

# A Computational Approach to Language Learning:

## Examining the Efficacy of Spaced Repetition

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### BACKGROUND

When learning languages, it is important to choose an effective method for learning. Spaced repetition is a newer method focused on having the learner review a piece of information just before they are about to forget it. With each review, the length of time between reviews gets larger. Several digital language learning applications implement spaced repetition, such as Duolingo and Anki. Duolingo's data suggests that spaced repetition works equally well across languages and parts of speech. In contrast, the author's Anki data suggests that spaced repetition's efficacy is inconsistent for reviews with an interval of 3 months or greater.

### INTRODUCTION

Working towards identifying which language learning models are objectively most effective, this project aims to quantitatively analyze the effectiveness of spaced repetition in language learning applications. This work promotes further research and data collection for language learning and spaced repetition, working towards a more rigorous study to find the best model for language learning. In identifying this model, it could be generalized and applied to any field of study, reducing the time it takes one to learn new concepts. It is also important to understand how to maximize learning productivity so that we can not only learn more efficiently, but more effectively overall. In learning new things quicker than before, we can better spend our time and efforts elsewhere.

### DATA

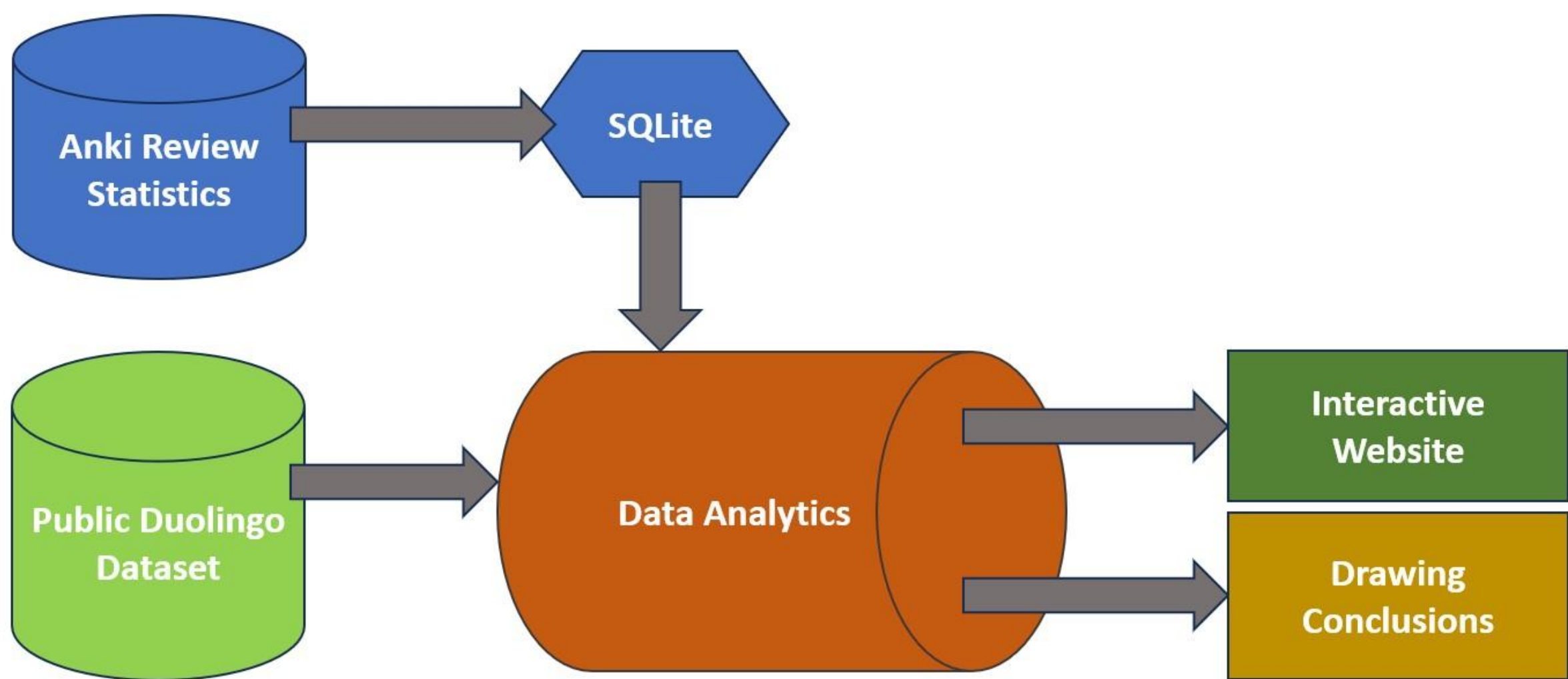
Interface Language	Learning Language	Lexeme String	History Seen	History Correct	Session Seen	Session Correct	P_Recall
English	Portuguese	come/comer <vblex>	21	20	1	1	1.0
Italian	English	newspaper/newspaper<n>	42	39	4	3	0.75
English	German	frau/frau<n><f>	6	5	2	1	0.5
English	Italian	mie/mio<det><f><pl>	7	7	3	2	0.67
English	Spanish	hermana/hermano<n><f>	12	10	1	1	1.0
English	French	et/et<conjoo>	38	27	2	1	0.5

