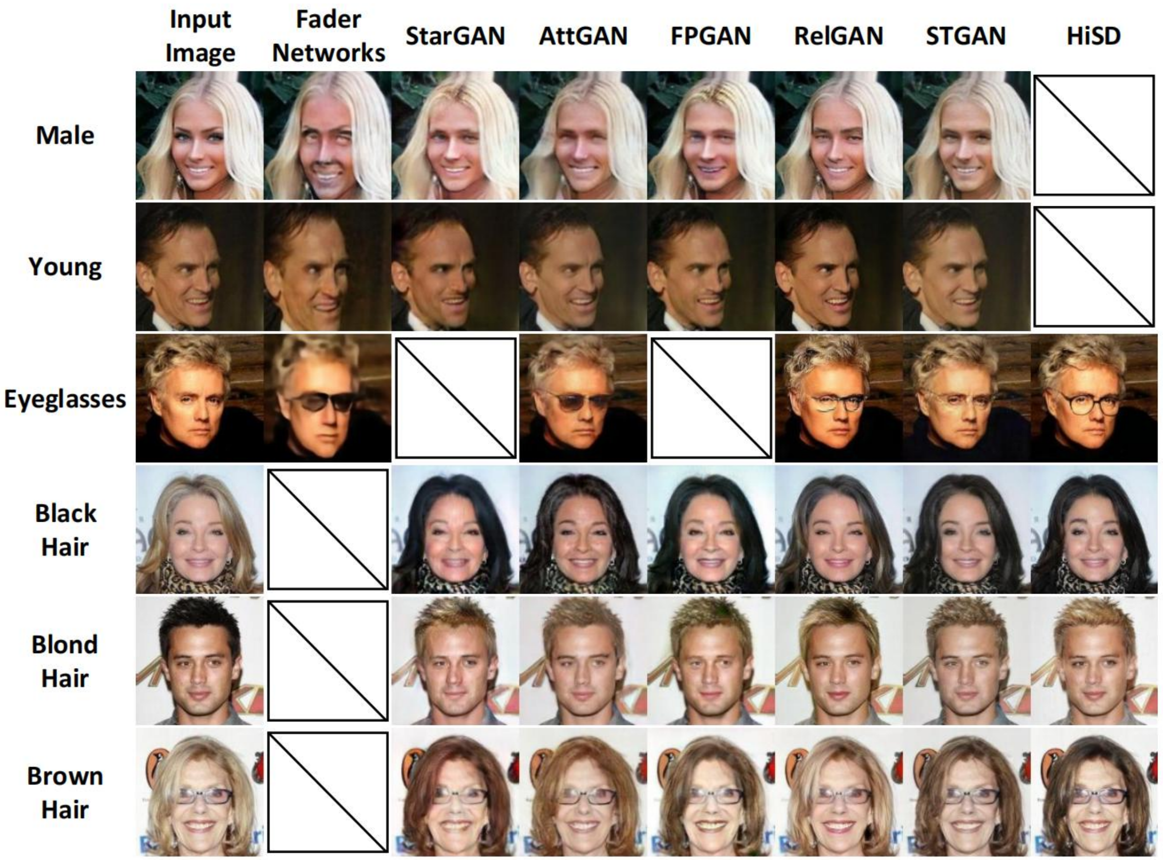
Progressive face swapping results

Face swapping results under large poses, drastic lighting changes, and exaggerated facial expressions.

GAN-based Facial Attribute Manipulation

We have made a comprehensive review on GAN-based facial attribute manipulation (FAM) methods and an in-depth discussion of important properties of FAM methods, open issues, and future research directions.

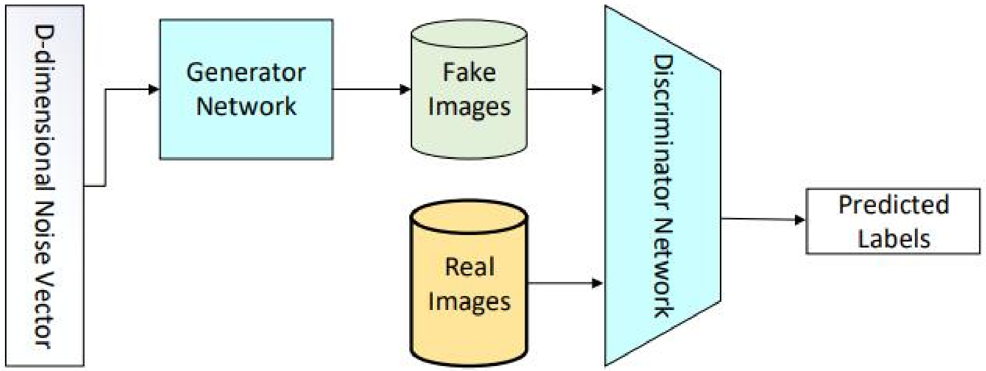


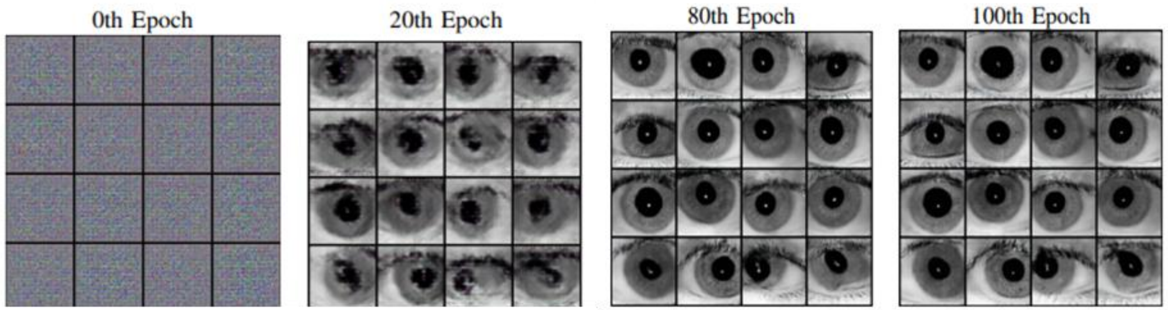


Li Q, Deng Q, et al. Gan-based facial attribute manipulation[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence (***TPAMI***), 2023.

Iris Generation and Synthesis with GAN

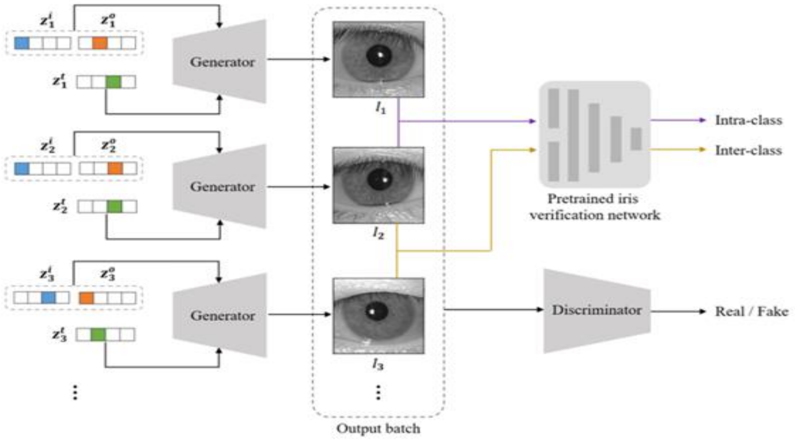
● Unconditional iris generation

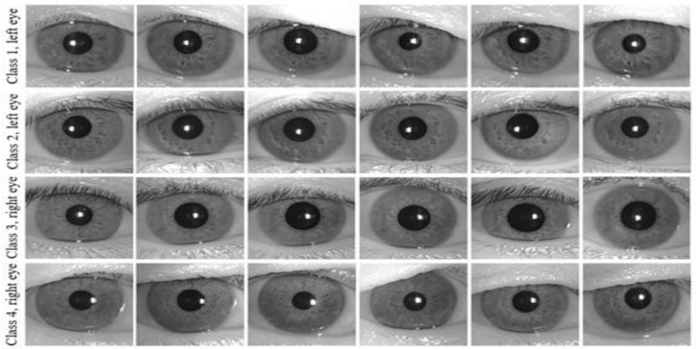




Iris-GAN [Minaee and Abdolrashidi, ***Arxiv'18***]

● Conditional iris generation

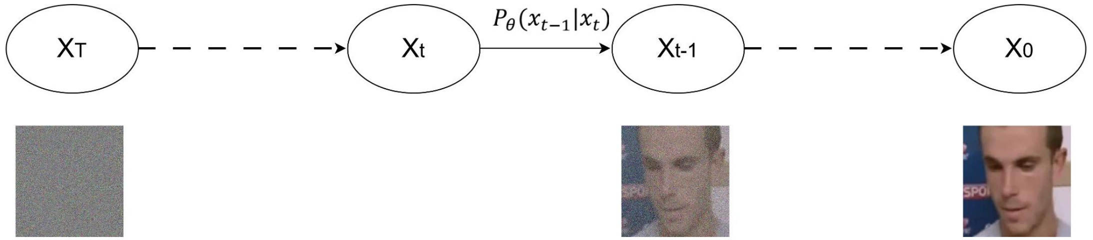




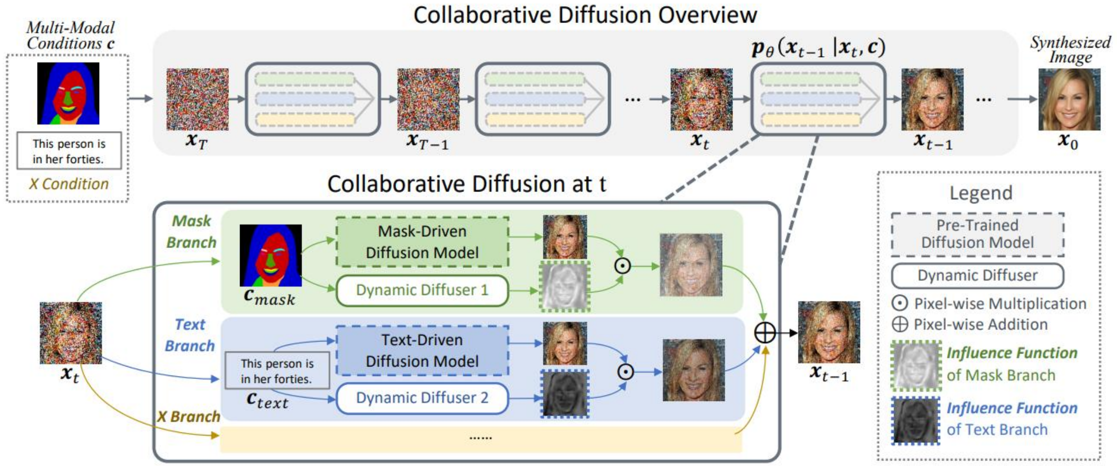
Identity control [Wang et al., ***IJCB'22***]

Biometric Data Generation with Diffusion Models

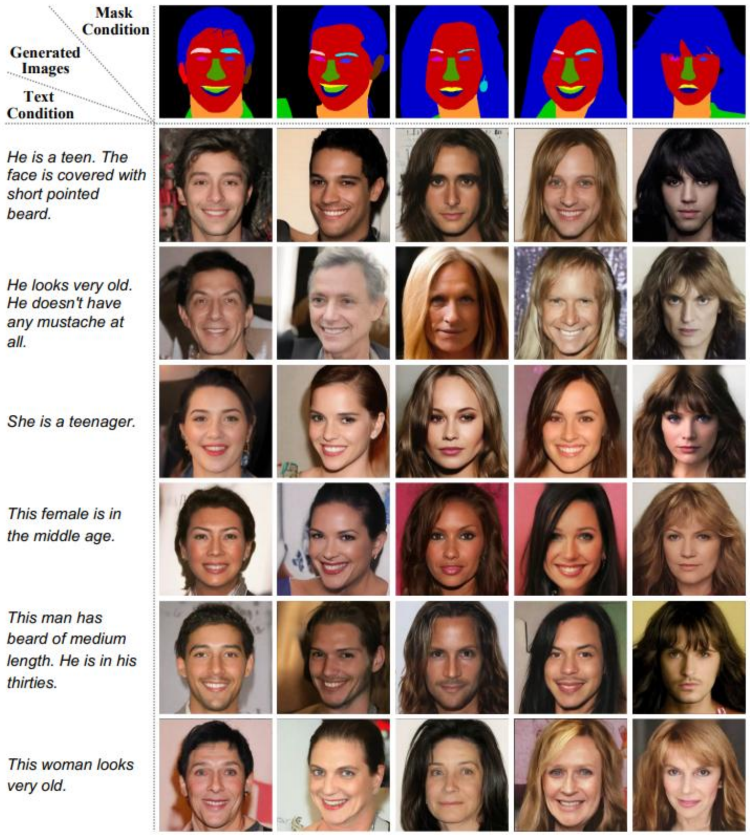
● Multimodal conditioned diffusion model



Face generation ***from noise*** using a diffusion model



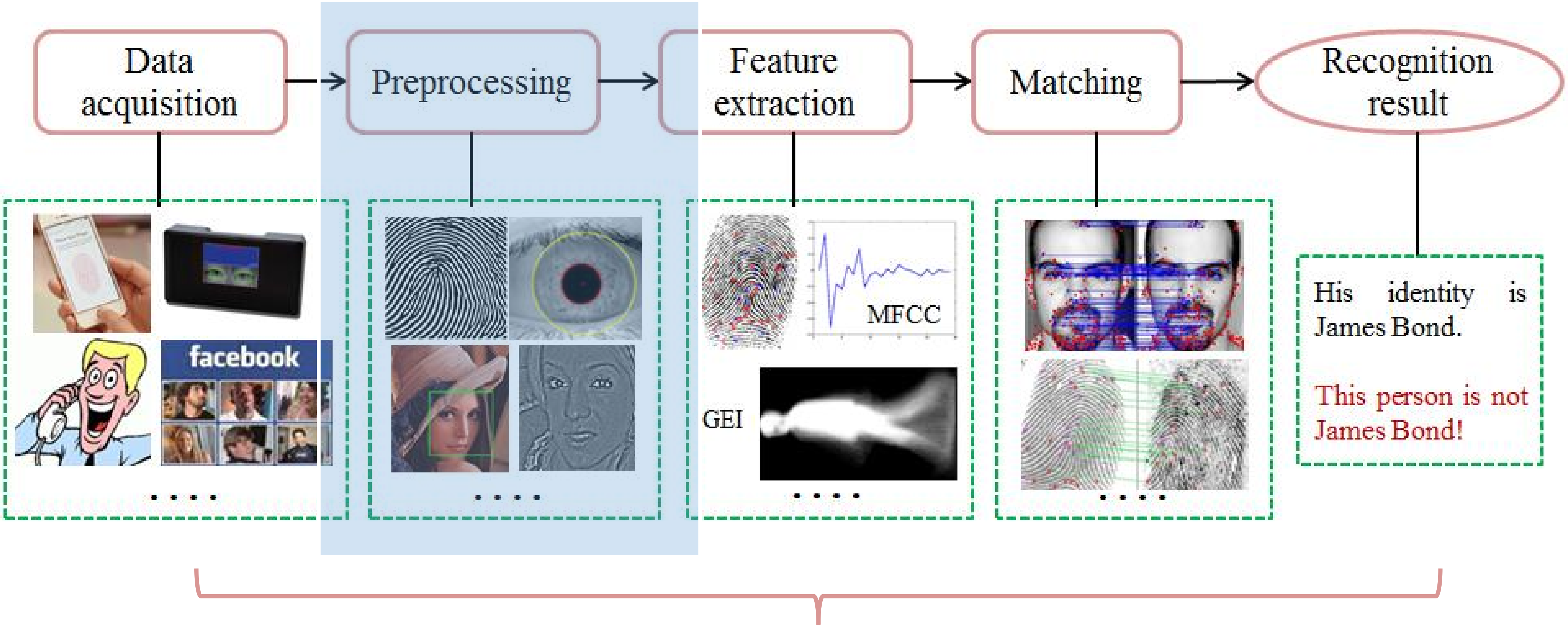
Multimodal (semantic mask, text, …) conditioned diffusion model for face generation



high-quality synthesized facial images consistent with the input conditions

Huang Z, Chan K C K, Jiang Y, et al. Collaborative diffusion for multi-modal face generation and editing[C]//Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR). 2023: 6080-6090.

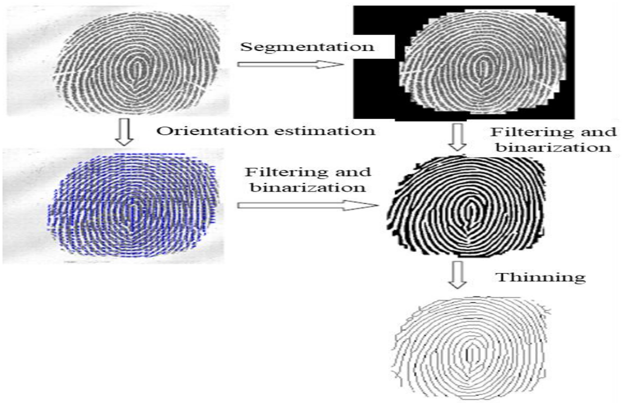
Recent Progress



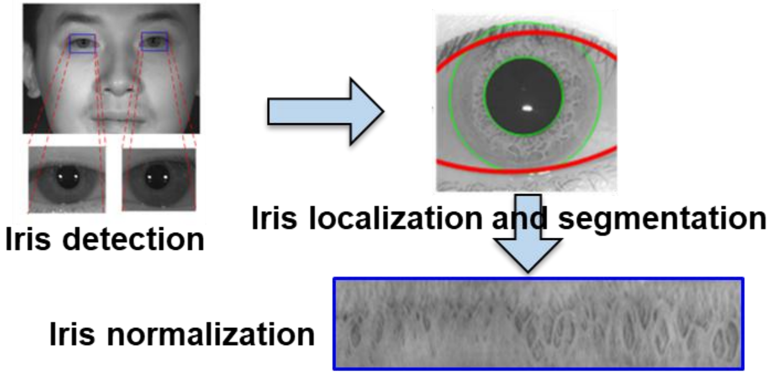
- ✓ **Security and privacy**
- ✓ **Fairness**
- ✓ **Explainability**

Preprocessing of Biometric Data

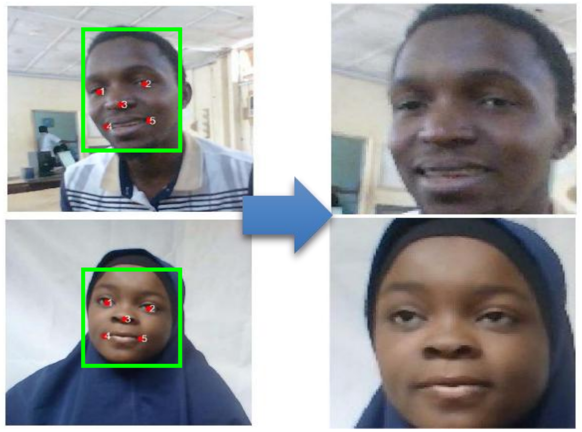
The preprocessing of biometric data aims to detect and segment out the target subject, align or normalize ROI to attenuate variations in scale, pose, illumination, etc.



Fingerprint image preprocessing



Iris image preprocessing

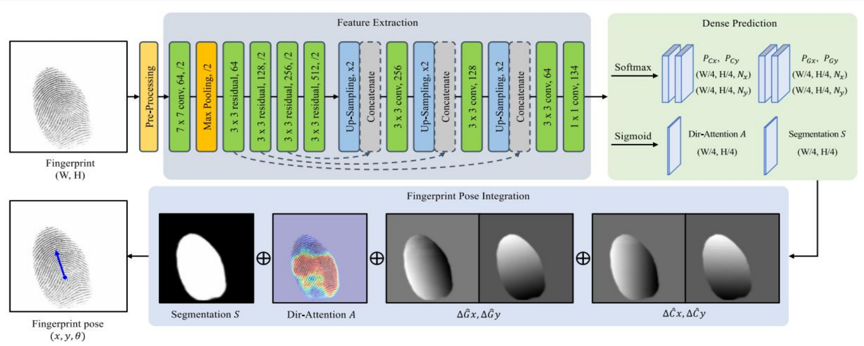


Face image preprocessing

Gait sequence preprocessing

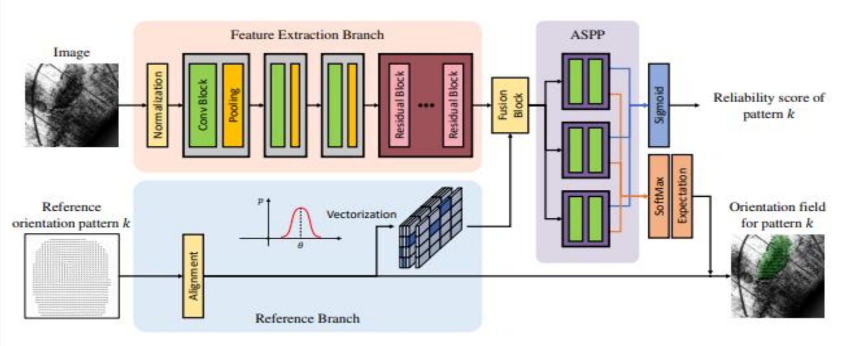
Progress in Fingerprint Preprocessing

● Fingerprint Pose Estimation



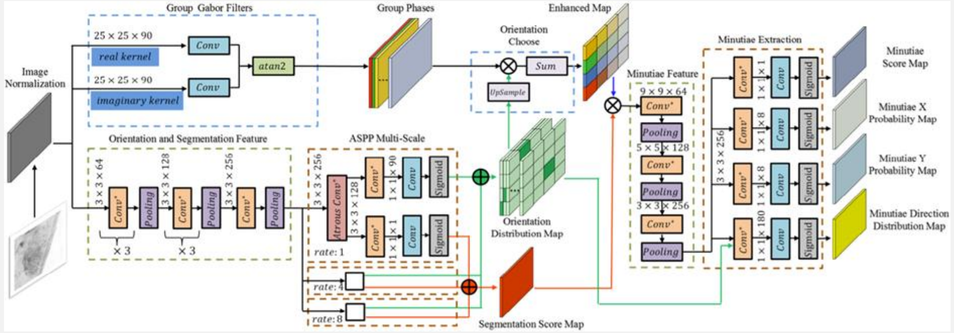
Voting strategy and deep network are fused to estimate fingerprint center and direction. [Duan et al. ***TIFS'23***]

● Orientation Field Estimation



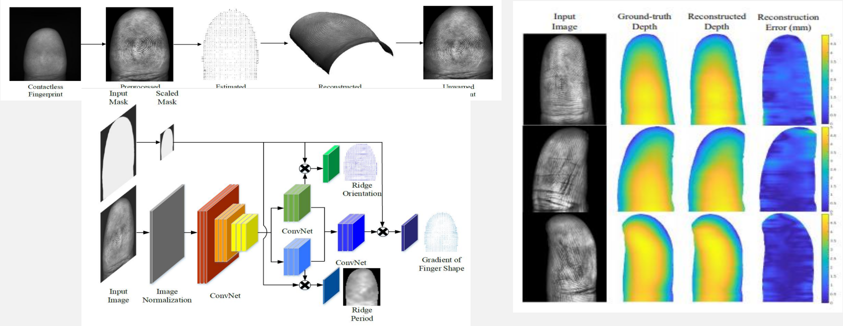
Residual orientation fields and reliability scores are estimated using a deep network. [Duan et al. ***IJCB'21***]

● 2D Minutiae Extraction



Domain knowledge and the representation ability of deep learning are combined for minutiae extraction. [Tang et al. ***IJCB'17***]

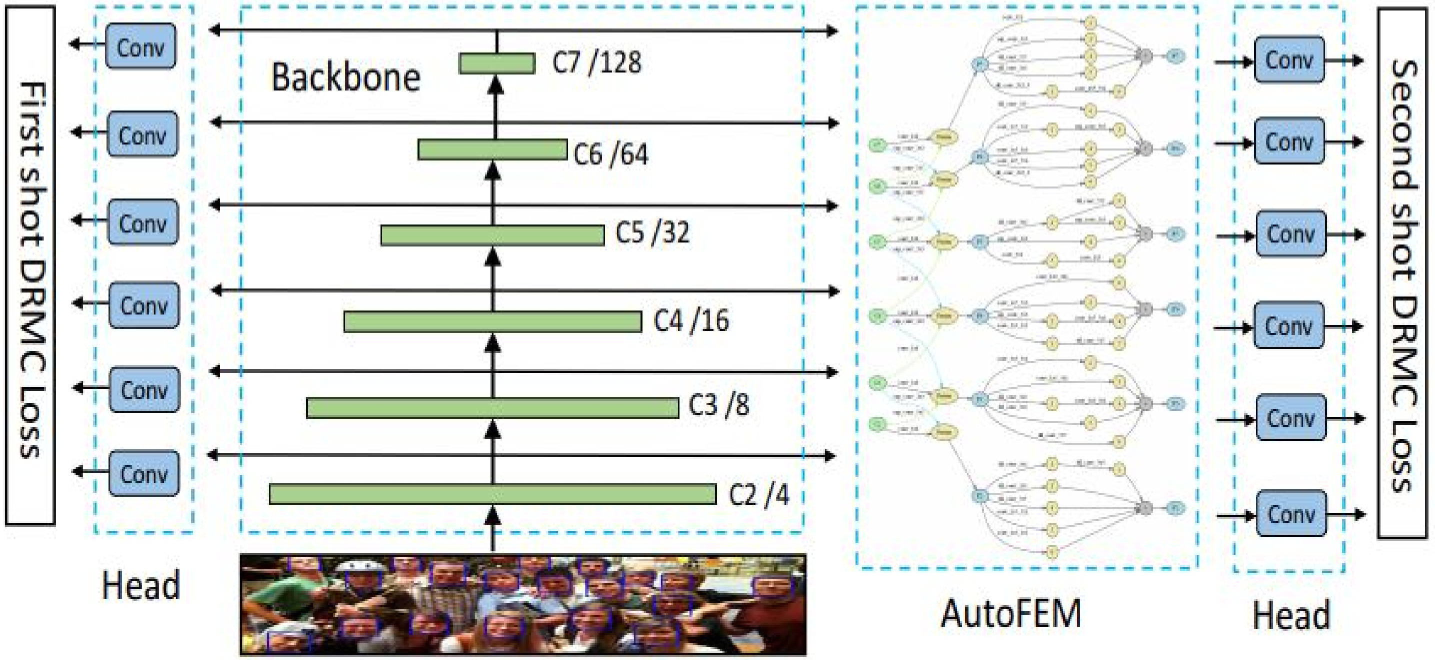
● 3D Finger Reconstruction



A 3D finger shape from a single image is reconstructed and the raw image is unwarped to suppress the perspective distortion. [Cui et al. ***TPAMI'23***]

