Connectionist Temporal Classification with Maximum Entropy Regularization

Hu Liu   Sheng Jin   Changshui Zhang

Department of Automation
Tsinghua University

NeurIPS, 2018

P('dog'| ) = P (dd_oo___g, doo____gg, _____dogg, ⋮, dddoooggg | )

The most suitable path

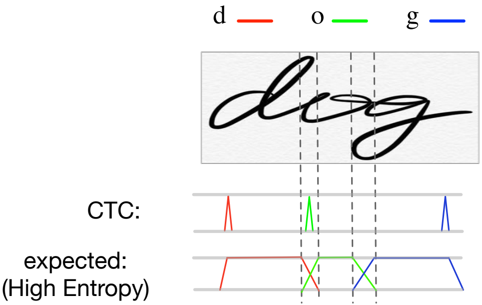
$$\frac{\partial L_{ctc}}{\partial y_k^t} = -\frac{1}{p(l|X)y_k^t} \sum_{\{\pi|\pi \in B^{-1}(l), \pi_t = k\}} p(\pi|X)$$

error signal
positive feedback

CTC Drawbacks:

- CTC lacks exploration and is prone to fall into worse local minima.
- Output overconfident paths (overfitting).
- Output paths with peaky distribution.

Maximum Conditional Entropy Regularization for CTC (EnCTC)



$$L_{enctc} = L_{ctc} - \boxed{\beta H(p(\pi|l, X))}$$ Entropy-based regularization

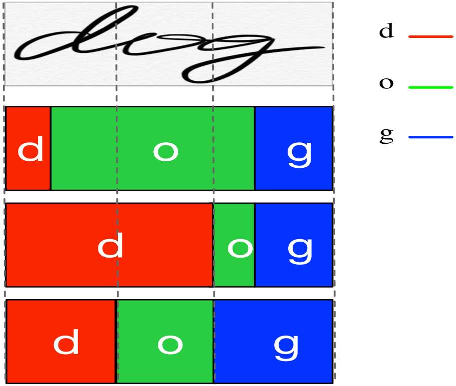
$$H(p(\pi|l, X)) = - \sum_{\pi \in B^{-1}(l)} p(\pi|X, l) \log p(\pi|X, l).$$

EnCTC:

- Better generalization and exploration.
- Solve peaky distribution problem.
- Depict ambiguous segmentation boundaries.

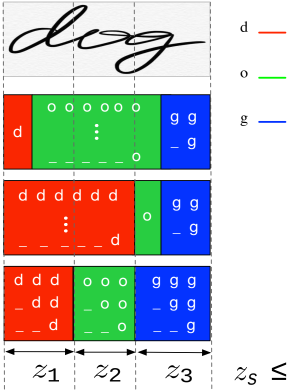
Equal Spacing CTC (EsCTC)

- The spacing of two consecutive elements is nearly the same in many sequential tasks.



- We adopt equal spacing as a pruning method to rule out unreasonable CTC paths.

Equal Spacing CTC (EsCTC)



$$z_s \leq \tau \frac{T}{|l|}$$

Theorem 3.1. *Among all segmentation sequences, the equal spacing one has the maximum entropy.*

$$\operatorname*{argmax}_{z} \max_{p} H(p(\pi|z,l,X)) = z_{es}$$

Equal spacing is the best prior without any subjective assumptions.

$$L_{esctc} = -\log \sum_{z \in C_{\tau,T}} \sum_{\pi \in B_z^{-1}(l)} p(\pi|X)$$

Algorithm and Complexity Analysis

We propose dynamic programming algorithms for EnCTC, EsCTC, and EnEsCTC.

EnCTC

$$\bar{\gamma}(t,s) = \begin{cases} \gamma(t-1,s)+\gamma(t-1,s-1) & \text{if } l_s = b \text{ or } l_{s-2} = l_s \\ \gamma(t-1,s)+\gamma(t-1,s-1)+\gamma(t-1,s-2) & \text{otherwise} \end{cases}$$

$$Q(l) = \gamma(T,|l'|)+\gamma(T,|l'|-1)$$

EsCTC

$$\alpha_\tau(t,s) = \begin{cases} \sum_{t'=1}^{\tau\frac{T}{|l|}} \alpha_\tau(t-t\,,s-1)\sigma(t-t\;+1,t,s) & \text{if } l_{s-1} \neq l_s \\ \sum_{t'=2}^{\tau\frac{T}{|l|}} \alpha_\tau(t-t\,,s-1) y_b^{t-t'+1}\sigma(t-t\;+2,t,s) & \text{otherwise} \end{cases}$$

$$p_\tau(l|X_{1:T}) = \alpha_\tau(T,|l|)+\sum_{t'=1}^{\tau\frac{T}{|l|}} \alpha_\tau(T-t',|l|)\sigma(T-t'+1,T,0)$$

