E9:261

26-02-2016

Recap …

- GMMs and EM algorithm
  - Relationship between neighboring samples is not considered.
- Time alignment and normalization
  - Dynamic Programming algorithms
    - recursive solution

Dynamic Programming

1. Initialization

$$\varphi_1(i,n) = \zeta(i,n)$$
$$\xi_1(n) = i$$
$$\text{for } n = 1, 2, \ldots, N.$$

2. Recursion

$$\varphi_{m+1}(i,n) = \min_{1 \le \ell \le N} [\varphi_m(i,\ell) + \zeta(\ell,n)]$$
$$\xi_{m+1}(n) = \arg\min_{1 \le \ell \le N} [\varphi_m(i,\ell) + \zeta(\ell,n)]$$
$$\text{for } n = 1, 2, \ldots, N \text{ and } m = 1, 2, \ldots, M-2$$

3. Termination

$$\varphi_M(i,j) = \min_{1 \le \ell \le N} [\varphi_{M-1}(i,\ell) + \zeta(\ell,j)]$$
$$\xi_M(j) = \arg\min_{1 \le \ell \le N} [\varphi_{M-1}(i,\ell) + \zeta(\ell,j)]$$

4. Path Backtracking

$$\text{optimal path} = (i, i_1, i_2, \ldots, i_{M-1}, j),$$

where

$$i_m = \xi_{m+1}(i_{m+1}), \qquad m = M-1, M-2, \ldots, 1$$

with $i_M = j$.

"Fundamentals of Speech Recognition", Rabiner and Juang

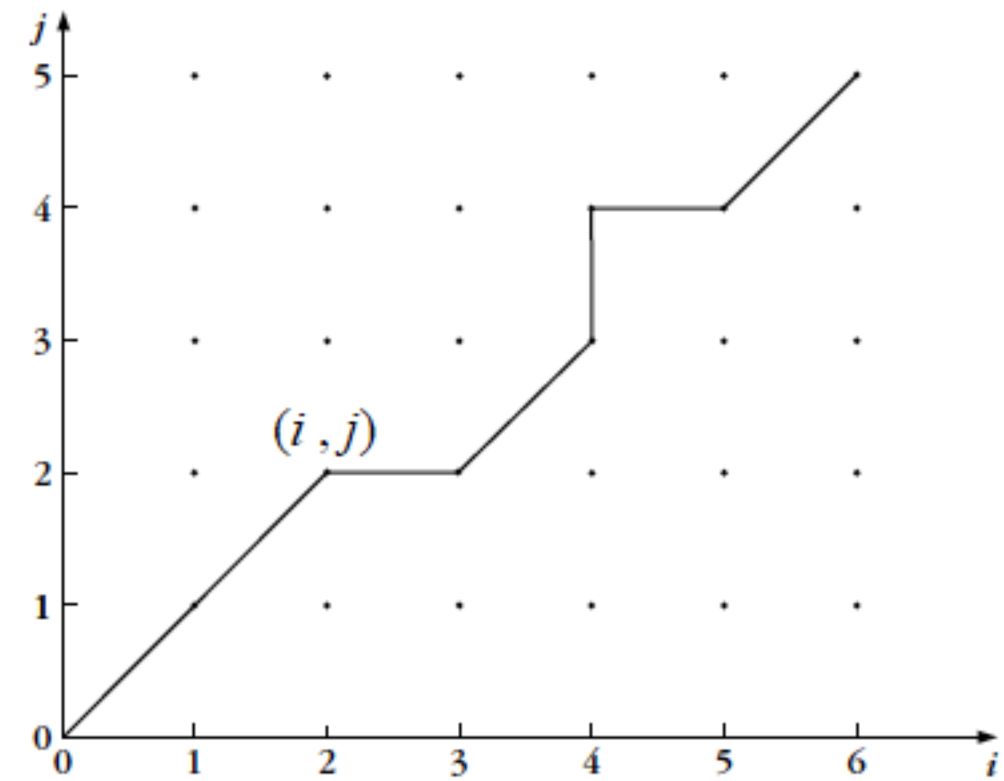
Dynamic Programming

- For an optimal path passing through $(i\ ,\ j)$:

