國立高雄科技大學

National Kaohsiung University of Science and Technology

Real-time Foreground-Background Segmentation Using Codebook Model

K. Kim, T. H. Chalidabhongse, D. Harwood,

and L. Davis

Real-Time Imaging, 2005

Speaker: Shih-Shinh Huang

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Outline

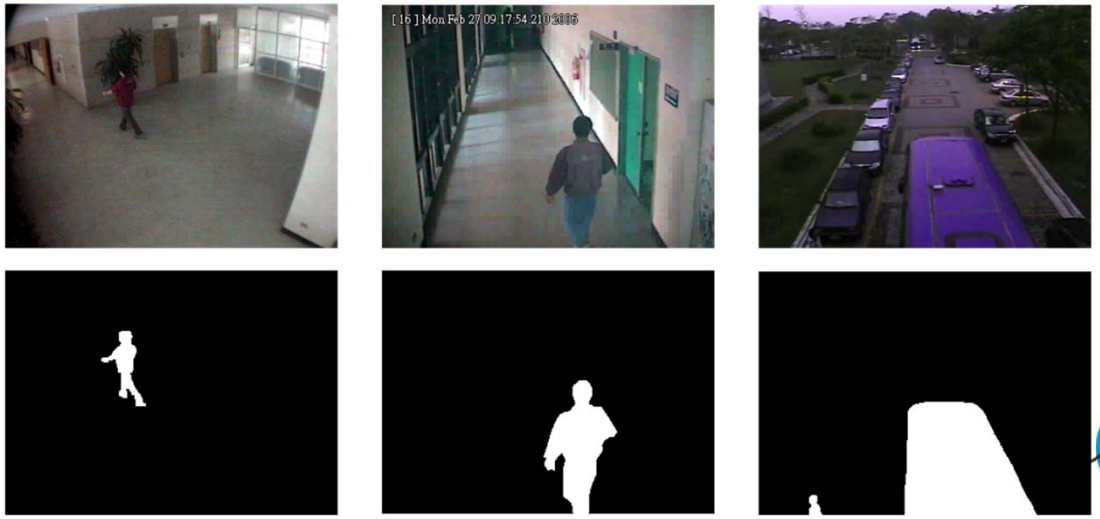
- Introduction
- Codebook Definition
- Codebook Construction
- Subtraction Process

Introduction

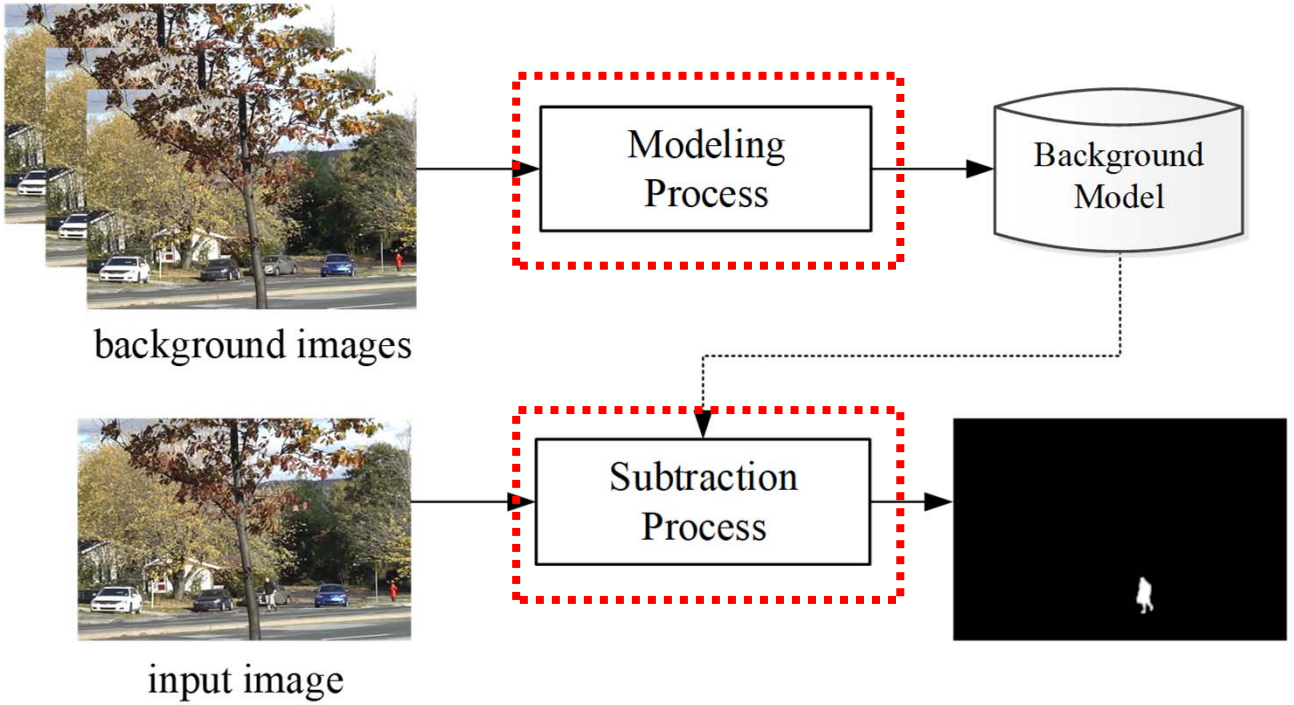
- About Background Subtraction
  - Assumption: camera is stationary
  - Objective: segment the region of interests (foreground) from the background scenes

