Human Gait Analysis and Recognition

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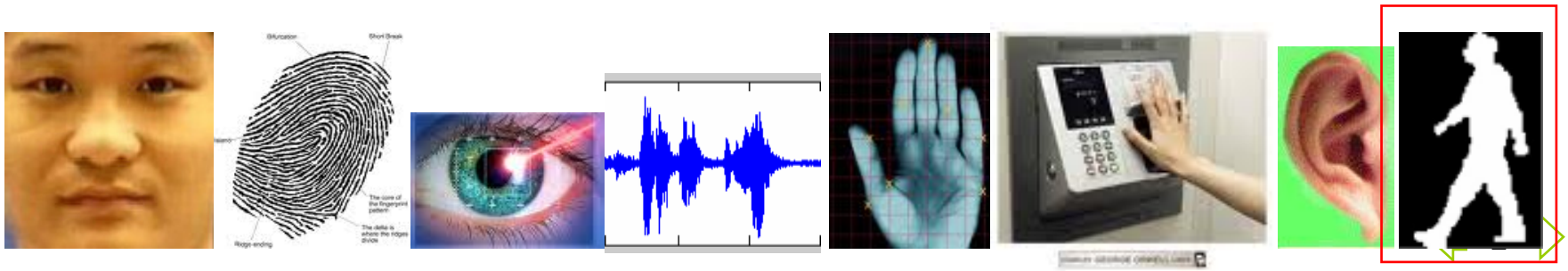
Biometrics

- What is it?
  - Human identification through the natural biological features of humans, rather than any carried certificates.
- Categories:
  - Intrinsic / static features: face, iris, finger-print, palm-print, vein-print, ear, etc.;
  - Behavior / dynamic features: voice, signature, gait, etc.



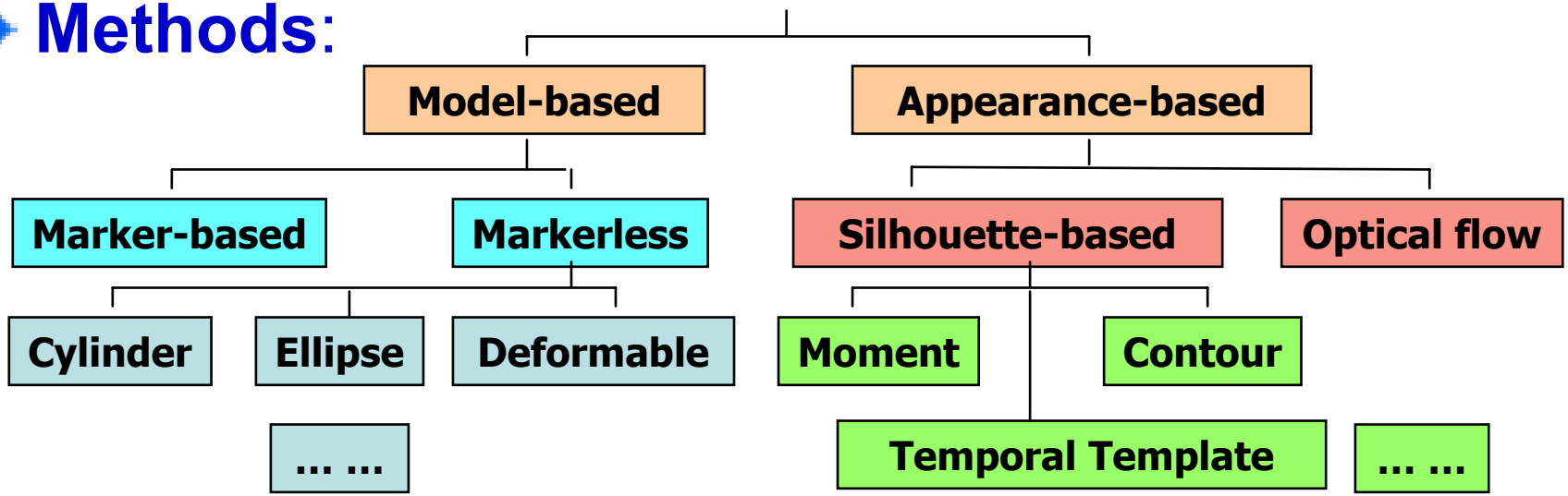
Gait Recognition——A Glance

——A young biometric with potential

- **Destination**: Automatic human identification and authentication by observation of their walking styles.
- **Rationality**: Human's ability to recognise people by their gait——heavy; humble; weary; gentle… (Shakespeare)
- **Advantage**: data acquisition from distance; non-invasive; hard to conceal, comparing to traditional biometrics.

——A challenging work

- **Subtle** discriminating features of gait are hiding behind similar motions.
- **Vulnerable** to variations in clothing, illumination, outdoor background, silhouette noise.
- **Methods**:



Groups with sound

- Mark Nixon, Soton@UK
- S. Sakar and Z. Liu, USF@US
- T.N. Tan, CASIA@CN
- D. Xu, NTU@SG
- R. Challapa, UMD@US
- ……

General Technique Framework of Gait Analysis & Recognition

Framework of Computer Vision by D. Marr

- **Basic elements：**

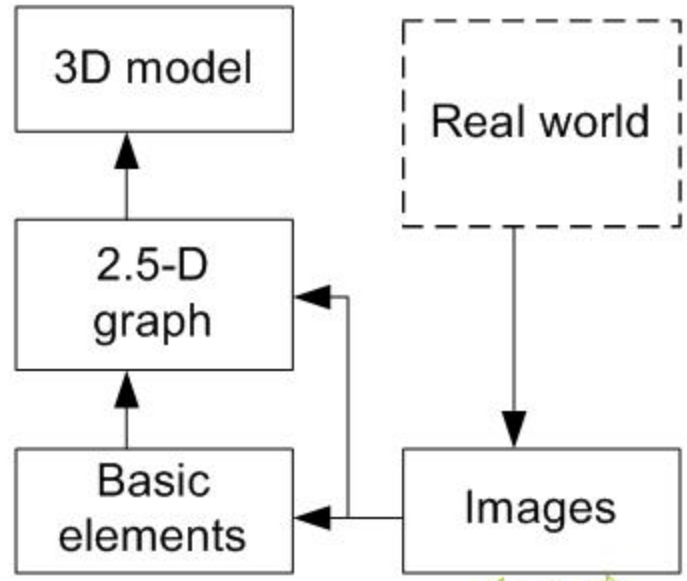
  Edge、corner、texture;

- **2.5-D elements graph：**

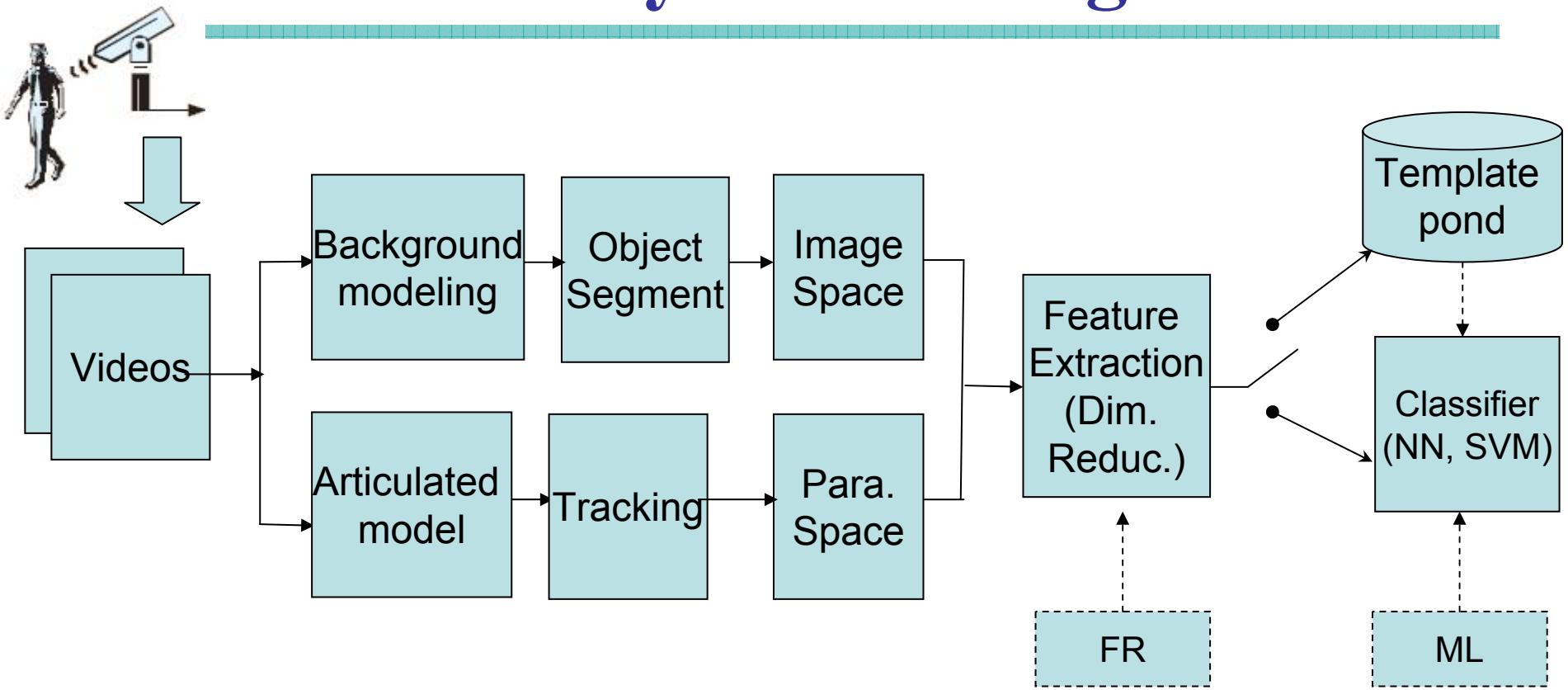
  From viewpoint of observer's coordinates, the normal, depth (stereo vision), discontinuities for each surfaces;

- **3D model description ：**

  3D scenario understanding and reconstruction.

