Evidence for an encoding of morphological blocking effects within two English word embedding models

Background on morphological blocking

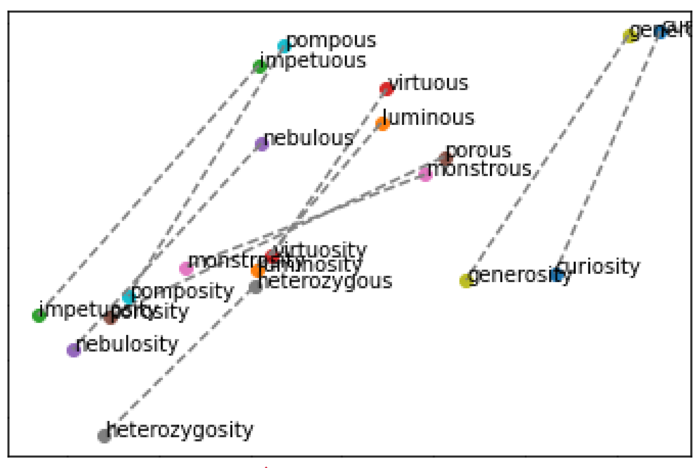
- Blocking is a process by which the existence of a word in the mental lexicon prevents regular affixation, if it would give rise to a complex word with the same meaning [1].
- In English, ***-ity*** and ***-ness*** affixation can apply to the same base: *monstros-**ity***, *monstrous-**ness***.
- **Yet, only *-ity* affixation is subject to blocking: *glory* blocks **glorios-ity* but not *glorious-ness* [1]. Why?**
  - Supposedly, *-ity* and ***-ness*** do not operate at the same "level": *-ity* is **L1** ("word-creating") while ***-ness*** is **L2** ("word-modifying").
  - This division also has phonological manifestations: *-ity* shifts stress (*glóbal* → *globál-ity*), while ***-ness*** does not (*glóbal-ness*).
  - **L1** -derived words may compete with **suppletive forms** from the lexicon, while **L2** -derived words may not.
- **But this does not explain why *-ity* is L1 and *-ness* L2 !**

Contribution

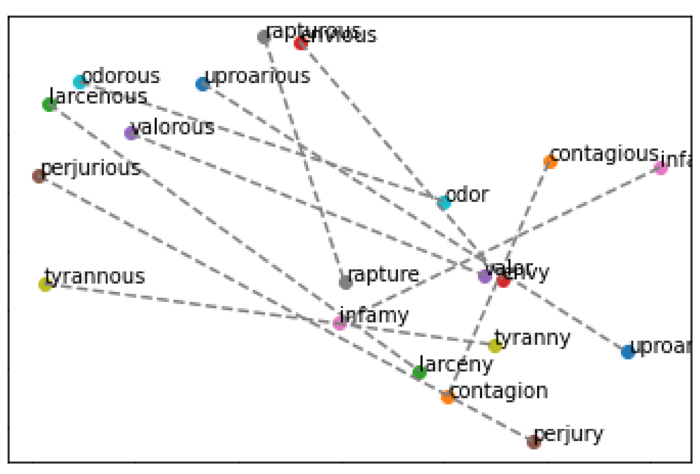
- We show that two recent word embedding models (GloVe [4] and fastText [2])...
  - Distinguish between **L1** and **L2** operations
  - Encode a stronger similarity between **suppletive operations** (such as *glorious* ↦ *glory*) and **L1** operations, as opposed to **L2** .
- We therefore argue that embeddings encode some notion of semantic competition between **L1** *vs* **suppletive operations**, rather than **L2** *vs* **suppletive operations**.
- This semantic competition might then drive blocking effects.

Relevance of word embedding models

- Word embeddings are representations of words as vectors encoding their meanings, s.t. the words that are close in the vector space (in terms of cosine similarity) are semantically similar [3].
- Embeddings have been shown to encode morphological operations, such as comparative or superlative affixation, as stable geometrical translations defined as the difference between the affixed word-vector and the word-vector itself [4].
- **We argue that the contrast between *-ity* and *-ness* affixation w.r.t. blocking is encoded as a configuration whereby $\overrightarrow{\textit{-ity}}$ is on average closer to $\overrightarrow{\textbf{sup.}}$ (vector of the related suppletive transformation) than $\overrightarrow{\textit{-ness}}$ is.**