original image

foreground mask



Introduction



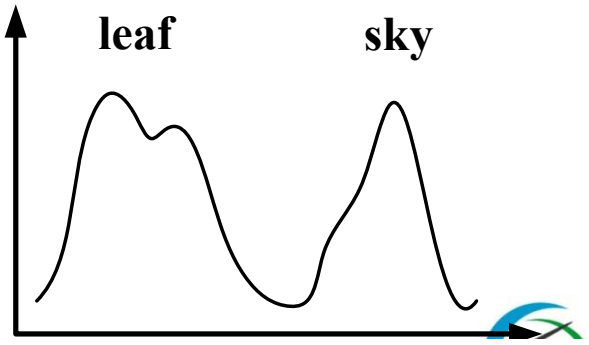
Modeling Process: construct a model (or background) describing the background scene.

Subtraction Process: subtract the background from the currently observed image.

Introduction

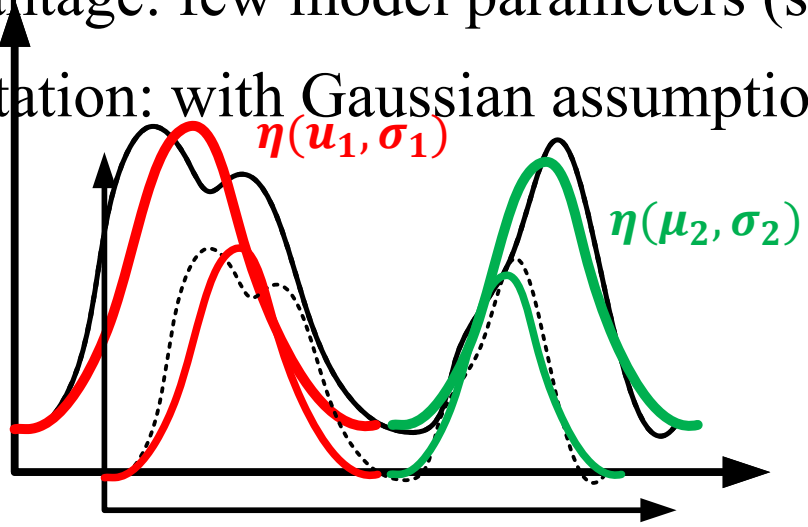
- About Background Subtraction
  - The major challenge in background subtraction is dynamic background.
    - contains non-stationary background objects
    - makes it unfeasible to model intensity of a point by a unimodal distribution.

waving tree



Introduction

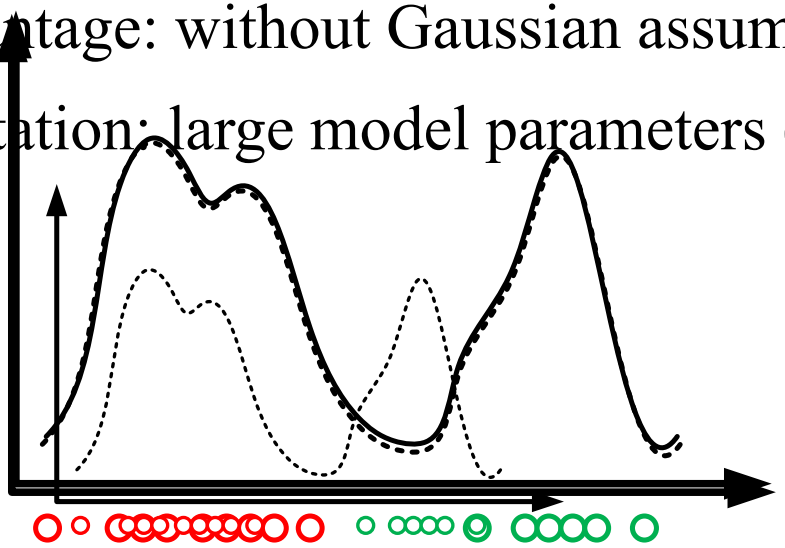
- Dynamic Background Handling
  - Gaussian Mixture Models (GMMs): approximate actual distribution by several Gaussians
    - Advantage: few model parameters (small memory)
    - Limitation: with Gaussian assumption