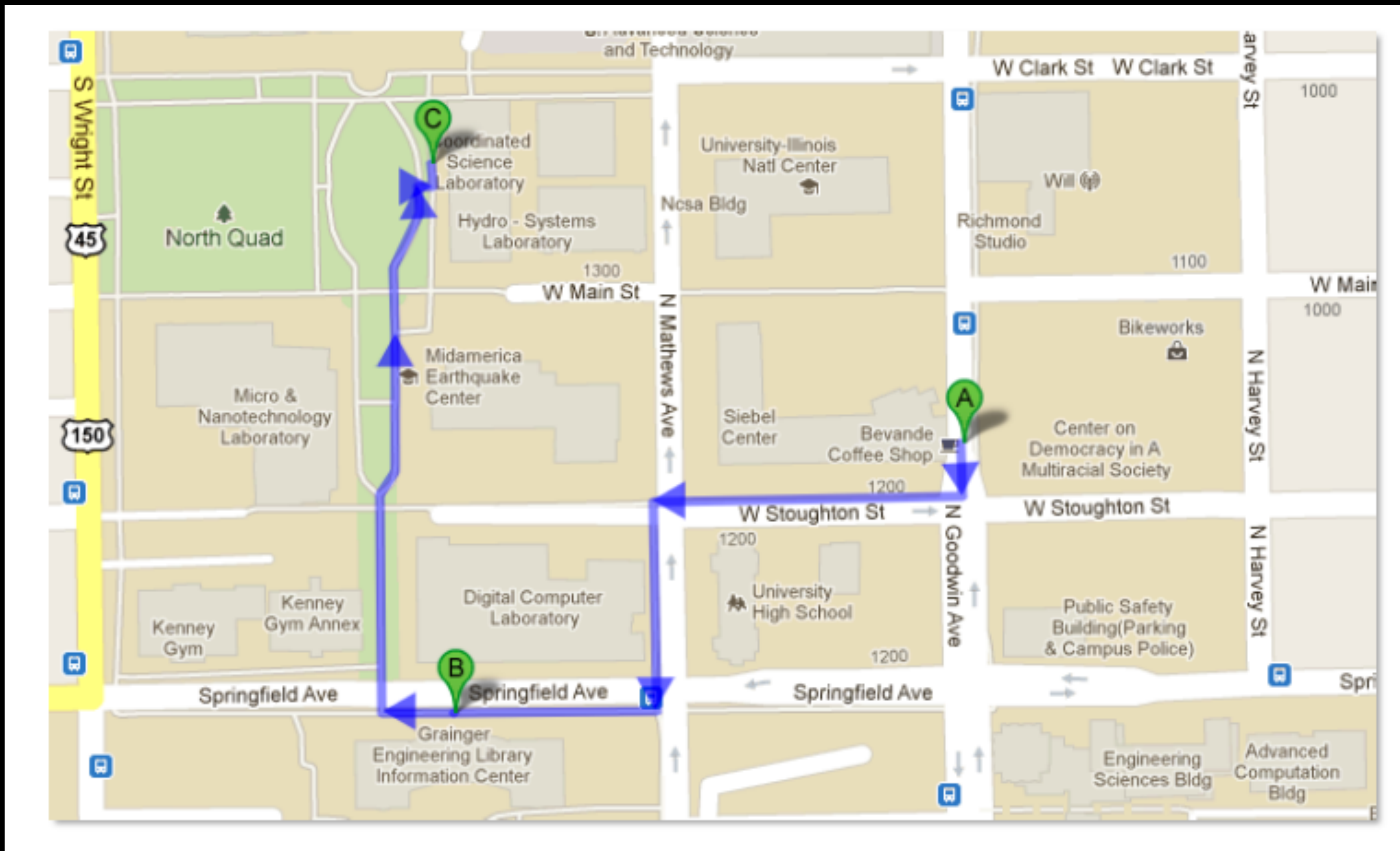
$$(i_0, j_0) \overset{opt}{\longrightarrow} (i_f, j_f)$$

- Then:

$$(i_0, j_0) \overset{opt}{\longrightarrow} (i_f, j_f) = \left\{ (i_0, j_0) \overset{opt}{\longrightarrow} (i, j), (i, j) \overset{opt}{\longrightarrow} (i_f, j_f) \right\}$$