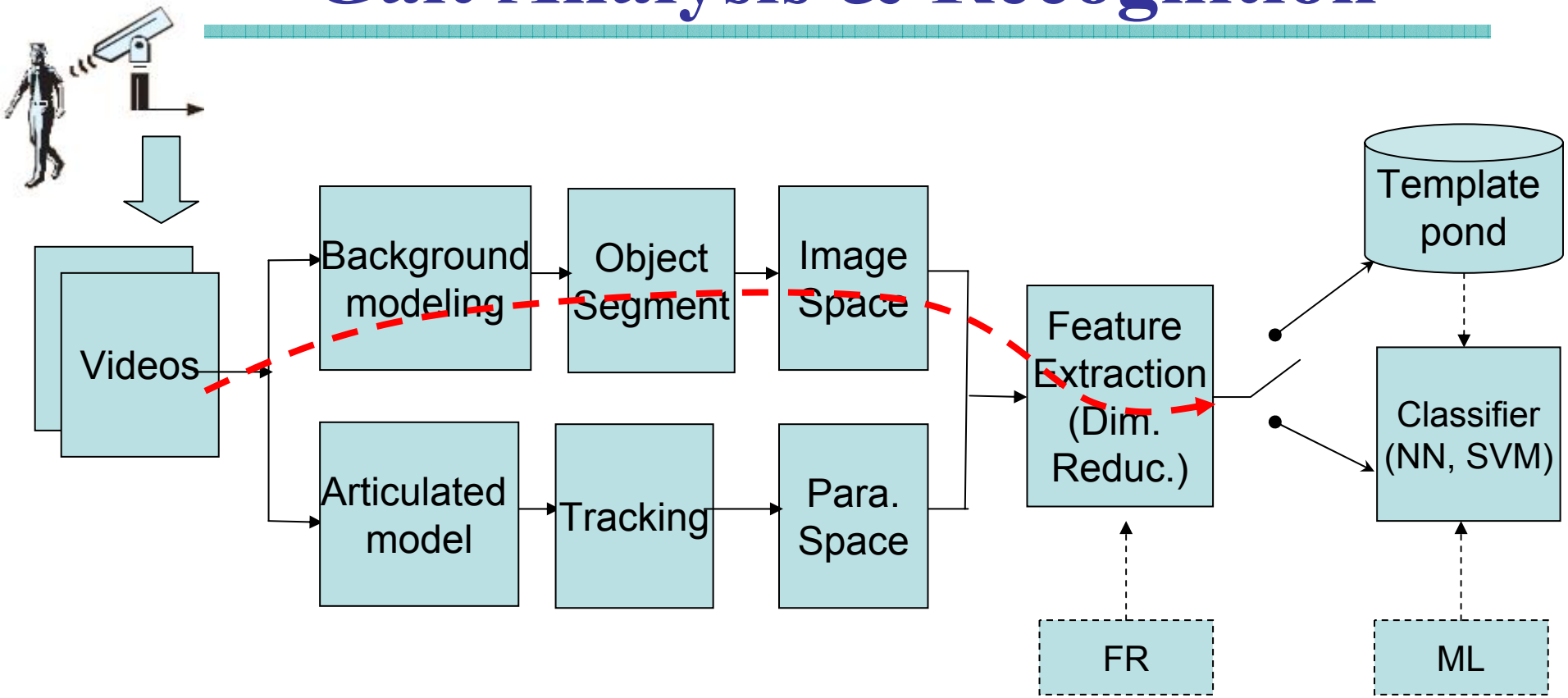


General Technique Framework of Gait Analysis & Recognition



- Two mainstream routes:
  - Model free: silhouette analysis
  - Model based: Articulated model

General Technique Framework of Gait Analysis & Recognition

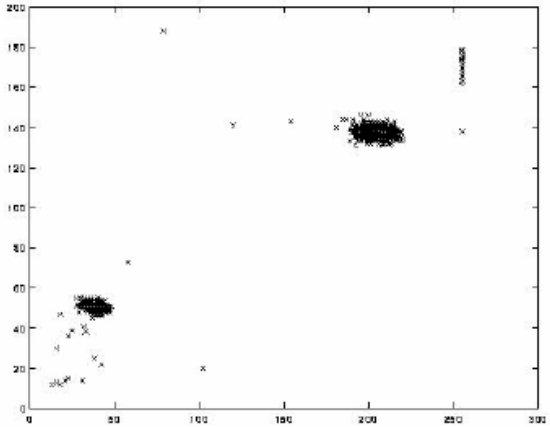


- Two mainstream routes:
  - **Model free: Silhouette analysis**
  - Model based: Articulated model

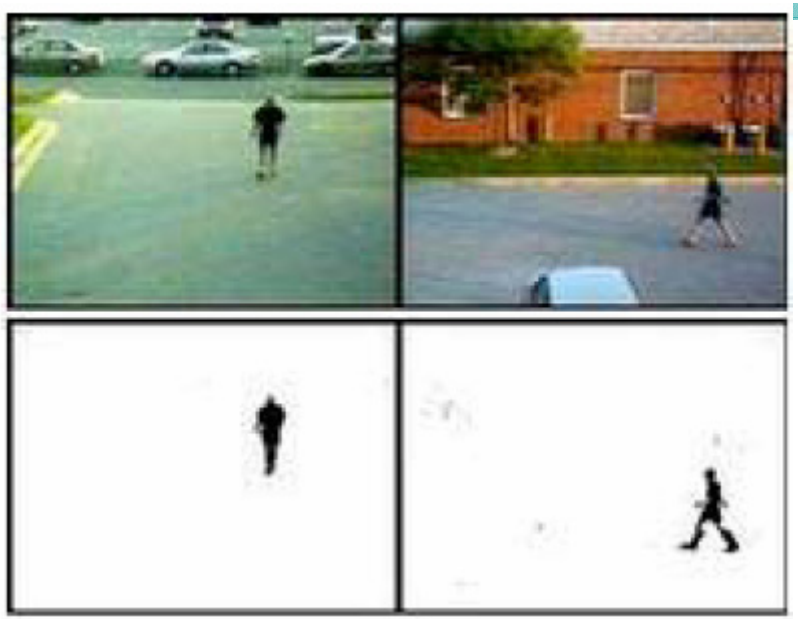
Classical method for background modeling ——（GMM）

- For some complicated background, i.e. lake wave、leaf swing、drizzle, Uni-Gaussian model is no longer competent.

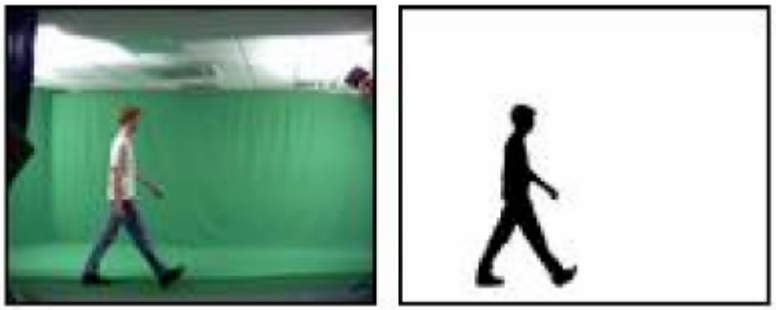
$$P(X_t) = \sum_{i=1}^{K} \omega_{i,t} * \eta(X_t, \mu_{i,t}, \Sigma_{i,t})$$



Silhouette extraction—— classical segmentation problem



Outdoor

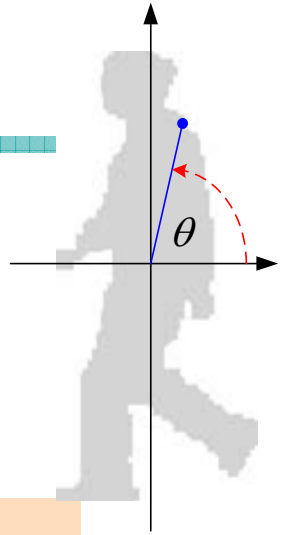


Indoor

- Typical method：GMM＋EM
- a two-class problem: {Foreground=w1, Background=w2}

$$P(d_k) = \sum_{i=1}^{2} P(\omega_i) p(d_k|\omega_i, \mu_i, \sigma_i) \qquad p(d_k|\omega_i, \mu_i, \sigma_i) = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(d_k-\mu_i)^2}{2\sigma_i^2}}$$

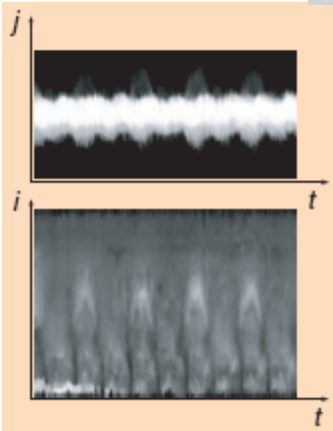
Typical algorithms in model-free gait recognition

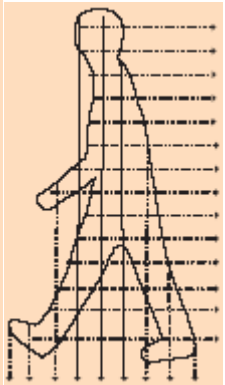


- Gait energy image （GEI）：

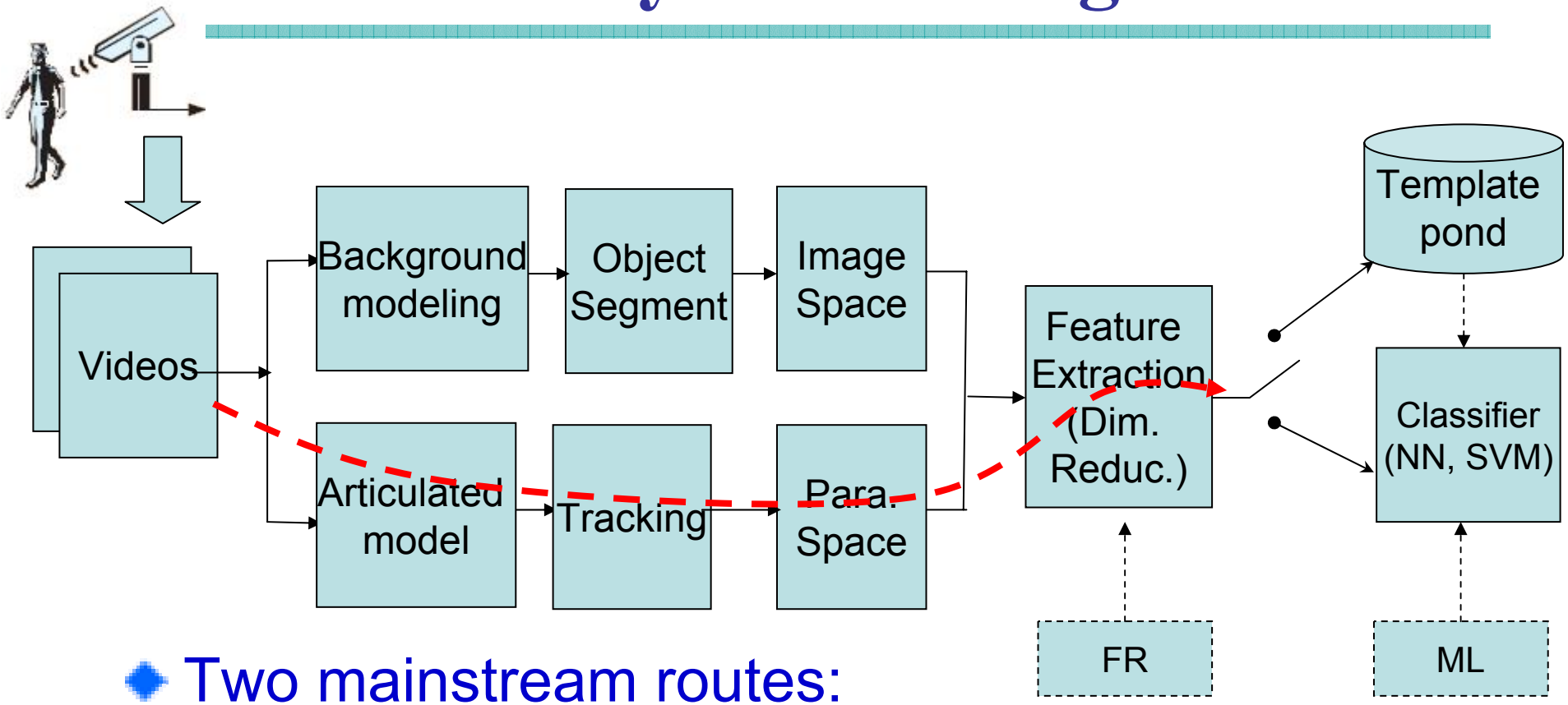
  represent sequence into image by overlapping;
- Tensor Discriminant Analysis：

  S(x,y,t), 3D data representation;
- Contour measurement:
- Vertical / horizonal projection.