C. Stauffer and W. Grimson, "Adaptive Background Mixture Models for Real Time Tracking", *CVPR*, 1999.

Introduction

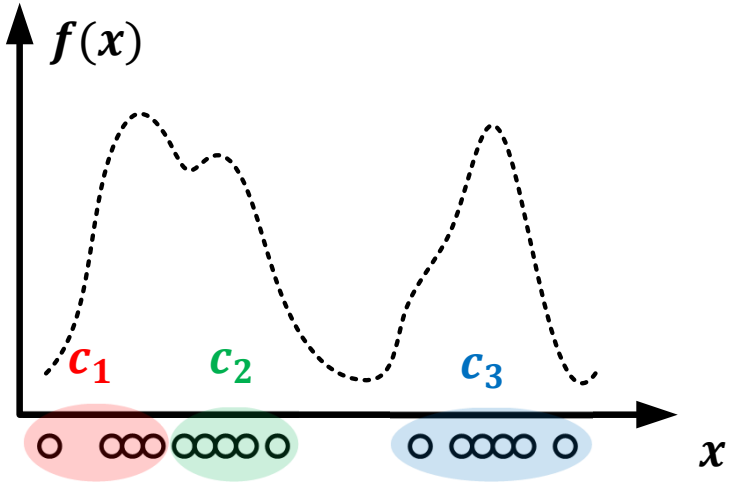
- Dynamic Background Handling
  - Non-Parametric Model: approximate actual distribution by a period of samples
    - Advantage: without Gaussian assumption
    - Limitation: large model parameters (large memory)



A. Elgammal, D. Harwood, and L. Davis, "Non-Parametric Model for Background Subtraction", *ECCV*, 2000.

Introduction

- Idea
  - similar to non-parametric model: approximate distributions by a sample set.
  - similar to GMM: describe the sample set by a compact form (called codebook)