Dynamic Programming in Real Life



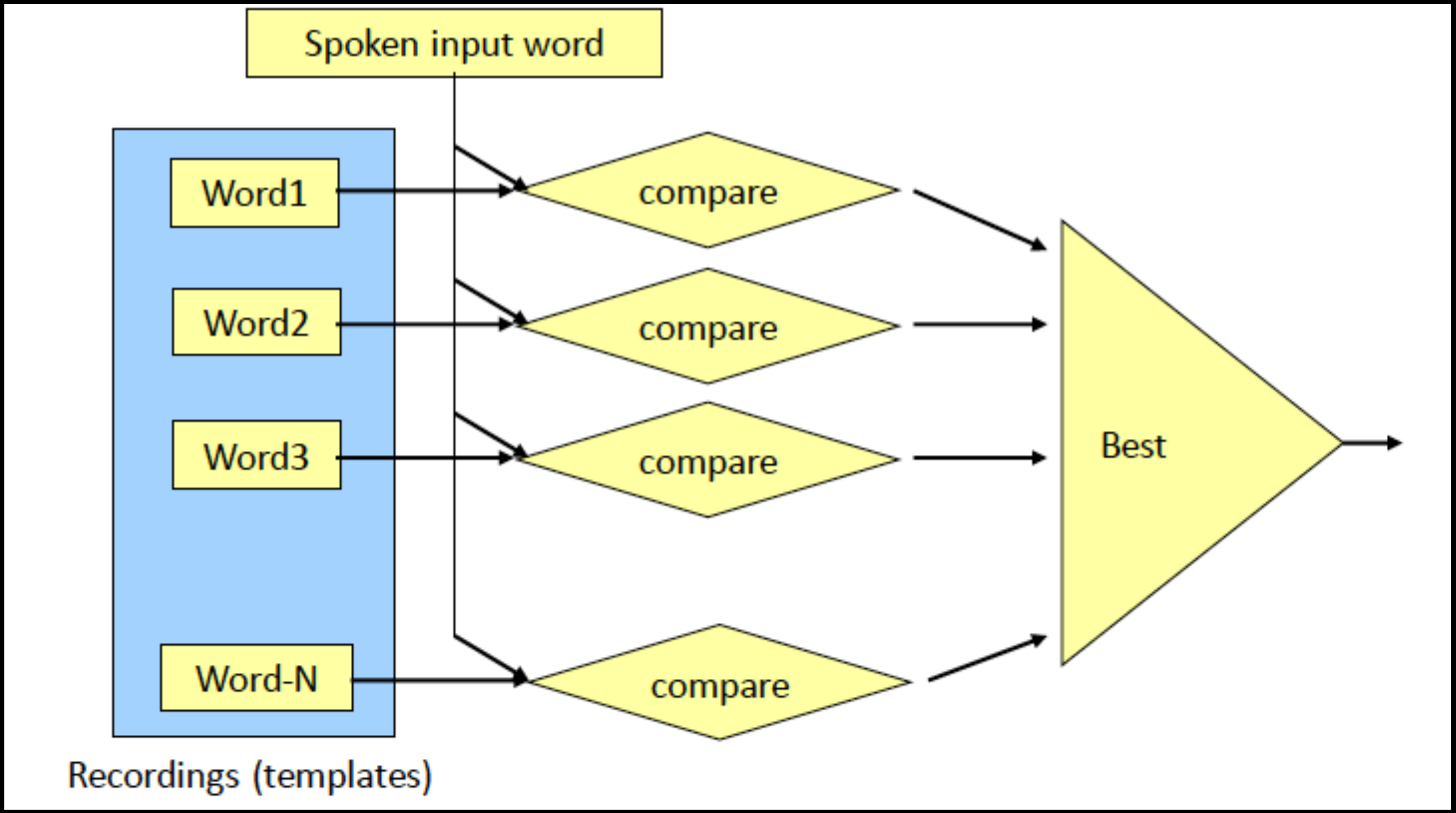
"Learning Time Series", UIUC Lecture Series

Template Matching

- Store "templates" for all words to be recognized
  - Template = example recording
    - Actually feature sequence from example recording
- Compute distance of input test data to all templates, select the closest