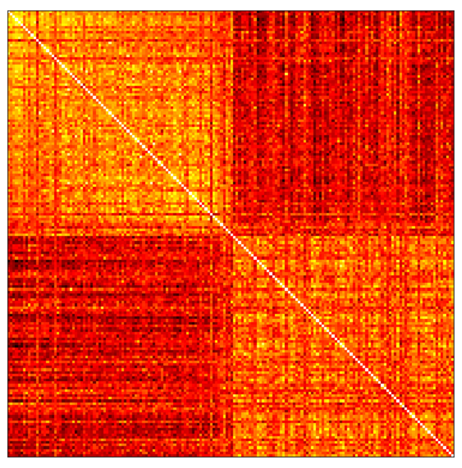


(a) $\overrightarrow{\textit{-ity}}$ transformations

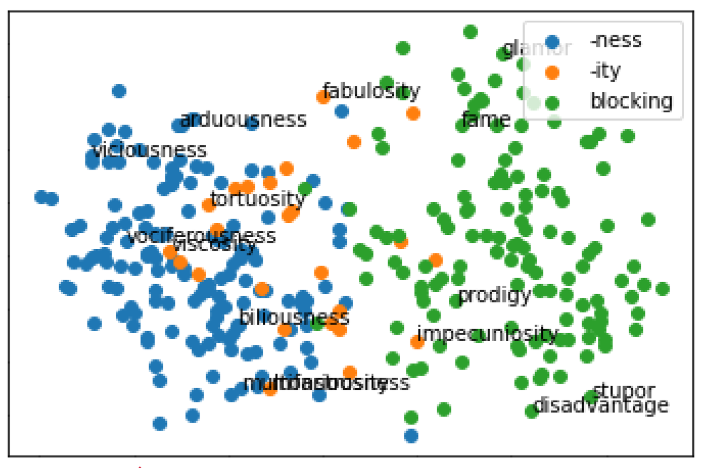


(b) Suppletive ($\overrightarrow{\textbf{sup.}}$) transformations

Figure 1: Morphological operations translate into systematic geometrical translations in a 2D-cosine-PCA-reduced space (GloVe embedding)



(a) Cosine smilarity matrix of $\overrightarrow{\textit{-ness}}$ -vectors *vs* $\overrightarrow{\textbf{sup.}}$ vectors



(b) $\overrightarrow{\textit{-ity}}$, $\overrightarrow{\textit{-ness}}$, and $\overrightarrow{\textbf{sup.}}$ vectors in a 2D-reduced space (cosine PCA)

Figure 2: Evidence for a clustering of the vectors corresponding to the 3 kinds of transformations at stake (H_1), and for differences in cluster proximities (H_2)

Modeling of the problem

- We define $\mathcal{B}_{\textit{-ity}}$, $\mathcal{B}_{\textit{-ness}}$ and $\mathcal{B}_{\textbf{sup.}}$ as the sets of base forms in *-ous* compatible with resp. *-ity* , ***-ness*** , and a **suppletive transformation** of the form *glorious* ↦ *glory*.
- For instance, *monstrous* $\in \mathcal{B}_{\textit{-ity}} \cap \mathcal{B}_{\textit{-ness}}$, and *glorious* $\in \mathcal{B}_{\textit{-ness}} \cap \mathcal{B}_{\textbf{sup.}}$, but also *glorious* $\notin \mathcal{B}_{\textit{-ity}}$
- For a base $b \in \mathcal{B}_{\textit{-ity}} \cup \mathcal{B}_{\textit{-ness}}$ we define the suffixal vector(s):

$$\overrightarrow{\textit{-ity}}_b = \overrightarrow{b\textit{-ity}} - \vec{b} \qquad \text{if } b \text{ in } \mathcal{B}_{\textit{-ity}}$$

$$\overrightarrow{\textit{-ness}}_b = \overrightarrow{b\textit{-ness}} - \vec{b} \qquad \text{if } b \text{ in } \mathcal{B}_{\textit{-ness}}$$

- For a base $b \in \mathcal{B}_{\textbf{sup.}}$ (e.g., *glorious*) we have a suppletive form s_b (e.g., *glory*). We then define the suppletive vector:

$$\overrightarrow{\textbf{sup.}}_b = \vec{s_b} - \vec{b}$$

- For each possible label X := *-ity* , ***-ness*** or **sup.** , we define the set of transformation vectors (suffixal or suppletive), and a measure of similarity between such sets:

$$\mathcal{V}_{\vec{X}} = \{\vec{X}_b \mid b \in \mathcal{B}_X\}$$

$$\mathcal{S}(X, Y) = Mean(\{CosSim(\vec{x}, \vec{y}) \mid (\vec{x}, \vec{y}) \in \mathcal{V}_{\vec{X}} \times \mathcal{V}_{\vec{Y}}\})$$