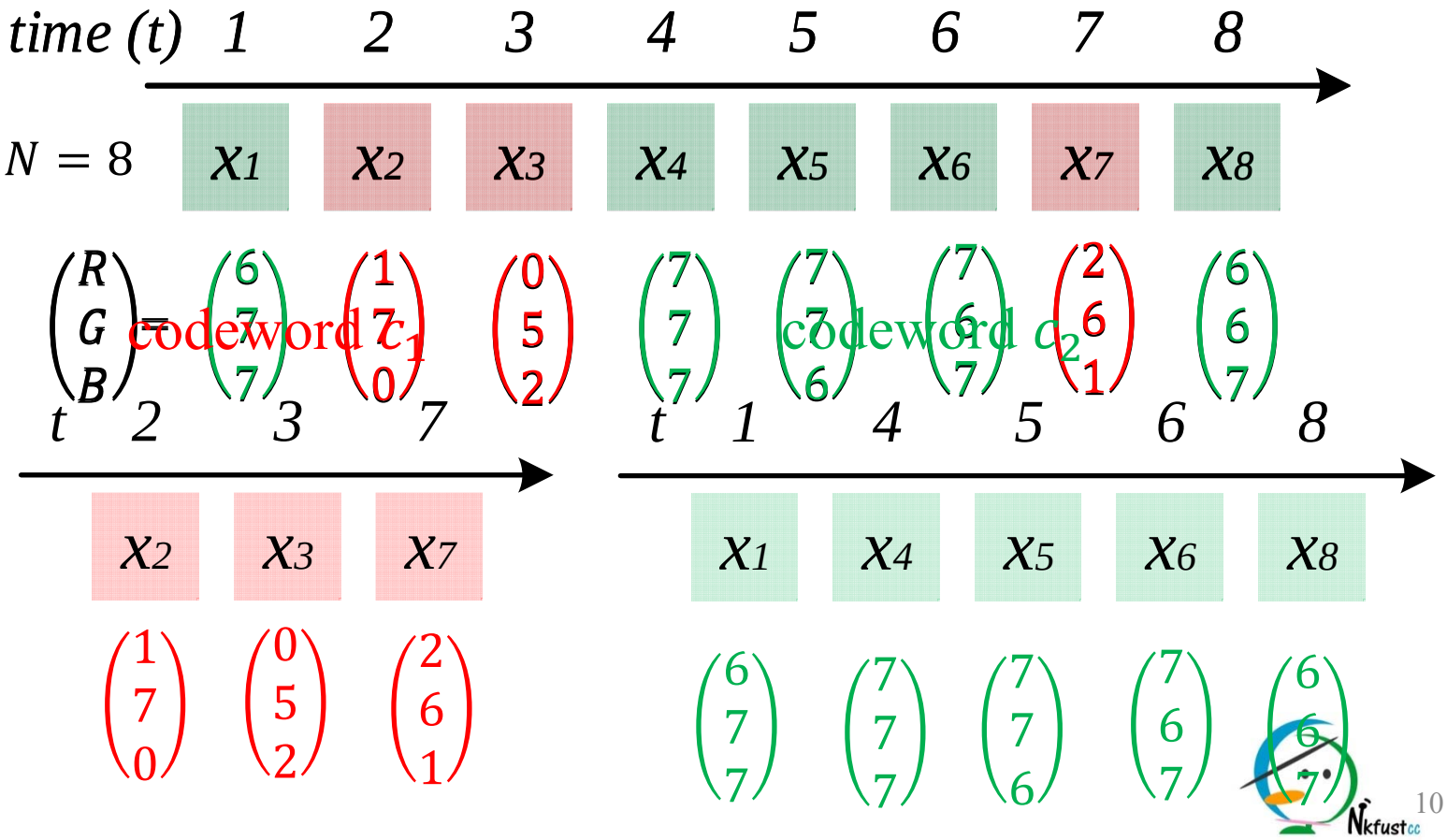


Codebook Definition

- About Codebook B
  - Let $\{x_1, x_2, \ldots x_N\}$ be a sequence of N background RGB-vectors of a single point
  - A codebook B is used to describe $\{x_1, x_2, \ldots x_N\}$ by L codewords $\{c_1, c_2, .., c_L\}$.
  - Each codeword stands for part of background RGB-vectors.

Codebook Definition

- About Codebook B



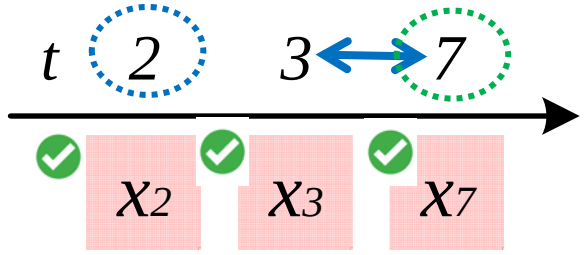
Codebook Definition

- About Codeword c_i
  - A codeword c_i models the sequence of RBG vectors in ith cluster
    - intensity property
    - temporal property
  - Codeword Definition: $c_i = (\mathbf{v}_i, \mathbf{aux}_i)$
    - $\mathbf{v}_i = (\bar{R}_i, \bar{G}_i, \bar{B}_i)$: mean RGB vector
    - $\mathbf{aux}_i = < \check{I}_i, \hat{I}_i, f_i, \lambda_i, p_i, q_i >$

$\check{I}_i$: minimum brightness; $\hat{I}_i$: maximum brightness; f_i: frequency; λ_i: maximum negative run-length (MNRL); p_i: first access time; q_i: last access time

Codebook Definition

- About Codeword $c_i = (\mathbf{v}_i, \mathbf{aux}_i)$



$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 \\ 7 \\ 0 \end{pmatrix} \quad \begin{pmatrix} 0 \\ 5 \\ 2 \end{pmatrix} \quad \begin{pmatrix} 2 \\ 6 \\ 1 \end{pmatrix}$$