"Design and Implementation of Speech Recognition", CMU, Spring 2013

Template Matching



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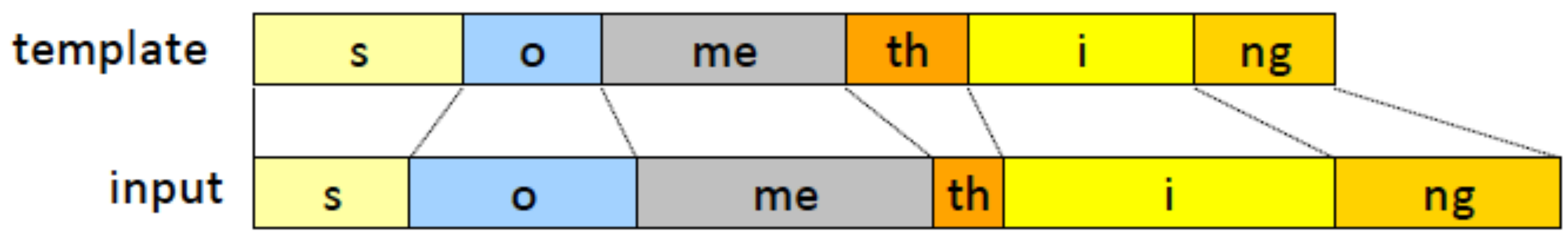
Template Matching

- Problem: Input and template may be different lengths



- Worse – the change in length may not be uniform

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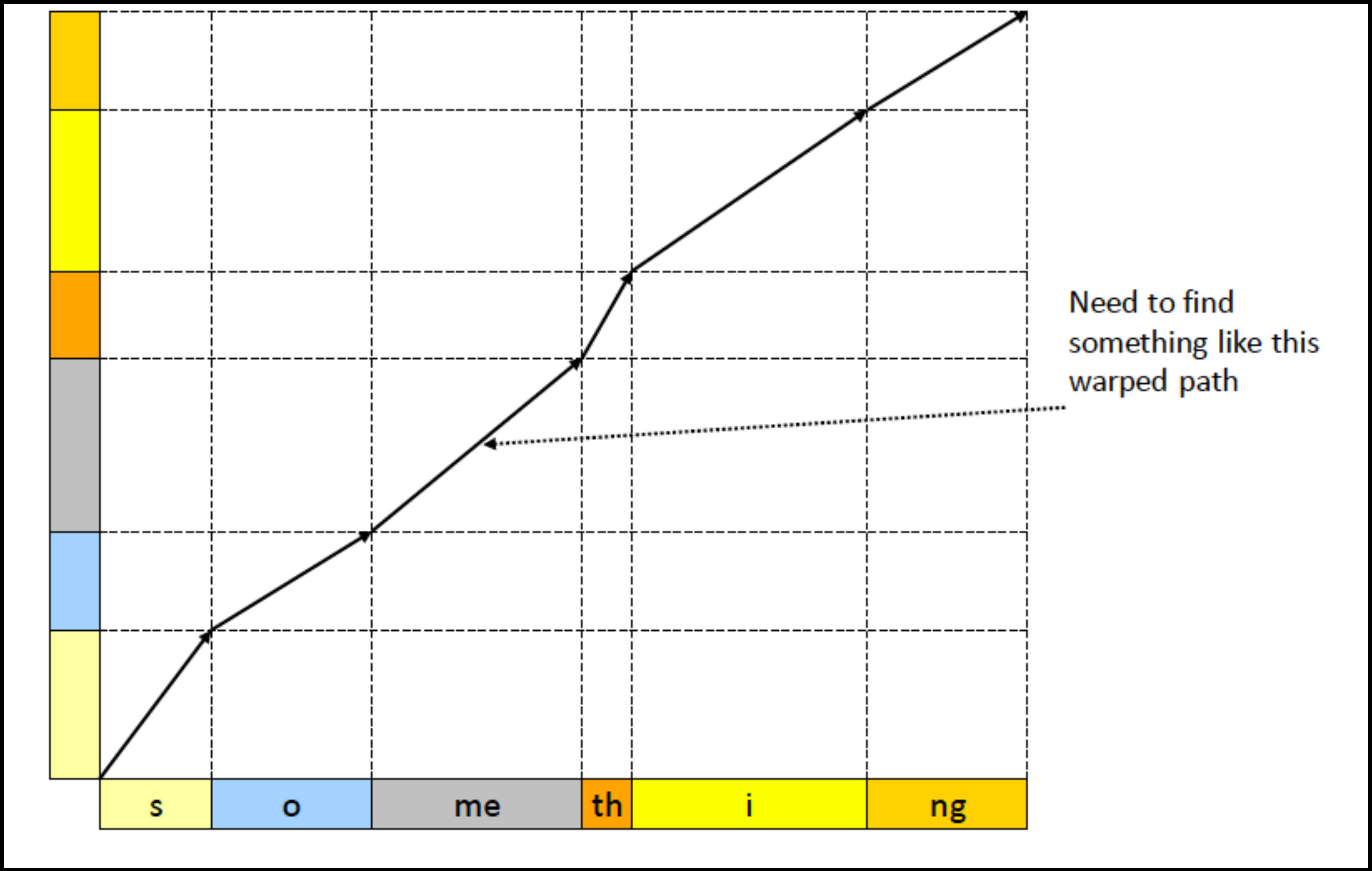
Template Matching



