TTIC 31230, Fundamentals of Deep Learning

David McAllester, Winter 2019

Connectionist Temporal Classification (CTC)

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A Successful Deep Latent Variable Model

Connectionist Temporal Classification: Labelling Unsegmented Sequence Data with Recurrent Neural Networks

Alex Graves, Santiago Fernandez, Faustino Gomez, Jurgen Schmidhuber, ICML 2006

CTC

A speech signal $x[T, J]$ is labeled with a phone sequence $y[N]$ with $N << T$.

$x[t, J]$ is a speech signal vector.

$y[n] \in \mathcal{P}$ for a set of phonemes $\mathcal{P}$. 音位

The length N of $y[N]$ is not determined by T and the correspondence between n and t is not given.

$$\Phi^* = \operatorname*{argmin}_{\Phi} \; E_{\langle x, y \rangle \sim \mathrm{Train}} \; P_\Phi(y[N] \mid x[T, J]) \quad N << T$$

The CTC Model

Run a RNN to calc

We define a model

$$\underbrace{P_\Phi(z[T] \mid x[T,J])}$$

phone or blank

$$\underbrace{z[t] \in \mathcal{P} \cup \{\perp\}}$$

$y[N]$ is the result of removing $\perp$ from $z[T]$.

$$z[T] \Rightarrow y[N]$$

$$\perp, a_1, \perp, \perp, \perp, a_2, \perp, \perp, a_3, \perp \Rightarrow a_1, a_2, a_3$$

The CTC Model

For $p \in \mathcal{P} \cup \{\perp\}$ we have an embedding vector $e[p, I]$. The embedding is a parameter of the model.

We take the phonemes $z[t]$ to be independently distributed.

$$p_\Phi(Z[T] \mid x[T, J]) = \prod_t P_\Phi(z[t] \mid x[T, J])$$

$$h[T, \tilde{J}] = \mathrm{RNN}_\Phi(x[T, J])$$

$$\underline{P_\Phi(z[t] \mid x[T, J])} = \operatorname*{softmax}_{z[t]} e[z[t], I]\, W[I, \tilde{J}]\, h[t, \tilde{J}]$$

each z is independent

?

?

Dynamic Programming

Let $\vec{y}[t]$ to be the prefix of $y[N]$ emitted by the first t elements of z.

n : index of phone

sequence of phone

t : index of time

$$\vec{y}[t] = z[1:t] - \perp$$

$$F[n,t] = P(\vec{y}[t] = y[1:n])$$

=> probability at time t you output first n phones of gold

$F[0,0] = 1$
For $n = 1, \ldots, N$ $F[n,0] = 0$
For $t = 1, \ldots, T$
  $F[0,t] = P(z[t] = \perp)F[0,t-1]$
  For $n = 1, \ldots, N$

z[t] is independent

$$F[n,t] = P(z[t] = \perp)F[n,t-1] + P(z[t] = y[n])F[n-1,t-1]$$

goal: at time t
I have y[1:n]

Back-Propagation

$$\mathcal{L} = -\ln F[N, T]$$

We can now back-propagate through this computation.

END