2. Isolated word speech recognition & HMMS

Task: Recognition of isolated spoken words from a given vocabulary

Problems:

- variable speed
- speaker independence
- prosody etc.

How do we (mammals) hear?

→ tympanic membrane → ossicles →

→ cochlea:

basilar membrane (scala media)

inner & outer hair cells

→ auditory cortex

A. Signal pre-processing

- Sample the pressure-time function $f(t)$, digitise

  highest frequency in speech signal < 10 KHz

  → Nyquist theorem → sample with 20 KHz

- Frequency analysis: apply digital Fourier transform with sliding window

$$c(\omega, t) = \int_{-\infty}^{\infty} W(t-t') f(t') e^{i\omega t'} dt'$$

simplest window function $W(t) = \begin{cases} 1 & \text{if } |t| \leq b \\ 0 & \text{otherwise} \end{cases}$

width b: lowest freq. vs. time resolution

- Energy in spectra (logarithmic, dB)

$$s(\omega, t) = 20 \cdot \log_{10} \sqrt{\mathrm{Re}^2 c(\omega,t) + \mathrm{Im}^2 c(\omega,t)}$$

discretise domain of ω into ~ 20 frequency channels with freq. dependent width

- possibly cluster spectral vectors

  pro: small number of feature vectors

  con: dominance of stationary parts

B. Dynamic time warping & word recognition

$$\text{feature sequence} \longrightarrow \boxed{\text{Algorithm}} \longrightarrow \text{word (class)}$$

$$\uparrow$$

$$\boxed{\text{Model}}\ ?$$

Model: a set of prototypes (i.e. feature sequences) for each word (i.e. class)

Algorithm: nearest neighbour classifier

We need a distance measure for sequences of feature vectors

prototype $x = (\vec{x}_1, \vec{x}_2, \dots, \vec{x}_n)$, signal $y = (\vec{y}_1, \vec{y}_2, \dots, \vec{y}_m)$

$\vec{x}_i, \vec{y}_i \in \mathbb{R}^{20}$. Distance $D(x,y) = ?$

Monotonous matching (aka time warping)

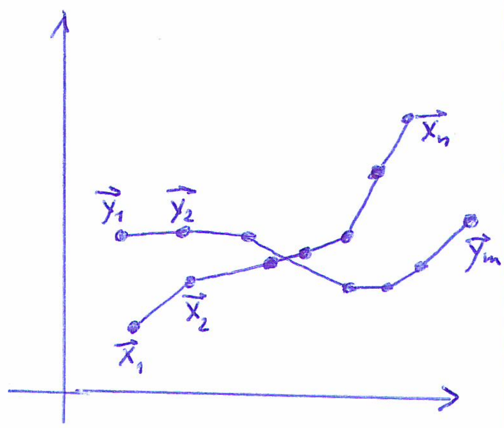
$\tau = ((i_1,j_1), (i_2,j_2), \dots, (i_e,j_e))$

$\tau \in \mathcal{T}$ if

(1) $(i_1,j_1) = (1,1)$, $(i_e,j_e) = (n,m)$

(2) $i_{k-1} \leq i_k \leq i_{k-1}+1$

and similar for j



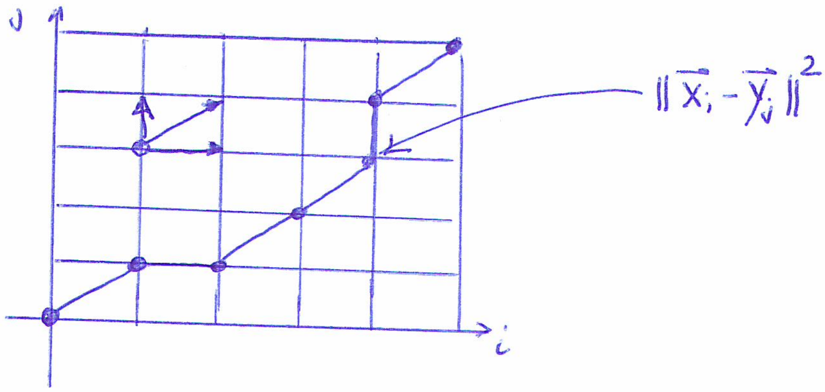
distance for a fixed matching $\tau \in \mathcal{T}$

$$D(x, y; \tau) = \sum_{k=1}^{|\tau|} \| \vec{x}_{i_k} - \vec{y}_{j_k} \|^2$$

distance

$$\boxed{D(x, y) = \min_{\tau \in \mathcal{T}} D(x, y; \tau)}$$

How to compute it efficiently?



i.e. shortest path, here by dynamic programming, complexity $O(nm)$

Discussion model & algorithm

- inference has high time complexity $O(n^2 p)$, where p – total number of prototypes
- learning: how to choose optimal prototypes?

Better: model each word (class) by an HMM

$x = (\vec{x}_1, \vec{x}_2, \dots, \vec{x}_n)$ – sequence of features

$s = (s_1, \dots, s_n)$ – sequence of hidden states (e.g. phonemes)

$$p(x, s) = p(s_1) \prod_{i=2}^{n} p(s_i | s_{i-1}) \prod_{i=1}^{n} p(\vec{x}_i | s_i)$$

- fast inference (linear in n)
- feasible learning of model parameters