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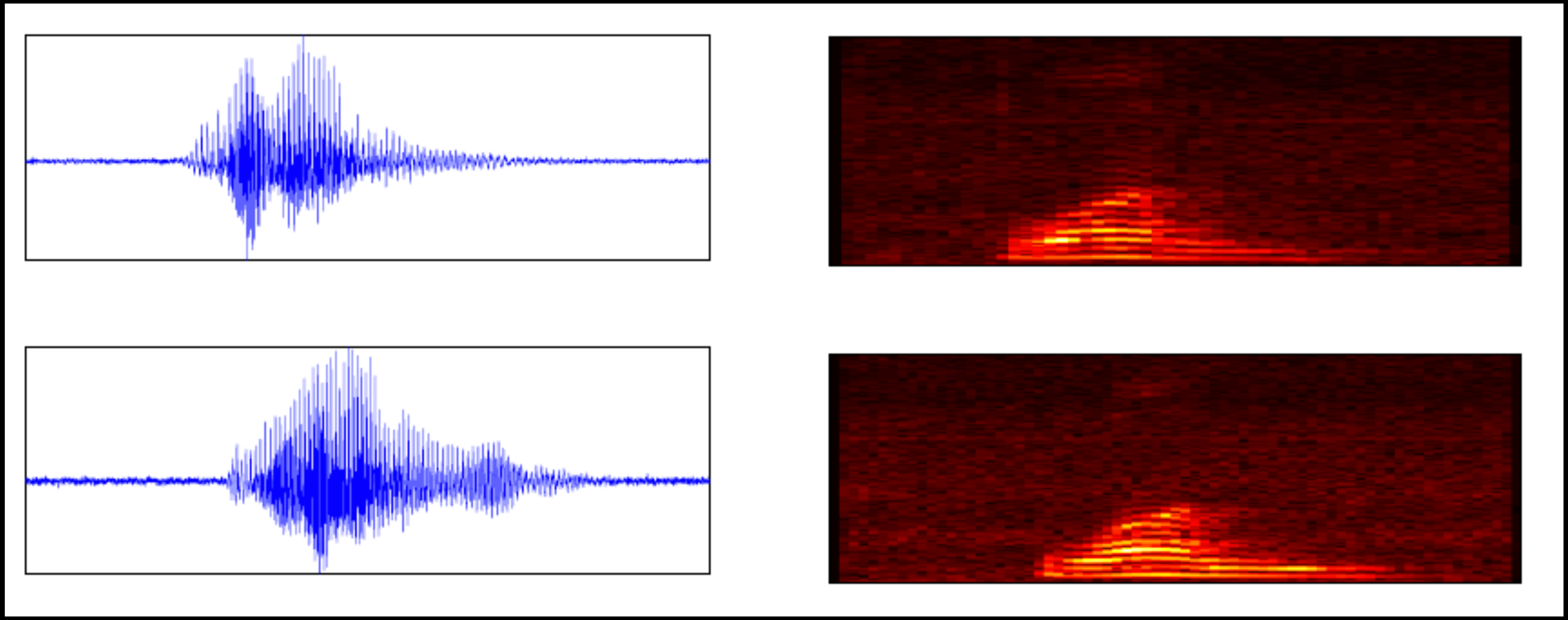
Template Matching