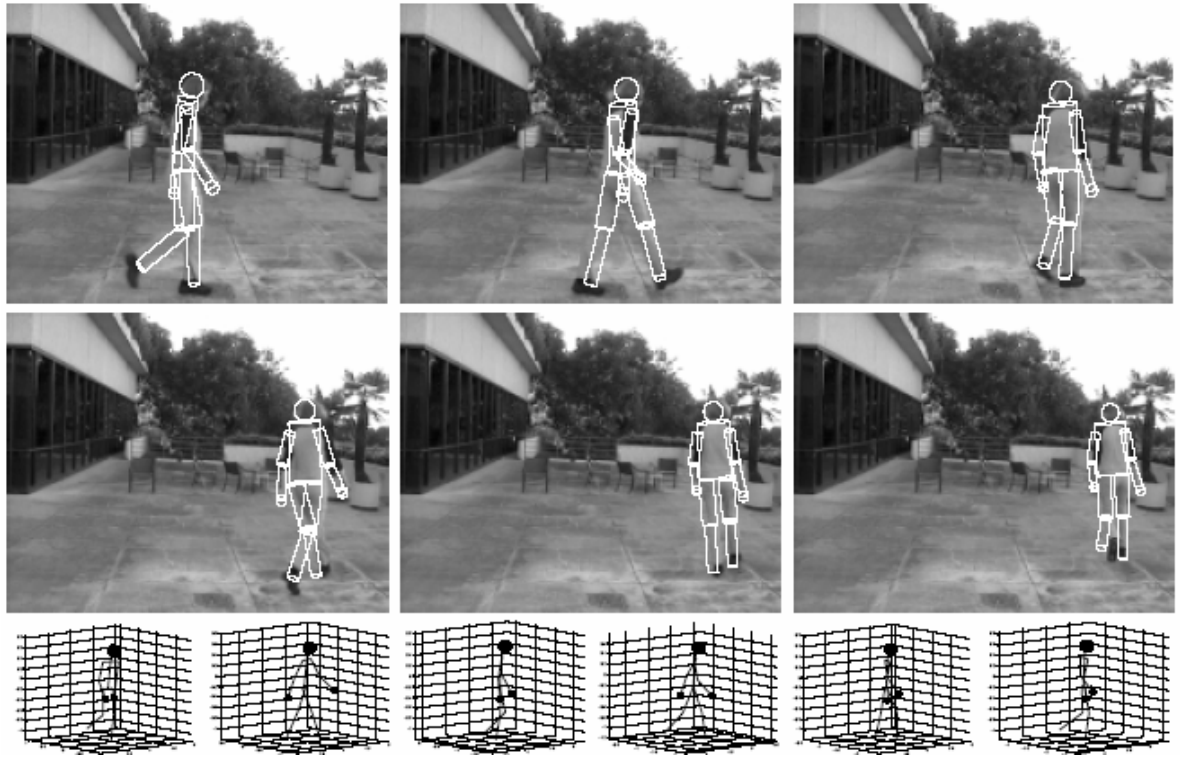
General Technique Framework of Gait Analysis & Recognition

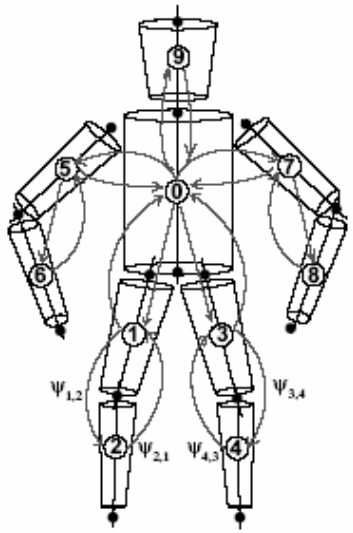


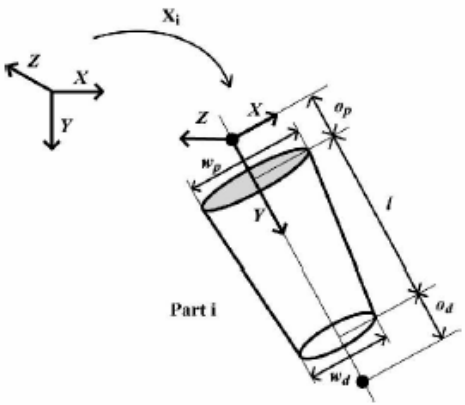
- Two mainstream routes:
  - Model free: silhouette analysis
  - **Model based: Articulated model**

Articulated body motion tracking

- 30+ DoF
- Cylinder model







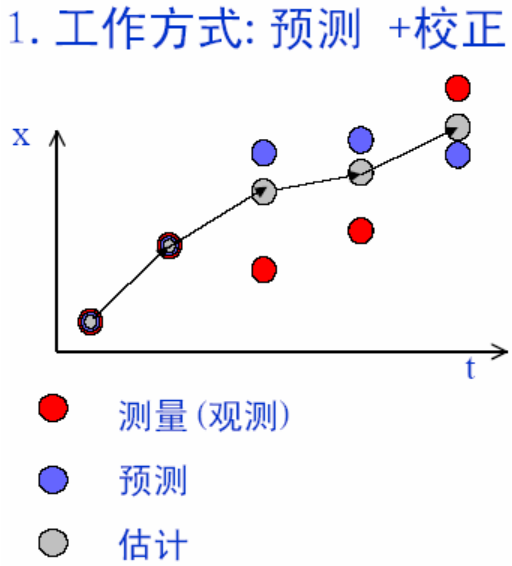
Kalman filtering based tracking

- Status equation: $x_k = Ax_{k-1} + u$
- Measurement equation: $y_k = Cx_k + v$
- Status updating equation: $\hat{x}_k = A\hat{x}_{k-1} + H_k\left(y_k - \hat{y}_k\right)$

Kalman gain

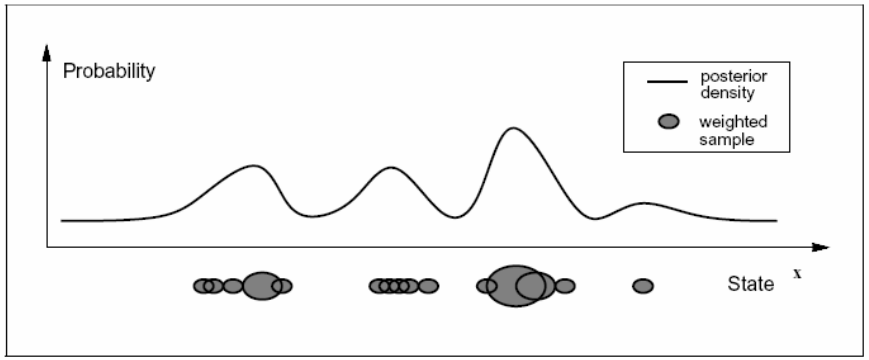
- Limitation:

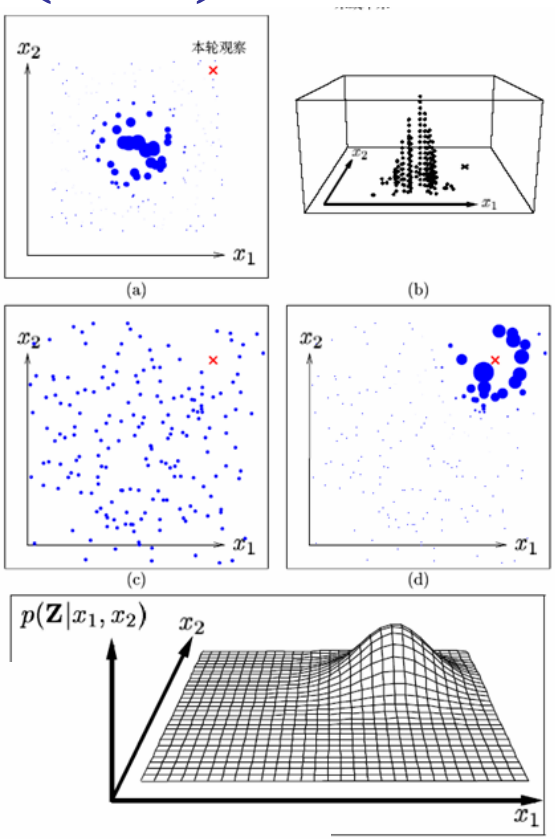
  only applicable to linear and Gaussian model.