Face Preprocessing: Face Detection

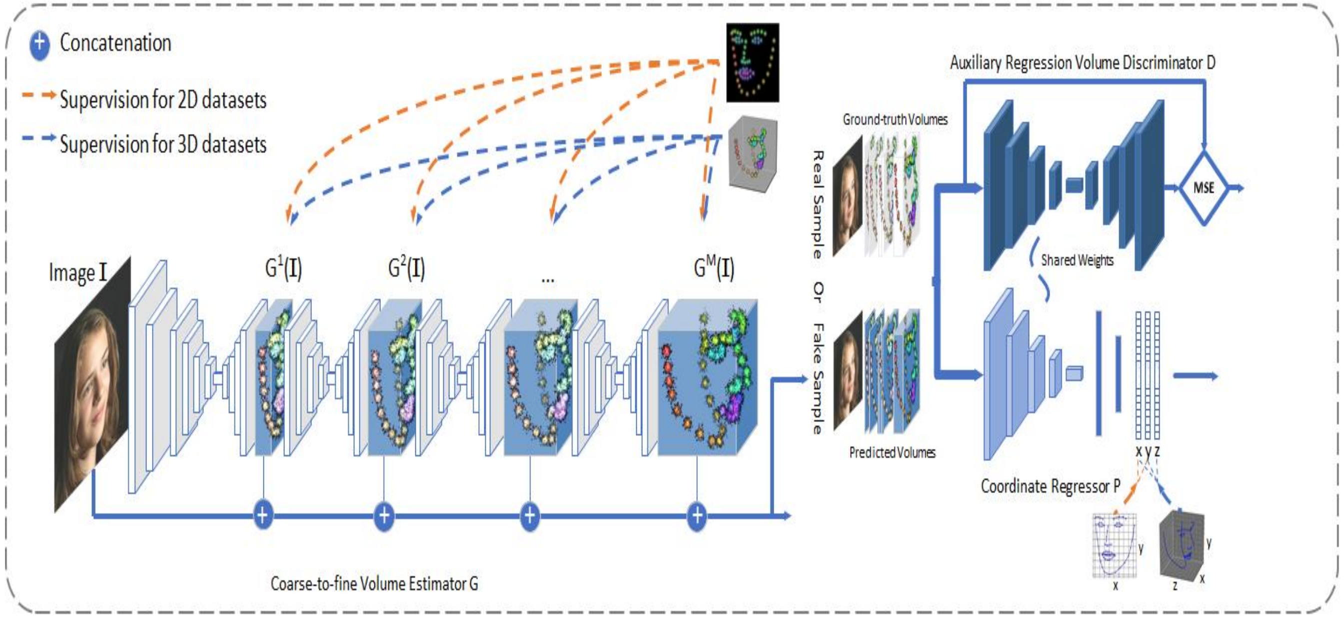
Feature aggregation and enhancement (FAE) modules are proven to be pivotal in deep learning based face detection frameworks. For instance, Automatic and Scalable Face Detector (ASFD) is able to automatically search an effective FAE architecture.

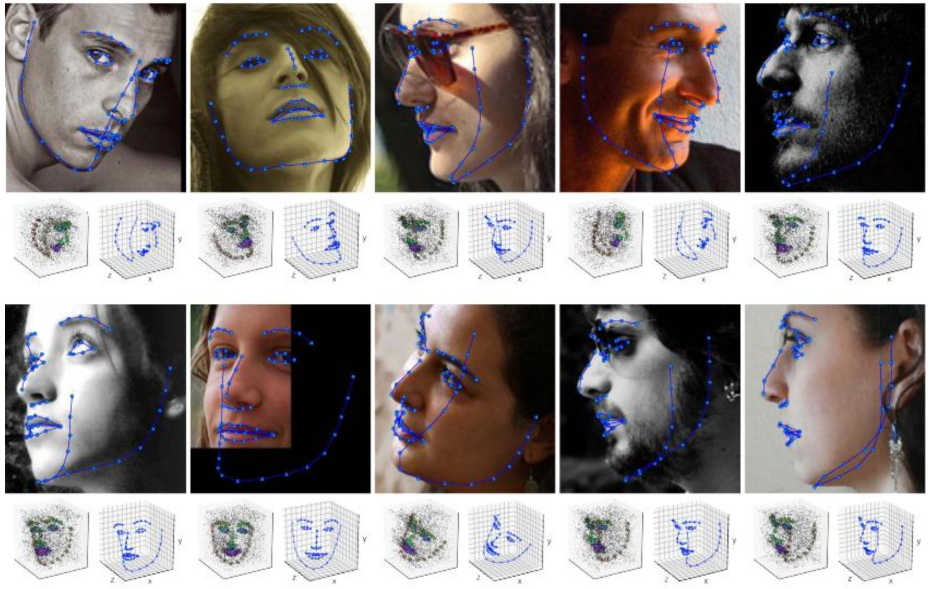


Li J, Zhang B, Wang Y, et al. ASFD: Automatic and scalable face detector[C]//Proceedings of the 29th ACM International Conference on Multimedia (*ACM MM*). 2021: 2139-2147.

Face Preprocessing: 2D/3D Facial Landmark Detection

We have proposed an adversarial voxel and coordinate regression framework for 2D and 3D facial landmark localization in real-world scenarios, in which an end-to-end pipeline is designed to jointly regress the proposed volumetric representation and the coordinate vector.

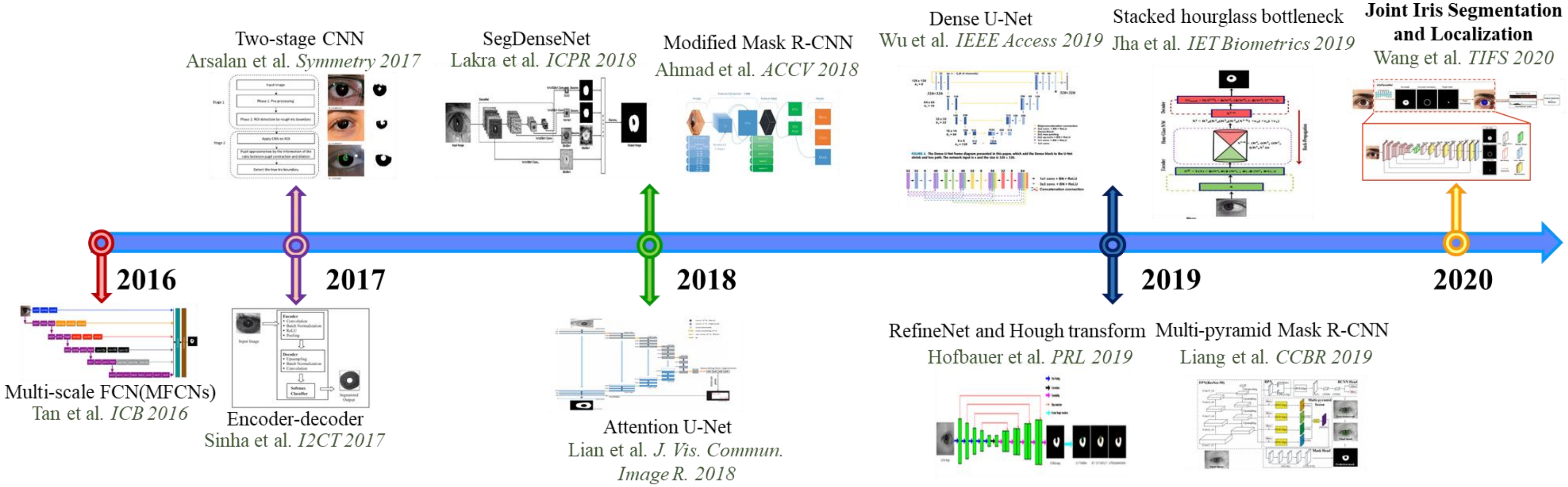




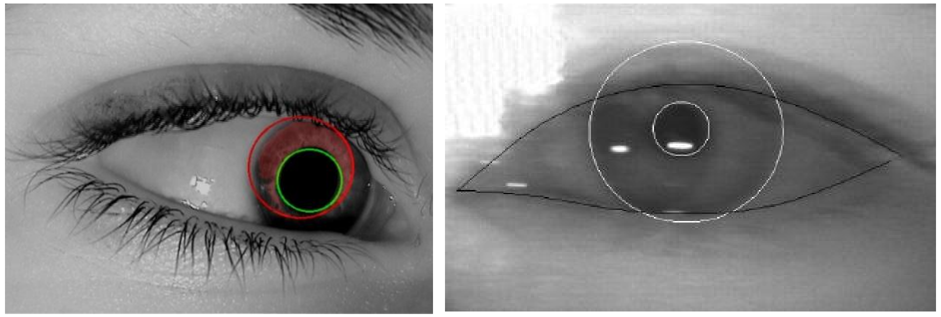
Zhang H, Li Q, Sun Z. Adversarial learning semantic volume for 2d/3d face shape regression in the wild[J]. IEEE Transactions on Image Processing (***TIP***), 2019, 28(9): 4526-4540.

Progress in Iris Preprocessing

The majority of current methods focus on predicting accurate iris masks by following popular semantic segmentation frameworks, but ignore the parameterized boundary for iris localization.



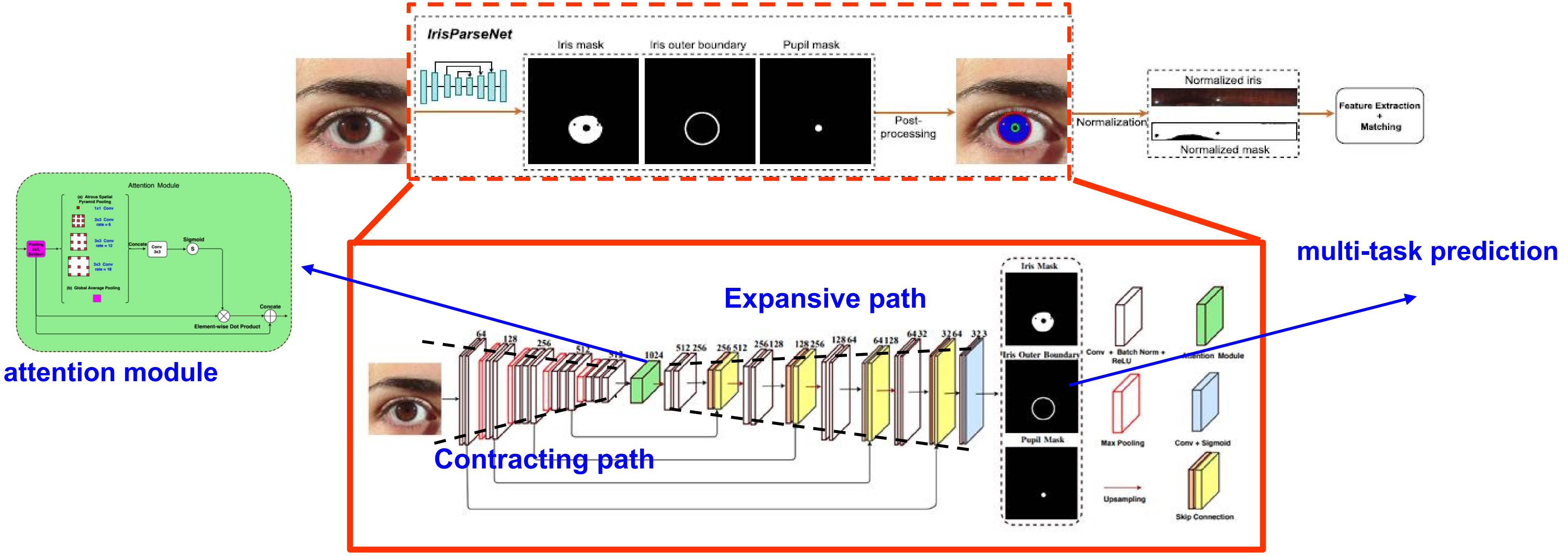
No boundary information for normalization



Dependent on training data and label quality

Our Solution: Simultaneous Iris Segmentation and Localization

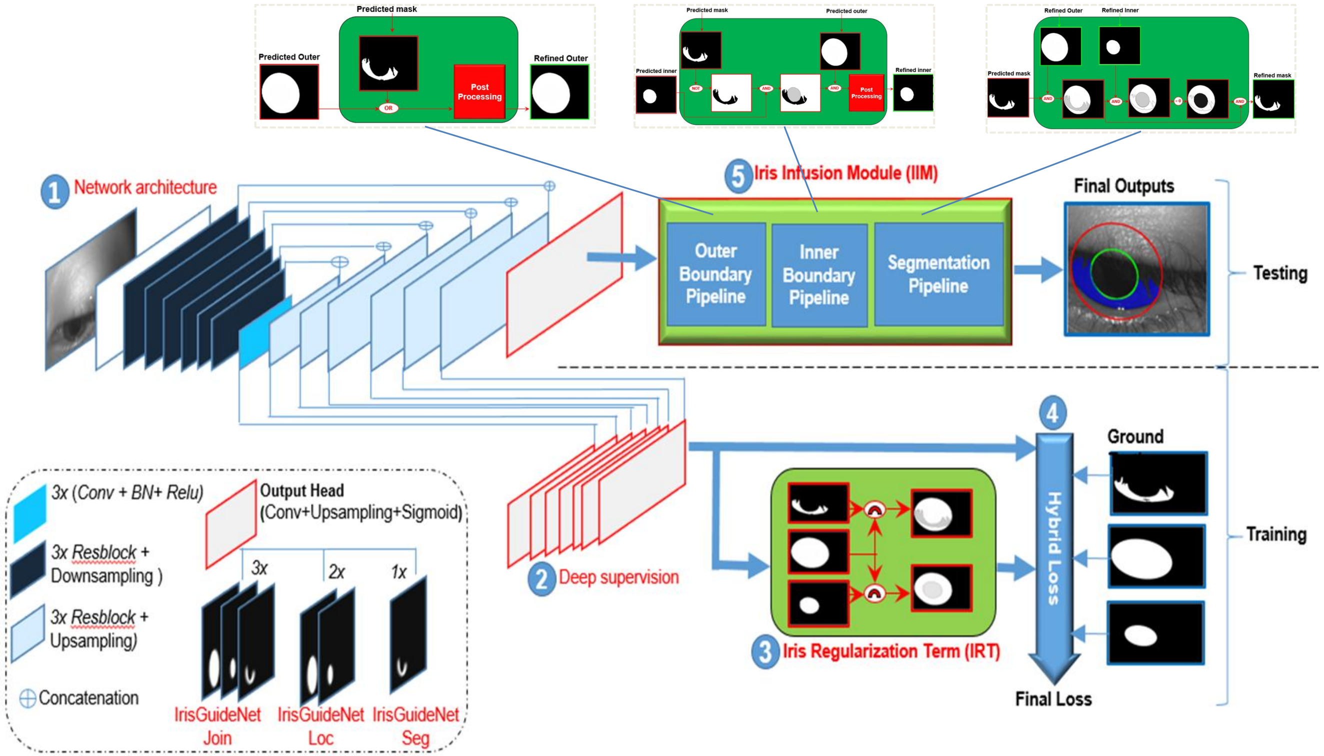
We proposed a unified framework for simultaneously learning segmentation mask and inner/outer iris boundaries, followed by simple yet efficient post-processing operations for complete iris segmentation.

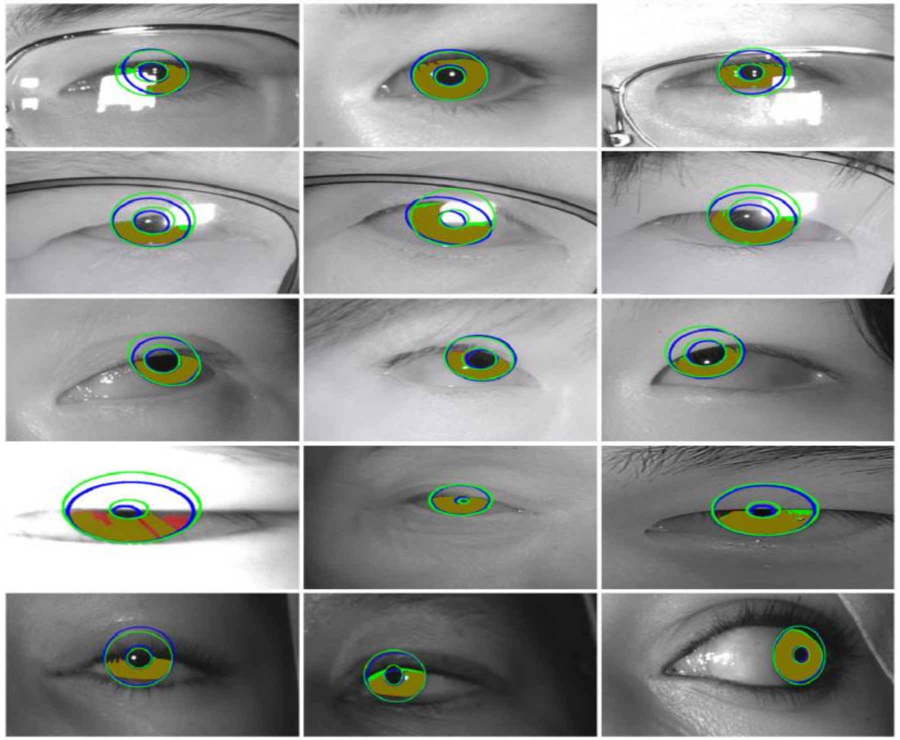


Wang C, Muhammad J, Wang Y, et al. Towards complete and accurate iris segmentation using deep multi-task attention network for non-cooperative iris recognition[J]. IEEE Transactions on information forensics and security (***TIFS***), 2020, 15: 2944-2959.

One Step Further: Iris Prior Guided Network

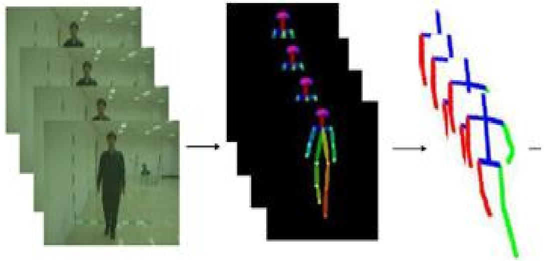
An iris prior infusion module and a prior regularization term are incorporated in deep learning models to reduce its dependence on training data, guide the model to converge better and faster, significantly enhance the localization and segmentation of low-quality iris images.





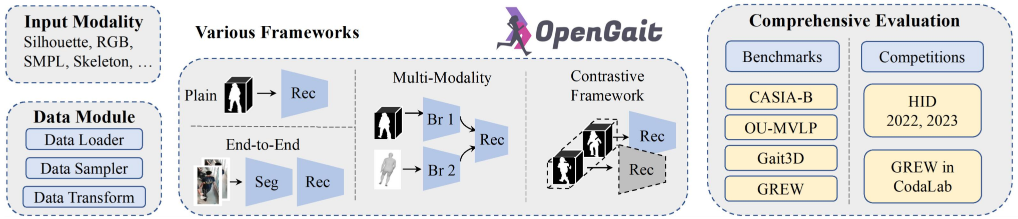
Jawad Muhammad, Caiyong Wang, Yunlong Wang, Kunbo Zhang, Zhenan Sun. “IrisGuideNet: Guided Localization and Segmentation Network for Unconstrained Iris Biometrics”, IEEE Transactions on Information Forensics and Security (***TIFS***), vol. 18, pp. 2723-2736, 2023.

Progress in Gait Preprocessing



Popular ways for gait sequence preprocessing
- ✓ Pedestrian detection: YOLO series or variants
- ✓ Pedestrian segmentation: U-Net or variants
- ✓ Pedestrian pose: HRNet, OpenPose, …

Benchmark

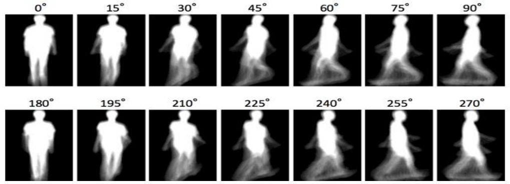


OpenGait
[Fan et al., *CVPR'23*]

Database

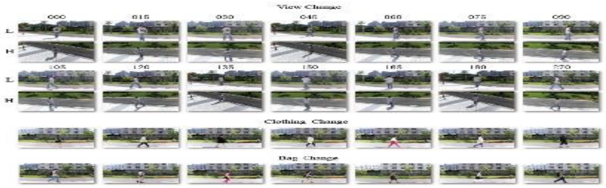
CASIA-B (cross-view)
[Yu et al., *ICPR'06*]

- The first cross-view and cross-dressing database in the world
- 124 people, 11 views per person
- covering backpack and clothing changes



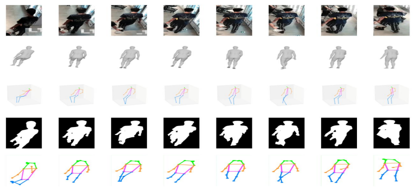
OU-MVLP
[Takemura et al., *CVA'18*]

Multi-view large population dataset



CASIA-E (the biggest ever)
[Song et al., *TPAMI'23*]

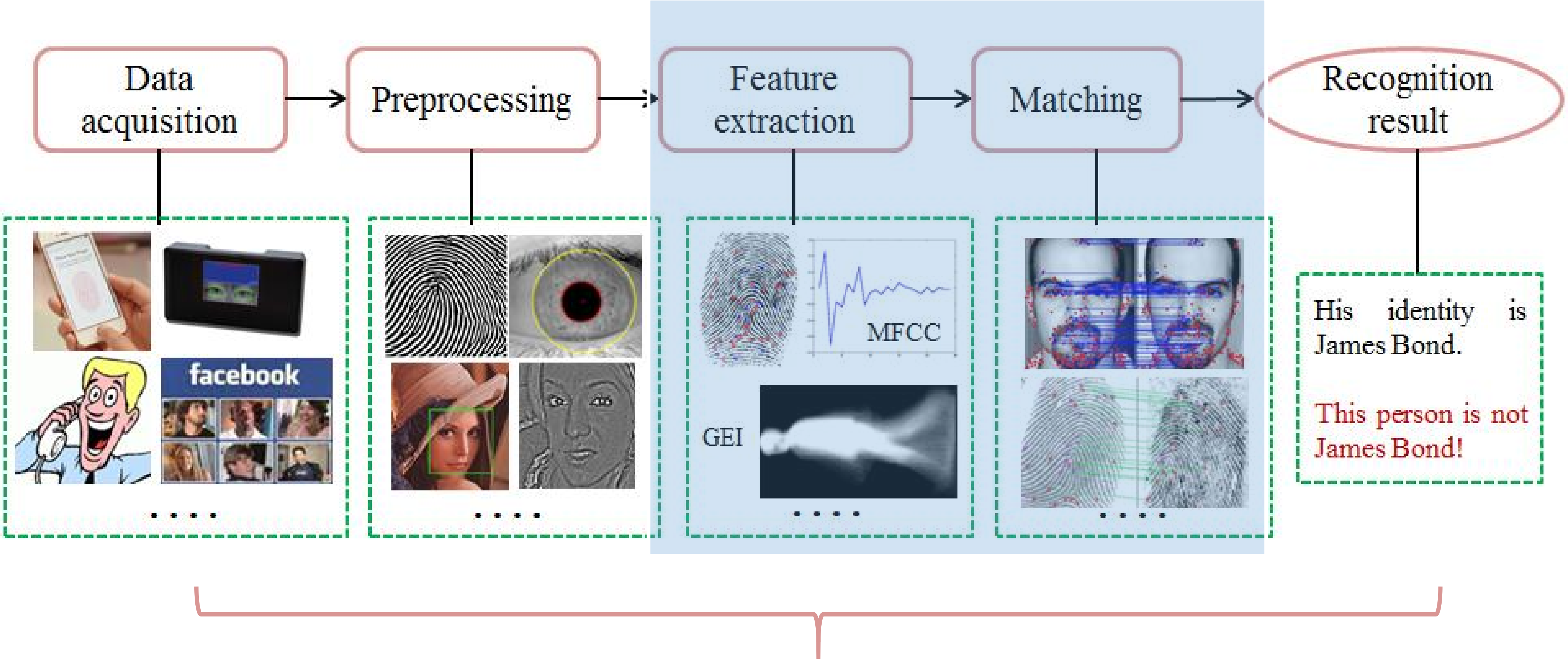
- more than 1000 persons, nearly 1 million video clips
- 3 kinds of clothing, 3 kinds of scenes, 2 kinds of walking patterns
- 13 horizontal views, 2 vertical views



