



# Tree Distribution Approximators

## 1 Why

We approximate a distribution with a distribution that factors according to a given tree. Such a distribution requires tabulating fewer numbers to express the probability of outcome.

## 2 Definition

We will use the relative entropy as a criterion of approximation. Given a distribution over a product of finite sets and a tree, we want to find the optimal approximator among distributions which factor according to the tree. We call such a distribution a *tree distribution approximator* or *tree approximator* of the given distribution for the tree. We call the tree the *approximator tree*.

## 3 Result

**Proposition 1.** *Let  $A_1, \dots, A_n$  be finite non-empty sets. Define  $A = \prod_{i=1}^n A_i$ . Let  $q : A \rightarrow [0, 1]$  a distribution and  $T$  a tree on  $\{1, \dots, n\}$ . The distribution  $p_T^* : A \rightarrow [0, 1]$  defined by*

$$p_T^* = q_1 \prod_{i \neq 1} q_{i|\mathbf{pa}_i}$$

*minimizes the relative entropy with  $q$  among all distributions on  $A$  which factor according to  $T$ .*

*Proof.* Let  $p : A \rightarrow [0, 1]$  be a distribution which factors according to  $T$ . First, express

$$p = p_1 \prod_{i \neq 1} p_{i|\mathbf{pa}_i}$$

where  $\mathbf{pa}_i$  is the parent of vertex  $i$  in  $T$  rooted at vertex 1 ( $i = 2, \dots, n$ ).

Second, recall that the relative entropy of  $q$  with  $p$  is  $H(q, p) - H(q)$ . Since  $H(q)$  does not depend on  $p$ ,  $p$  is a minimizer of the relative of  $q$  with  $p$  if and only if  $p$  is a minimizer of  $H(q, p)$ .

Third, express

$$\begin{aligned} H(q, p) &= - \sum_{a \in A} q(a) \log p(a) \\ &= - \sum_{a \in A} q(a) \left( \log p_1(a_1) + \sum_{i \neq 1} \log p_{i|\mathbf{pa}_i}(a_i, a_{\mathbf{pa}_i}) \right) \\ &= H(q_1, p_1) + \sum_{i \neq 1} \sum_{a_{\mathbf{pa}_i} \in A_{\mathbf{pa}_i}} q_{\mathbf{pa}_i}(a_{\mathbf{pa}_i}) H(q_{i|\mathbf{pa}_i}(\cdot, a_{\mathbf{pa}_i}), p_{i|\mathbf{pa}_i}(\cdot, a_{\mathbf{pa}_i})) \end{aligned}$$

which separates across  $p_1$  and  $p_{i|\mathbf{pa}_i}(\cdot, a_{\mathbf{pa}_i})$  for  $i = 2, \dots, n$  and  $a_{\mathbf{pa}_i} \in A_{\mathbf{pa}_i}$ .

Fourth, recall  $H(\cdot, \cdot) \geq 0$  and is zero on repeated pairs. By this, we mean, for example,  $H(p_1, p_1) = 0$ . So  $p_1 = q_1$  and  $p_{i|\mathbf{pa}_i} = q_{i|\mathbf{pa}_i}$  are solutions.

□

Proposition 1 states the form of an optimal approximator given a tree. A natural next question is to select the tree.