$$\sqrt{R^2 + G^2 + B^2}$$

$$I = 7 \quad 5 \quad 6$$

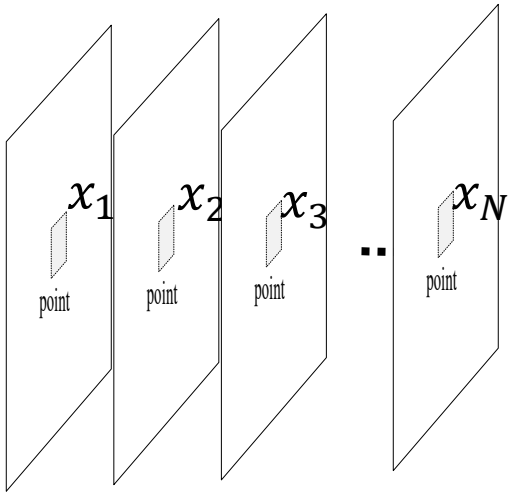
$$\mathbf{v}_i \equiv \frac{1}{3}\left(\begin{pmatrix} 1 \\ 7 \\ 0 \end{pmatrix}^T + \begin{pmatrix} 0 \\ 5 \\ 2 \end{pmatrix}^T + \begin{pmatrix} 2 \\ 6 \\ 1 \end{pmatrix}^T\right) = \begin{pmatrix} 1 \\ 6 \\ 1 \end{pmatrix}^T$$

$$\mathbf{aux}_i = < \check{I}_i, \hat{I}_i, f_i, \lambda_i, p_i, q_i >$$

- $\check{I}_i = 5, \quad \hat{I}_i = 7$
- $f_i = 3, \quad \lambda_i = 7 - 3 = 4$
- $p_i = 2, \quad q_i = 7$

Codebook Construction

- Formulation
  - Input: $\{x_1, x_2, \ldots x_N\}$: a sequence of N training RGB-vectors of a point
  - Output: $B = \{c_1, c_2, .., c_L\}$



incremental clustering

+ background codeword selection

$c_1 = (\mathbf{v}_1, \mathbf{aux}_1)$

$c_2 = (\mathbf{v}_2, \mathbf{aux}_2)$

$c_3 = (\mathbf{v}_3, \mathbf{aux}_3)$

$\vdots$

$c_L = (\mathbf{v}_L, \mathbf{aux}_L)$

may contain foreground objects

Codebook Construction

- Incremental Clustering
  - Initialization: $B \leftarrow \emptyset$ (empty set)
  - Iterative Step ($t = 1,2, \ldots, N$): sequentially match observation x_t to all codewords $c_i \in B$
    - Case 1 (no match): create a new codeword
    - Case 2 (match found): update the first matched codeword c_m and move it to the first codeword in B

Codebook Construction

- Case 1 (no match)
  - create a new codeword $c = (\mathbf{v}, \mathbf{aux})$ using x_t
    - **v** ← x_t=(R_t, G_t, B_t)
    - **aux** ← $< I_t, I_t, 1, t-1, t, t >$

$$\begin{pmatrix} R_2 \\ G_2 \\ B_2 \end{pmatrix} = \begin{pmatrix} 1 \\ 7 \\ 0 \end{pmatrix}$$

$$I_2 = 7$$

v =< 1,7,0 >

aux =$< \check{I}, \hat{I}, f, \lambda, p, q >$

- $\check{I} = \hat{I} = 7$
- $f = 1, \quad \lambda = 2 - 1 = 1$
- $p = 2, \quad q = 2$

Codebook Construction

- Case 2 (match found)
  - update first matched $c_m = (\mathbf{v}_m, \mathbf{aux}_m)$

$$\mathbf{v}_m = (\bar{R}_m, \bar{G}_m, \bar{B}_m) \qquad \mathbf{aux}_m = < \check{I}_m, \hat{I}_m, f_m, \lambda_m, p_m, q_m >$$

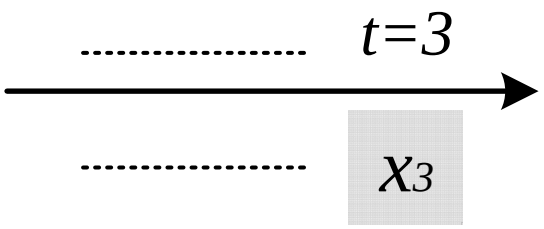
$$x_t = (R_t, G_t, B_t)$$

$$\mathbf{v}_m = \left(\frac{f_m \times \bar{R}_m + R_t}{f_m + 1}, \frac{f_m \times \bar{G}_m + G_t}{f_m + 1}, \frac{f_m \times \bar{B}_m + B_t}{f_m + 1} \right)$$

$$\mathbf{aux}_m = < \min(\check{I}_m, I_t), \max(\hat{I}_m, I_t), f_m + 1, \max(\lambda_m, t - q_m), p_m, t >$$