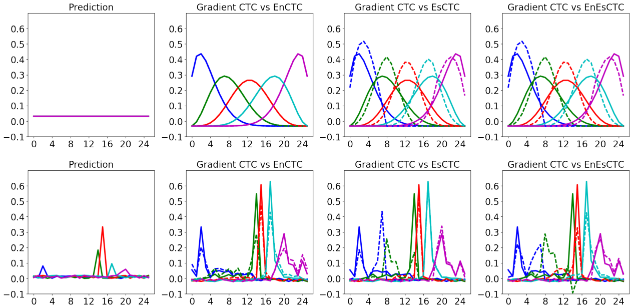
EnEsCTC

$$\gamma_\tau(t,s) = \begin{cases} \sum_{t'=1}^{\tau\frac{T}{|l|}} \quad \gamma_\tau(t-t\,,s-1)\sigma(t-t\;+1,t,s)+\alpha_\tau(t-t\,,s-1)\eta(t-t\;+1,t,s) \\ \quad \text{if } l_{s-1} \neq l_s \\ \sum_{t'=2}^{\tau\frac{T}{|l|}} \quad \gamma_\tau(t-t\,,s-1)y_b^{t-t'+1}\sigma(t-t\;+2,t,s)+ \\ \quad \alpha_\tau(t-t\,,s-1)y_b^{t-t'+1}\eta(t-t\;+2,t,s)+ \\ \quad \alpha_\tau(t-t\,,s-1)y_b^{t-t'+1}\log y_b^{t-t'+1}\sigma(t-t\;+2,t,s) \\ \quad \text{otherwise} \end{cases}$$

$$Q_\tau(l) = \gamma_\tau(T,|l|)+\sum_{t'=1}^{\tau\frac{T}{|l|}} \gamma_\tau(T-t',|l|)\sigma(T-t'+1,T,0) + \alpha_\tau(T-t',|l|)\sigma(T-t'+1,T,0)\log\sigma(T-t'+1,T,0)$$

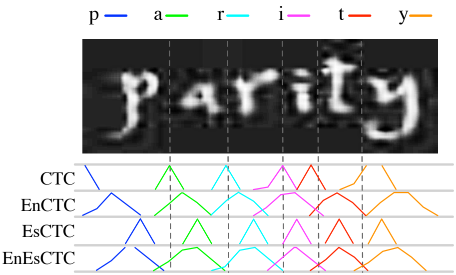
Complexity	CTC	EnCTC	EsCTC	EnEsCTC
Time	$O(T)$	$O(T)$	$O(\frac{T^2}{\lvert l\rvert}) \backsim O(T^2)$	$O(\frac{T^2}{\lvert l\rvert}) \backsim O(T^2)$
Space	$O(T\lvert l\rvert)$	$O(T\lvert l\rvert)$	$O(T^2\lvert l\rvert)$	$O(T^2\lvert l\rvert)$

Qualitative Analysis



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

Error Signal in Training



Alignment Evaluation

Results on Scene Text Recognition Benchmarks

Evaluation of model generalization.

Method	Synth5K
CTC	38.1
CTC + LS	42.9
CTC + CP	44.4
EnCTC	45.5
EsCTC	46.3
EnEsCTC	**47.2**

Comparisons with the state-of-the-art methods.

Method	IC03	IC13	IIIT5K	SVT
CRNN	89.4	86.7	78.2	80.8
STAR-Net	89.9	89.1	**83.3**	**83.6**
R2AM	88.7	90.0	78.4	80.7
RARE	90.1	88.6	81.9	81.9
EnCTC	90.8	90.0	82.6	81.5
EsCTC	**92.6**	87.4	81.7	81.5
EnEsCTC	92.0	**90.6**	82.0	80.6

For more results and analyses, please come

Poster: Room 210 & 230 AB #106

https://github.com/liuhu-bigeye/enctc.crnn