Gait3D
[Zheng et al., *CVPR'22*]

the first large-scale 3D representation-based gait recognition dataset

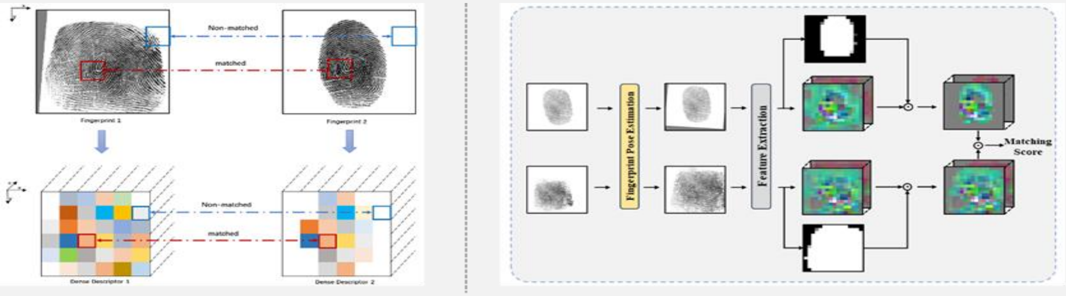
Recent Progress



- ✓ Security and privacy
- ✓ Fairness
- ✓ Explainability

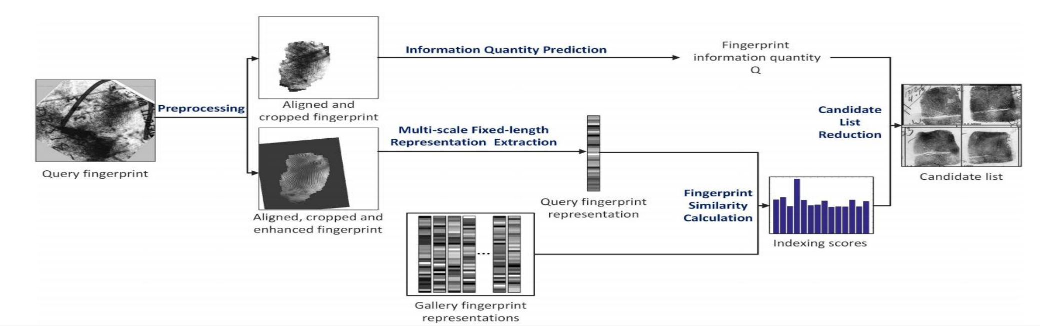
Progress in Fingerprint Feature Extraction and Matching

Fixed-length Dense Descriptor



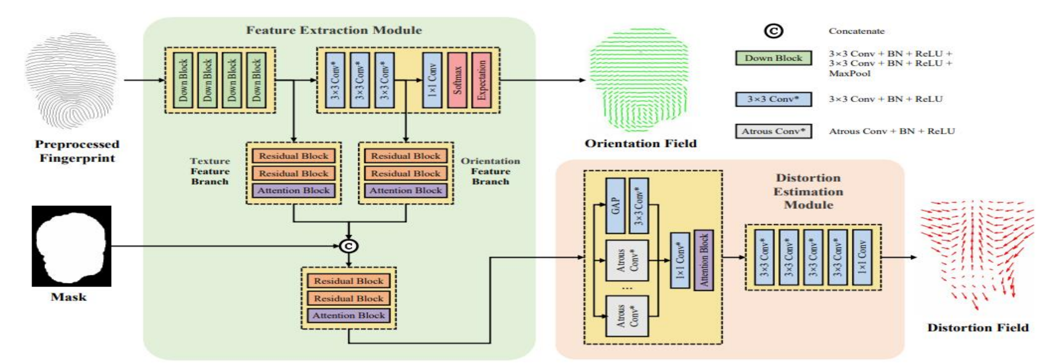
A three-dimensional representation Fixed length Dense Descriptor (FDD) for efficient fingerprint matching [Pan et al., ***WIFS'24***]

Latent fingerprint matching



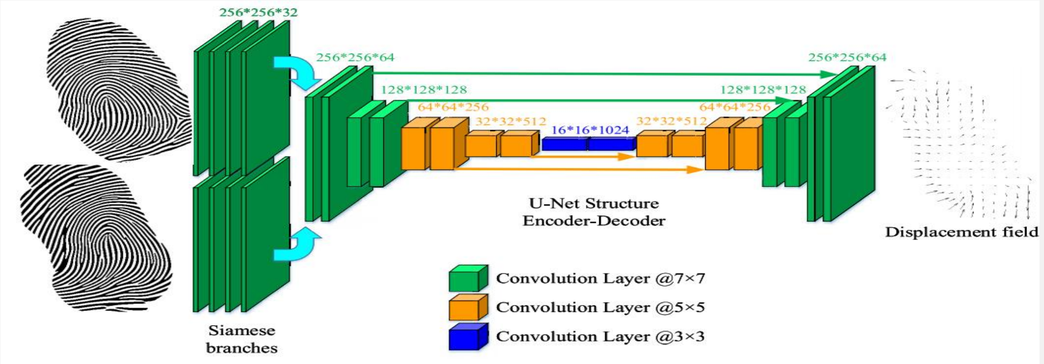
A multi-scale fixed-length representation approach for latent fingerprint indexing [Gu et al., ***TIFS'22***]

Fingerprint distortion rectification



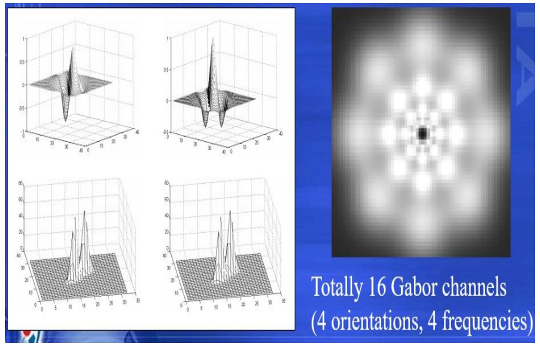
A self-reference based network is utilized to directly estimate the dense distortion field of distorted fingerprint [Guan et al., ***TIFS'23***]

Fingerprint dense registration

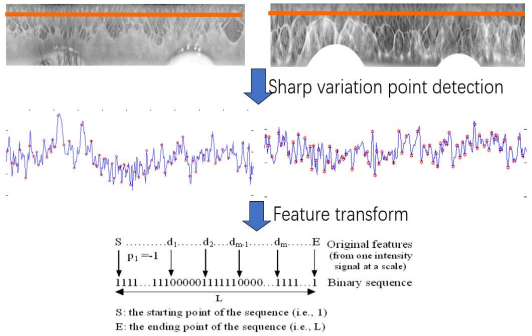


An end-to-end network to directly output pixel-wise displacement field between two fingerprints [Cui et al., ***TIFS'21***]

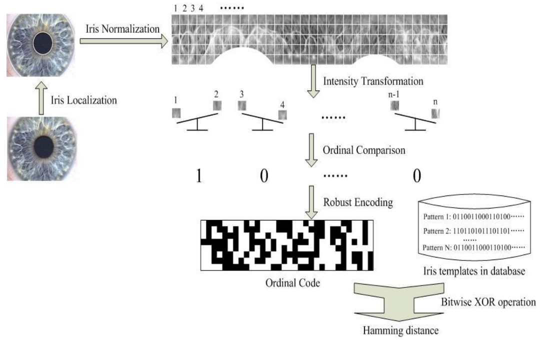
Progress in Iris Feature Extraction and Matching



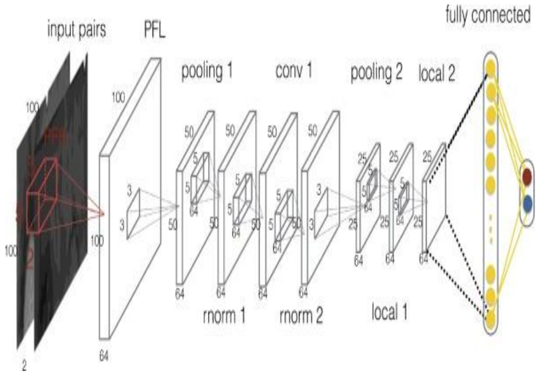
Gabor texture (Tan, PAMI2003)



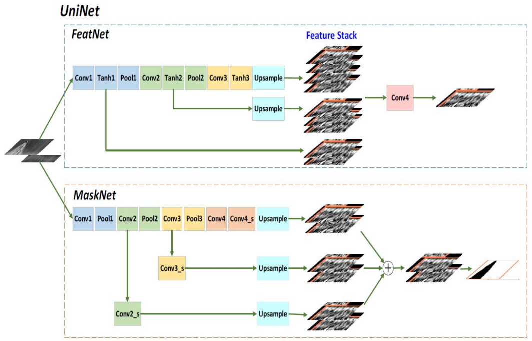
Local variations (Tan, TIP2004)



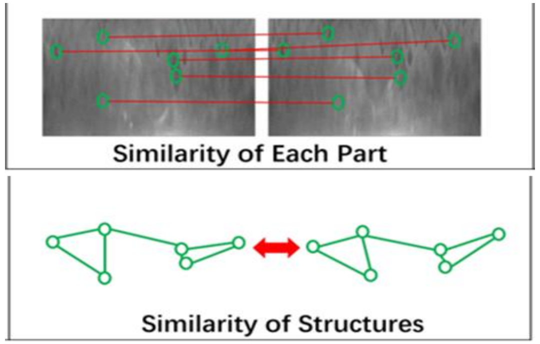
Ordinal measures (Tan, PAMI2009)



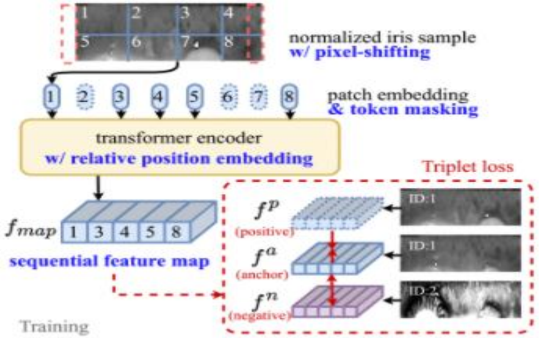
DeepIris (Tan, PRL2016)



UniNet (Kumar, ICCV2017)

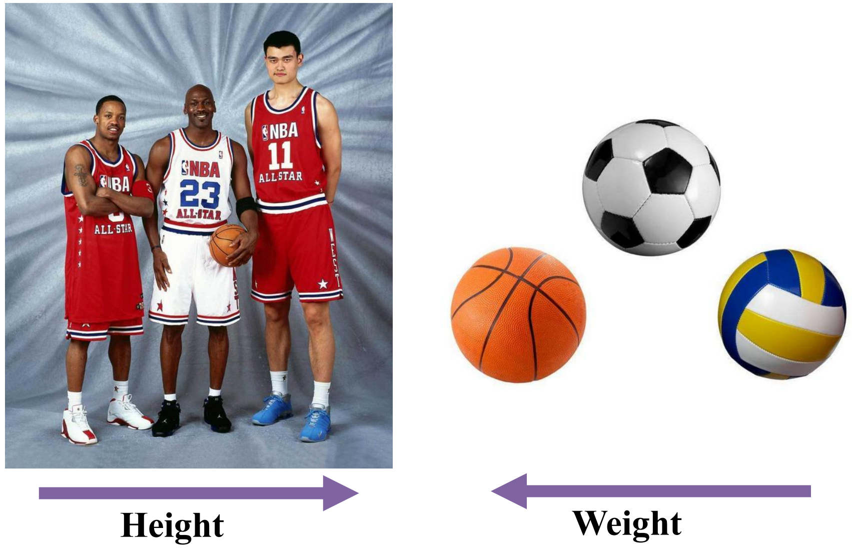


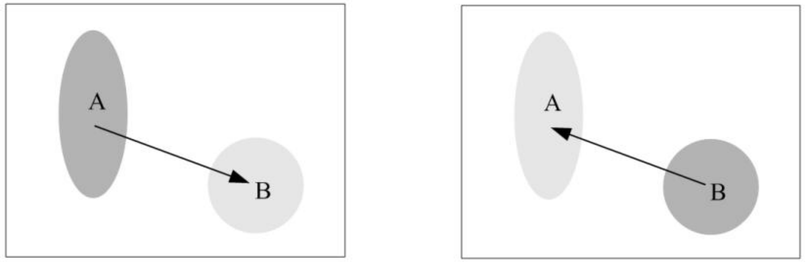
DGR (Tan, AAAI2020, TPAMI 2023)



IrisFormer (Sun, SPL2024)

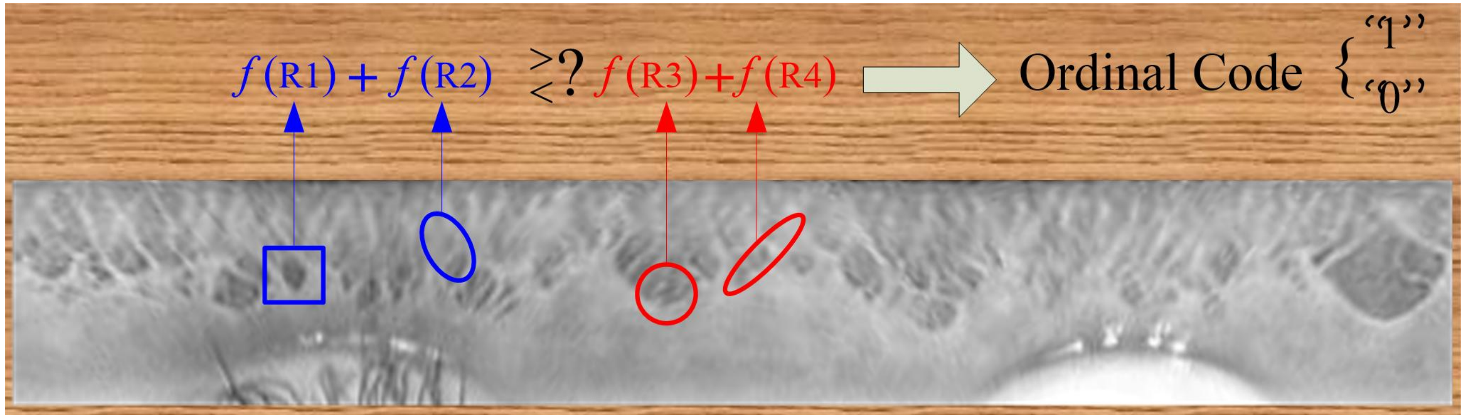
Ordinal Measures for Iris Pattern Recognition

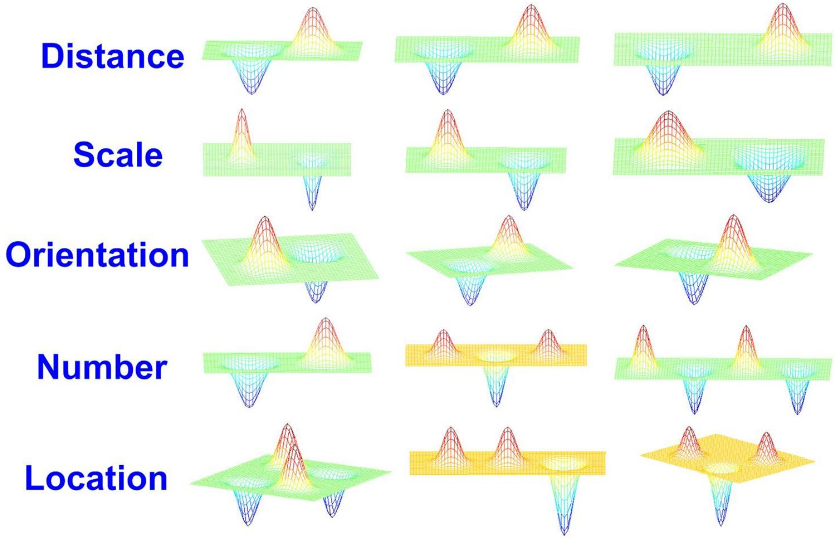




$A \prec B$ $\quad$ $A \succ B$.

1 one bit code 0

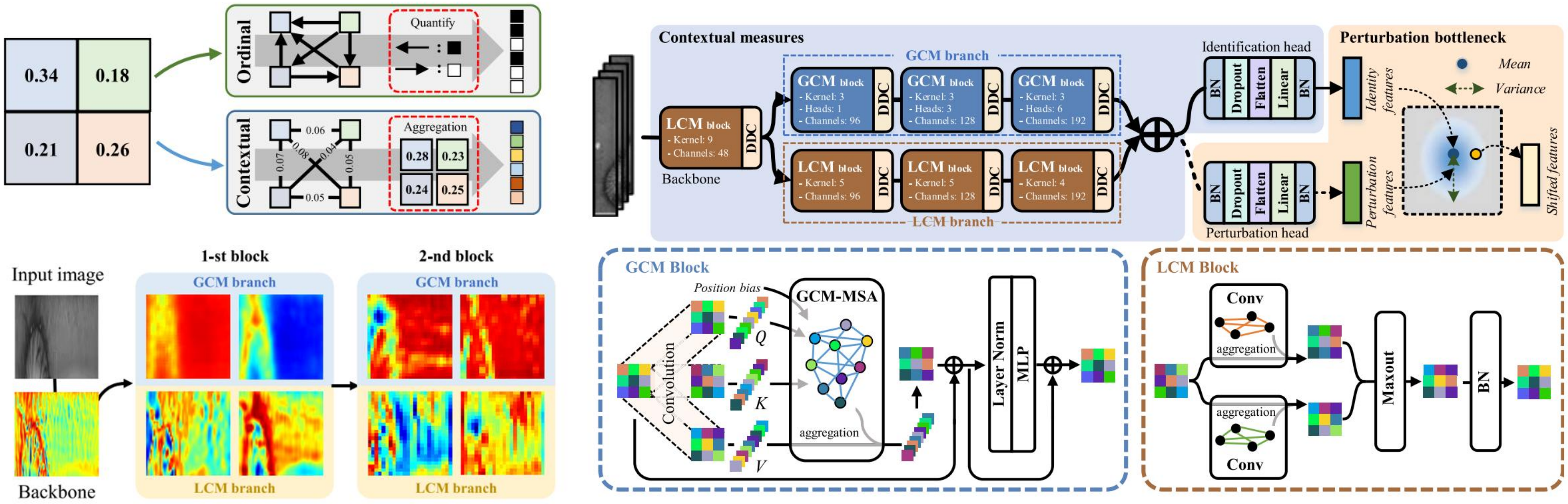




Zhenan Sun and Tieniu Tan, "Ordinal Measures for Iris Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence (***T-PAMI***), Vol. 31, No. 12, 2009, pp. 2211 - 2226.

Contextual Measures for Iris Recognition

Estimate quantitative relationships between different regions and aggregate features from a global contextual measure (GCM) branch and a local contextual measure (LCM) branch for iris recognition



Jianze Wei, Yunlong Wang*, Huaibo Huang, Ran He, Zhenan Sun, Xingyu Gao*. “Contextual Measures for Iris Recognition”, IEEE Transactions on Information Forensics and Security (***TIFS***), vol. 18, pp. 57-70, 2023.

Occlusion in Biometrics

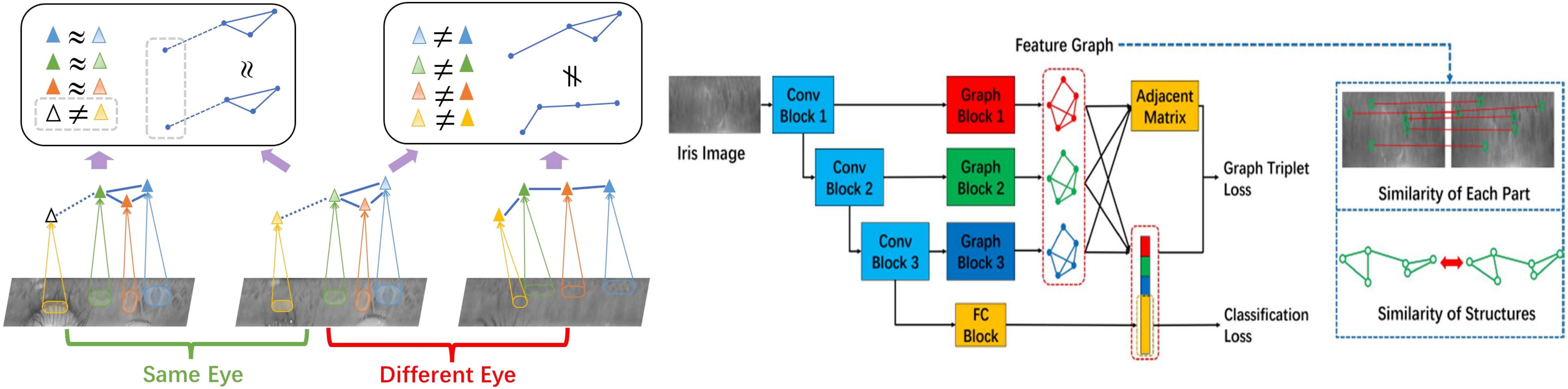
Iris

Face

Re-ID

Dynamic Graph Representation for Iris Recognition

- Modelling both local features and geometric relationships between local regions using deep graphical models
- The nodes of the occluded parts are removed during matching
- Robust against occlusions in iris recognition, face recognition and person ReID tasks

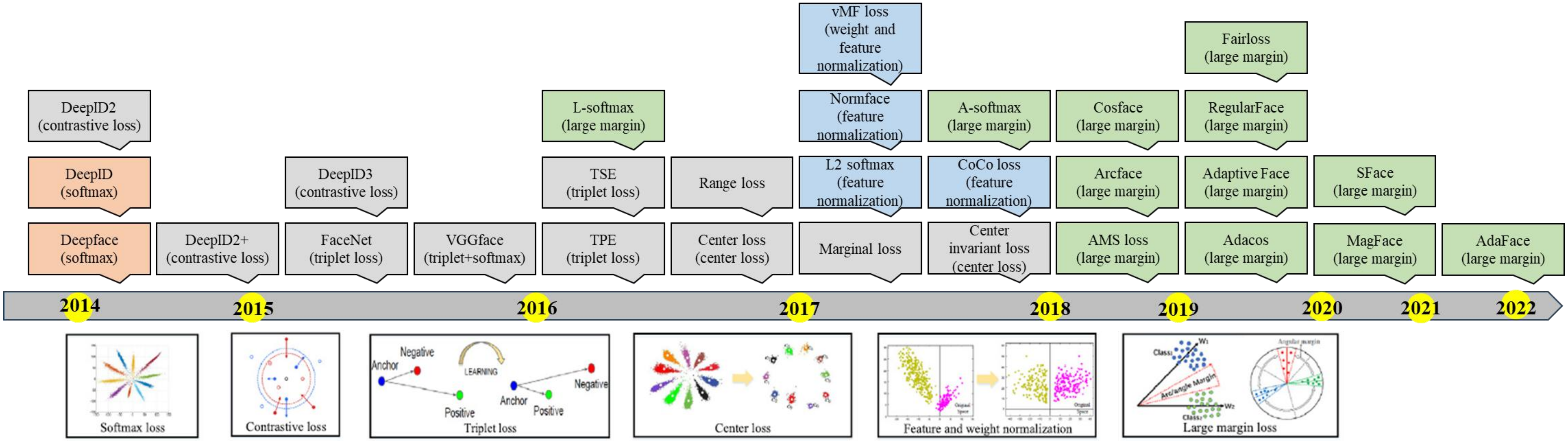


[1] Ren M, Wang Y, Sun Z, et al. Dynamic graph representation for occlusion handling in biometrics[C]//Proceedings of the AAAI Conference on Artificial Intelligence (***AAAI***). 2020, 34(07): 11940-11947.

[2] Ren M, Wang Y, Zhu Y, et al. Multiscale Dynamic Graph Representation for Biometric Recognition with Occlusions[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence (***TPAMI***), 2023.

Progress in Deep Facial Feature Extraction

Deep learning has become the mainstream method for facial feature extraction and the main development centres around network architecture and loss function design.

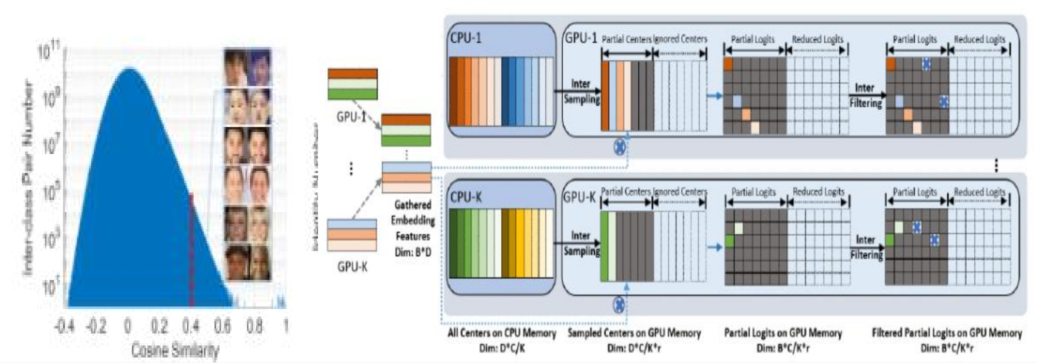


The development of loss functions for facial feature extraction

Mostly from Wang et al. Deep face recognition: A survey[J]. Neurocomputing, 2021, 429: 215-244.