Codebook Construction

- Case 2 (match found)



$$\begin{pmatrix} R_3 \\ G_3 \\ B_3 \end{pmatrix} = \begin{pmatrix} 0 \\ 5 \\ 2 \end{pmatrix}$$

$$I_3 = 5$$

$$\mathbf{v}_m =< 1,7,0 >$$

$$\mathbf{aux_m} =< \check{I}_m = 7, \hat{I}_m = 7, f_m = 1, \lambda_m = 1, p_m = 2, q_m = 2 >$$

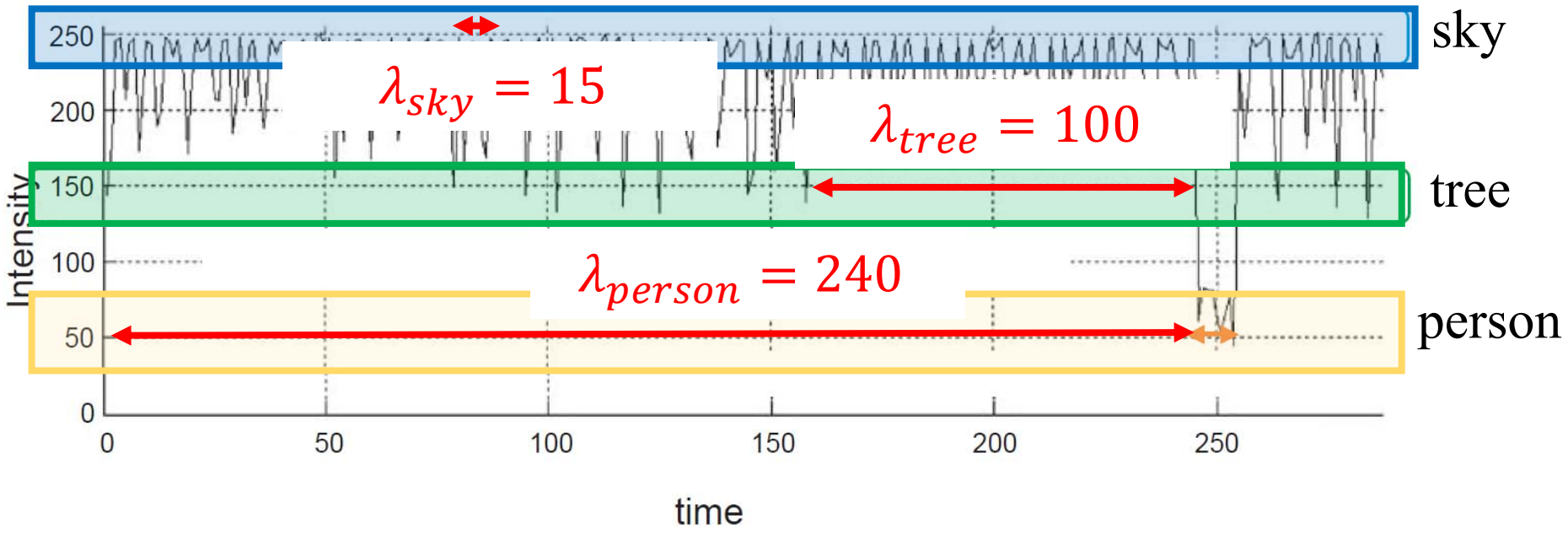
$$x_3 = (0,5,2)$$

$$\mathbf{v}_m =< \frac{1 \times 1 + 0}{1+1}, \frac{1 \times 7 + 5}{1+1}, \frac{1 \times 0 + 2}{1+1} >$$

$$\mathbf{aux_m} =< \check{I}_m = \min(7,5) = 5, \hat{I}_m = \max(7,5) = 7, f_m = 1 + 1, \lambda_m = \max(1,3) = 3, p_m = 2, q_m = 2 >$$

Codebook Construction

- Background Codeword Selection
  - Objective: select codewords representing the static or dynamic background points.