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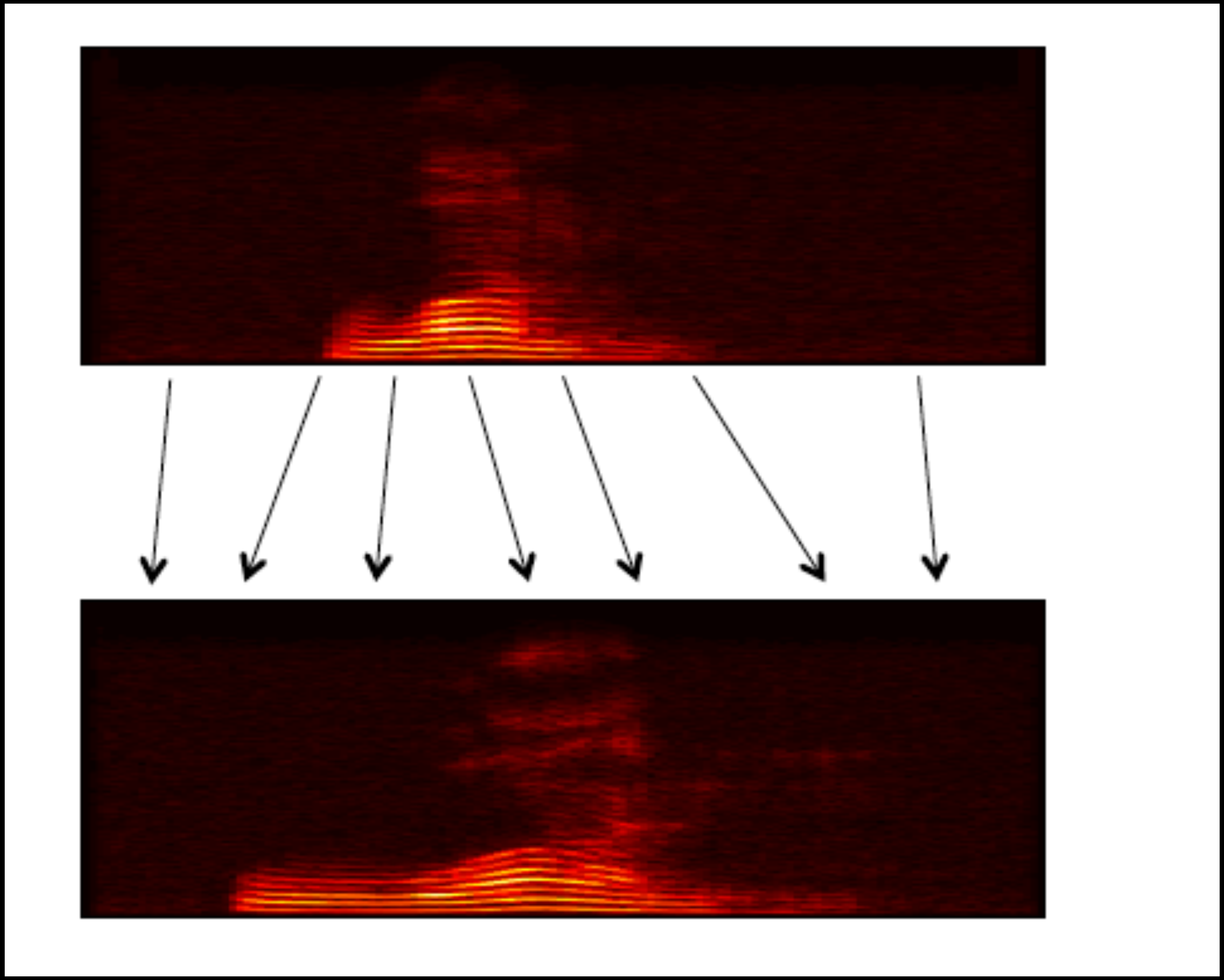
Template Matching



