Reasoning With Neural Tensor Networks for Knowledge Base Completion

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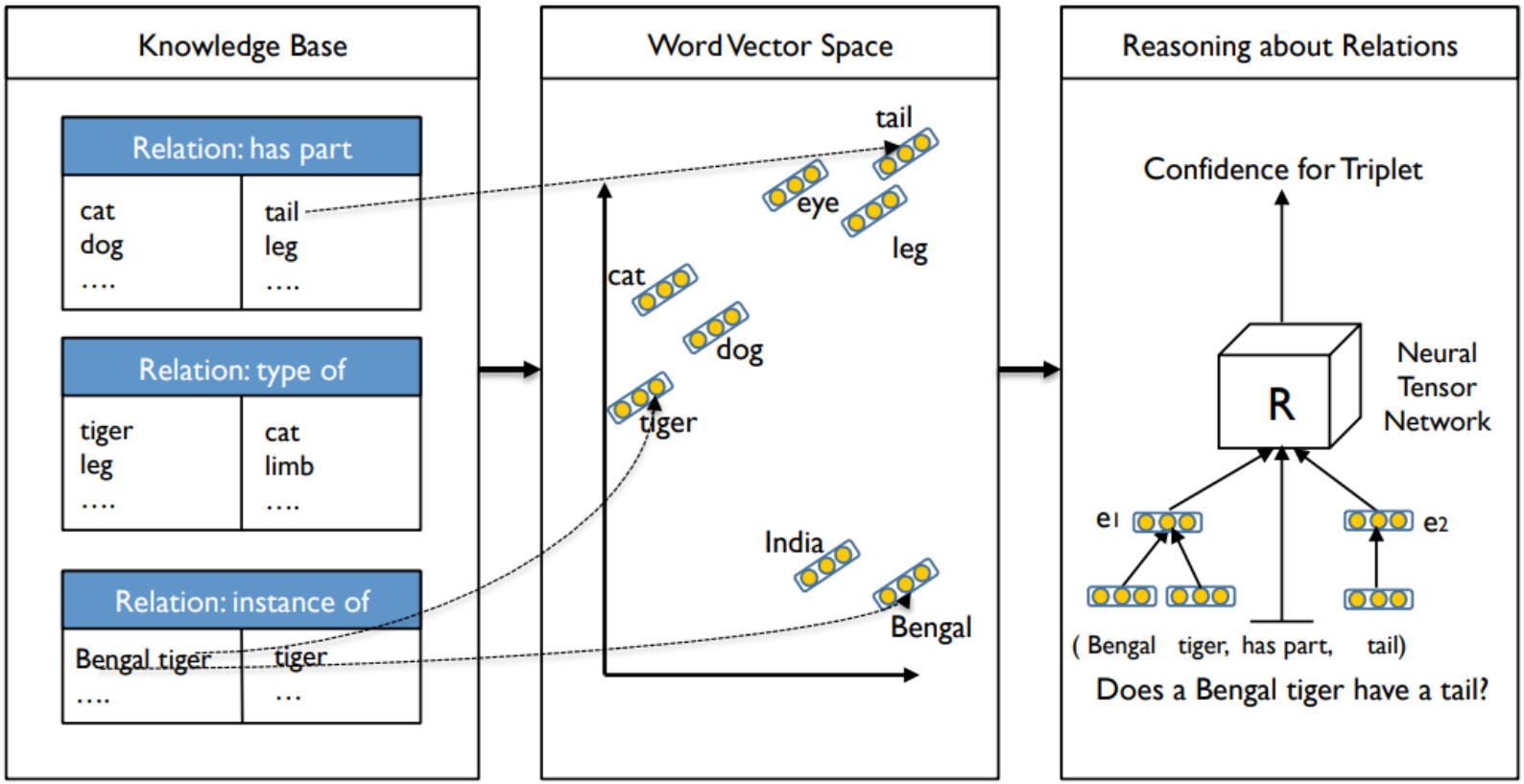
Knowledge bases

- incompleteness
- lack of ability to reason over discrete entities and relationships

Main ideas

- Neural Tensor Network
- entities = average of their constituting word vectors
- use vectors learned from unsupervised large corpora for initialization

Reasoning example



Goal

- e_1, e_2 — entities
- R — certain relationship
- is relationship (e_1, R, e_2) true, and with what certainty?
- example: $(e_1, R, e_2) = (\text{Bengal tiger}, \text{has part}, \text{tail})$

Neural Tensor Network (NTN)