Codebook Construction

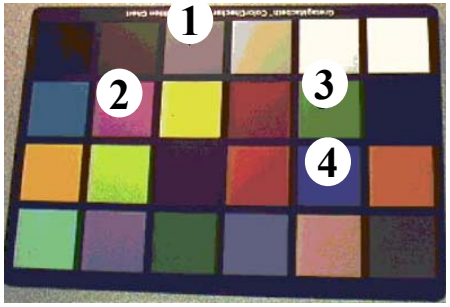
- Background Codeword Selection
  - Observation: true background is quasi-periodic, that is, values recur in a bounded period
  - Rule: take the codewords with small λ

$$B = \{c_m | \lambda_m \leq T\}$$

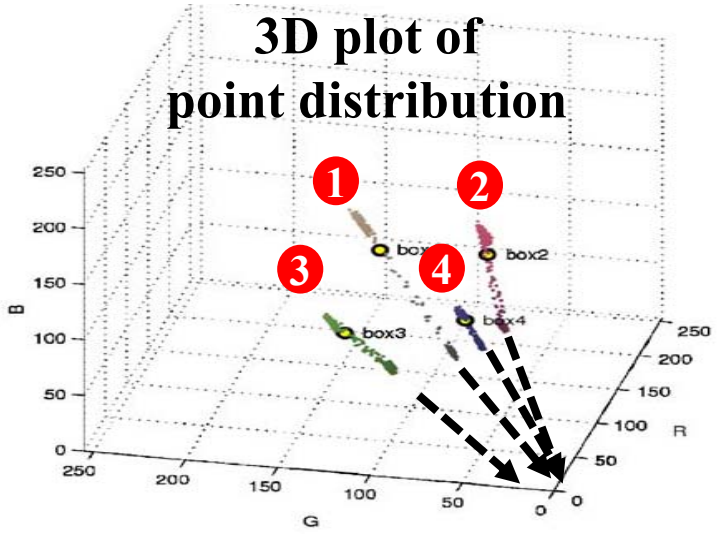
    - T: a threshold value (half the number of training frames $N/2$)

Subtraction Process

- Color Model of a Codeword
  - The shape of point intensity distribution has two attributes.
    - elongated
    - toward the origin (0,0,0)



color chart image

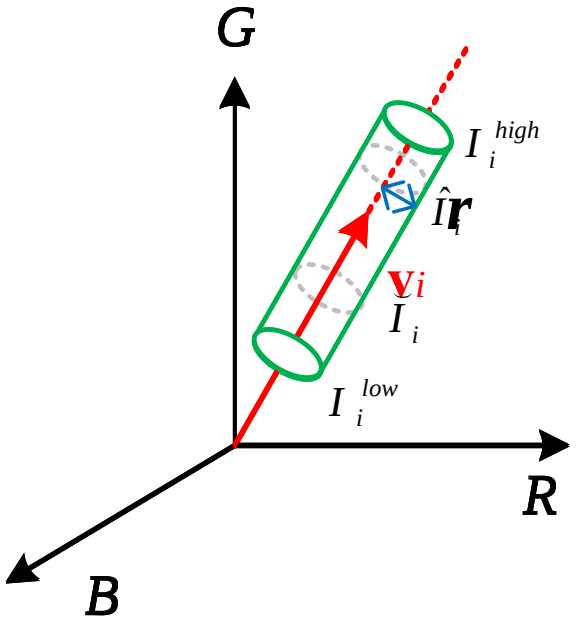


Subtraction Process

- Color Model of a Codeword
  - The color model defined by $c_i = (\mathbf{v}_i, \mathbf{aux}_i)$ is a cylinder.
    - $\mathbf{v}_i$: major axis of cylinder
    - γ: cylinder radius (constant)
    - $[I_i^{low}, I_i^{high}]$: top/bottom bases

$$I_i^{low} = \alpha \hat{I}_i \quad [0.4, 0.7]$$

$$I_i^{high} = \min(\beta \hat{I}_i, \frac{\check{I}_i}{\alpha}) \quad [1.1, 1.5]$$