Particle Filtering (PF)

Importance Sampling:





Bayesian framework of PF:

$$p_t(\mathbf{x}_t|\mathcal{Z}_t) = \frac{p_t(\mathbf{Z}_t|\mathbf{x}_t)p_{t-1}(\mathbf{x}_t|\mathcal{Z}_{t-1})}{p_t(\mathbf{Z}_t)},$$

$$p_t(\mathbf{x}_t|\mathcal{Z}_t) = \frac{p_t(\mathbf{Z}_t|\mathbf{x}_t)\int_{\mathbf{x}_{t-1}} p_t(\mathbf{x}_t|\mathbf{x}_{t-1})p_{t-1}(\mathbf{x}_{t-1}|\mathcal{Z}_{t-1})\,d\mathbf{x}_{t-1}}{p_t(\mathbf{Z}_t)}.$$

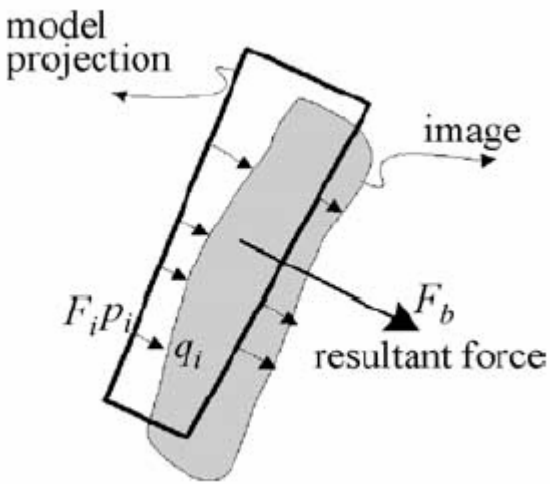
$$p_{t-1}(\mathbf{x}_{t-1}|\mathcal{Z}_{t-1}) \longmapsto p_{t-1}(\mathbf{x}_t|\mathcal{Z}_{t-1}) \longmapsto p_t(\mathbf{x}_t|\mathcal{Z}_t)$$

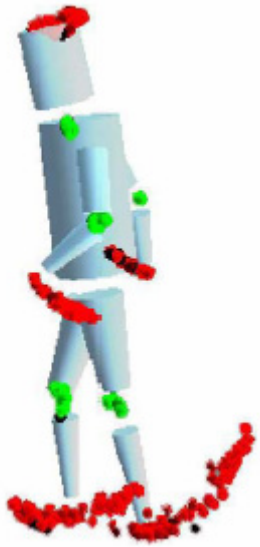
convolve with dynamics $p(\mathbf{x}'|\mathbf{x})$

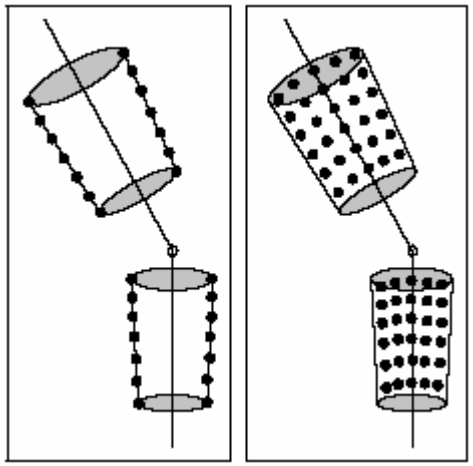
multiply by observation density $p(\mathbf{Z}|\mathbf{x}')$

Tracking

- Status equation —— description of kinematics characteristics;
- Measurement vector —— low level visual cues: edge detection 、 foreground segmentation、centroid、color……



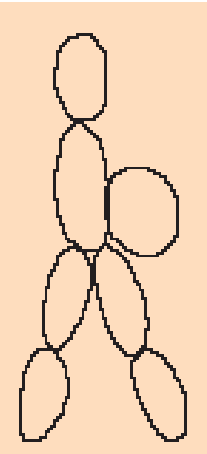


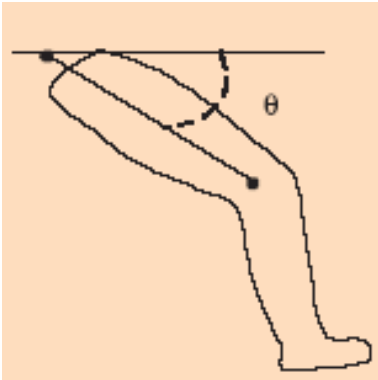


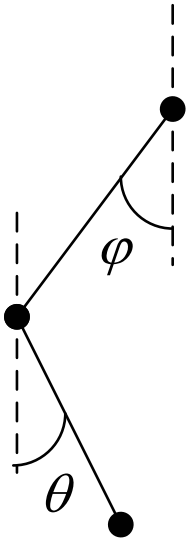
Edge Foreground

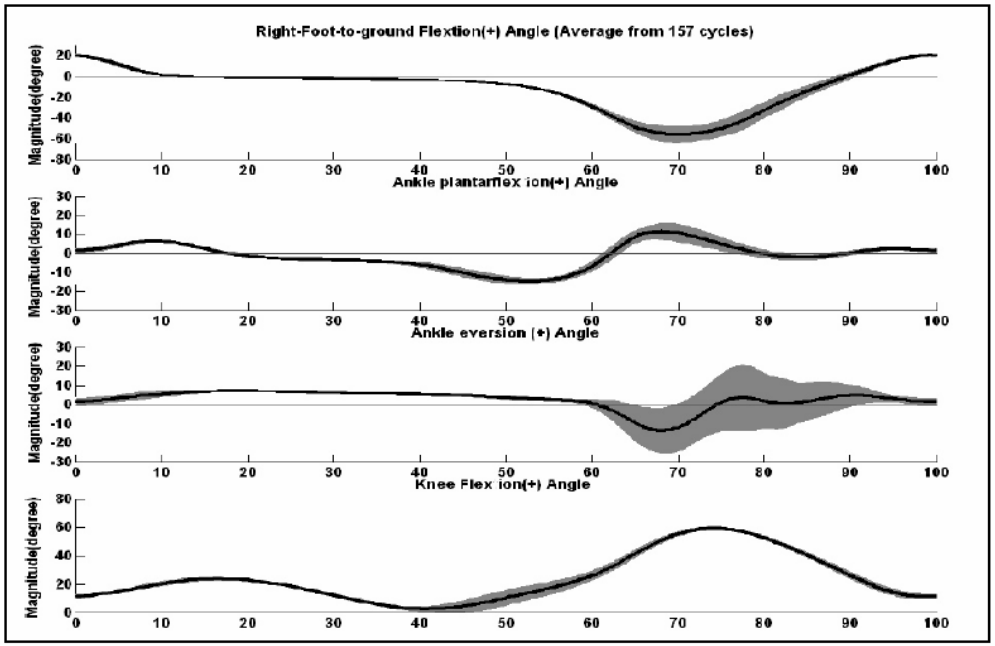
Typical algorithms in model-based gait recognition

- Hip rotation model
- Ellipse fitting
- Two-joint pendulum model









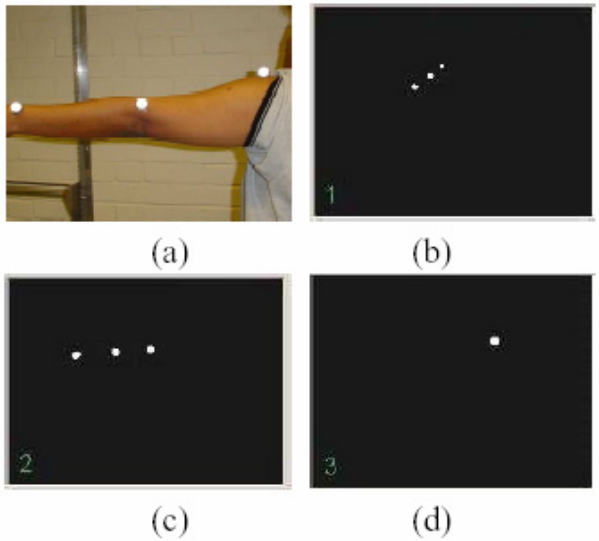
Trajectory analysis of rotation angles

Other solutions for gait?

—— extend our mind!

Marker-based motion capture

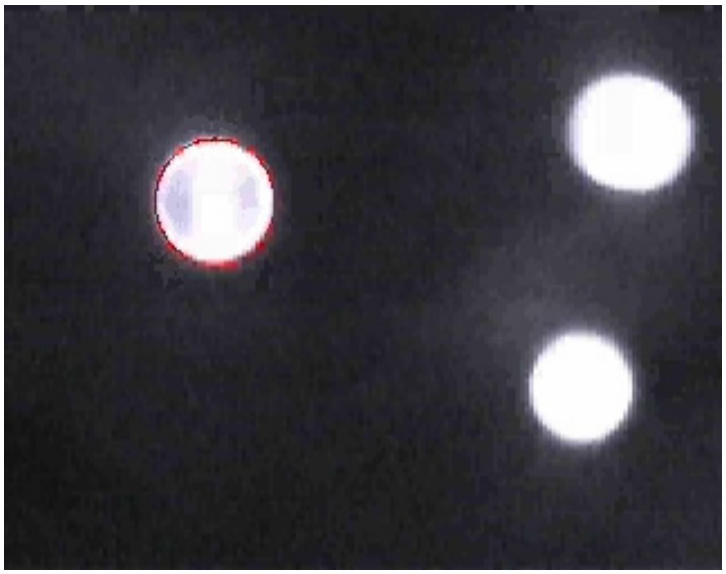
- Marker's type:
  - LED, infra-red, radio
- Application
  - Movie production
  - Animation
  - Athlete training aid
  - Human gait analysis



(a) (b) (c) (d)

Multiple-Circle Tracking

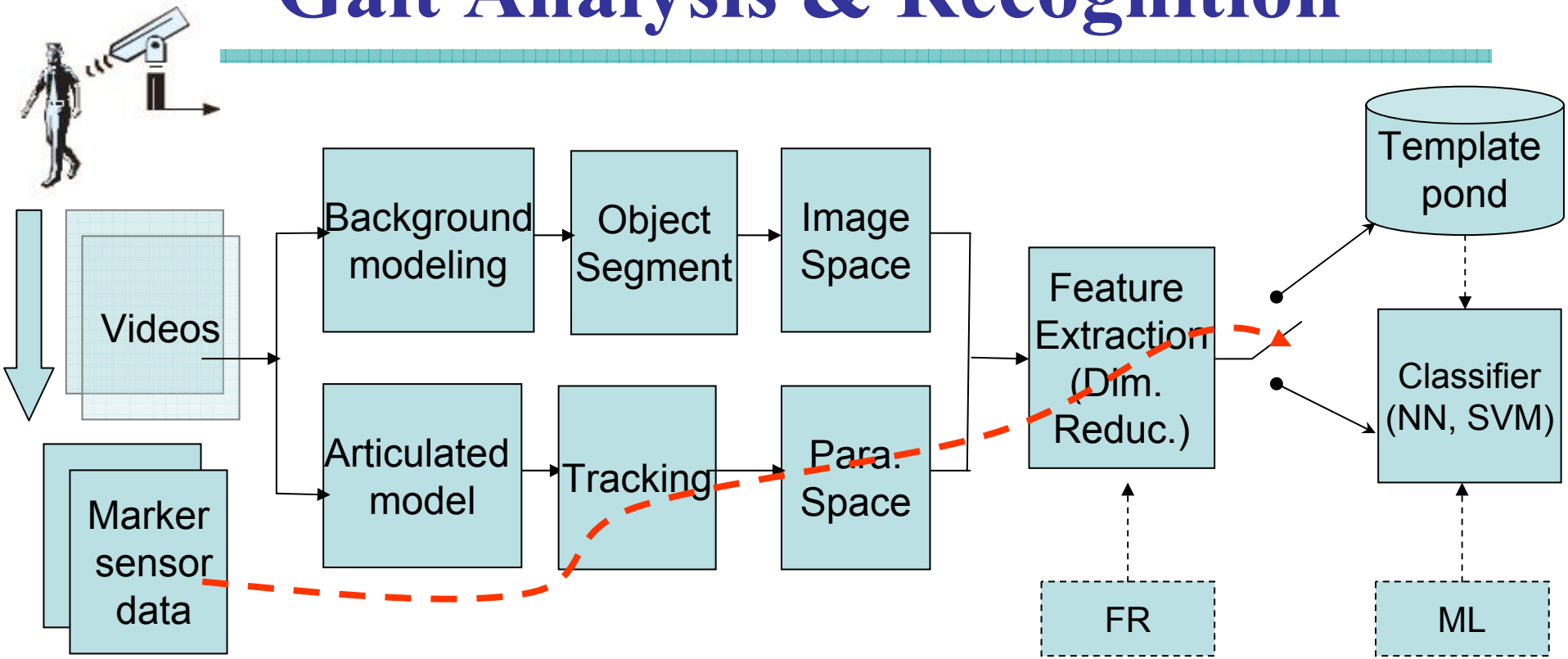
- Single tracking:



Multiple Tracking:

- Difficulties: Overlapping, Agile-movement, Real-time, ID-confusing …

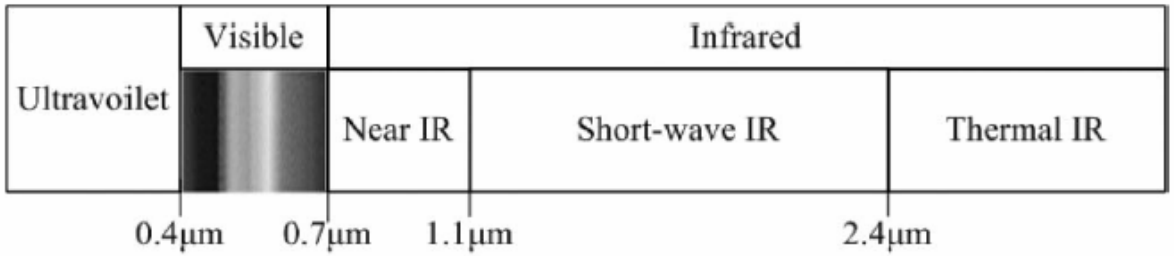
General Technique Framework of Gait Analysis & Recognition



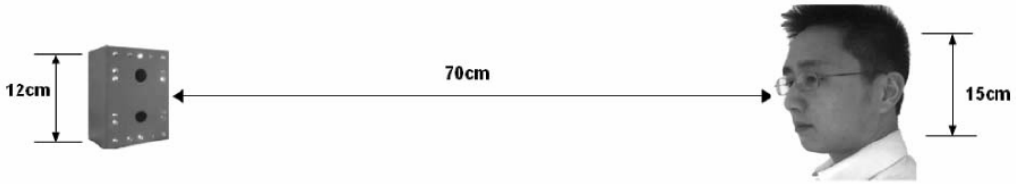
- **Model free:** silhouette analysis
- **Model based**
  - Markerless: Articulated model
  - **Marker-based analysis**

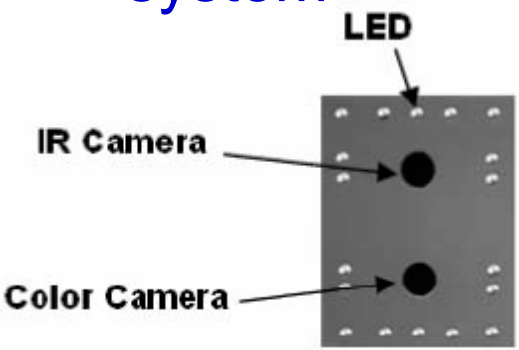
Look at Another Case: Face Recognition by NIR

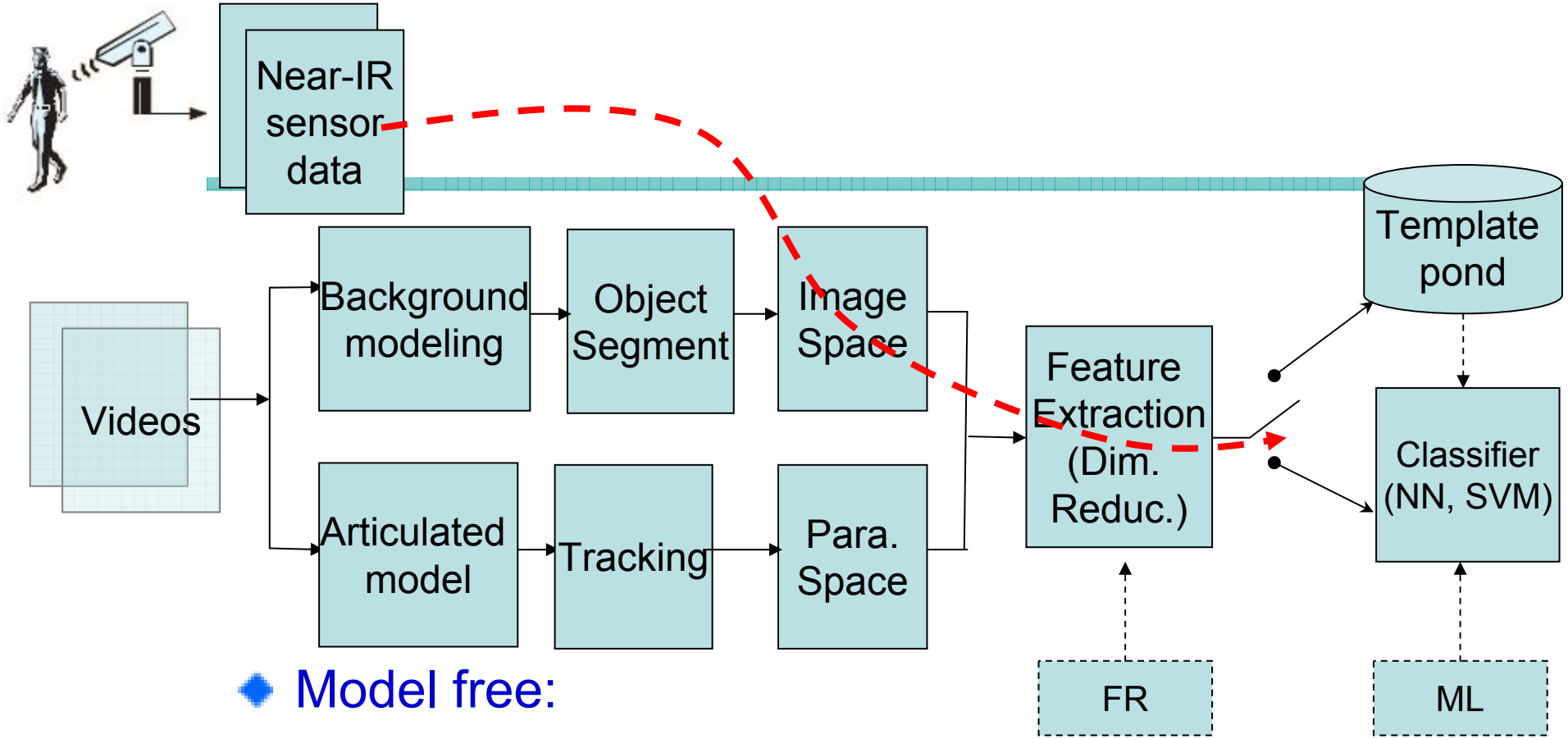
- Why NIR (Near Infra-Red) ?
  - Radiation Spectrum Ranges



  - Robust to illumination variant
  - Non-invasive
- Active NIR imaging system

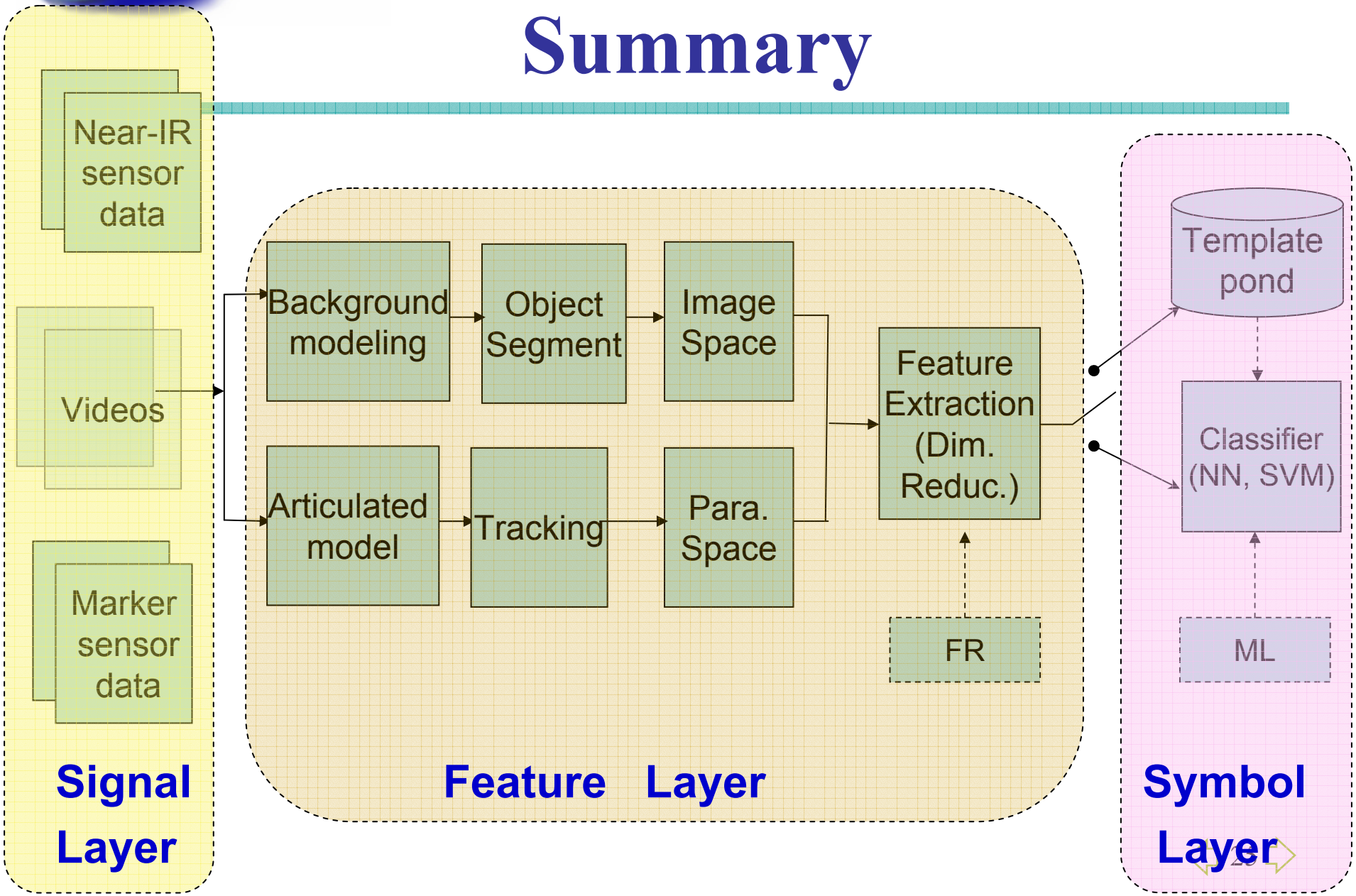






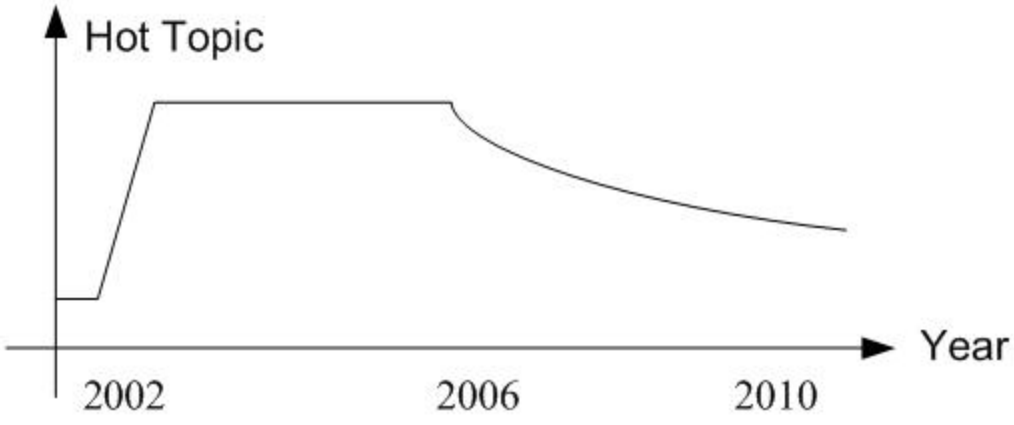
- Model free:
  - Silhouette analysis
  - **Near Infra-red image:** **Non-invasive**
- Model based
  - Markerless: Articulated model
  - Marker-based analysis: **Invasive**