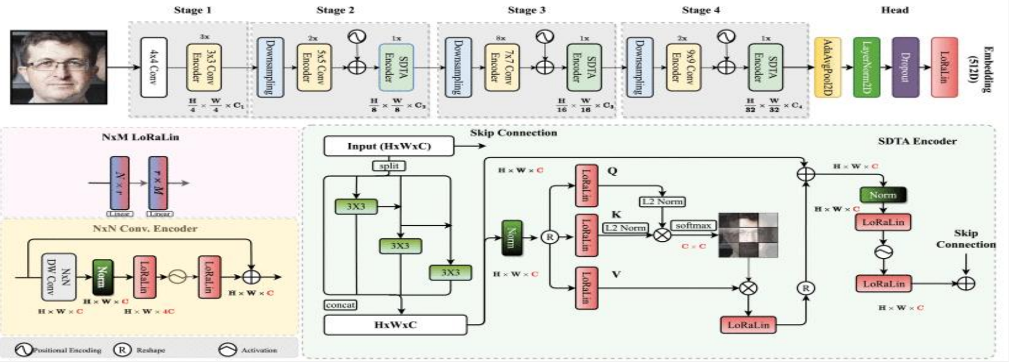
Progress in Deep Facial Feature Extraction

- Very Large Scale Face Recognition



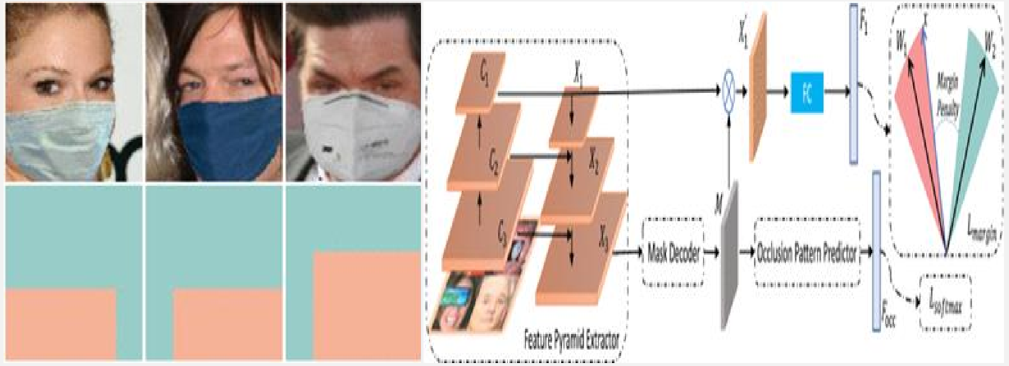
Partial FC [An et al., ***CVPR'22***]

- Extremely Efficient Face Recognition



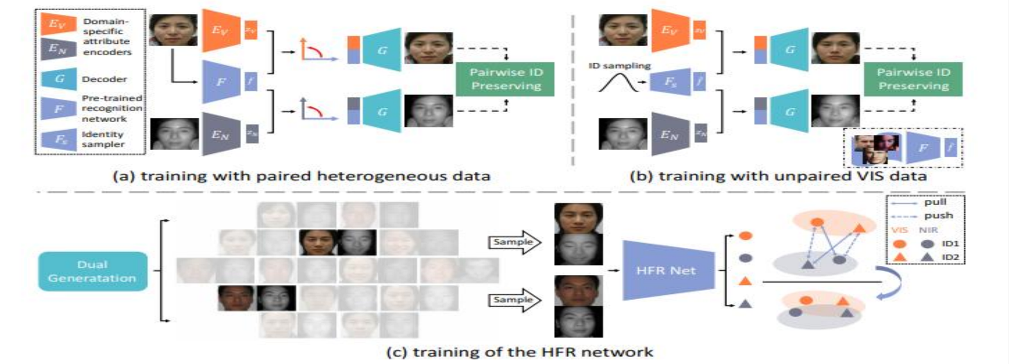
EdgeFace [George et al., ***TBIOM'24***]

- Masked Face Recognition



FROM [Qiu et al., ***TPAMI'21***]

- Cross-spectral Face Recognition

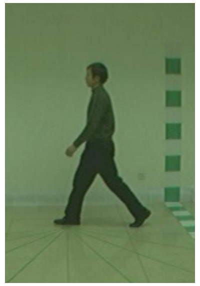


DVG-Face [Fu et al., ***TPAMI'22***]

Progress in Gait Recognition

Appearance-based

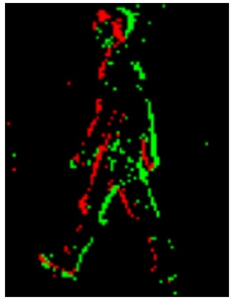

Template


RGB

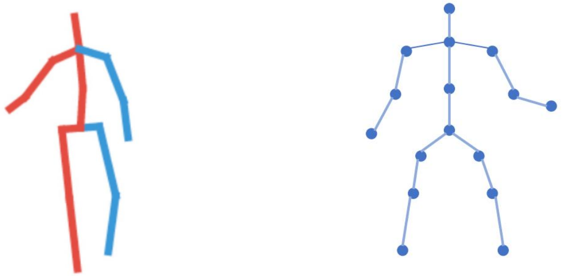

Parsing

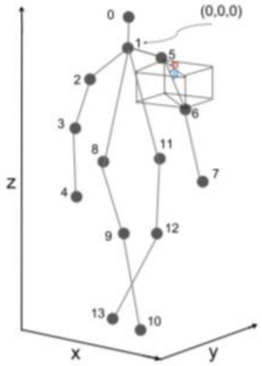

Silhouettes

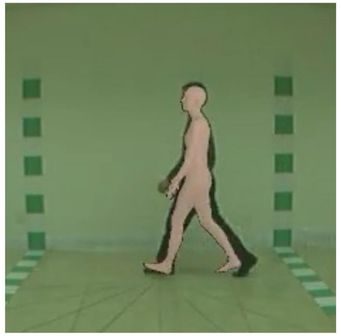

Point Cloud


Event Image

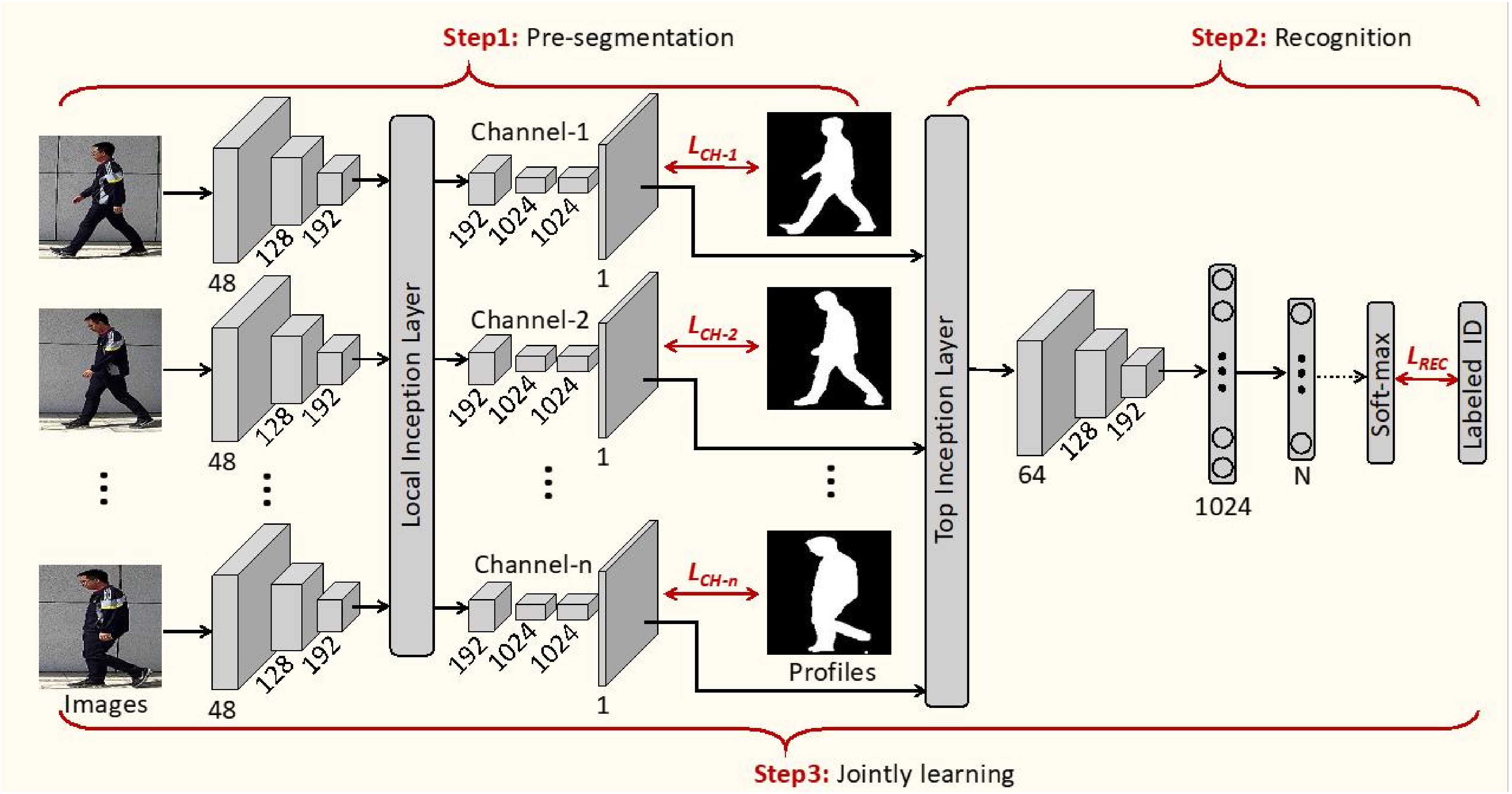
Model-based


2D Pose


3D Pose


SMPL

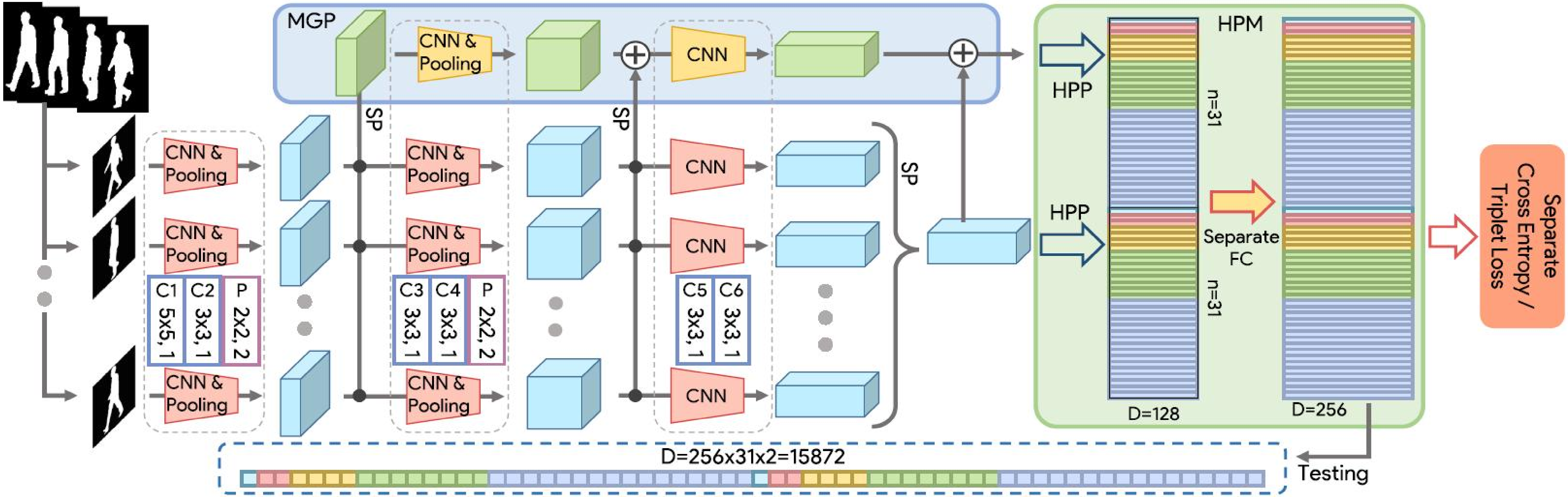
GaitNet: End-to-end Gait Recognition



Song C, Huang Y, Huang Y, et al. GaitNet: An end-to-end network for gait based human identification[J]. Pattern recognition, 2019.

GaitSet: Regarding Gait as a Deep Set

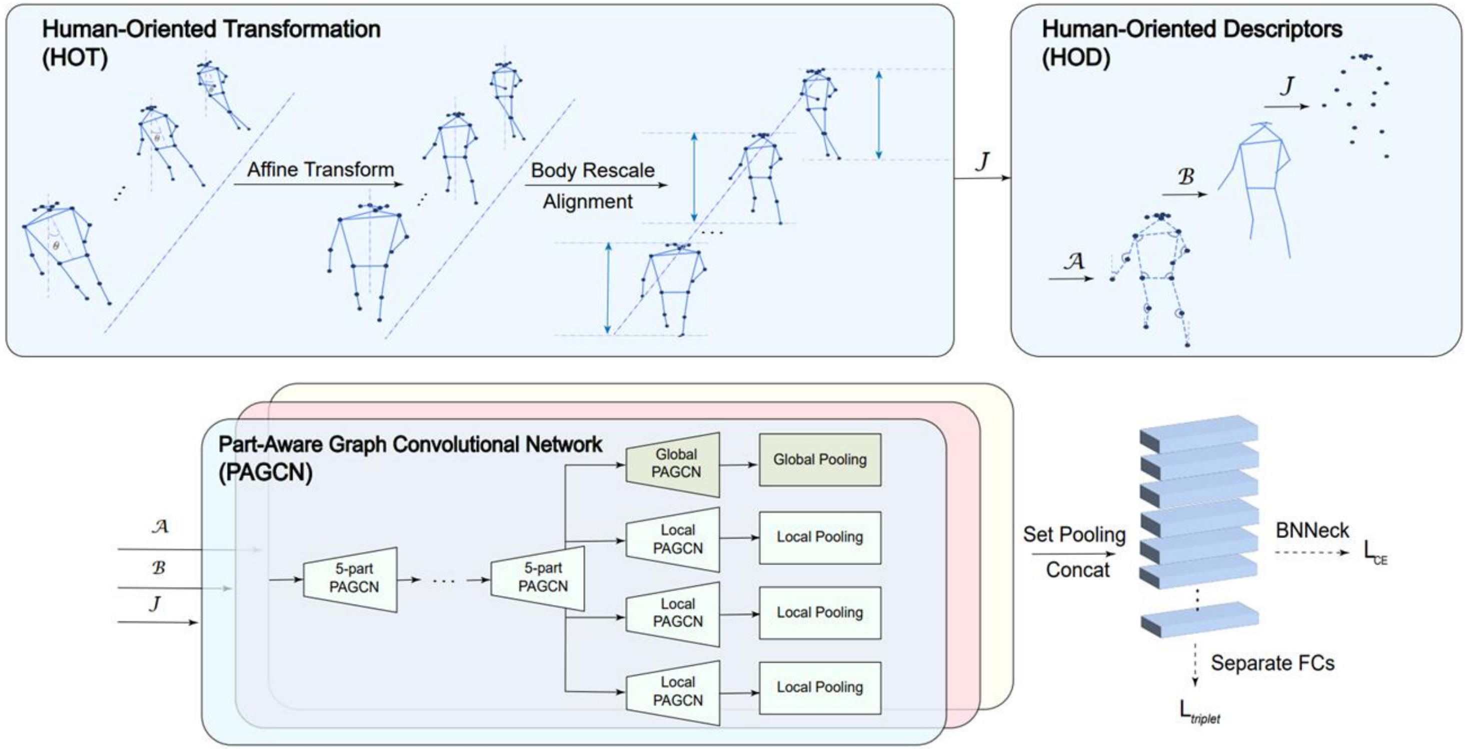
A set of gait frames are integrated by a global-local fused deep network. The advantages are that GaitSet is immune to frame permutations, and can naturally integrate frames from different videos that have been acquired under different scenarios.

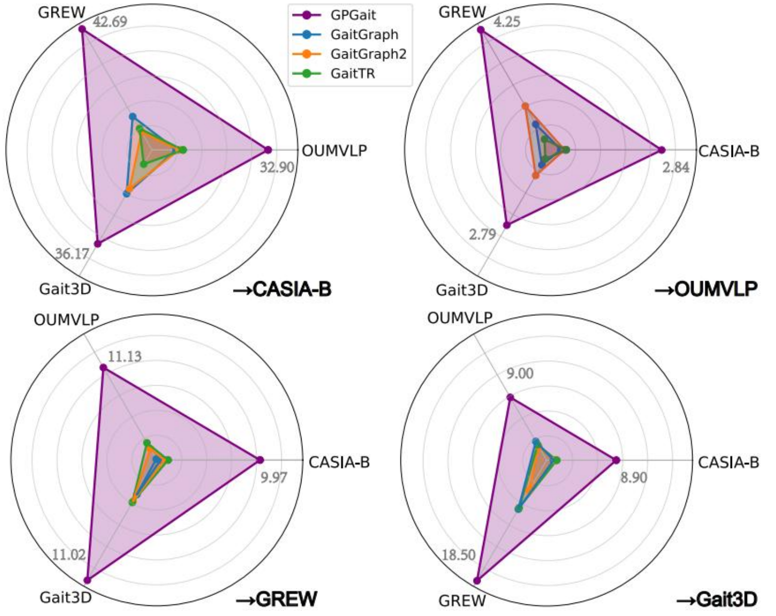


Chao H, Wang K, He Y, et al. GaitSet: Cross-view gait recognition through utilizing gait as a deep set[J]. IEEE transactions on pattern analysis and machine intelligence (***TPAMI***), 2021, 44(7): 3467-3478.

GPGait: Generalized Pose-based Gait Recognition

A series of human-oriented operations are proposed to facilitate a uniform pose input that overcomes problems caused by various environmental covariances, and a part-aware GCN is proposed to achieve efficient graph partition and local-global feature relation extraction.

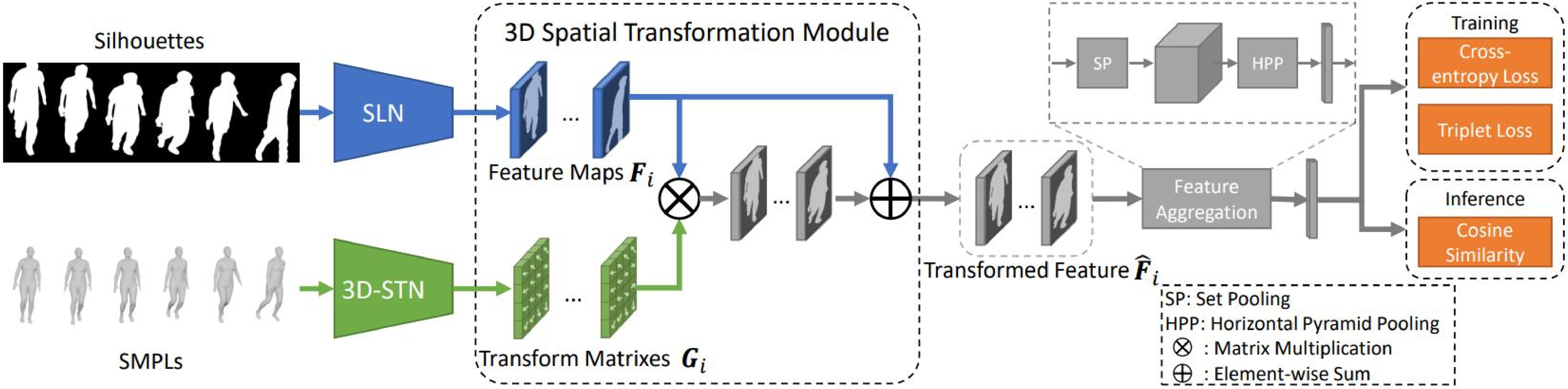




Fu Y, Meng S, Hou S, et al. GPGait: Generalized pose-based gait recognition[C]//Proceedings of the IEEE/CVF International Conference on Computer Vision (***CVPR***). 2023: 19595-19604.

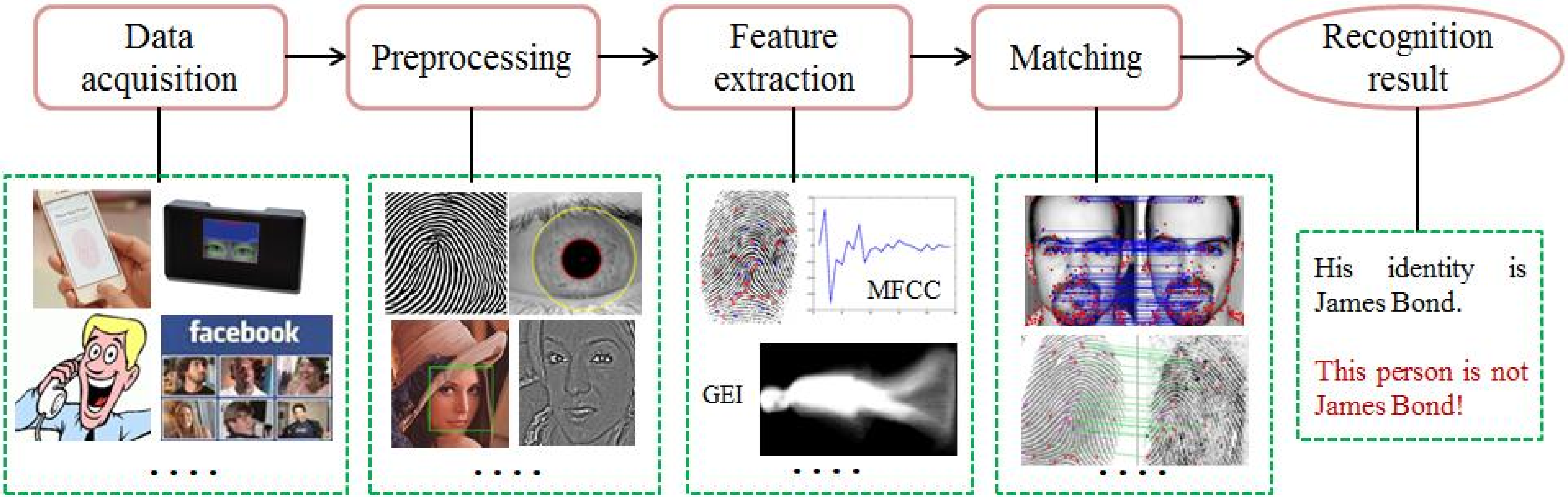
SMPLGait: Leverage SMPL Model

The 3D Skinned Multi-Person Linear (SMPL) model of the human body is explored for gait recognition. 3D gait representations are learnt by combining appearance features from silhouettes and knowledge learnt from 3D viewpoints and shapes of SMPL model.



Zheng J, Liu X, Liu W, et al. Gait recognition in the wild with dense 3d representations and a benchmark[C]//Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (***CVPR***). 2022: 20228-20237.

Recent Progress



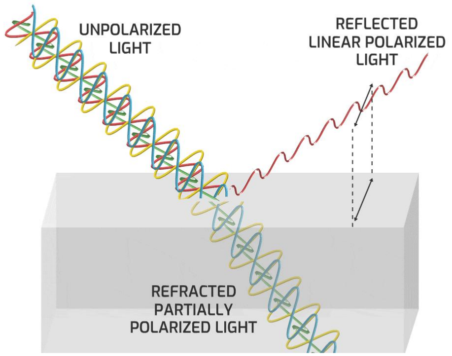
- ✓ Security and privacy
- ✓ Fairness
- ✓ Explainability

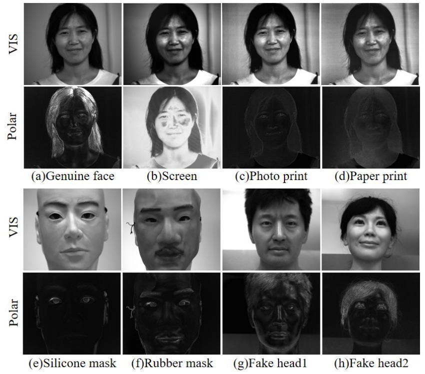
Factors to consider in a trustworthy biometric system

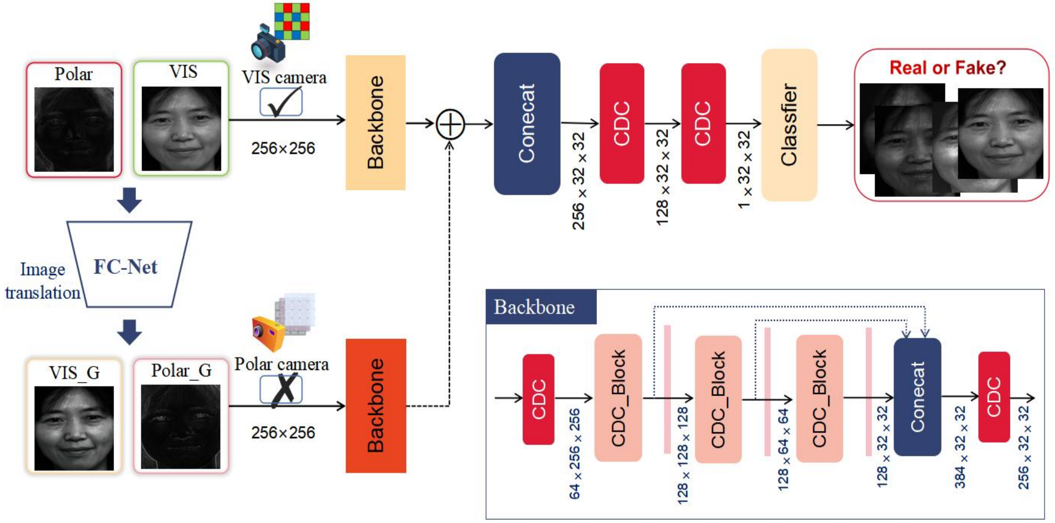
Polarized Image Translation for Face Anti-spoofing

Polarized Image Translation from Nonpolarized Cameras for Multimodal Face Anti-spoofing

The polarization characteristics of reflected light are closely related to the target's material, texture, and roughness.