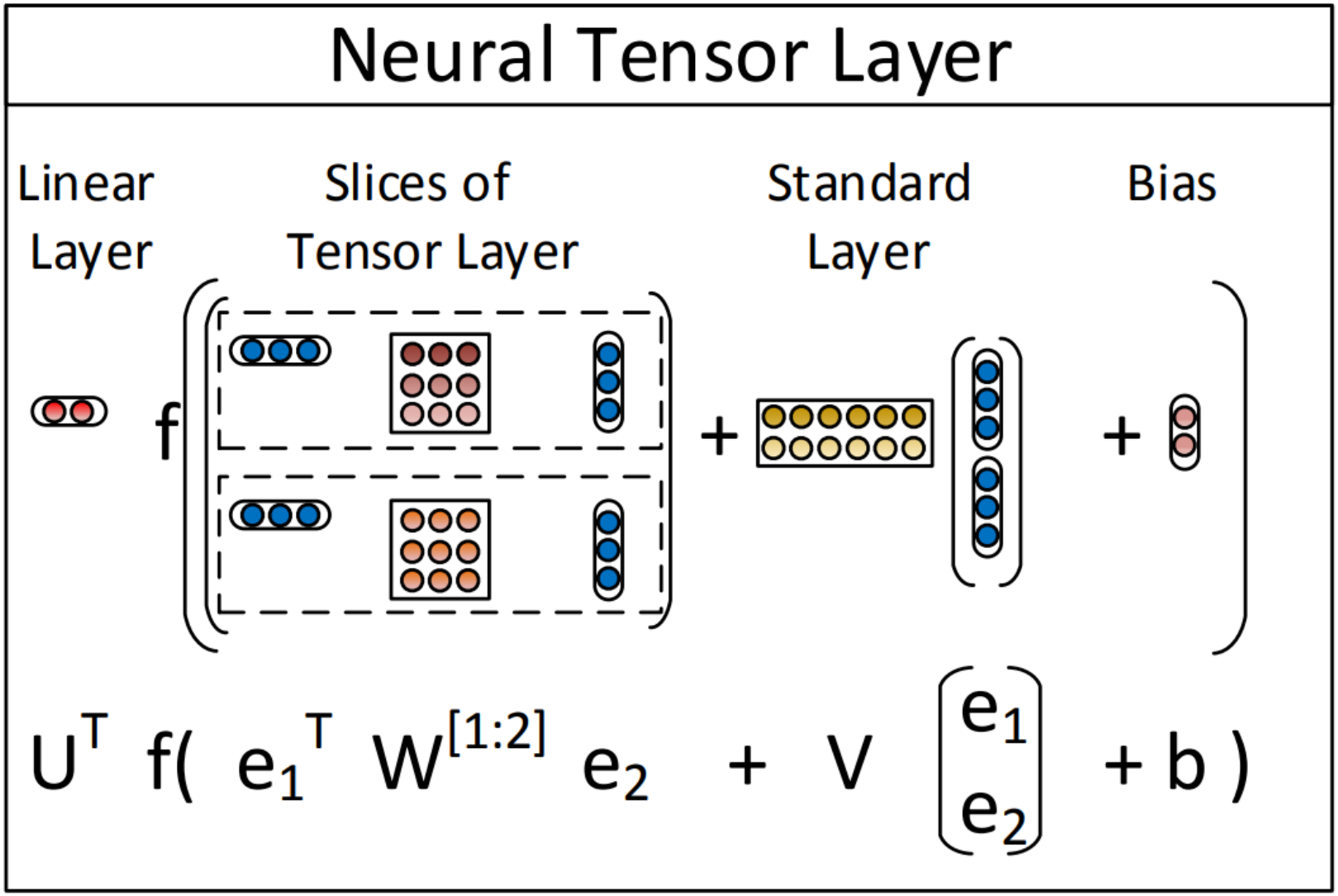
- $e_1, e_2 \in \mathbb{R}^d$ — vector representations of the two entities
- scoring function:

$$g(e_1, R, e_2) = u_R^T f\left(e_1^T W_R^{[1:k]} e_2 + V_R \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} + b_R\right)$$

- $f = \tanh$ applied element-wise
- $W_R^{[1:k]} \in \mathbb{R}^{d \times d \times k}$ — a tensor
- $e_1^T W_R^{[1:k]} e_2 = h \in \mathbb{R}^k$, $h_i = e_1^T W_R^{[i]} e_2$ (one slice $i = 1, \ldots, k$ of the tensor
- Other parameters for relation R are the standard form of a neural network:

$$V_R \in \mathbb{R}^{k \times 2d}, U \in \mathbb{R}^k, b_R \in \mathbb{R}^k$$

Neural Tensor Layer



Why slices?