Summary


Near-IR sensor data
Videos
Marker sensor data
Signal Layer
Background modeling
Object Segment
Image Space
Articulated model
Tracking
Para. Space
Feature Extraction (Dim. Reduc.)
FR
Feature Layer
Template pond
Classifier (NN, SVM)
ML
Symbol Layer

From Gait to body motion analysis —— possible future trends

- Tensor based approaches
- Abnormal behavior detection
- Body motion capture & driven
- ……



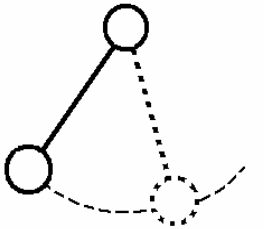
Selected our work on gait recognition

- Gait history image (GHI)
- Silhouette Quality Quantification (SQQ)

Temporal Template

- **Definition**: In template image, each pixel value is defined as a function of time (frame number) along whole silhouette sequence.
- **Purpose:** binary image sequence can be represented as a compact image with temporal information reserved.

Temporal Template: Some examples



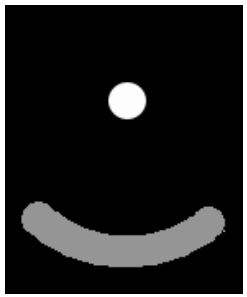
A scenario of pendulum's motion

- **Motion Energy Image (MEI):**

$$E_{\mathrm{MEI}}(x,y)=\bigcup_{t=1}^{\tau} D(x,y,t)$$

- **Motion History Image (MHI):**

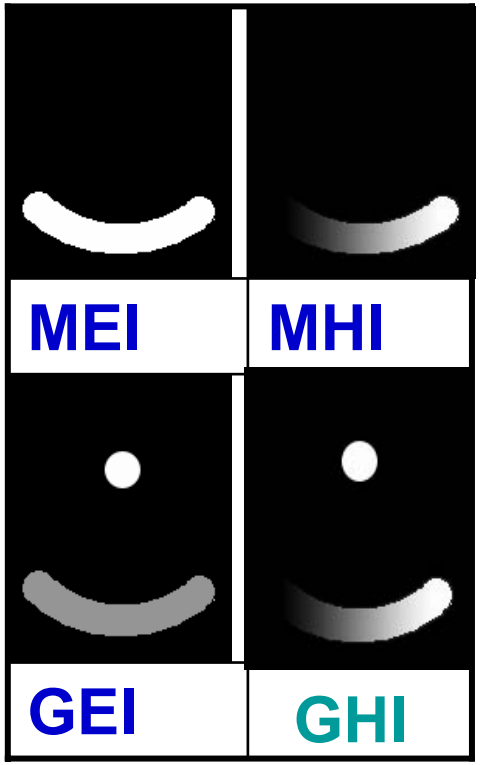
$$E_{\mathrm{MHI}}(x,y,t)=\begin{cases}\tau & \text{if } D(x,y,t)=1\\ max\left(0,E_{\mathrm{MHI}}(x,y,t-1)-1\right) & \text{otherwise}\end{cases}$$



- **Gait Energy Image (GEI):**

$$E_{\mathrm{GEI}}(x,y)=\frac{1}{\tau}\sum_{t=1}^{\tau} I(x,y,t)$$

Comparison of GHI with other templates



	MEI	MHI	GEI	GHI
Static Parts	×	×	√	√
Dynamic Parts	√	√	√	√
Temporal Info	×	√	×	√

Gait History Image

- **Aim**:

  A novel temporal template should have finer representing ability for gait motion.

- **Definition**:

$$E_{\mathrm{GHI}}(x,y)=\begin{cases}\tau & if \quad S(x,y)=1\\ \sum_{t=1}^{\tau} D(x,y,t)\cdot(t-1) & otherwise\end{cases}$$

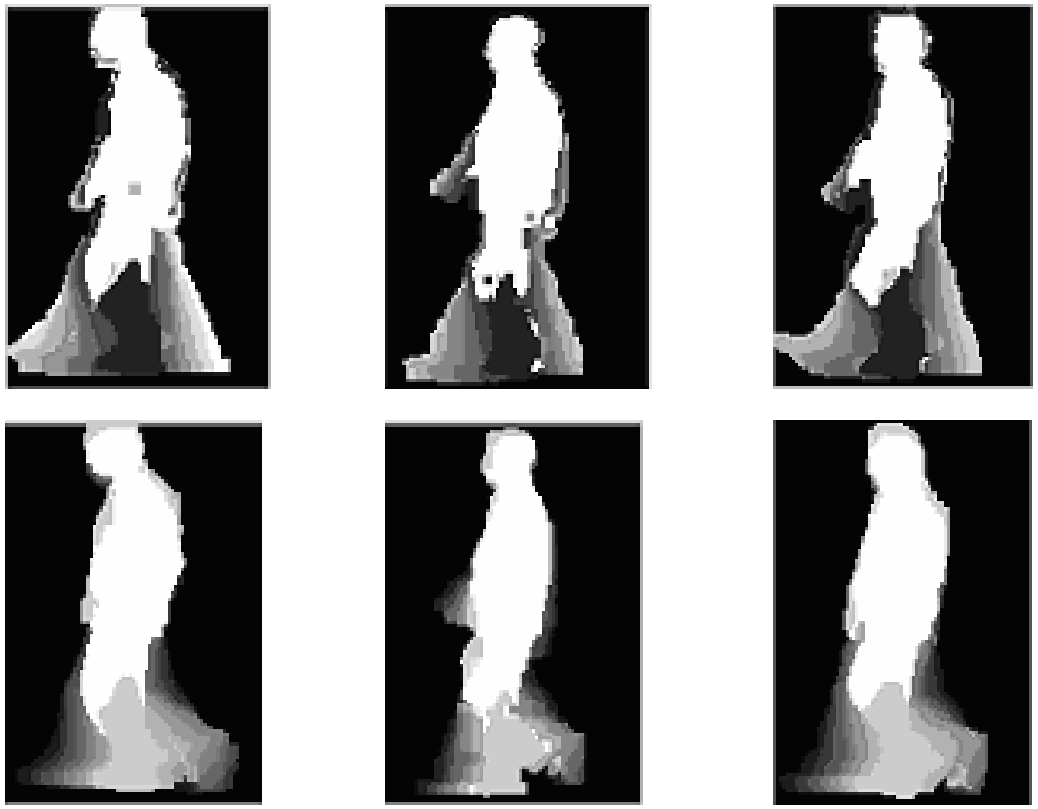
Where $S(x,y)=\begin{cases}1 & E_{\mathrm{GEI}}(x,y)\geq th\\ 0 & otherwise\end{cases}$ $\quad th=\max_{(x,y)}(E_{\mathrm{GHI}})\times 80\%$

- **Merit**:
  - Static and dynamic characteristics can be represented;
  - spatial and temporal variations can be represented.

Some examples of GHI

E^{O}_{GHI}

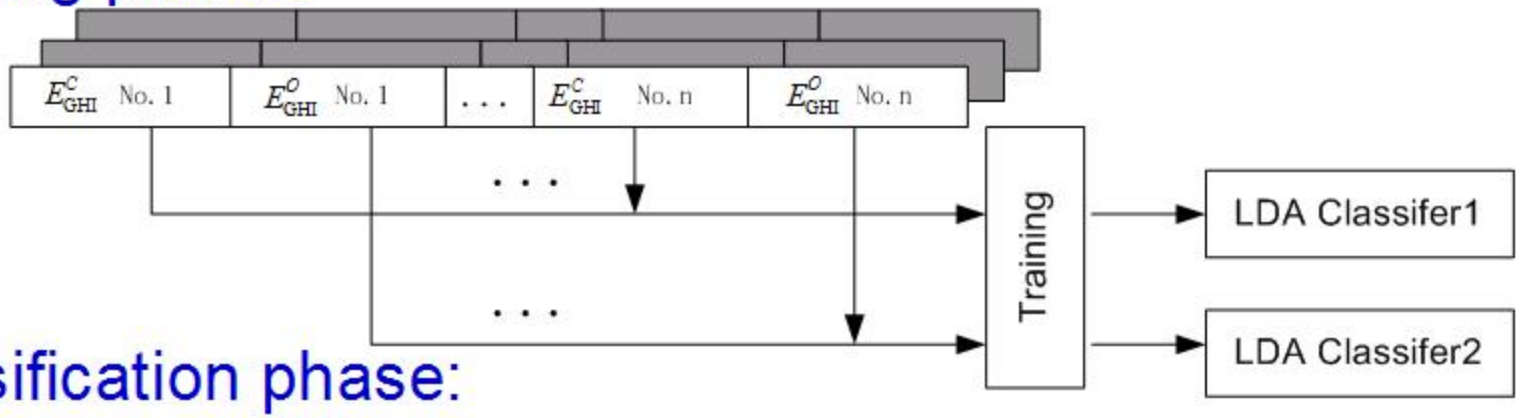
E^{C}_{GHI}



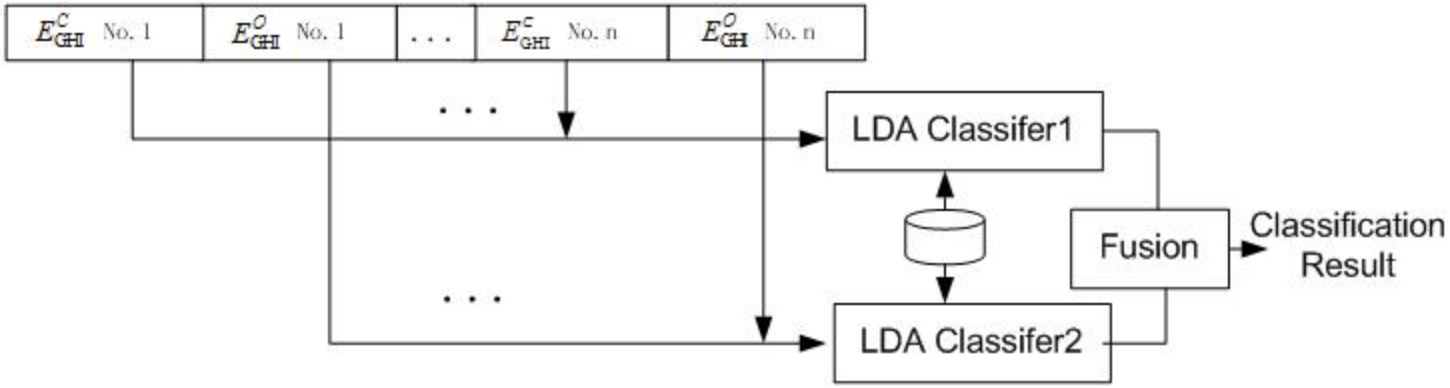
Subject 1 | Subject 2 | Subject 3

Gait Recognition using GHI

- Training phase:



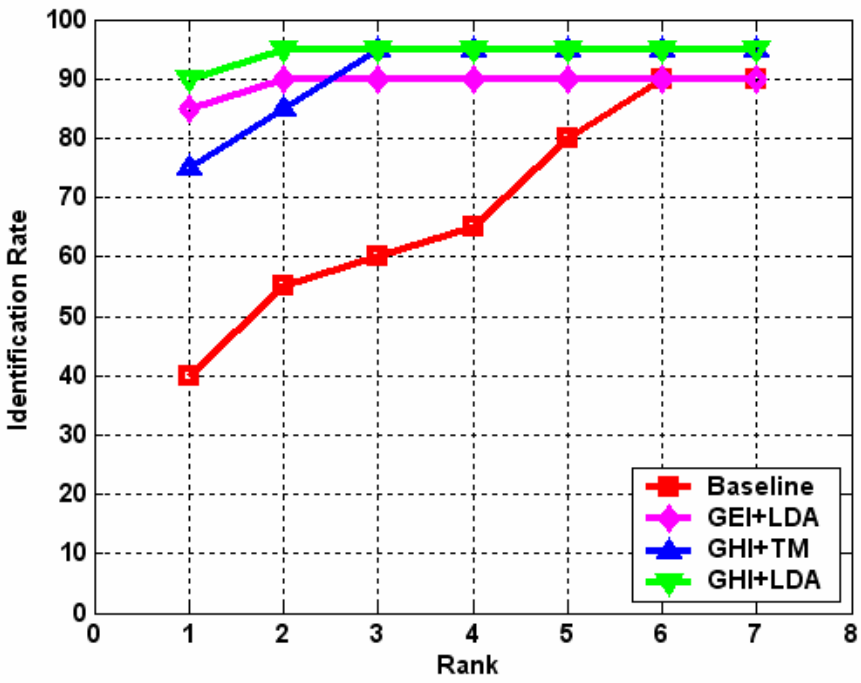
- Classification phase:



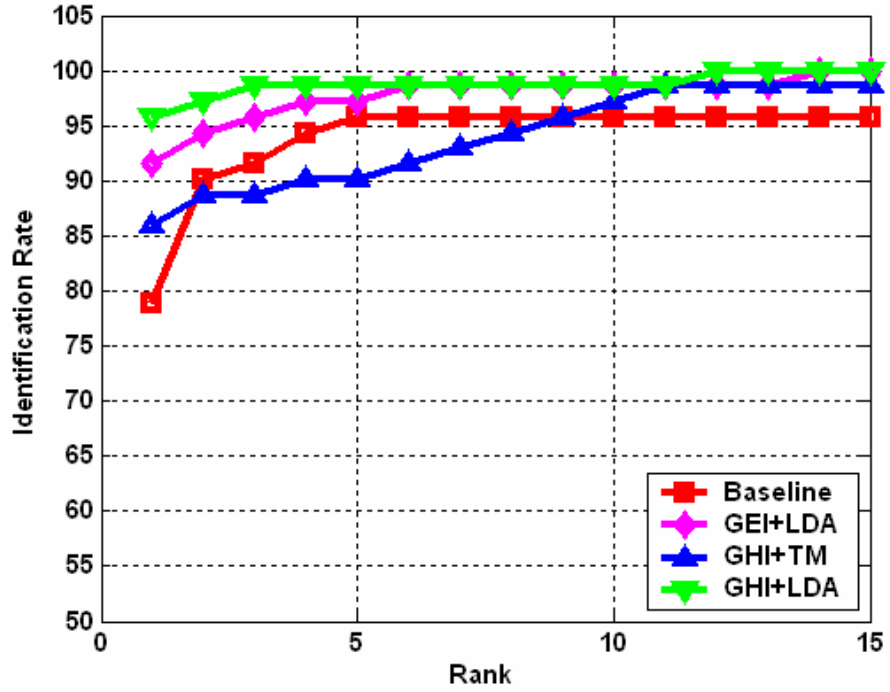
  - Nearest Center of Class (NCC) criterion is used here:

$$\chi_p = \arg\min_{1 \le i \le C} \left[D\left(\tilde{\boldsymbol{G}}^O, \boldsymbol{G}_i^O\right) + D\left(\tilde{\boldsymbol{G}}^C, \boldsymbol{G}_i^C\right) \right]$$

Experimental results



Cumulative Matching Score (CMS) results on CASIA dataset



CMS scores on USF dataset

Selected our work on gait recognition

- Gait history image (GHI)
- Silhouette Quality Quantification (SQQ)

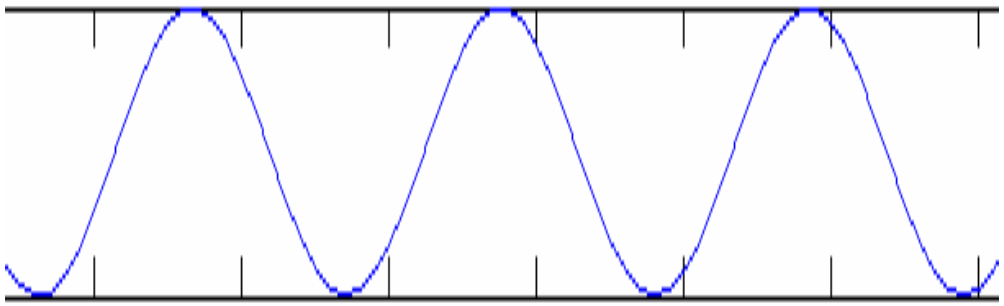
Motivation

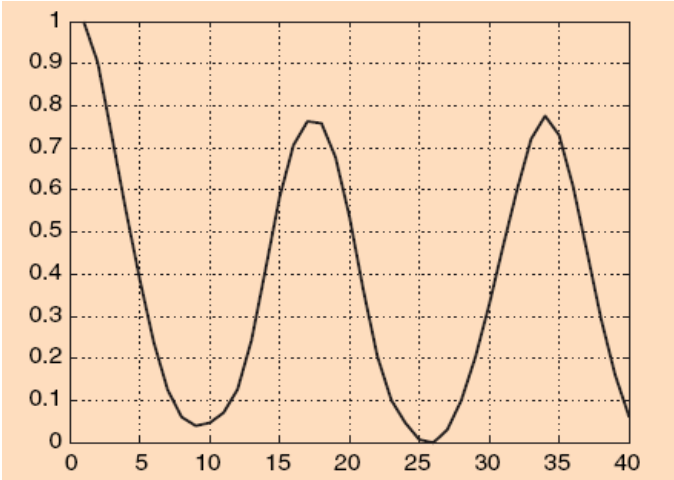
- Most gait recognition approaches are designed based on binary images (silhouettes).
  - Simpler compared to articulated model.
  - clothing color / texture information contribute nothing to identification;
  - So, many gait datasets opened public provide silhouette versions.
- However, In reality, silhouette noise occurs inevitably after *Background Subtraction.*

Periodicity and Cycles in gait sequence

- Time duration of a full walking cycle:

- Foreground sum signal & its Autocorrelation signal:



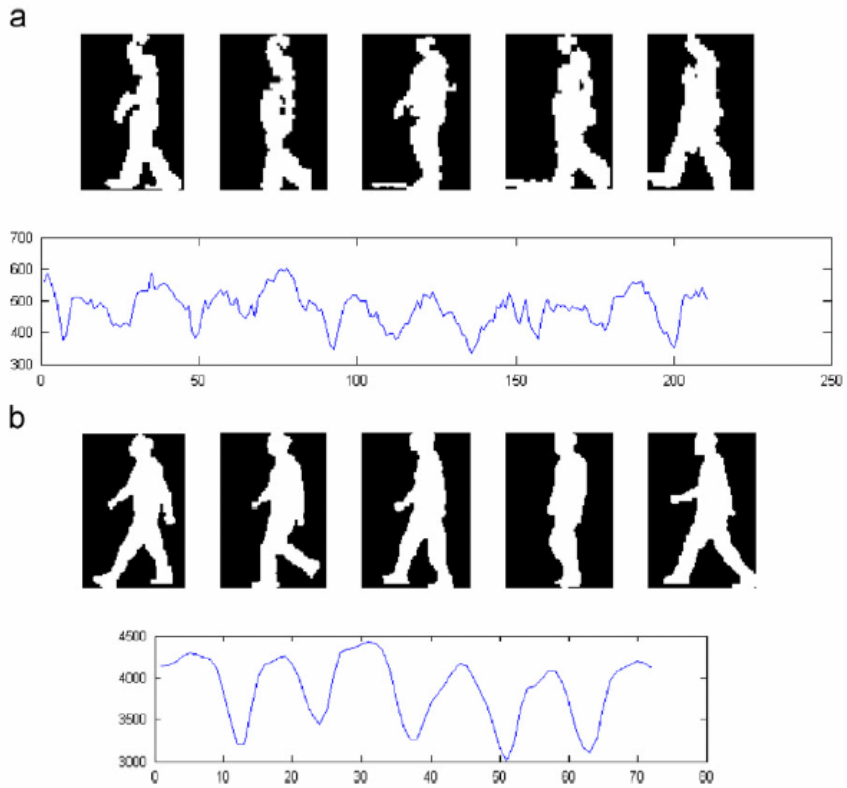


Observation

- **What is FS signal?**
  - **Definition:**

$$x(t) = \sum_u \sum_v s(u, v, t)$$

foreground-sum signal



- **Observation**

  The noise in FS signal is correlated to noise in silhouettes.