Polarized Face Dataset（CASIA-Polar）

- **Polarized Face**

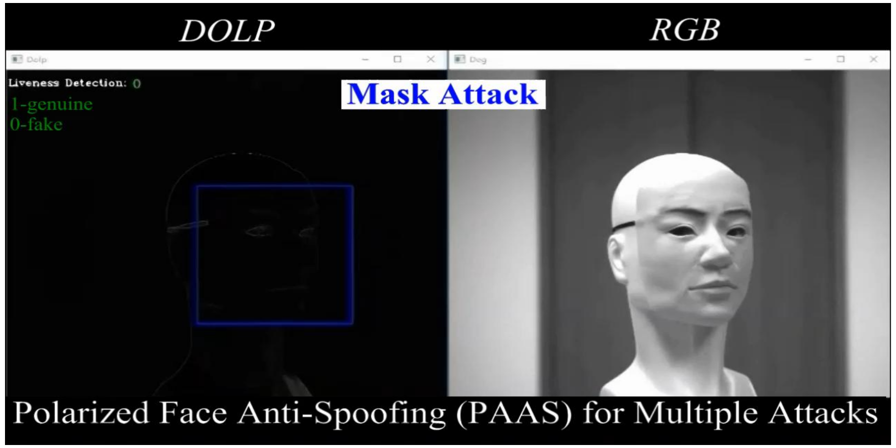
  121 subjects, 22,174 images, 3 types of images

- **RGB Face** **2,104 images**
- **Five Categories of spoofing**

  photo/paper print, replay, 3D mask, dummy head

- **Multi-Illumination**

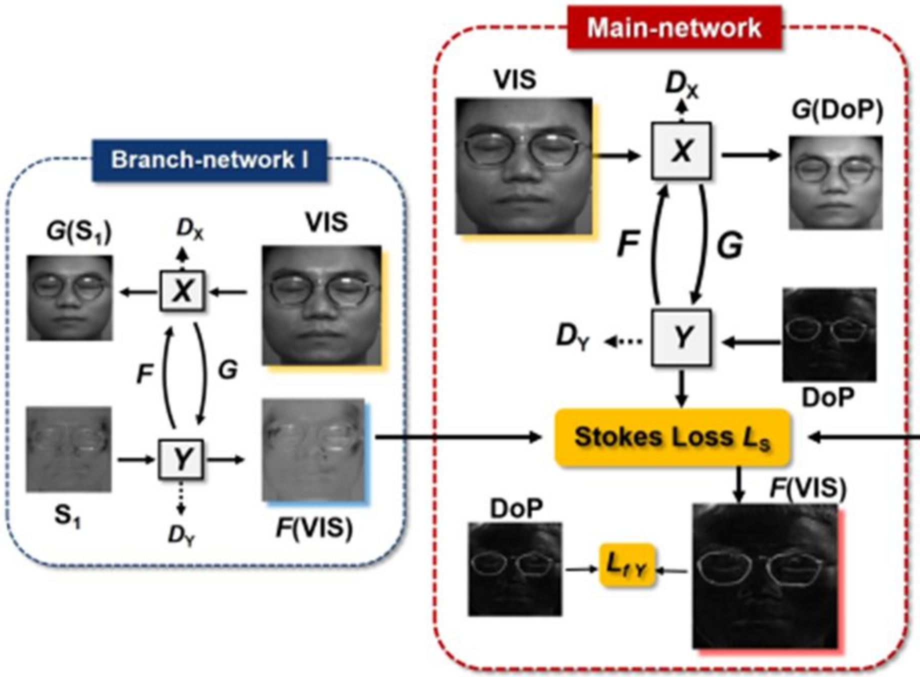
  VIS, polarized VIS, NIR, and polarized NIR



Tian Y, Huang Y, Zhang K, et al. Polarized Image Translation from Nonpolarized Cameras for Multimodal Face Anti-spoofing[J]. IEEE Transactions on Information Forensics and Security (***TIFS***), 2023.

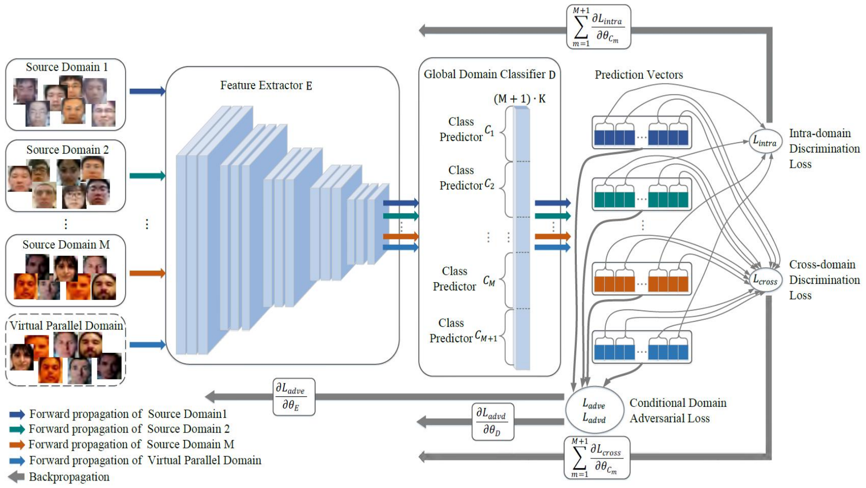
Polarized Image Translation for Face Anti-spoofing

We further translate VIS images into degree of polarization (DoP) images and Stokes polarization parameters, and employ frequency domain loss and the Stokes loss conforming to objective physical laws.

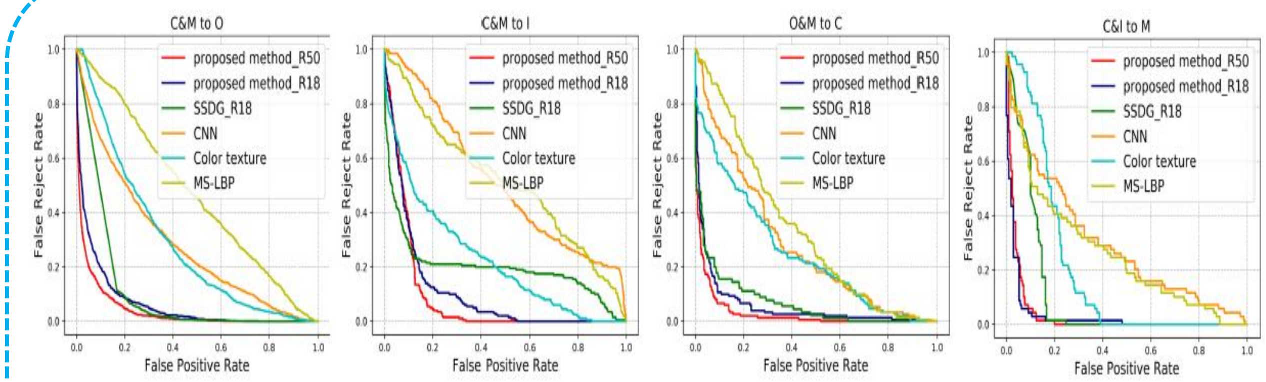


Yu Tian, Kunbo Zhang, Yalin Huang, Leyuan Wang, Yue Liu, Zhenan Sun.Cross-Optical Property Image Translation for Face Anti-Spoofing: From Visible to Polarization. IEEE Transactions on Information Forensics and Security (***TIFS***), 2024.

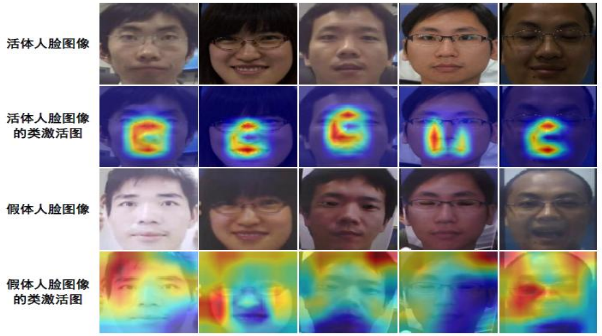
Improvement of Robustness of Face Anti-spoofing via Domain Generalization



We propose a simple but effective **conditional domain adversarial framework** for face anti-spoofing, which learns generalized features for the classification of unseen target domain samples.



Achieves SOTA performance on 14 different protocols

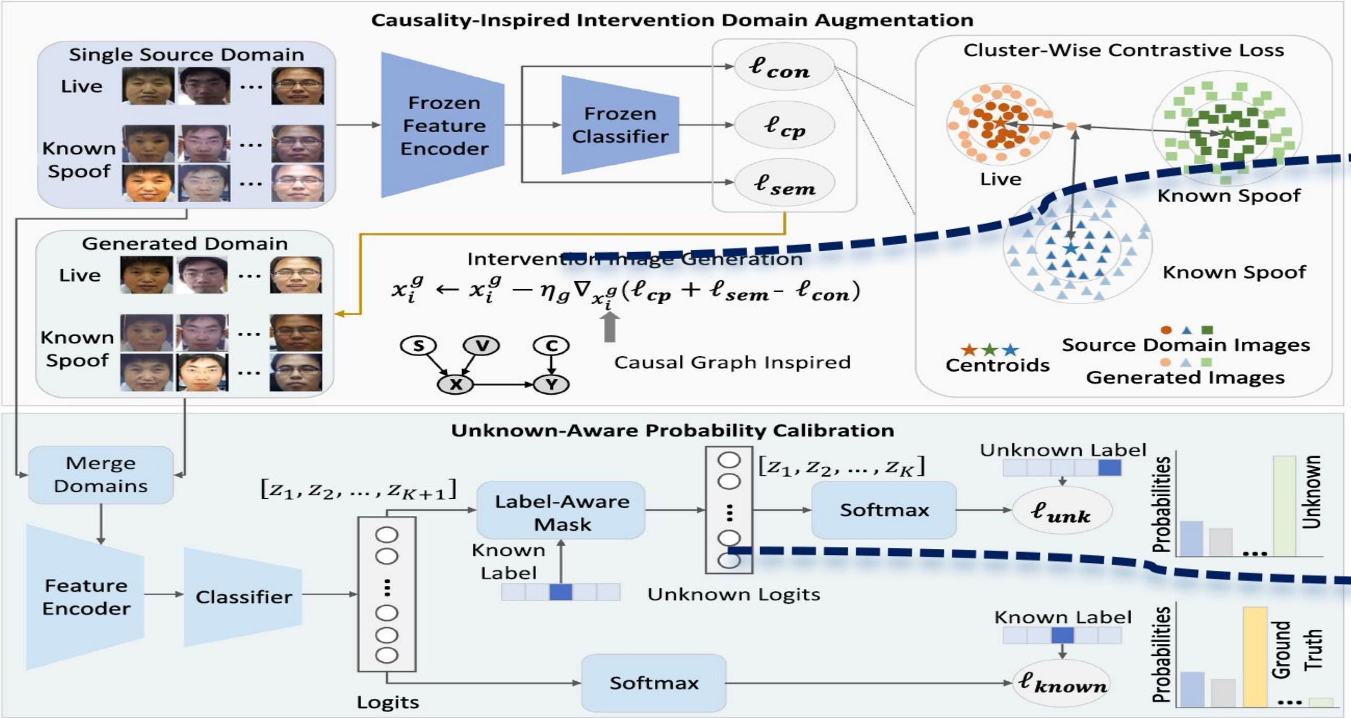


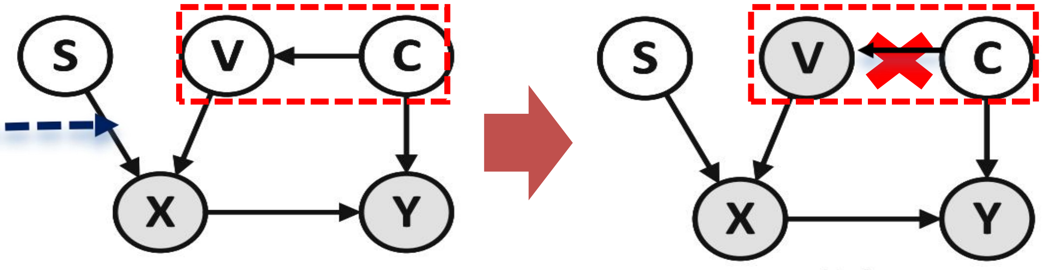
Grad-CAM of live and spoof faces

Jiang F, Li Q, Liu P, et al. Adversarial learning domain-invariant conditional features for robust face anti-spoofing[J]. International Journal of Computer Vision (***IJCV***), 2023, 131: 1680-1703.

Causality-based Face Anti-spoofing

We propose a causal inference-based face anti-spoofing method. This method enhances the diversity of training samples in the source domain through visual intervention while preserving semantic consistency.





$X \leftarrow V \leftarrow C \rightarrow Y.$ $\quad$ $V \rightarrow X \rightarrow Y$

Causal Intervention

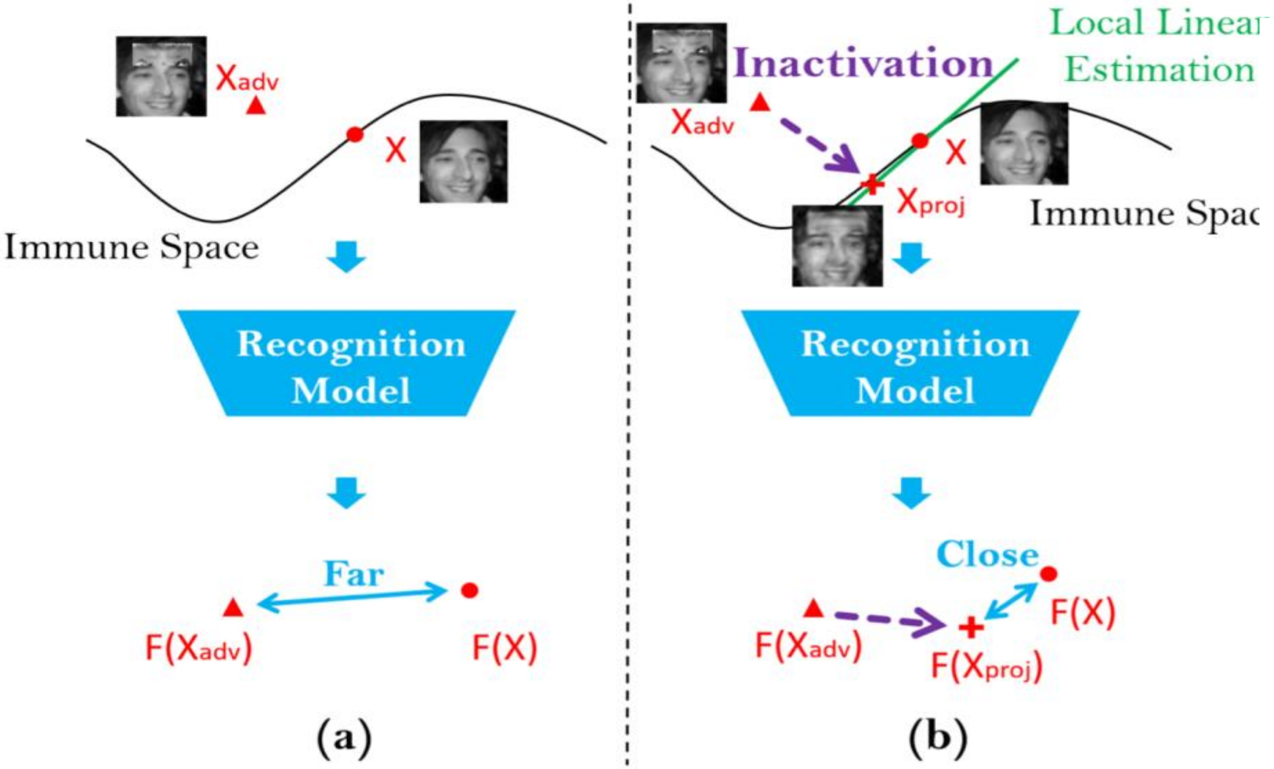
Randomly select samples, mask their label tags, and force the classification of these samples as unknown category samples.

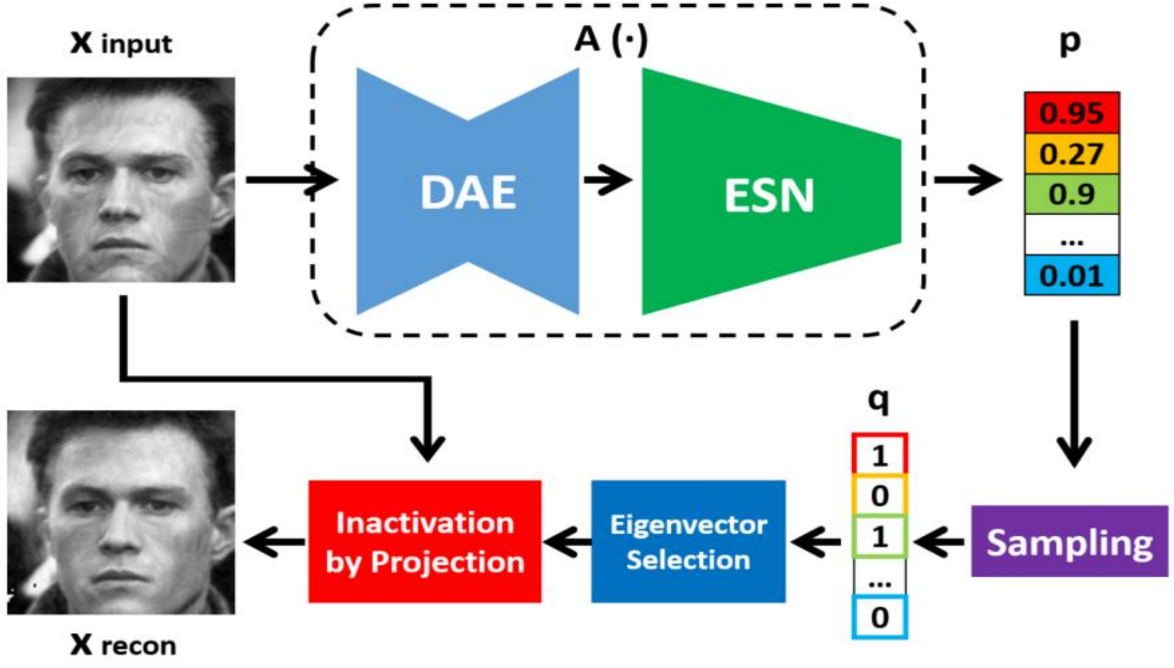
Probability Correction Module

Jiang F, Li Q, Sun Z, et al. Open-set single-domain generalization for robust face anti-spoofing[J]. International Journal of Computer Vision (*IJCV*), 2024, 132: 5151-5172.

Perturbation Inactivation based Adversarial Defense

We propose to solve the unknown adversarial noises problem by estimating the immune space and inactivate the adversarial perturbations by restricting them to this subspace.

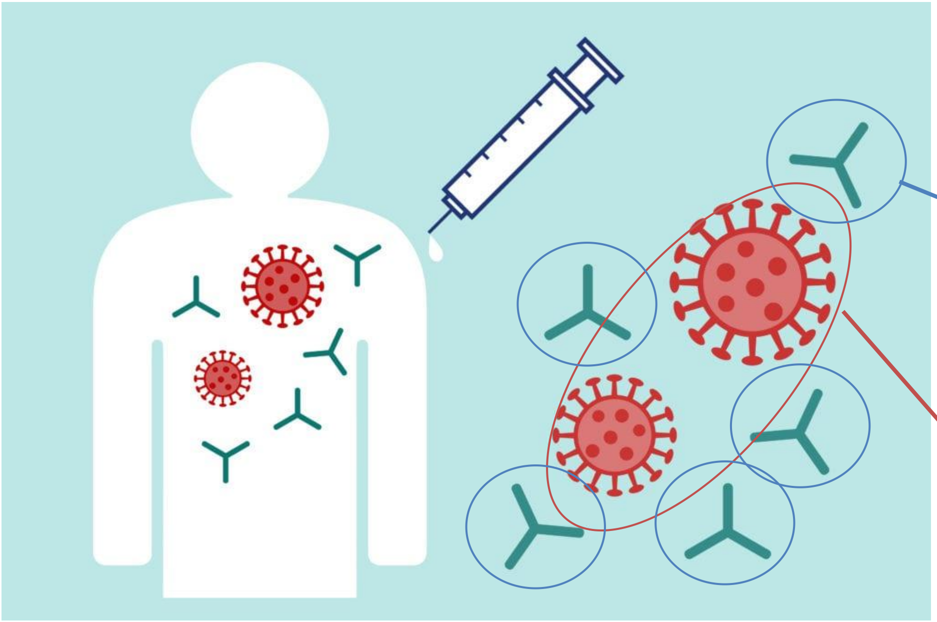


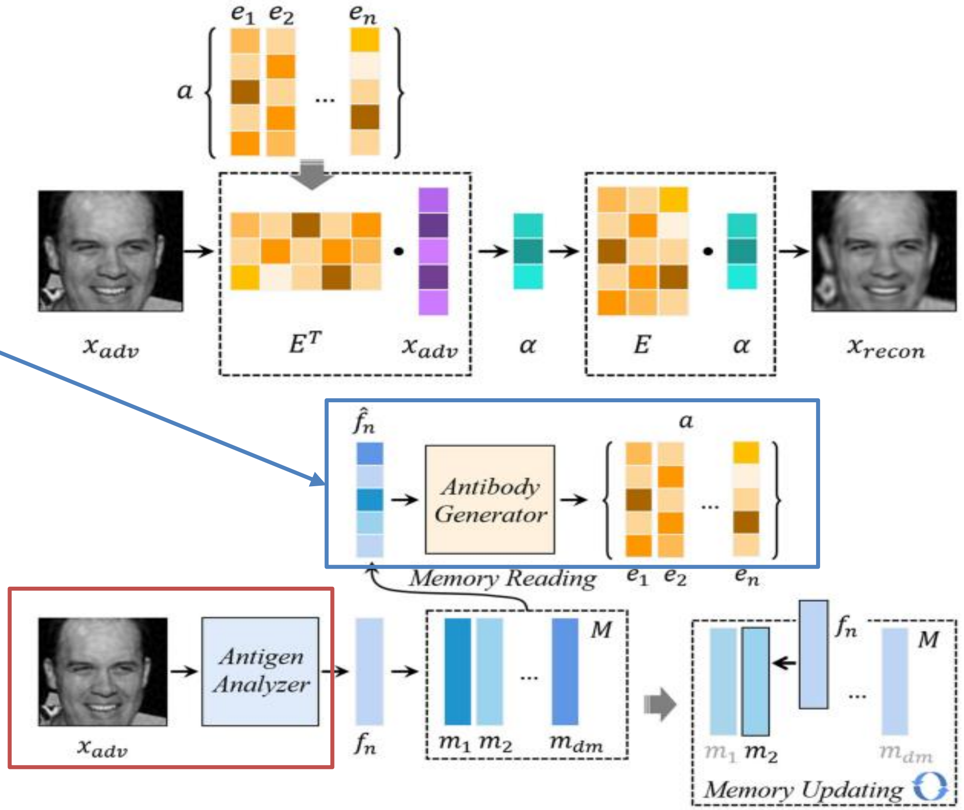


Ren M, Zhu Y, Wang Y, et al. Perturbation Inactivation Based Adversarial Defense for Face Recognition[J]. IEEE Transactions on Information Forensics and Security (***TIFS***), 2022, 17: 2947-2962.

Artificial Immune System for Adversarial Defense in Face Recognition

Inspired by biological immune system, an artificial immune system is proposed to provide adversarial defense for face recognition. It incorporates the principles of antibody cloning, mutation, selection, and memory mechanisms to generate a distinct "antibody" for each sample

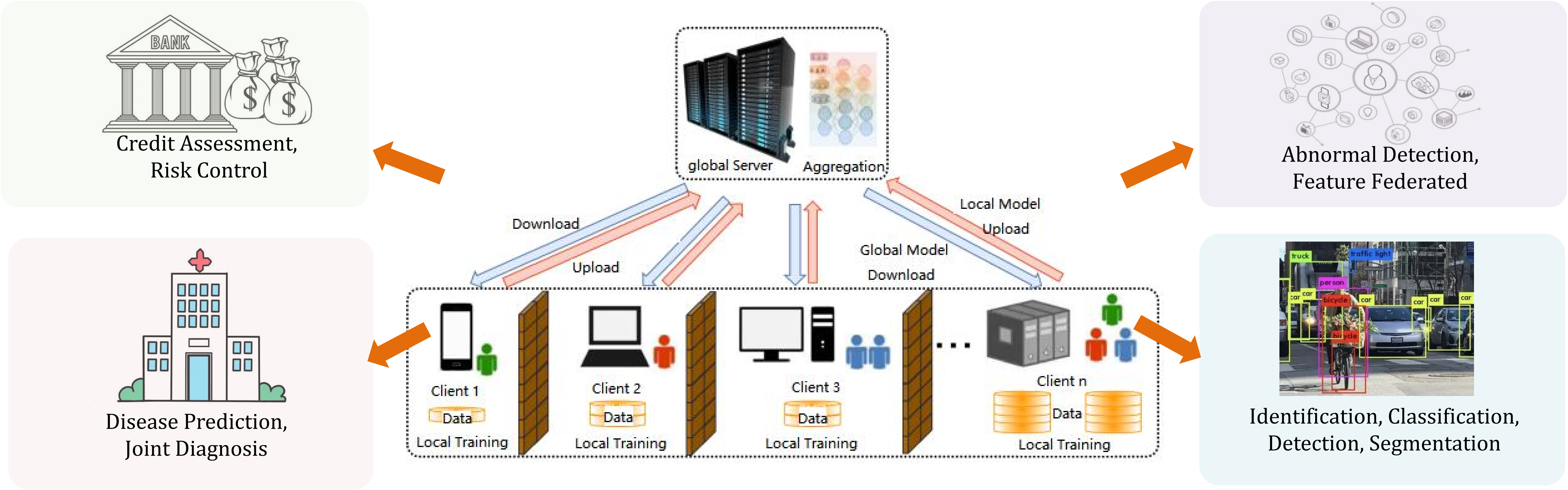




Min Ren#, Yunlong Wang#, Yuhao Zhu, Yongzhen Huang, Zhenan Sun, Qi Li, Tieniu Tan. "Artificial Immune System of Secure Face Recognition Against Adversarial Attacks", International Journal of Computer Vision (***IJCV***), Vol. 132, 2024, pp. 5718-5740.