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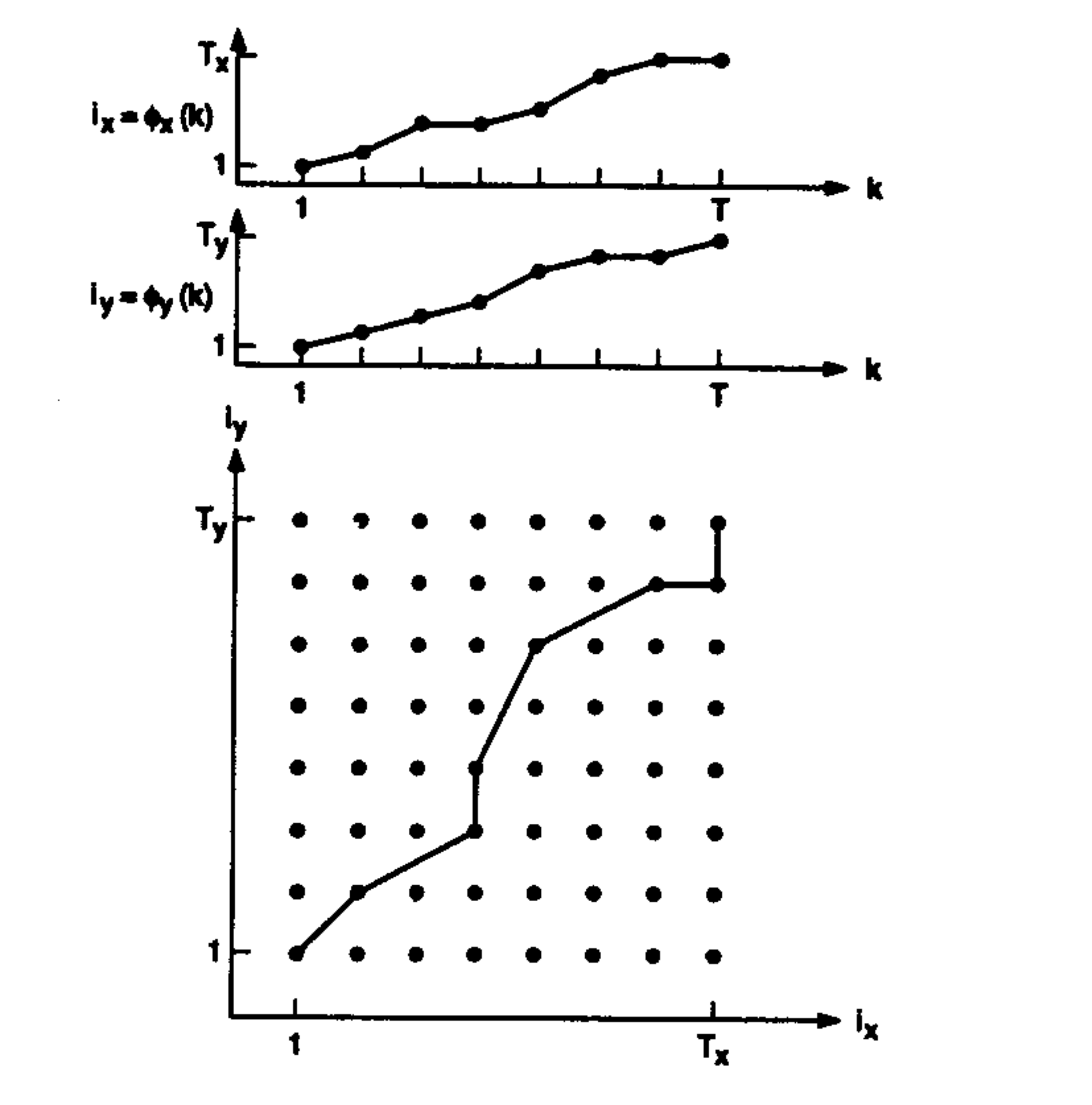
DTW



