A Memory-Sensitive Classification Model of Errors in Early Second Language Learning

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INTRODUCTION

Acquiring a second language (L2) as an adult is notoriously difficult.
By understanding where individual learners make mistakes, we can improve efficiency and durability of L2 learning

- Linguistic factors:
  - E.g. Cognates, concrete words are easier (de Groot & Keizer, 2000) while interlingual homographs are harder (Dijkstra, Timmermans & Schriefers, 2000)
- Memory factors:
  - Since language is learned, it must be stored in memory.
    - What improves memory in general should also improve memory for language
  - Spaced repetition: words (and other items) are remembered better when they are encountered repeatedly, with temporal gaps in between (vs. repeated all at once).
    - Longer gaps are better (e.g. Cepeda et al. 2006)
    - Robust over seconds, minutes, days, weeks, years (e.g. Cepeda et al. 2008)
    - Applies to a wide variety of materials (e.g. Donovan & Radosevich, 1999)
    - Including language (e.g. Ullman & Lovelett, 2018)
  - Retrieval Practice: Recalling information from memory makes that information easier to recall in the future
    - Duolingo frequently prompts users to retrieve from memory
    - Retrieval practice enhances the efficacy of spaced repetition

By better understanding the factors that influence learning and retention of L2, systems like Duolingo can:

- Devote more resources to the most difficult aspects of the L2 (for each learner)
- Schedule review of learned material when it is of most benefit to the learner
- Leverage their own users' data to improve understanding of the learning process, and in turn improve learning outcomes

DATA Settles et al. 2018

POPULATIONS

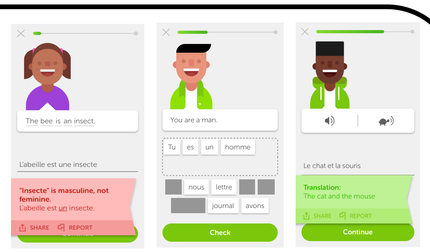
Three groups were analyzed separately:

- English-speaking learners of Spanish
- English-speaking learners of French
- Spanish-speaking learners of English

THREE SETS

The first 30 days of each users learning broken are broken down into:

- Training: each user's first 80% of sessions
- Development: the next 10% of each user's data
- Test: the final 10% of exercises for each user



Reverse Translate | Reverse Tap | Listen

Figure 1. *Examples of Duolingo exercises and error markings present in the data*

MODEL

Random forest classifier

- Each decision tree branched a number of times equal to the square root of the total number of features
- An ensemble of 1000 trees was created for each of the three language datasets
- Each tree branched until leaves were pure (contained only a single label: "error" or "no error")
- Out-of-bag error was used to estimate prediction error of the classifier
- The classifier was trained in Python 3, using sklearn.ensemble.RandomForestClassifier()

ENGINEERED FEATURES

Linguistic		Memory		Categorical		Interactions
orthoLength	Word length in characters	**nthOccurance**	Number of times a token has been seen	**pos**	Part of speech	**stemLag1 x stemLag2**
phonLength	Word length in phonemes	**userTrial**	Number of trials a user has seen	**format**	Trial format (see Figure 1)	**stemLag1 x stemLag2 x lagTr1Tr2**
orthoNei	Number of orthographic word neighbors	**tokenLag1**	Amount of time since token last seen	**prevFormat**	Previous trial format	**lagTr1Tr2 x morphoComplexity**
phonNei	Number of phonological word neighbors	**tokenLag2**	Amount of time between last time a word has been seen and the time before that	**client**	User's client (collapsed to mobile or web)	**lagTr1Tr2 x morphoLag1**
logWordFreq	log-transformed word frequency	**stemLag1**	Amount of time since stemmed token has been seen	**userMeanError**	Average of a user's accuracy across trials	**Format x prevFormat**
logOrthoNeiFreq	Average log-transformed word frequency of orthographic neighbors	**stemLag2**	Amount of time between last time a stemmed token has been seen and the time before that	**userVarError**	Variance in a user's accuracy across trials	**orthoNei x format**
logPhonNeiFreq	Average log-transformed word frequency of phonological neighbors	**morphoLag1**	Amount of time since morphological features have last been seen			**phonNei x format**
Edit Distance	Levenshtein distance between translations of word	**lagTr1Tr2**	Amount of time between first and second trials containing that token			**format x client**
Interlingual homograph	Whether a given translation was identical to a different word in the source language					**morphoComplexity x pos**
morphoCompexity	Number of morphological features					
Concreteness	Subject ratings of how perceptible an entity is					

Table 1. *Names and descriptions of the engineered features*

RESULTS & DISCUSSION

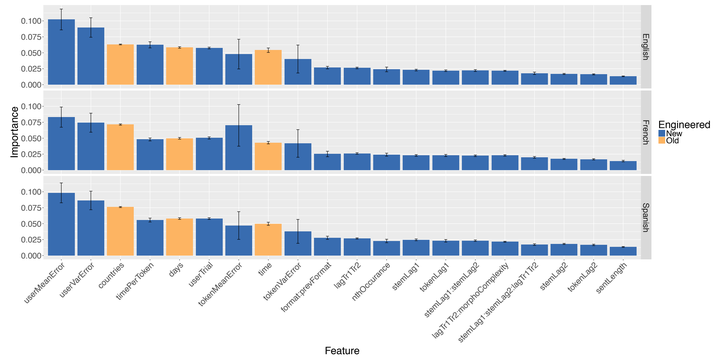


Figure 2. *Importance measures for each of the top 20 features.*

- Most important features: u*serMeanError*; *userVarError*:
  - mean and variance of each user's error rate (under each combination of levels of a small set of features)
  - Computational savings over fitting a more comprehensive random effect structure (i.e. random effects for all users, all tokens, and all user-token combinations, at minimum)
- The more time users spend per token (on average) within an exercise (*timePerToken*) the more likely they are to make errors in that exercise
- Users make more errors on average the longer they've spent using the app (*Days, userTrial*). Perhaps because item difficulty also increases with experience.
- Words that repeat more often (*nthOccurrence*) are remembered better.
- The more time that passed since the previous occurrence of a word, the higher the error rate (*tokenLag1*, *tokenLag2)*
  - Contra spacing effect: perhaps more consideration of full item history is needed (or gaps too long; see Cepeda et al. 2008)
- There seems to be a cost to switching formats: error rates are higher when the current task type is different from the previous (*format:prevFormat*)
- Future models will include ablation experiments and word embeddings

	AUROC	F1	Log-loss
SLAM English	.7730	.1899	.3580
English	.8286	.4242	.3191
SLAM French	.7707	.2814	.3952
French	.8228	.4416	.3561
SLAM Spanish	.7456	.1753	.3862
Spanish	.8027	.4353	.3571

Table 2. *Model outcomes compared to SLAM baselines.*

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