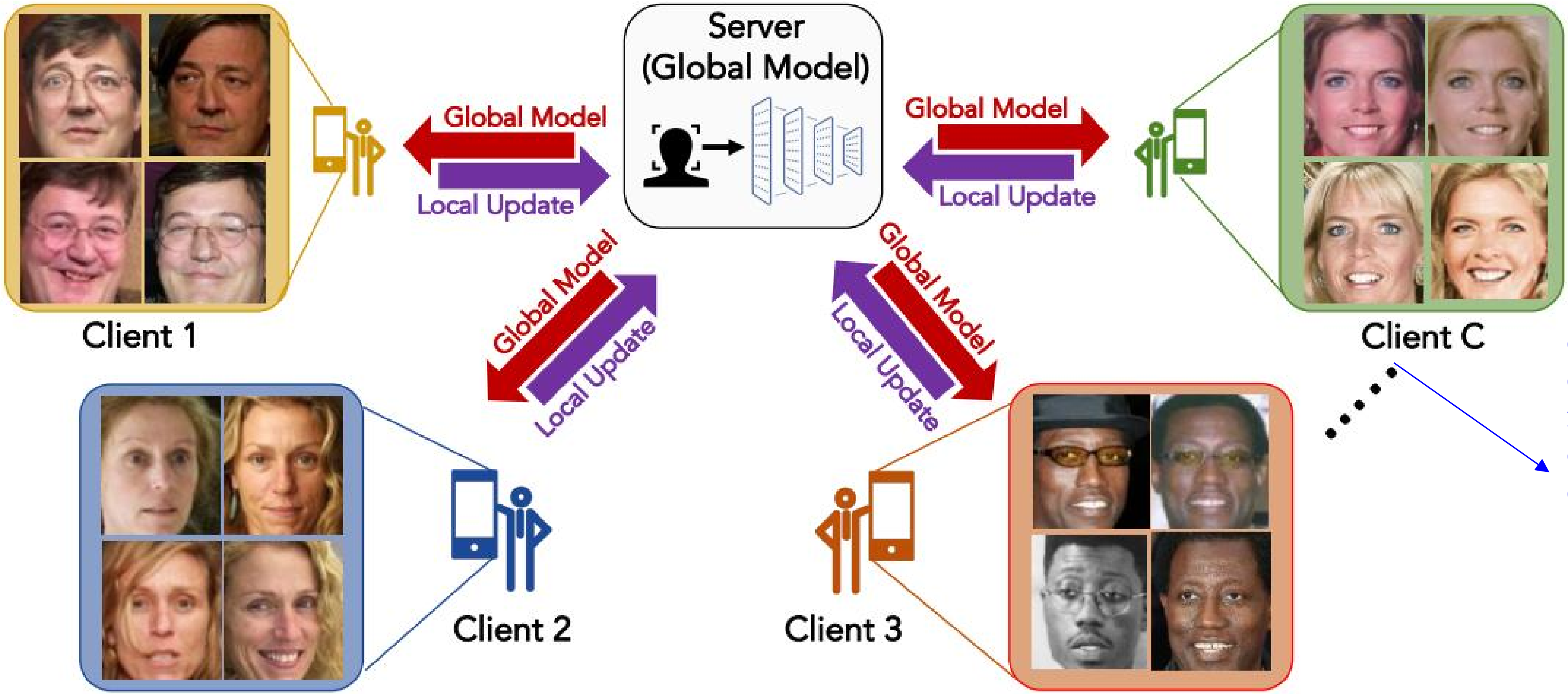
Privacy-preserving Biometrics

Federated learning (FL) framework is suitable for privacy-preserving biometrics, which collaboratively trains biometric recognition models without sharing each client's source biometric data with the server or with other clients.



Federated Learning for Face Recognition

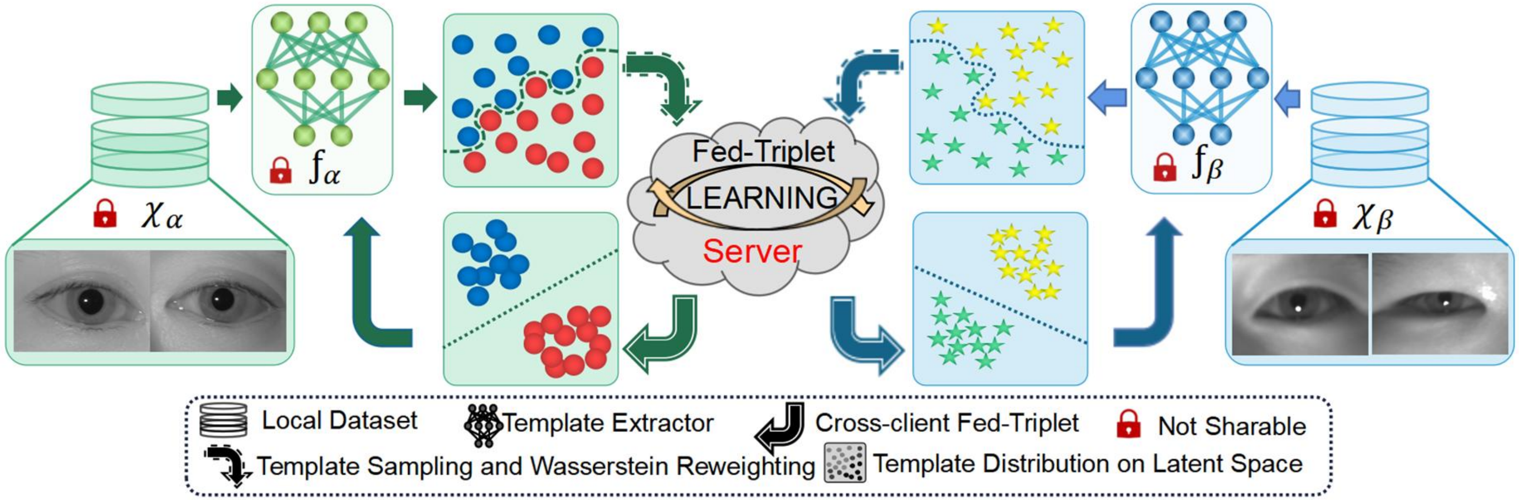
A federated learning (FL) framework can be applied for collaborative learning of face recognition models in a privacy-aware manner.



each client is a mobile device containing face images pertaining to only the owner of the device

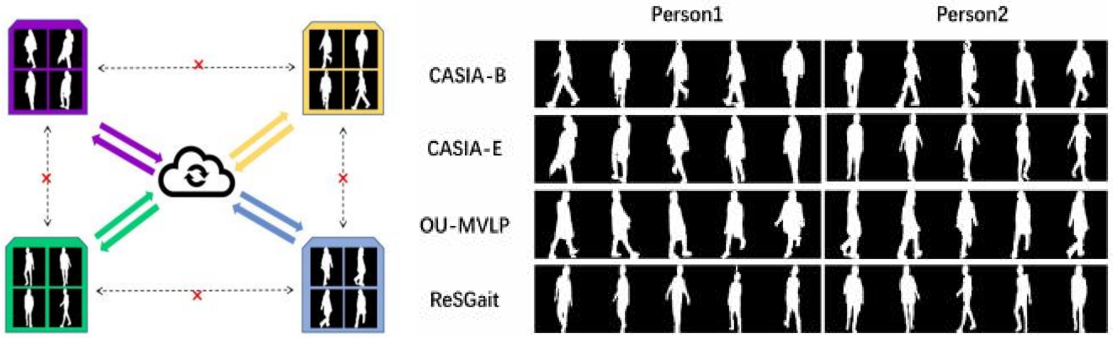
Aggarwal D, Zhou J, Jain A K. Fedface: Collaborative learning of face recognition model[C]//2021 IEEE International Joint Conference on Biometrics (***IJCB***), 2021.

Federated Learning for Other Biometric Modalities



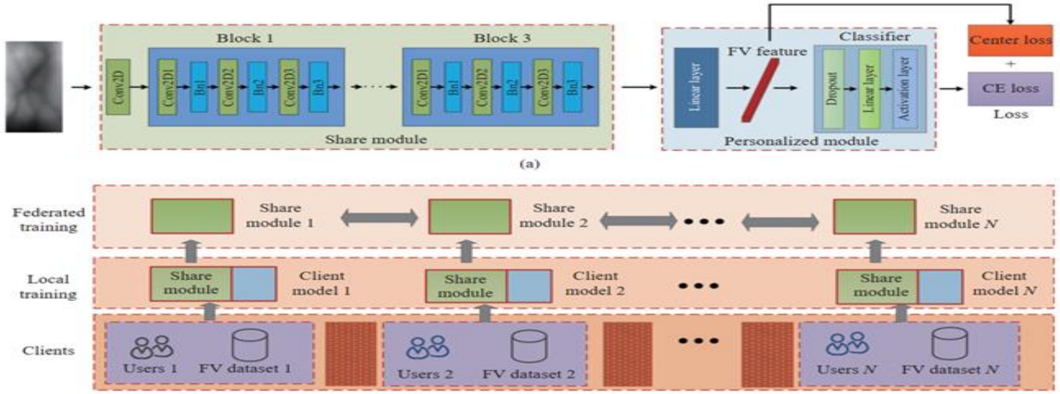
Federated Iris Template Communication

FedIris [Tan et al., ***CVPRW'22***]



Distributed gait data on multiple clients

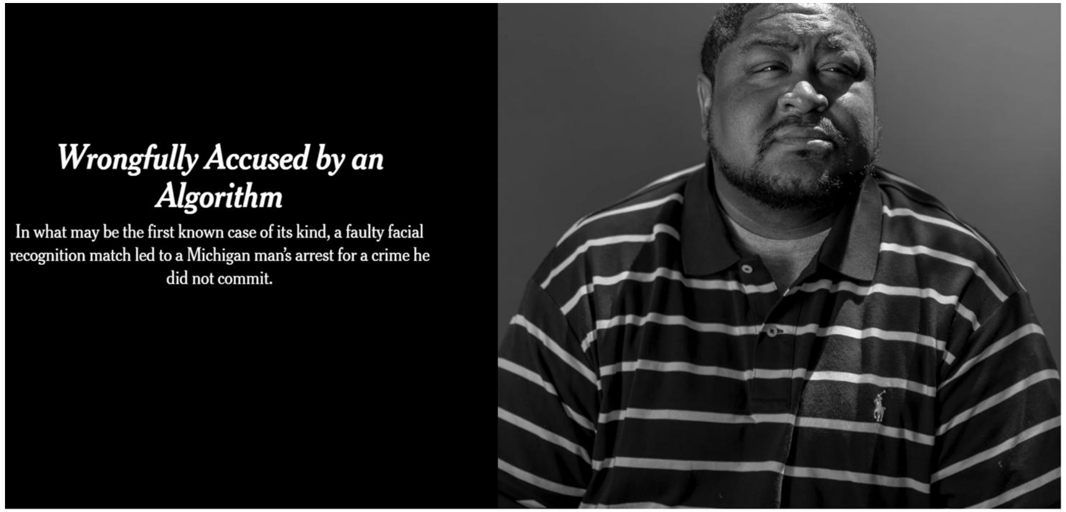
FedGait [Yu et al., ***ICPR'22***]



Personalized federated finger vein authentication framework

FedFV [Kang et al., ***MIR'23***]

Fair Biometrics



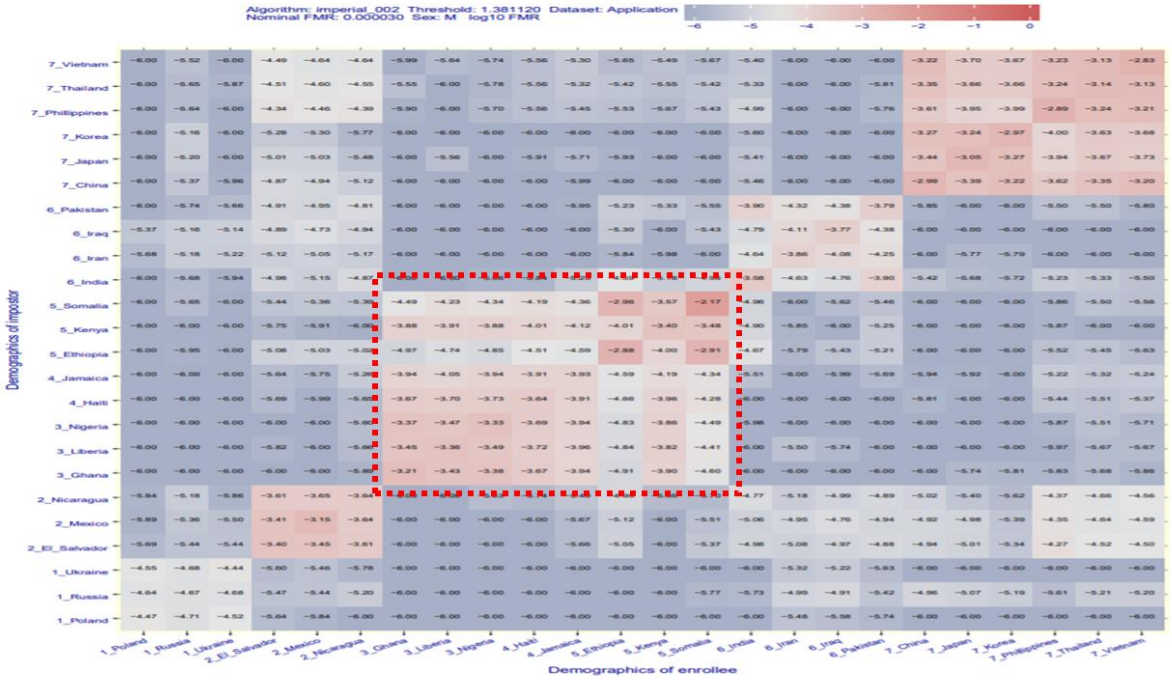
"This is not me," Robert Julian-Borchak Williams told investigators. "You think all Black men look alike?" Sylvia Jarrus for The New York Times

A faulty facial recognition match led to a Michigan man's arrest for a crime he did not commit.

--New York Times, https://www.nytimes.com/2020/06/24/technology/facial-recognition-arrest.html

The majority of the 106 face recognition algorithms have **relatively higher false positive rates on subjects from African and Asian countries** than those of other races

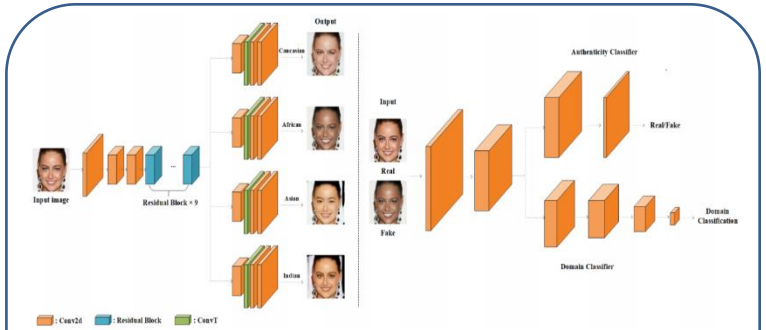
-- NIST report "Face Recognition Vendor Test Part 3: Demographic Effects", https://www.nist.gov/publications/face-recognition-vendor-test-part-3-demographic-effects



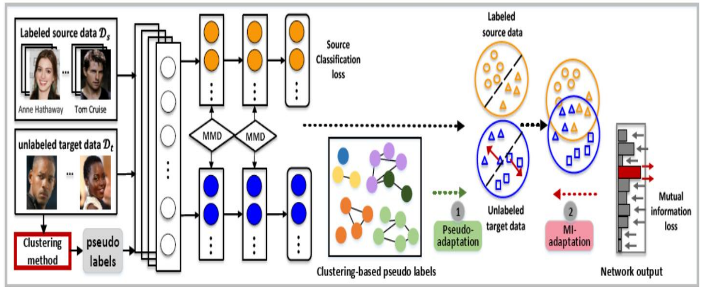
Racial Bias Mitigation

Data: **transfer the facial images of one race to other faces with generative models (GAN, etc.)**

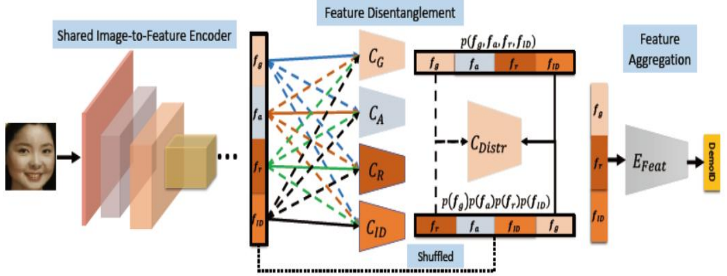
Model: **mimic the model paradigm in transfer learning or disentanglement learning to bridge the domain gap and transfer knowledge between races**



Fan-Shaped GAN
[Ge et al., *IJCB'20*]

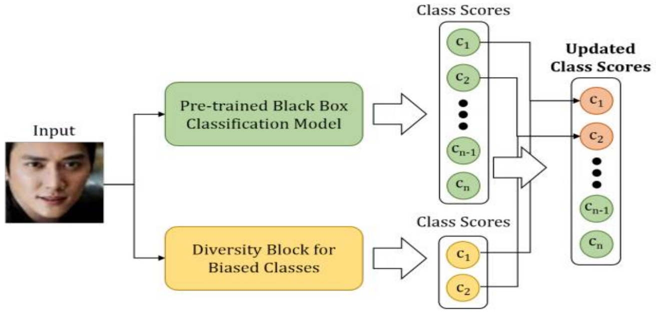


Domain adaptation
[Wang et al., *ICCV'19*]

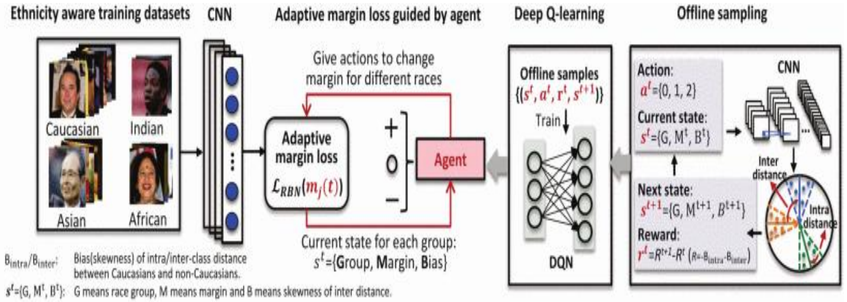


Feature disentanglement
[Gong et al., *ECCV'20*]

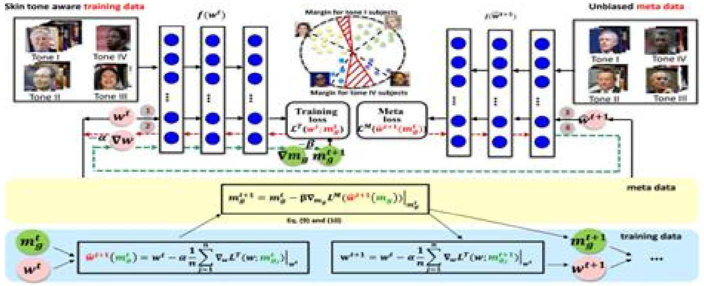
Result generation: **impose constraints (biased class scores, margin loss, etc.) on the model's output to perform fairly across different races**



Re-classification by diversity block
[Nagpal et al., *IJCB'20*]



Adaptive margin loss
[Wang et al., *CVPR'20*]



Meta margin learning
[Wang et al., *TPAMI'21*]

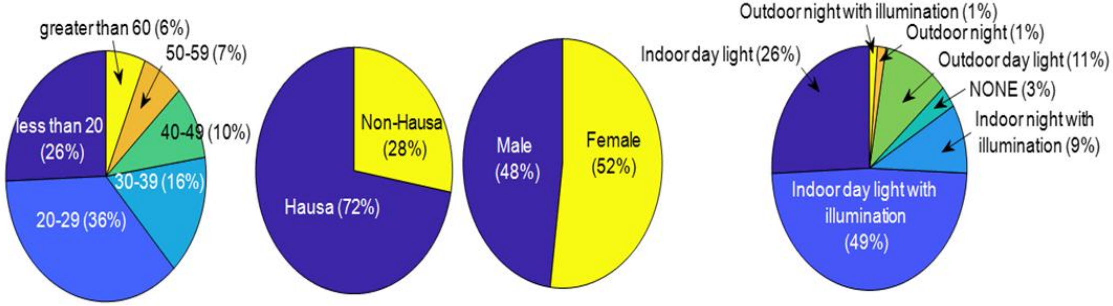
Racial Bias Mitigation through Database Balancing

Jawad Muhammad

CASIA-Face-Africa is the first large-scale African face image database. The proposed database along with its annotations, evaluation protocols and preliminary results forms **a good benchmark to study face racial bias problem for African subjects.**

Capture setup

1183 African subjects, 38546 face images



Data distribution

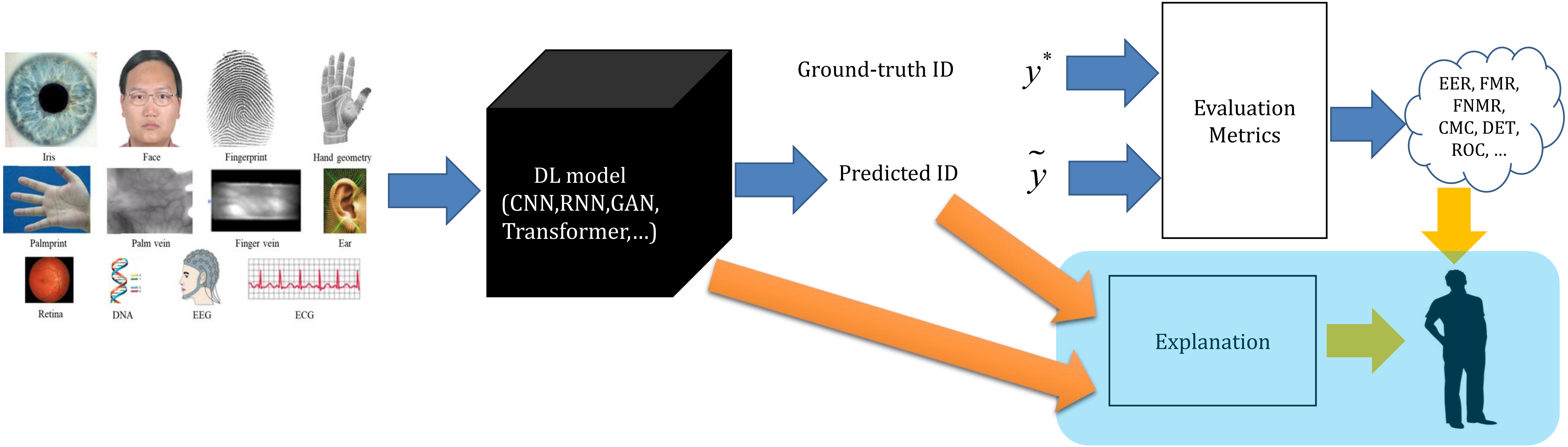
Facial expressions

Lighting conditions

Muhammad J, Wang Y, Wang C, et al. CASIA-Face-Africa: A large-scale African face image database[J]. IEEE Transactions on Information Forensics and Security (***TIFS***), 2021, 16: 3634-3646.

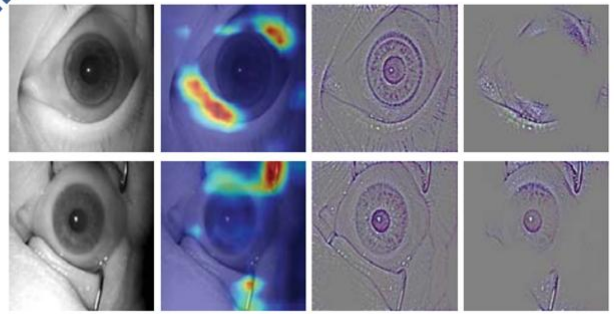
Explainability

Due to the **lack of transparency and explainability of DL models**, it is difficult to understand the reasons that lead to an ID prediction, which reduces trust from users and hinders the ability to verify their decisions and behavior.