- relation R may have different variations
- each slice represents a single variation of R
- example: «has part» has meaning for non-living things like cars and for living things like mammals

Training Objective and Derivatives

- $T^{(i)} = \left(e_1^{(i)}, R^{(i)}, e_2^{(i)}\right)$ — training set consists of N such triplets
- $T_c^{(i)} = \left(e_1^{(i)}, R^{(i)}, e_c\right)$ — corrupted triplet (with a random entity corrupted) — C for each $T^{(i)}$
- $T^{(i)}$ should receive a higher score than $T_c^{(i)}$
- $\Omega = u, W, V, b, E$ — the set of all relationships' NTN parameters
- objective:

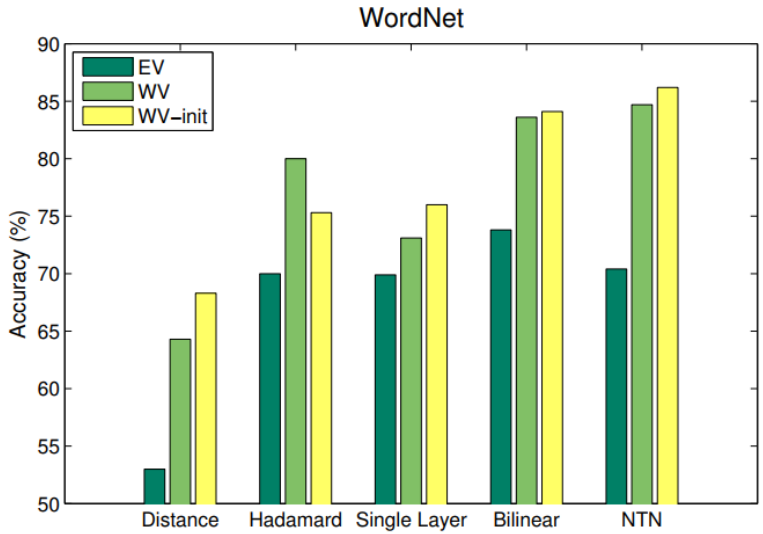
$$J(\Omega) = \sum_{i=1}^{N} \sum_{c=1}^{C} \max\left(0, 1 - g\left(T^{(i)}\right) + g\left(T_c^{(i)}\right)\right) + \lambda \|\Omega\|_2^2 \rightarrow \min$$

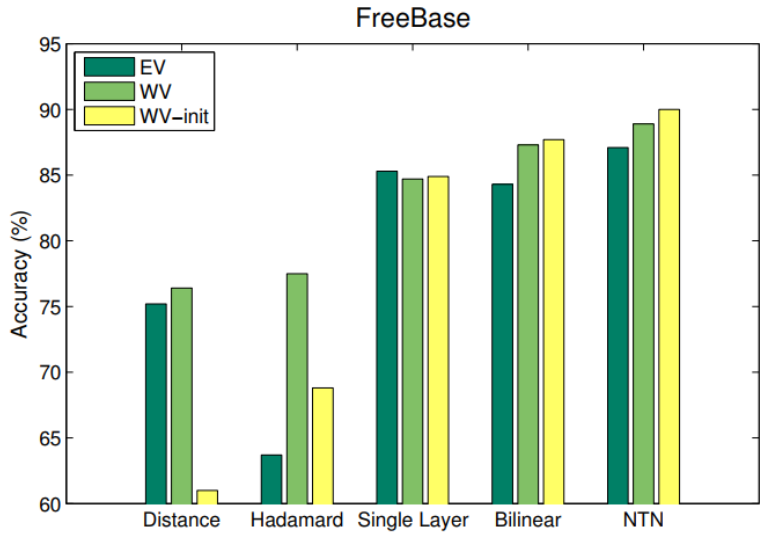
Entity Representations Revisited

- each word = d-dimensional vector $\in \mathbb{R}^d$
- each entity = composition of its word vectors
- allows the sharing of statistical strength between the words describing each entity
- example: homo sapiens is a type of hominid

  $v_{\text{homo sapiens}} = 0.5\left(v_{\text{homo}} + v_{\text{sapiens}}\right) \Rightarrow$ we may extend the fact to the previously unseen homo erectus
- in general pre-trained unsupervised word vectors capture some distributional syntactic and semantic information, so we can also benefit from them

Comparison of accuracy of the different models and entity representations on WordNet and FreeBase