Silhouette Quality Quantification (SQQ)

- **Idea: Using FS signal to measure the quality of silhouette sequence.**
- **Modeling the FS signal:**

$$x(t) = a_0(t) + a_1(t)\cos\omega t + a_2(t)\cos 2\omega t + z(t)$$

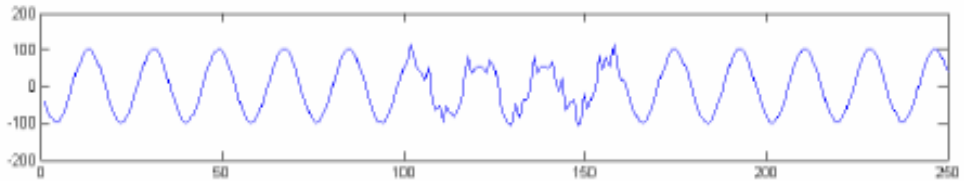
- **Proposed a silhouette quality evaluation function:**

$$Q(i) = \sigma_s^2 - \sigma_z^2, \text{ over } f_i(t), \text{ for all } f_i \subset f$$

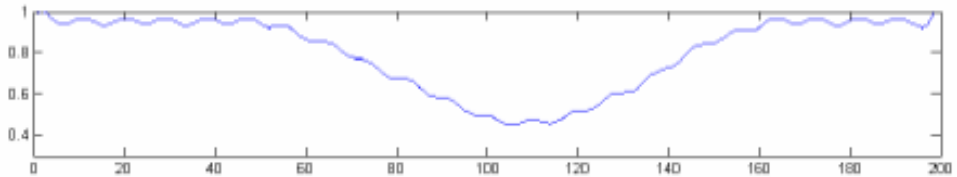
by using the autocorrelation matrix eigen-analysis approach.

Visualization of the evaluation

- SQQ curve upon simulated data:

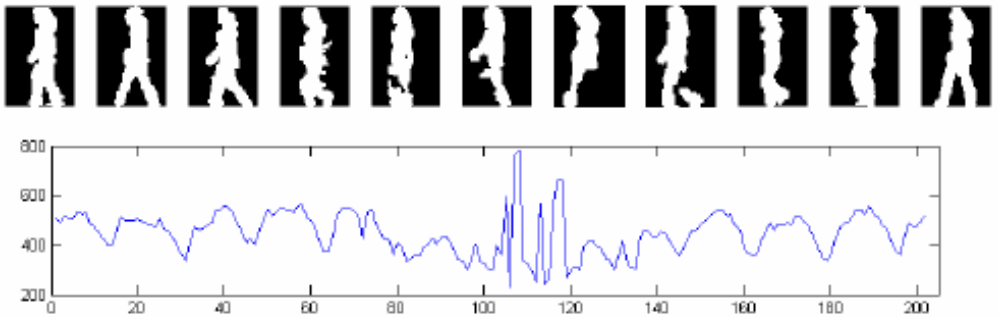


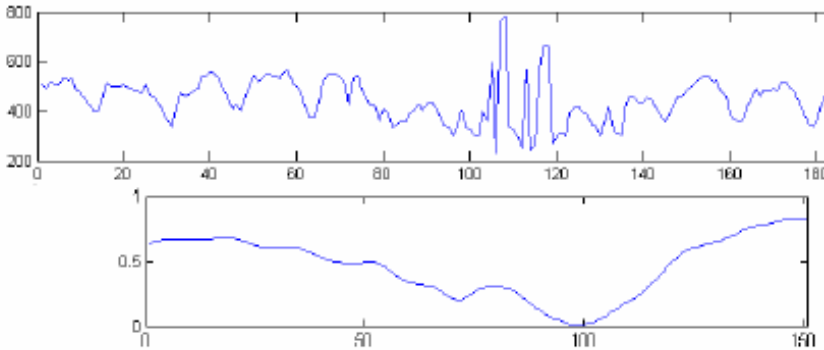
(a) $f(t)$



(b) $\mathcal{Q}(i)$

- SQQ curve upon real silhouette data:



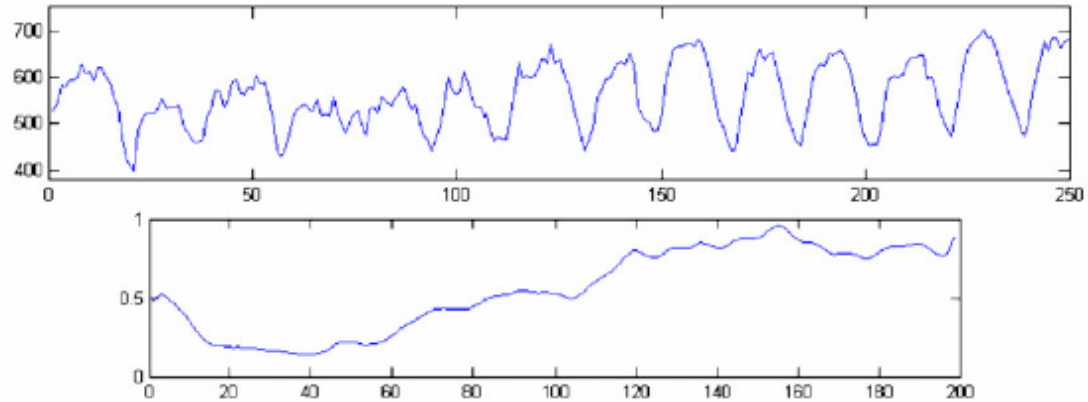


Silhouette Quality Weighted (SQW) Gait Recognition

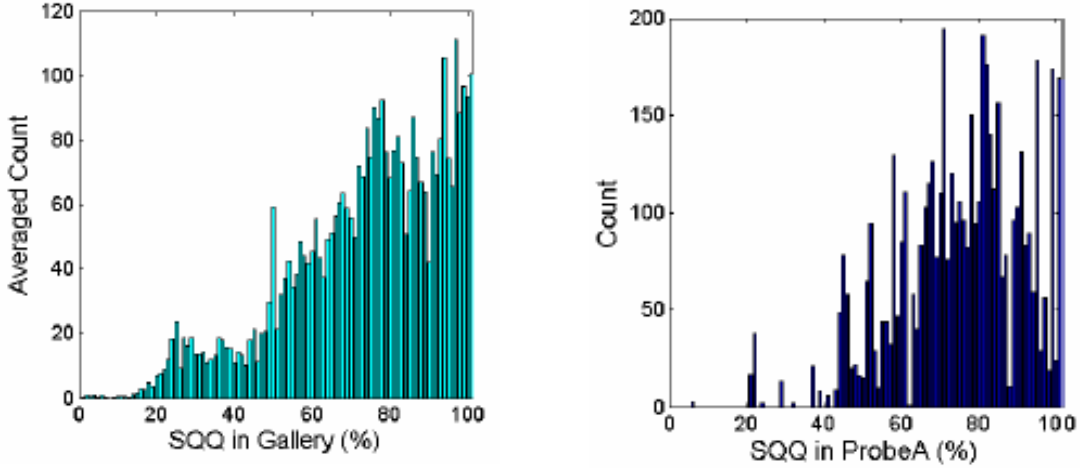
- Extending the application of SQQ for gait recognition.
- Proposed the Silhouette quality weighted (SQW) gait recognition algorithm:

$$k = \arg\min_i \left(\mathrm{Sim}_{(\chi)}\left(\mathbf{S}_P, \mathbf{S}_i\right)\right), \text{ with } \mathbf{S}_i \in \{\mathbf{S}_G\}$$

$$\mathrm{Sim'}_{(\chi)}\left(\langle \mathbf{S}_P, \mathcal{Q}_{\mathbf{S}_P}\rangle, \langle \mathbf{S}_G, \mathcal{Q}_{\mathbf{S}_G}\rangle\right)$$



Experimental results



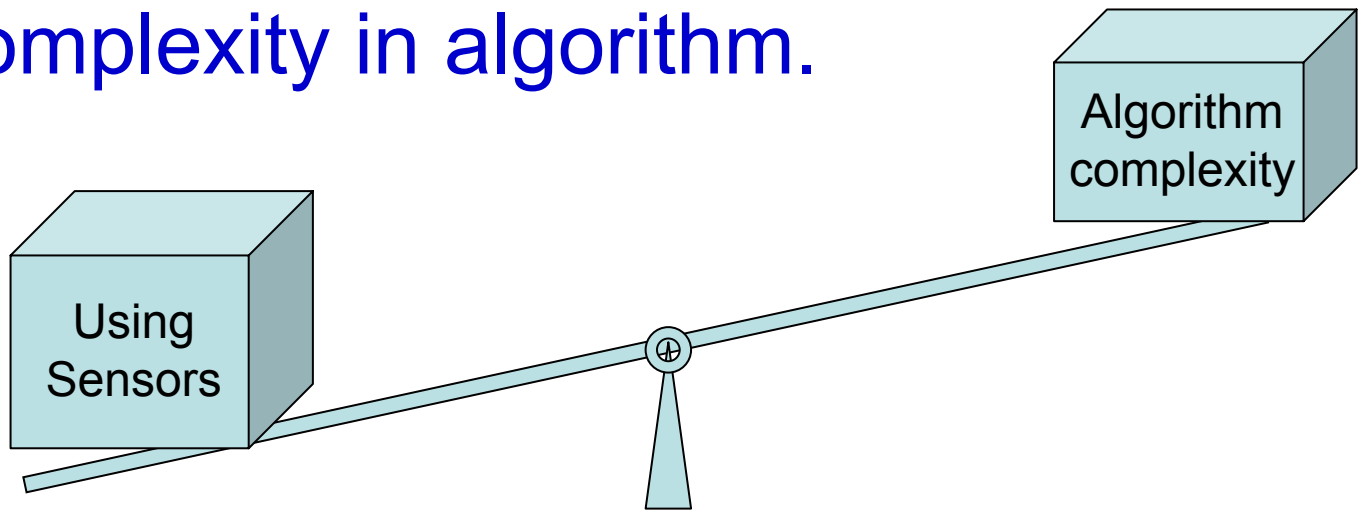
(a) Histogram of SQQ scores for the Baseline algorithm

Exp.	P_I(%) at rank = 1, 5							
Method	TM		$SQW_{rectangle}$ + TM		$SQW_{hamming}$ + TM		$SQW_{hamming}$ + FLD	
Rank	1	5	1	5	1	5	1	5
A	95.77	97.18	97.18	100	97.18	100	98.59	100
B	80.49	92.68	85.37	95.12	82.93	95.12	87.80	92.68
C	68.29	92.68	70.73	95.12	68.29	97.56	85.37	90.24
D	30.30	50.00	33.33	57.58	33.33	57.58	39.39	66.67
E	28.57	40.48	33.33	54.76	35.71	54.76	45.24	69.05
F	22.73	37.88	25.76	50.00	24.24	48.48	36.36	62.12
G	26.19	42.86	30.95	45.24	30.95	50.00	30.95	59.52
Mean	50.33	64.82	53.81	71.12	53.23	71.93	60.53	77.18

(b) Identification performances on the USF ver1.7 dataset.

My Advises on GR system building

- Frontal view is more discriminative,
- Never discard static feature —— cascade
- Room is harder than corridor,
- The more sensor uses, the less complexity in algorithm.



Thank You!