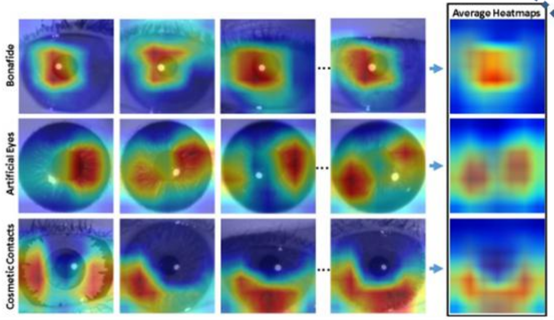


Progress in Explainable Biometrics

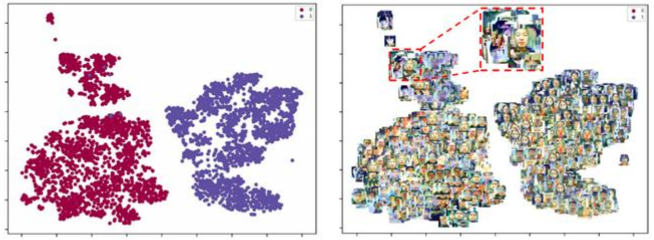
Visualizations



Cadaver Iris PAD
[Trokielewicz et al. ***BTAS'2018***]



D-NetPAD
[Sharma and Ross, ***IJCB'20***]

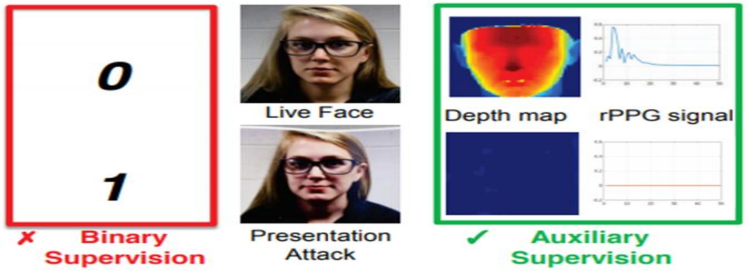


Face Anti-spoofing
[Yang et al. ***CVPR'19***]

Face Recognition
[Yin et al. ***ICCV'19***]

t-SNE: make a visualization of ID predictions in a smaller latent space
Grad-CAM: generate a heatmap to spatially highlight the most relevant areas for ID predictions

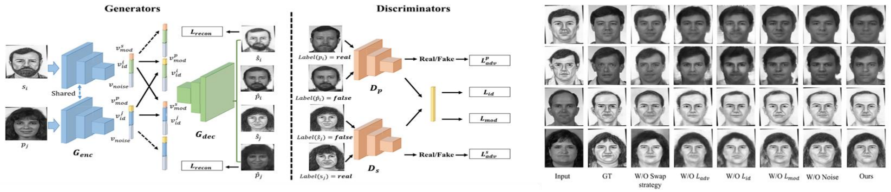
Auxiliary Supervision



rPPG estimation
[Liu et al. ***CVPR'18***]

Attaining explainable decisions through auxiliary supervision, e.g., rPPG estimation in face anti-spoofing

Interpretable Feature Disentanglement

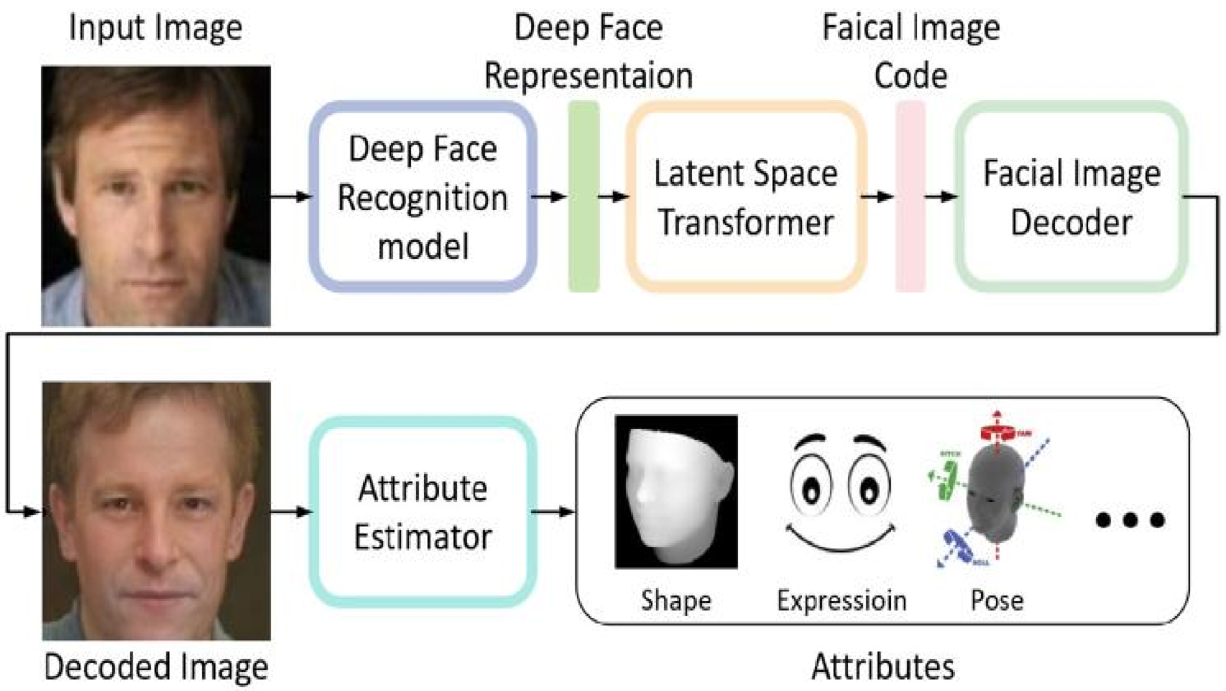


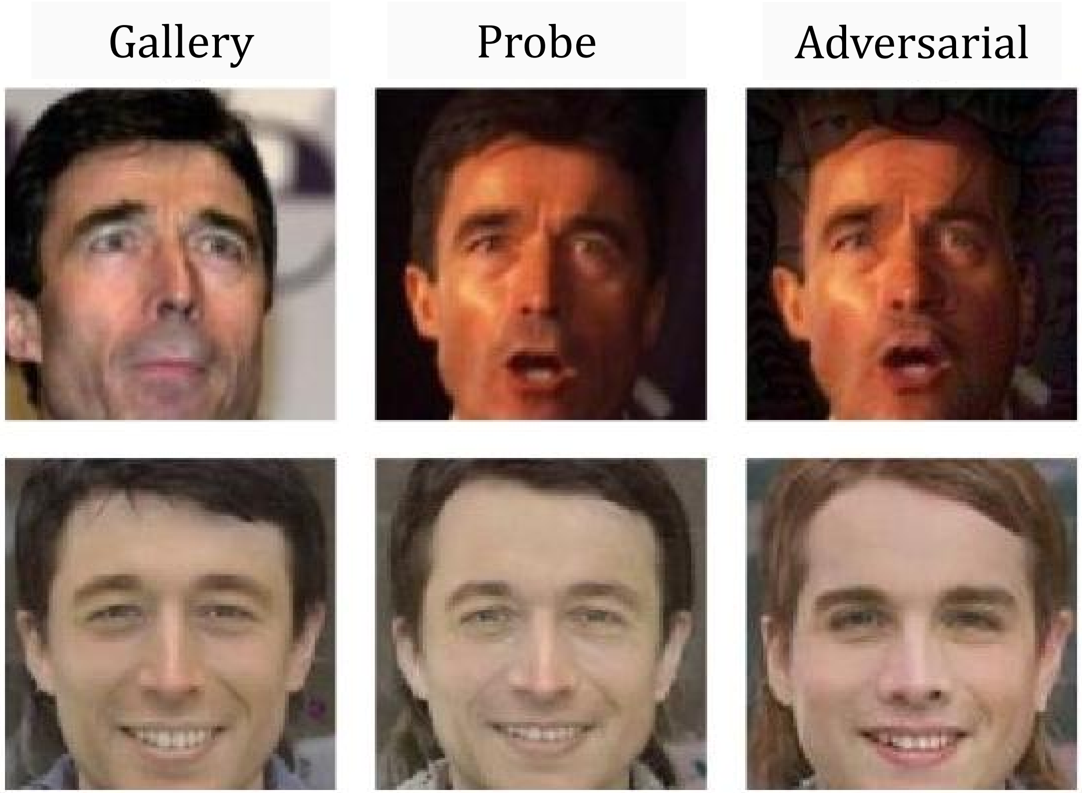
HFIDR [Liu et al. ***TNNLS'21***]

Disentangling the biometric features into semantic components for interpretable disentangled representation

Understanding Deep Face Representation via Attribute Recovery

By utilizing attributes as an interpretable interface, we are able to acquire a deeper understanding of how the recognition model conceptualizes the notion of "identity" and understand the reasons behind the error decisions made by the deep models.





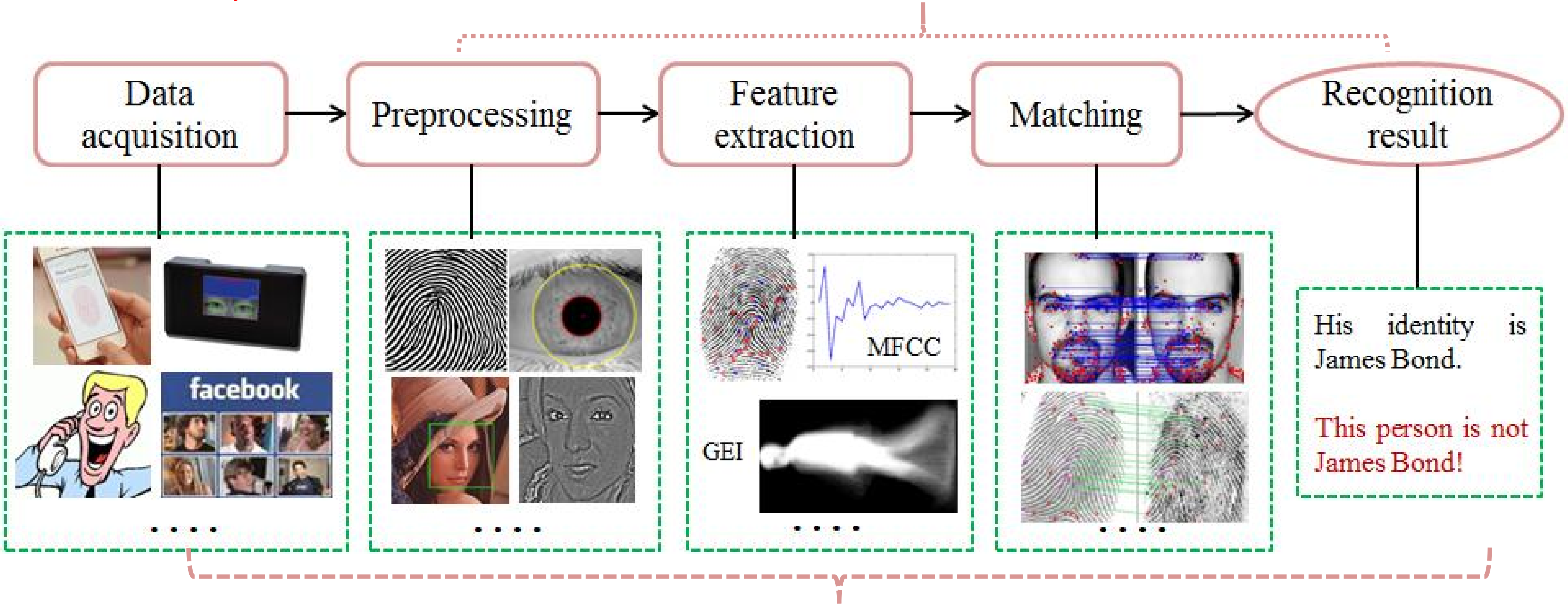
Min Ren, Yuhao Zhu, Yunlong Wang, Yongzhen Huang, Zhenan Sun. "Understanding Deep Face Representation via Attribute Recovery," IEEE Transactions on Information Forensics and Security (***TIFS***), vol. 19, pp. 6949-6961, 2024.

Outline

- Preamble
- Recent Progress
- Remaining Challenges
- Future Directions and Prospects
- Conclusions

Remaining Challenges

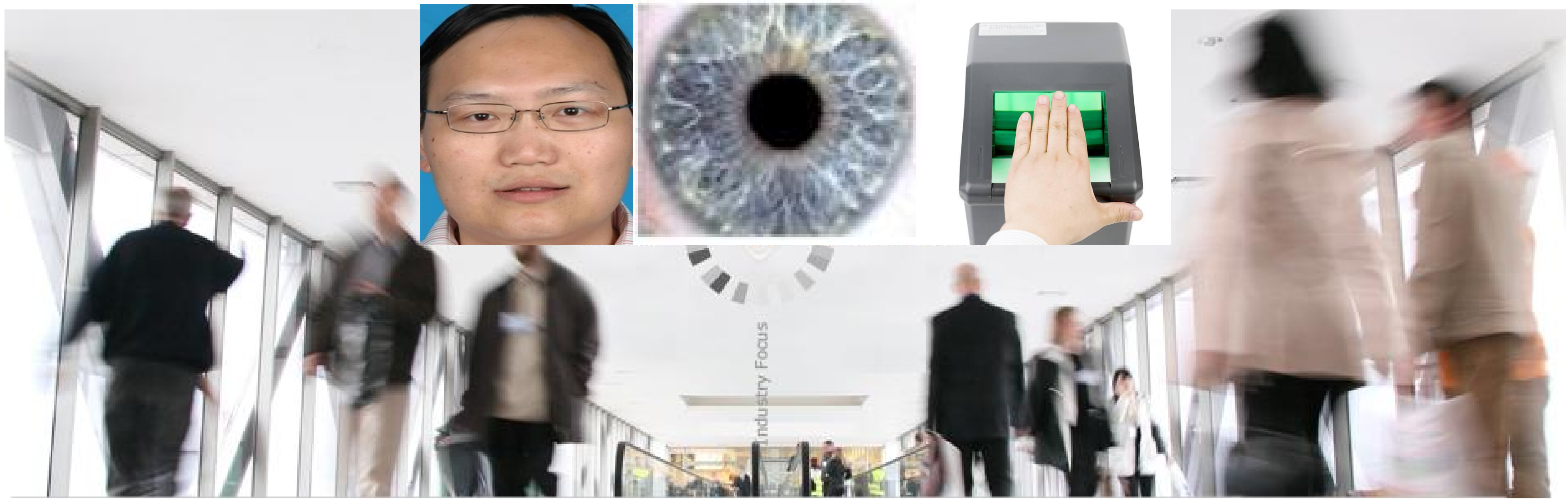
- Limited usability
- Lack of robustness

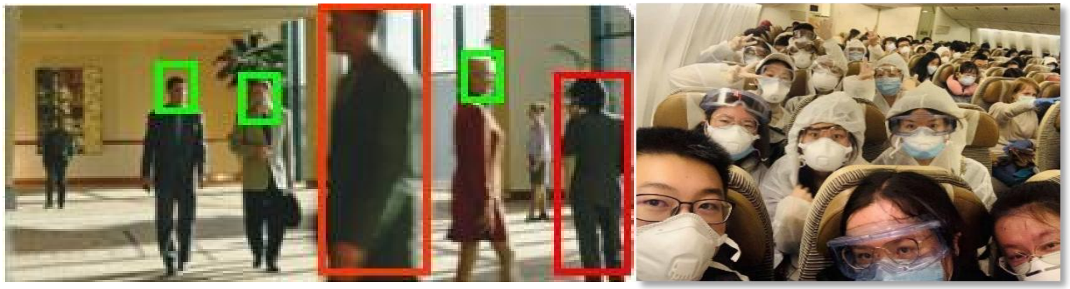


- Security vulnerabilities
- Privacy concerns
- Legal and ethical concerns
- Demographic bias
- Expainability
- Cross-system compatibility

Remaining Challenges

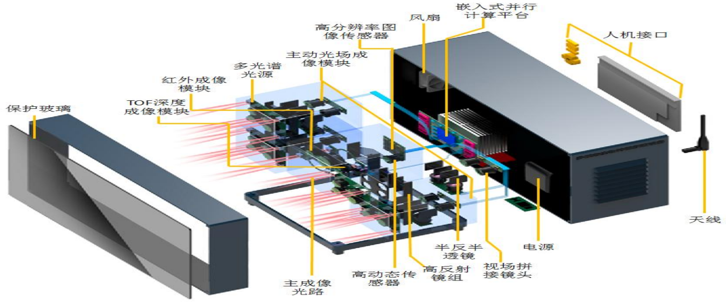
- High level of requirements on user cooperation





Varying real-world scenarios (user, occlusions, etc.)

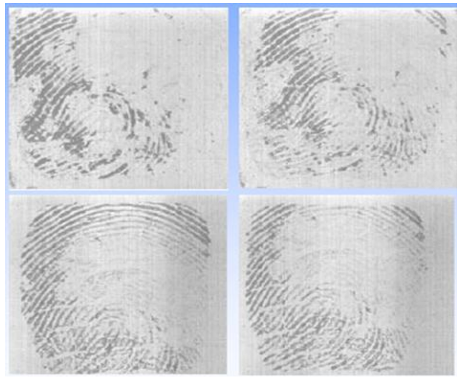
VS



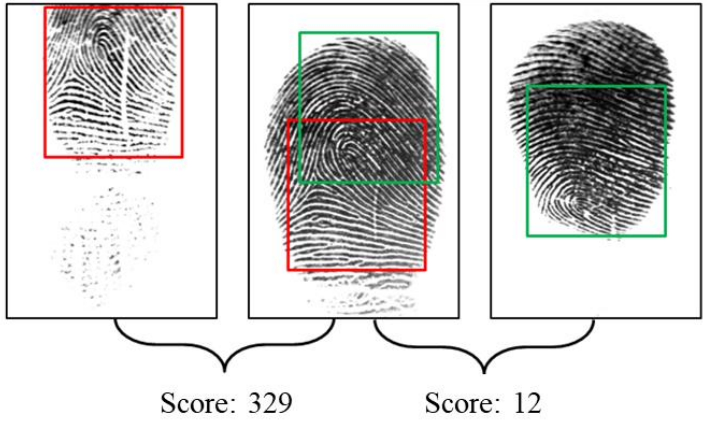
Fixed optics settings of biometric sensors

Remaining Challenges

- Deteriorated performance on degraded or non-ideal biometric data

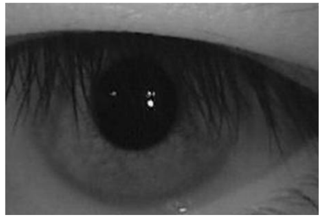


Latent fingerprint images

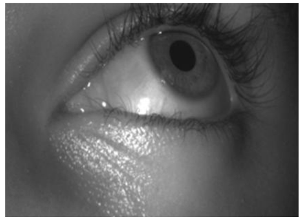


Distorted fingerprint images

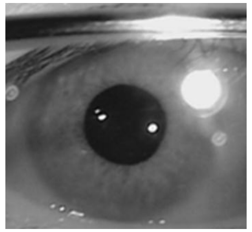
Eyelid obscuration



Eyelash obscuration

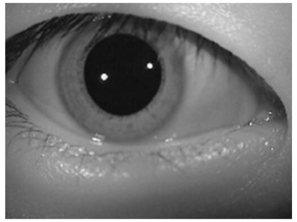


Off-angel



Specular Reflection

Motion blur



Iris Deformation

Face images in surveillance

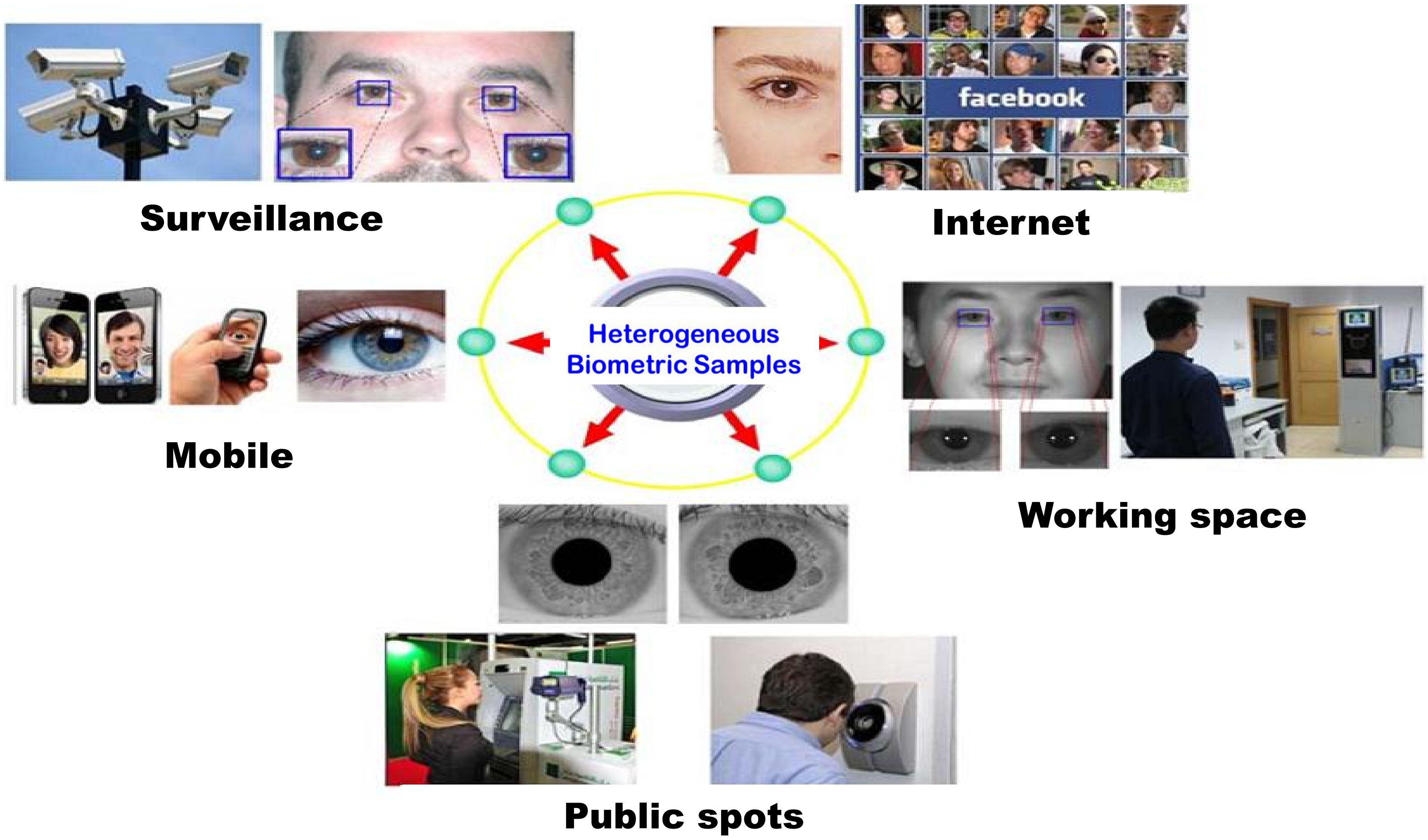
Masked Face Images

PIE (Pose, Illumination, Expression)

Blurred, Low-resolution, Side-view gait sequences

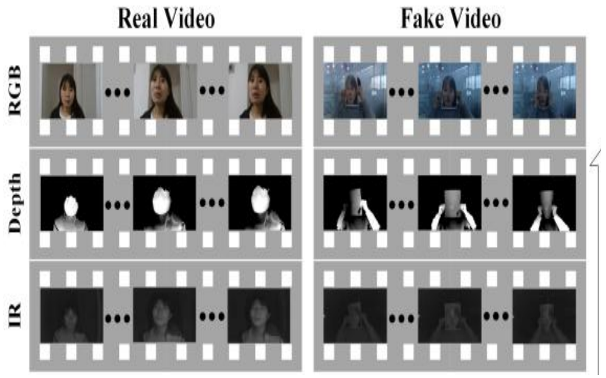
Remaining Challenges

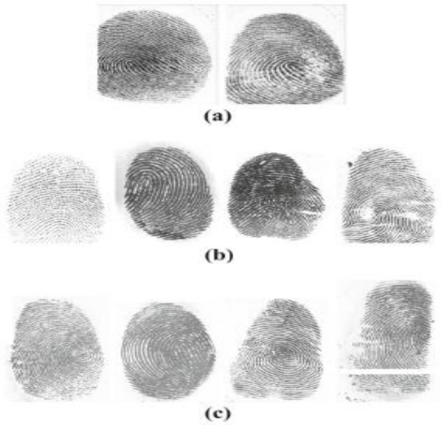
- Poor generalization ability on heterogenous biometric samples