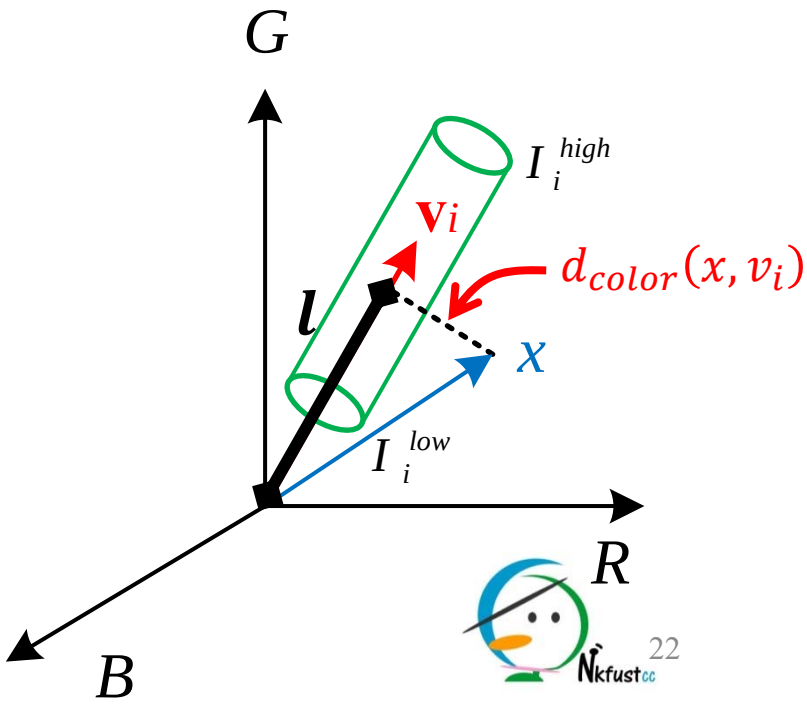


Subtraction Process

- Match Definition $M(x, c_i)$
  - $M(x, c_i)$=1 : x is in the c_i-defined cylinder.
    - $d_{color}(x, \mathbf{v}_i) \leq \gamma$ and
    - $I_i^{low} \leq ||x|| \leq I_i^{high}$

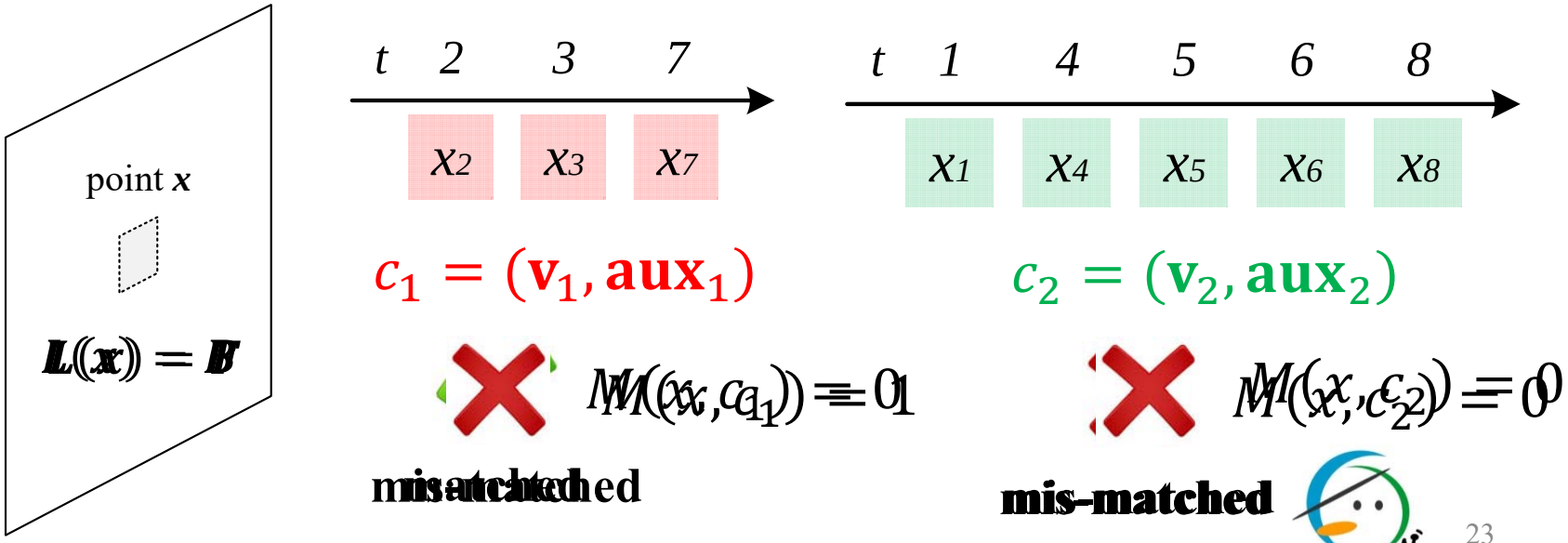
$$d_{color}(x, v_i) = \sqrt{||x||^2 - l^2}$$

$$l^2 = \frac{< x, \mathbf{v}_i >^2}{||\mathbf{v}_i||^2}$$



Subtraction Process

- Point Labelling ($L(x)$)
  - $L(x) = B$: at least one codeword is matched.
  - $L(x) = F$: none of codewords are matched




thank you
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