$\mathcal{S}(X, X) \triangleq \mathcal{S}(X)$: **Intra-group similarity**

$\mathcal{S}(X, Y),\ X \neq Y$: **Inter-group similarity**

Hypotheses and testing

- H_1: $\mathcal{V}_{\overrightarrow{\textit{-ity}}}$, $\mathcal{V}_{\overrightarrow{\textit{-ness}}}$ and $\mathcal{V}_{\overrightarrow{\textbf{sup.}}}$. form *clusters*, i.e.:

$$\forall X \neq Y \in \{\textit{-ity}, \textit{-ness}, \textbf{sup.}\}.\ \mathcal{S}(X) > \mathcal{S}(X, Y) \qquad (H_1)$$

- H_2: $\mathcal{V}_{\overrightarrow{\textit{-ity}}}$ is closer to $\mathcal{V}_{\overrightarrow{\textbf{sup.}}}$ than $\mathcal{V}_{\overrightarrow{\textit{-ness}}}$ is, i.e.:

$$\mathcal{S}(\textit{-ity}, \textbf{sup.}) > \mathcal{S}(\textit{-ness}, \textbf{sup.}) \qquad (H_2)$$

- Prior to testing, the embedding (GloVe or fastText) dimension was reduced twice using PCA:
  1. Reduction based on the word vectors from the dataset (base words, plus their suffixed or suppletive counterparts).
  2. Reduction based on the transformation vectors ($\overrightarrow{\textit{-ity}}_b$, $\overrightarrow{\textit{-ness}}_b$, $\overrightarrow{\textbf{sup.}}_b$) computed in the intermediate space.
- Dimension was reduced to 39 for GloVe and 28 for fastText.
- H_1 and H_2 yielded significant p-values (cf. Tab. 1).
- H_2 is corroborated by Tab. 2 which shows higher clustering scores (*-ed cells) between the ***-ness*** and **sup.** clusters as opposed to the *-ity* and **sup.** clusters.

	Similarities compared	fastText	GloVe
H_1	$\mathcal{S}$(*-ness*) / $\mathcal{S}$(*-ness*, *-ity*)	1.2e-16	2.1e-6
	$\mathcal{S}$(*-ness*) / $\mathcal{S}$(*-ness*, **sup.**)	0.	0.
	$\mathcal{S}$(*-ity*) / $\mathcal{S}$(*-ity*, *-ness*)	4.5e-129	2.3e-83
	$\mathcal{S}$(*-ity*) / $\mathcal{S}$(*-ity*, **sup.**)	2.9e-21	6.7e-10
	$\mathcal{S}$(**sup.**) / $\mathcal{S}$(**sup.**, *-ness*)	3.4e-42	3.7e-13
	$\mathcal{S}$(**sup.**) / $\mathcal{S}$(**sup.**, *-ity*)	4.2e-10	9.0e-4
H_2	$\mathcal{S}$(*-ity*, **sup.**) / $\mathcal{S}$(*-ness*, **sup.**)	3.9e-5	4.2e-3

Table 1: p-values for H_1 and H_2 (independent t-tests, Holm-Bonferroni corrected for H_1)

Score	fastText		GloVe	
	sup. / *-ness*	**sup.** / *-ity*	**sup.** / *-ness*	**sup.** / *-ity*
Silhouette	0.20*	0.12	0.23*	0.13
Calinski-Harabasz	23.99*	3.77	32.31*	4.40
Davies-Bouldin	3.08*	3.56	2.36*	3.14

Table 2: Clustering scores for the ***-ness*** /**sup.** and *-ity* /**sup.** cluster pairs.

Conclusion

- Word embeddings distinguish between **L1** (*-ity*), **L2** (***-ness***) and **suppletive operations**.
- **L1** operations are closer to the latter than **L2** operations are.
- This implies that blocking is driven by semantic competition, and motivates the **L1** / **L2** distinction.

[1] M. Aronoff. *Word Formation in Generative Grammar.* 1976.

[2] Piotr Bojanowski et al. "Enriching Word Vectors with Subword Information". In: *arXiv:1607.04606* (2016).

[3] Daniel Jurafsky and Martin H. James. *Speech and language processing.* 2000.

[4] Jeffrey Pennington, Richard Socher, and Christopher D Manning. "Global Vectors for Word Representation.". In: *EMNLP.* 2014.

Adèle Hénot-Mortier
mortier@mit.edu
Massachusetts Institute of Technology