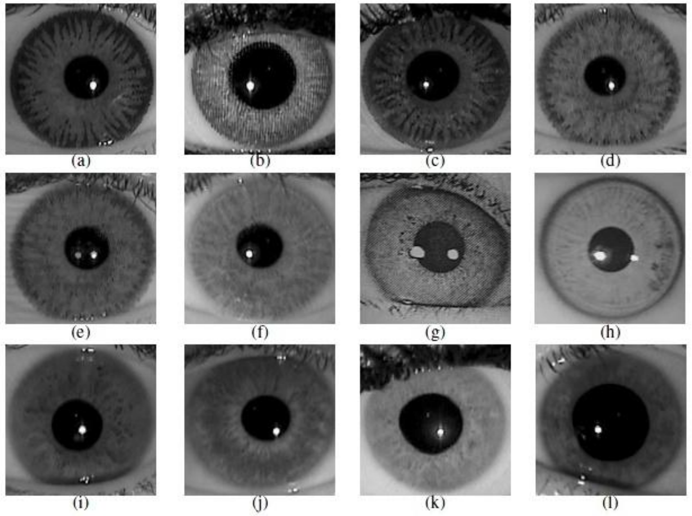


Remaining Challenges

- Security vulnerabilities to unpredictable attacks

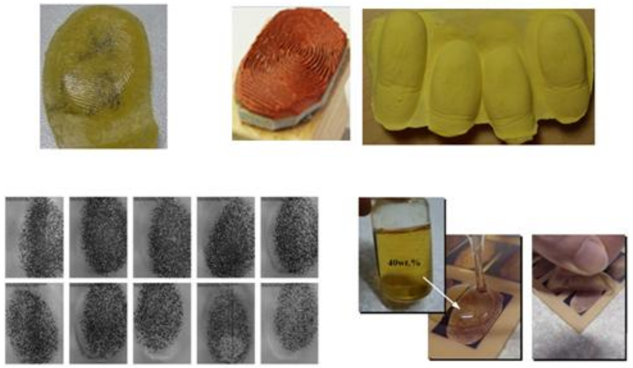


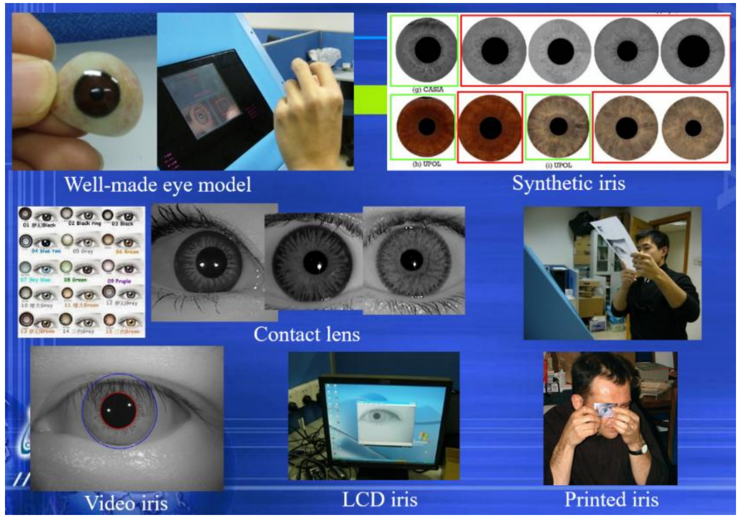




Limited training data

VS





Unpredictable spoof attacks

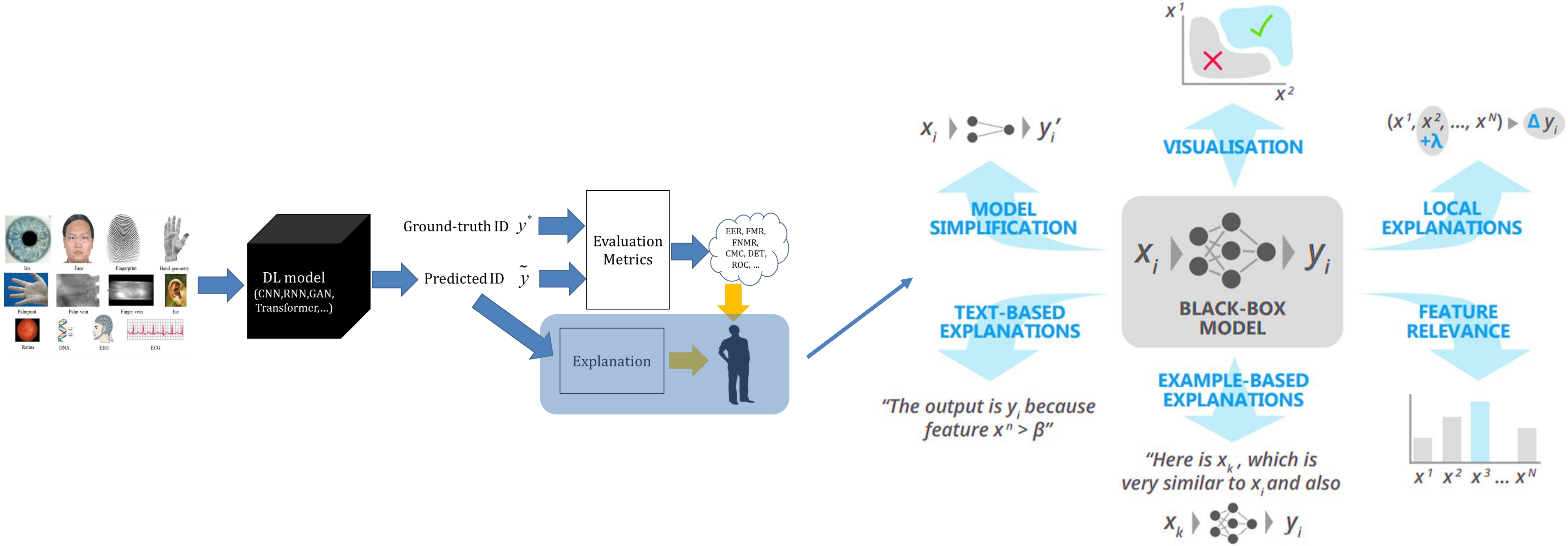
Remaining Challenges

- Security vulnerabilities to unpredictable attacks - AIGC

Finance worker pays out $25 million after
video call with "deepfake CFO"

Remaining Challenges

- Very limited explainability



Neto P C, Gonçalves T, Pinto J R, et al. Explainable biometrics in the age of deep learning[J]. arXiv preprint arXiv:2208.09500, 2022.

Remaining Challenges

- Privacy concerns

“Iris Photography” threatens customers’ biometric data privacy

Remaining Challenges

- Demographic bias

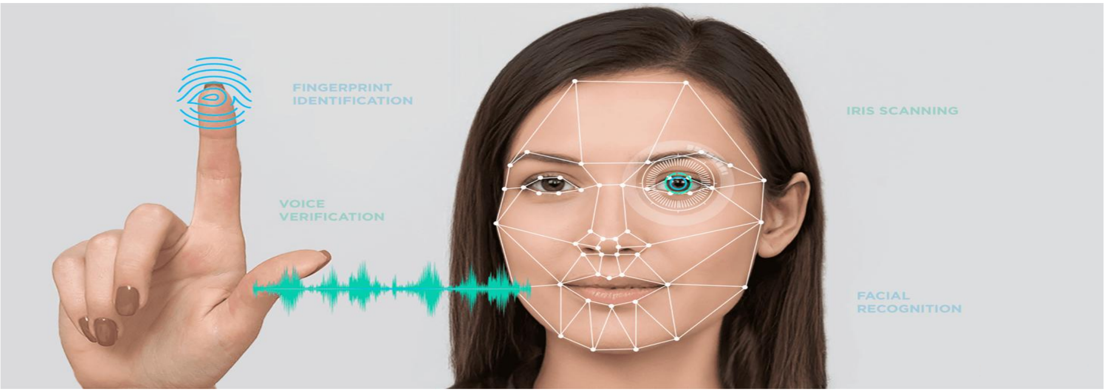
Error Rate$_{(1\text{-PPV})}$ By Female $_{\times}$ Skin Type

	TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V	TYPE VI
Microsoft	1.7%	1.1%	3.3%	0%	23.2%	25.0%
FACE++	11.9%	9.7%	8.2%	13.9%	32.4%	46.5%
IBM	5.1%	7.4%	8.2%	8.3%	33.3%	46.8%

Not only racial bias, but also bias in other demographic attributes such as age, gender, hair color, etc.
(***Gender shades projects***, http://gendershades.org/)

Remaining Challenges

- Legislation and standards lag behind technology innovation



全国人民代表大会常务委员会关于加强网络信息保护的决定

中华人民共和国网络安全法

美国《加利福尼亚州消费者隐私法》（CCPA）

国家健康医疗大数据标准安全和服务管理办法（试行）

互联网个人信息安全保护指南

中国人民银行关于发布金融行业标准做好个人金融信息保护技术管理工作的通知

信息安全技术个人信息安全规范

中华人民共和国个人信息保护法

欧盟《人工智能法案》

2009.01.28　2015.08.29　2018.05.25　2018.03.17　2018.08.31　2019.05.28　2020.02.13　2021.09.01

2012.12.28　2016.11.07　2018.06.28　2018.07.12　2019.04.10　2020.03.04　2020.10.01　2021.11.01　2023.06

刑法修正案（七）

刑法修正案（九）

欧盟《通用数据保护条例》GDPR

科学数据管理办法

中华人民共和国电子商务法

数据安全管理办法（征求意见稿）

个人金融信息保护技术规范

中华人民共和国数据安全法

Outline

- Preamble
- Recent Progress
- Remaining Challenges
- Future Directions and Prospects
- Conclusions

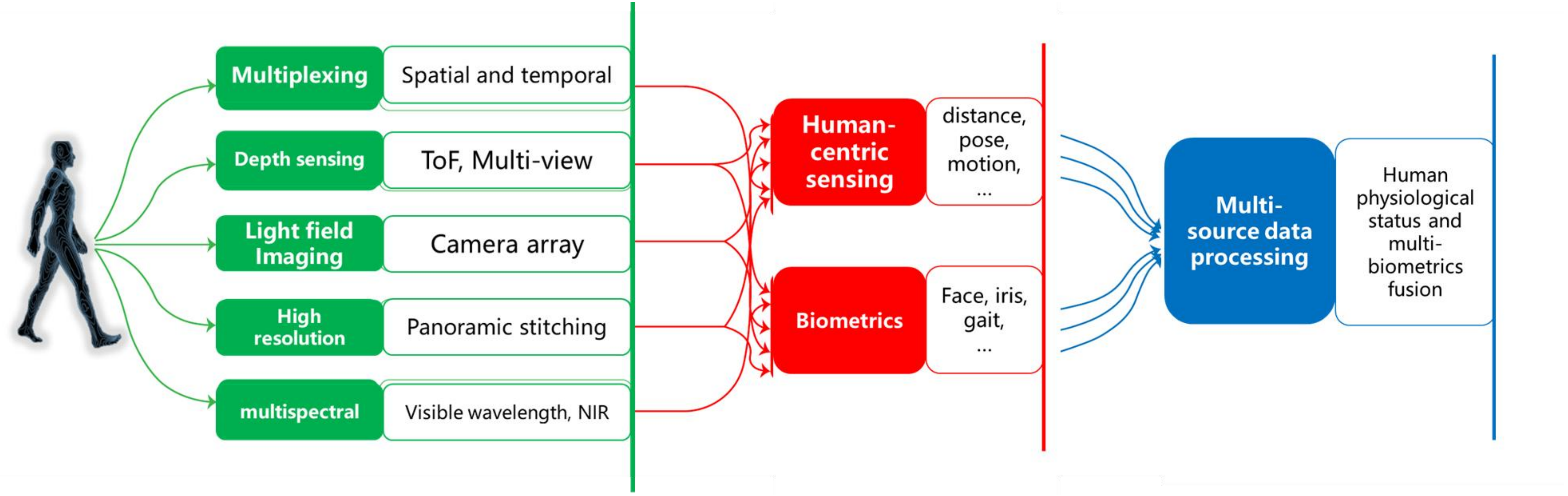
Future Directions and Prospects

- Human-centric biometrics

- Prioritizing user experience in the design of biometric systems is essential for user acceptance, ease of use, efficiency, etc.
- Biometric sensors and algorithms should be co-designed for better adaptation to user situations
- Biometric data should be captured and recognized successfully under various conditions and scenarios while accommodating the needs and preferences of the user

Future Directions and Prospects

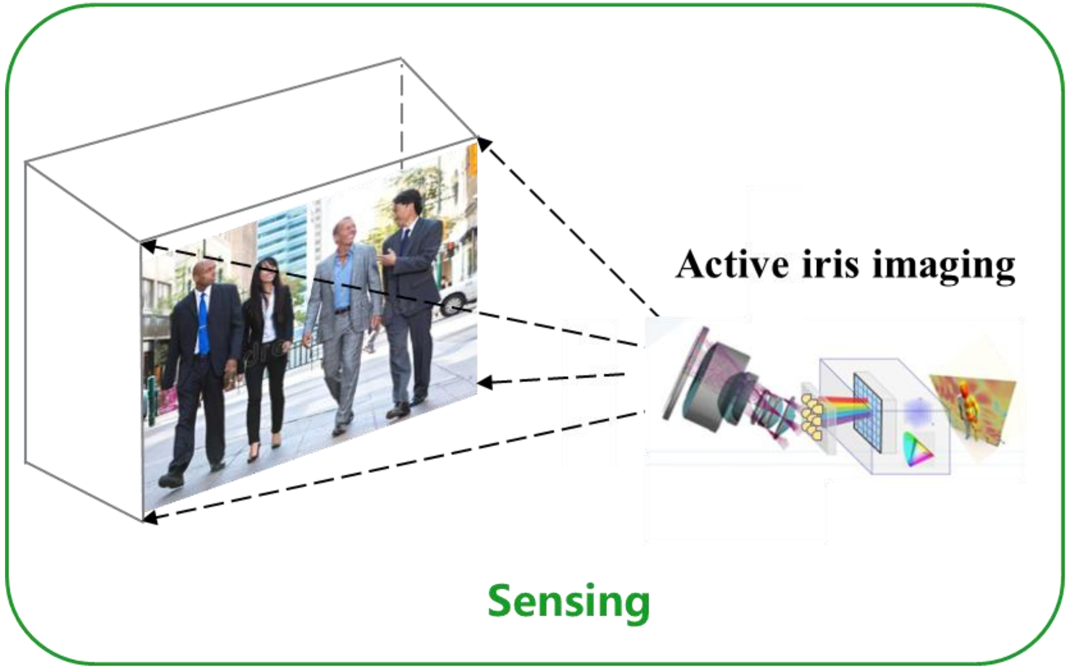
- Multi-modal biometrics and adaptive spatial-temporal fusion



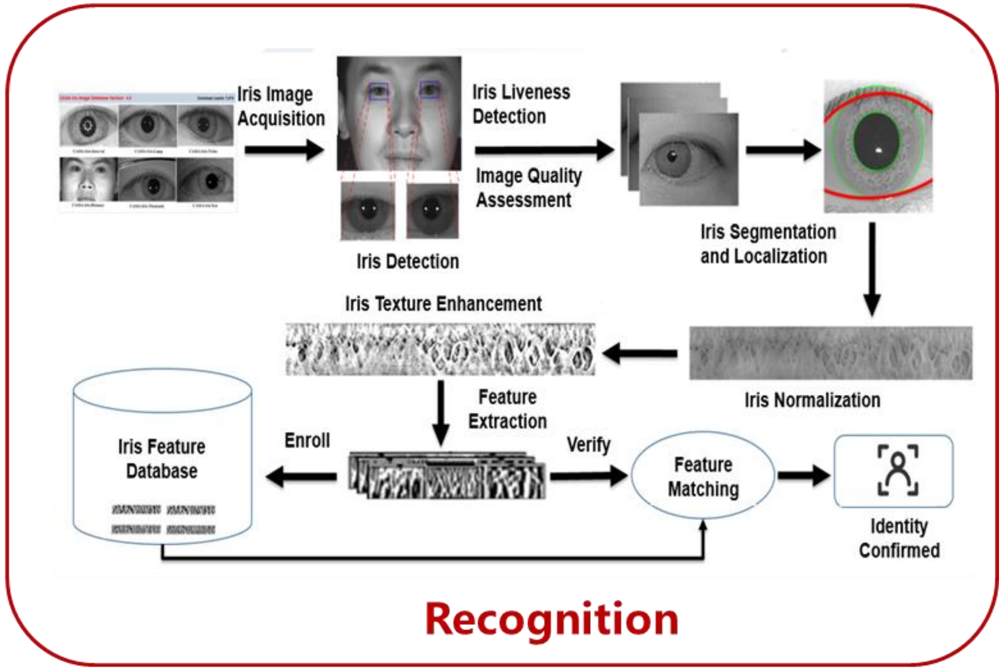
Future Directions and Prospects

- Co-design and coordination of biometric sensing and recognition

Streaming iris data



Feedback Loop



Imaging control signal (focal lens, aperture, exposure…)

Hardware-software co-design	Acquisition and processing coordination

Future Directions and Prospects

- Lightweight biometrics

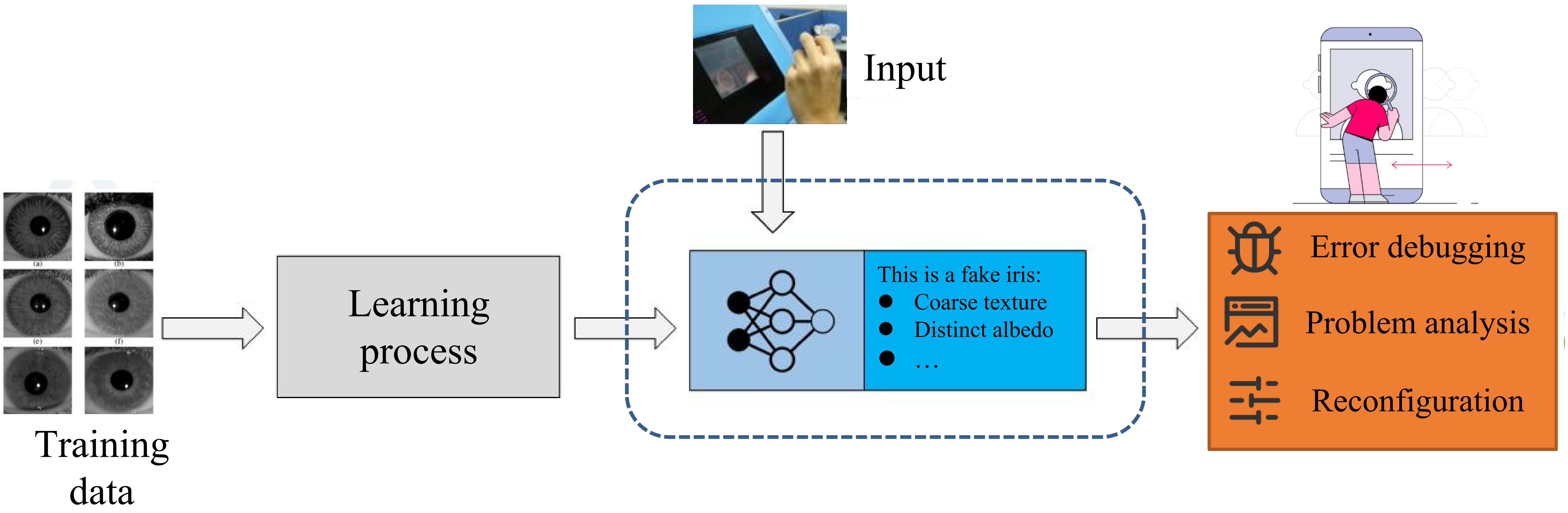
Smartwatch with iris recognition

Iris sensor on an embedded device (from Irisking)

All-in-one gait recognition device (from Watrix.ai)

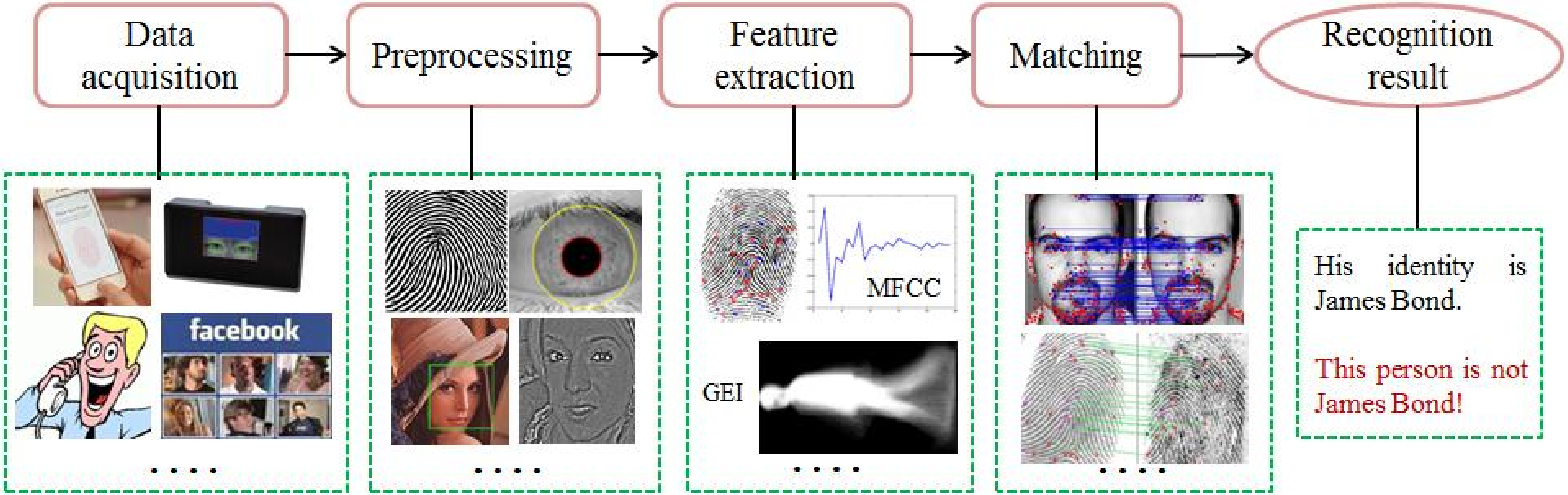
Future Directions and Prospects

- Explainable biometrics



Future Directions and Prospects

- Secure and trustworthy biometrics



  - Biometric data security (template security)
  - Liveness detection (anti-spoofing)
  - ......

Future Directions and Prospects

- Secure and trustworthy biometrics
    - Growing importance of AIGC detection
    - AIGC detection based on LLM

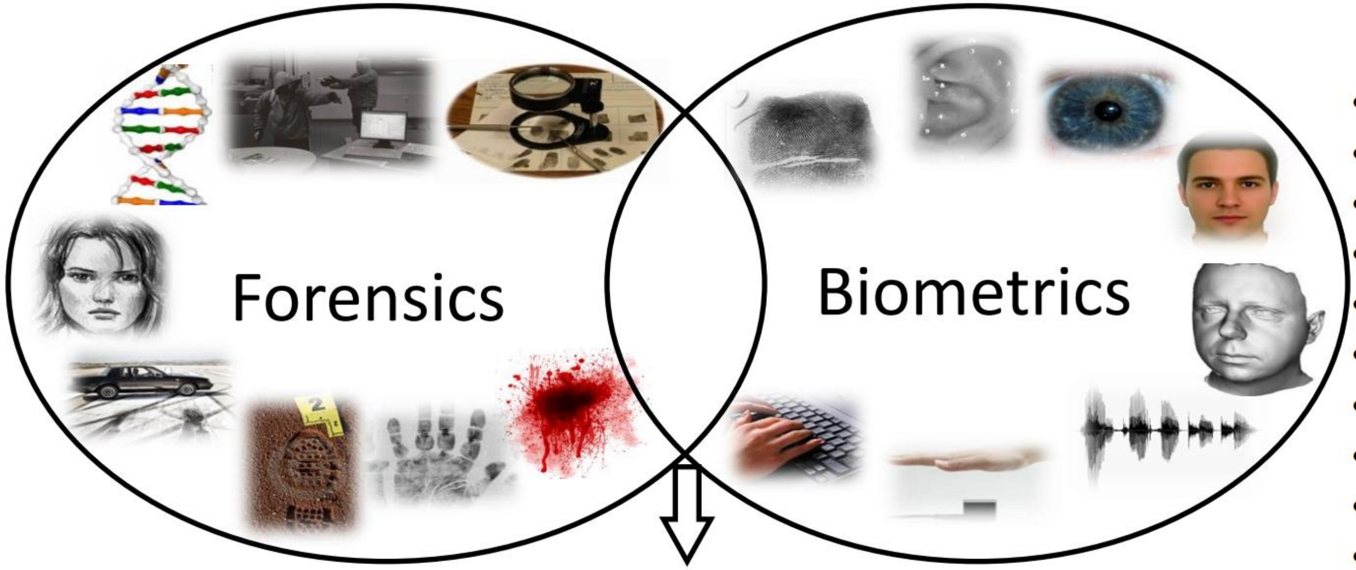
@From Internet

Future Directions and Prospects

- Biometrics for forensic applications

Forensics & Biometrics: Shared Goals

- Latent prints
- Fibers
- Explosives
- Paint chips
- DNA
- Tire marks
- Shoe prints
- Bite marks
- SMT



- 2D Face
- 3D Face
- Fingerprint
- Iris
- Speech
- Signature
- Gait
- Ear
- Palmprint
- Keystroke

Forensics: Identify suspects from crime scene evidence

Biometrics: Automated person recognition from *body traits*

Future Directions and Prospects

- Biometrics in Internet of Everything (IoE) applications

Outline

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Conclusions

- **Significant progress has been made in biometrics. Innovations in sensor design and GAI algorithms have collectively contributed to improved usability, reliability and security.**
- **Many challenges and concerns remain to be resolved such as privacy issues, security vulnerabilities, robustness, fairness, explainability, etc.**
- **Future efforts should focus on human-centric biometrics, trustworthy biometrics, multimodal biometrics, lightweight biometrics, fair and just biometrics, etc.**
- **Good balance between the benefits of biometrics and the protection of individuals' rights and ethics is crucial to the sustainable and widespread deployment of biometrics.**

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Student Grant Sponsors:

Thanks!