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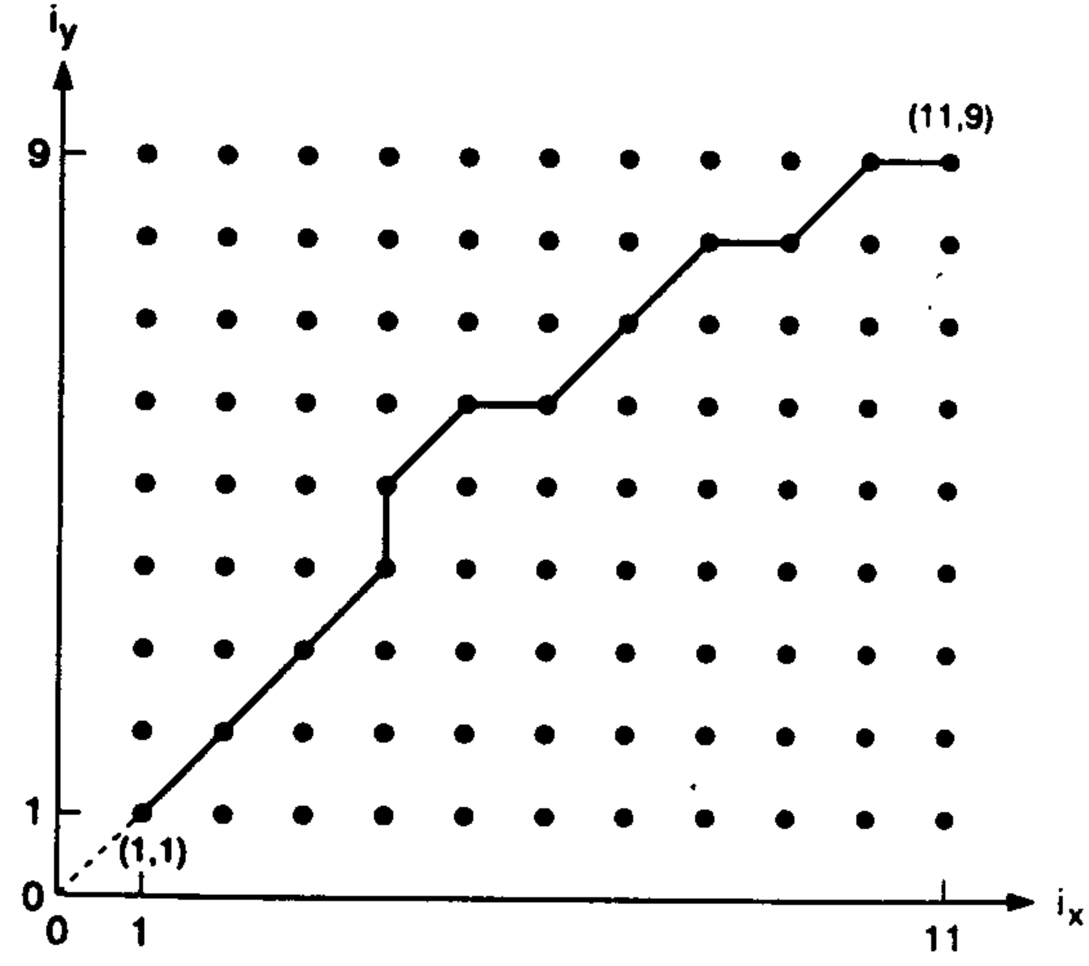
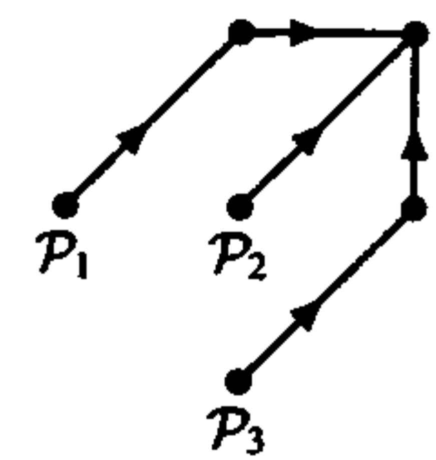
DTW





$$\mathcal{P}_1 \rightarrow (1,1)(1,0)$$
$$\mathcal{P}_2 \rightarrow (1,1)$$
$$\mathcal{P}_3 \rightarrow (1,1)(0,1)$$

$$\mathcal{P} \rightarrow \mathcal{P}_2\ \mathcal{P}_2\ \mathcal{P}_2\ \mathcal{P}_3\ \mathcal{P}_1\ \mathcal{P}_2\ \mathcal{P}_1\ \mathcal{P}_1.$$

“Fundamentals of Speech Recognition”, Rabiner and Juang

Disadvantages of DTW

- **Based on heuristics**
- **Creating templates from large number of examples can be hard.**
- **With large vocabulary sizes, computationally intractable.**
- **Not a statistical method.**

EARLY VOICE RECOGNITION