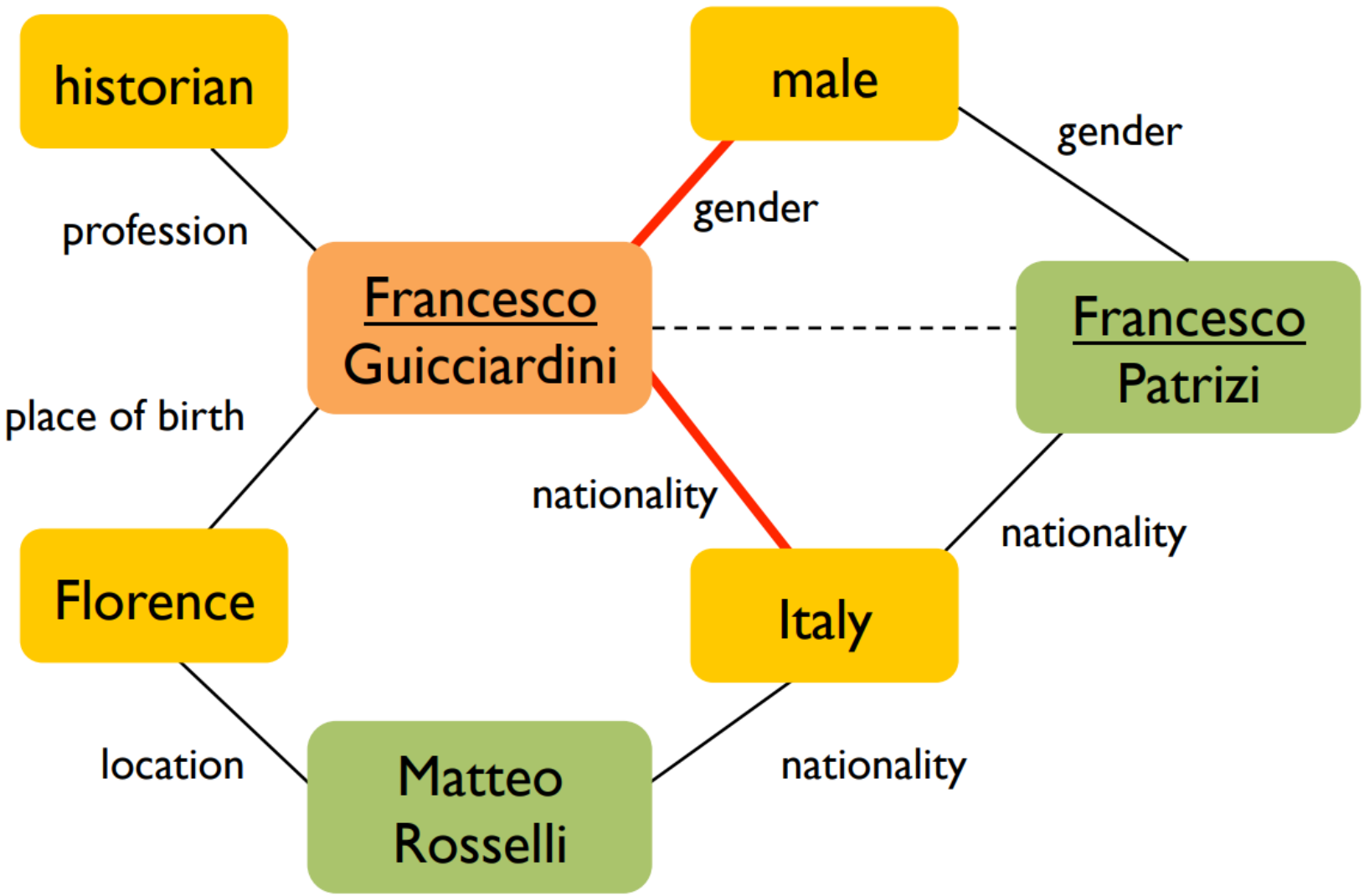




Examples of a ranking by the model for right hand side entities in WordNet

Entity e_1	Relationship R	Sorted list of entities likely to be in this relationship
tube	type of	structure; anatomical structure; device; body; body part; organ
creator	type of	individual; adult; worker; man; communicator; instrumentalist
dubrovnik	subordinate instance of	city; town; city district; port; river; region; island
armed forces	domain region	military operation; naval forces; military officier; military court
boldness	has instance	audaciousness; aggro; abductor; interloper; confession;
peole	type of	group; agency; social group; organisation; alphabet; race

A reasoning example in FreeBase



Thank you for your attention!