Table 1: Example Table of Learning Traces (Simplified)

The Duolingo dataset above contains 12.9 million learning traces that were collected over a 2 week period. These traces were used for a 2016 study on the Half-Life Regression Model that is implemented in Duolingo's mobile app. The Anki dataset below contains over 92,000 reviews performed on 5,000 cards from the author's personal use of the app.

Time of Review	Card ID	Ease of Recall	Interval for Next Review
1566452085029	1528564711188	2	1
1566452447881	1528565827041	2	2
1566626988674	1528564661613	3	5
1596122830309	1444182700694	3	62
1626313041376	1603083802365	4	108

### PIPELINE



Duolingo's dataset was publicly available on their official github, while the Anki dataset was retrievable through SQLite. After running some basic data analytics and visualizations with tools like pandas and Seaborn, conclusions were drawn from the general trends in the data. To increase the audience of the findings, Bokeh was also used to create graphs and an interactive webpage. The website, anki dataset, and data analytics can be found on this project's Github page.

### DUOLINGO RESULTS

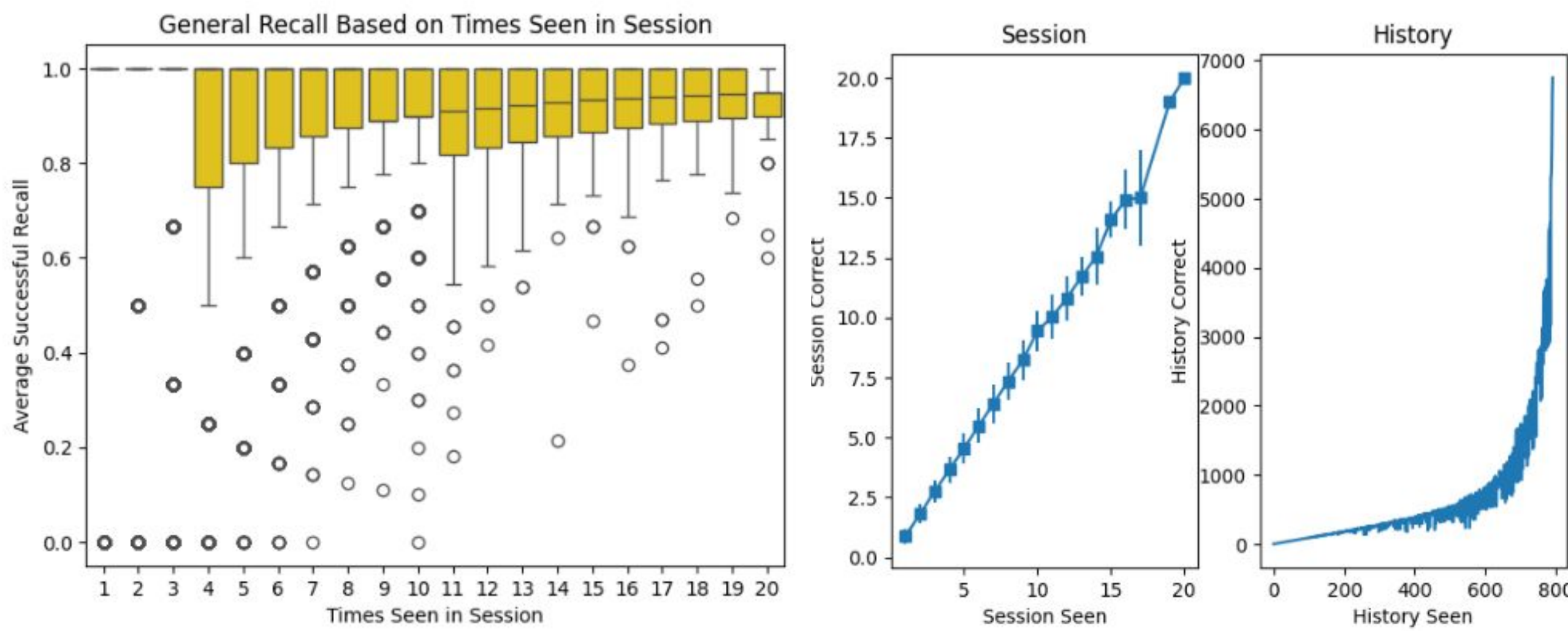


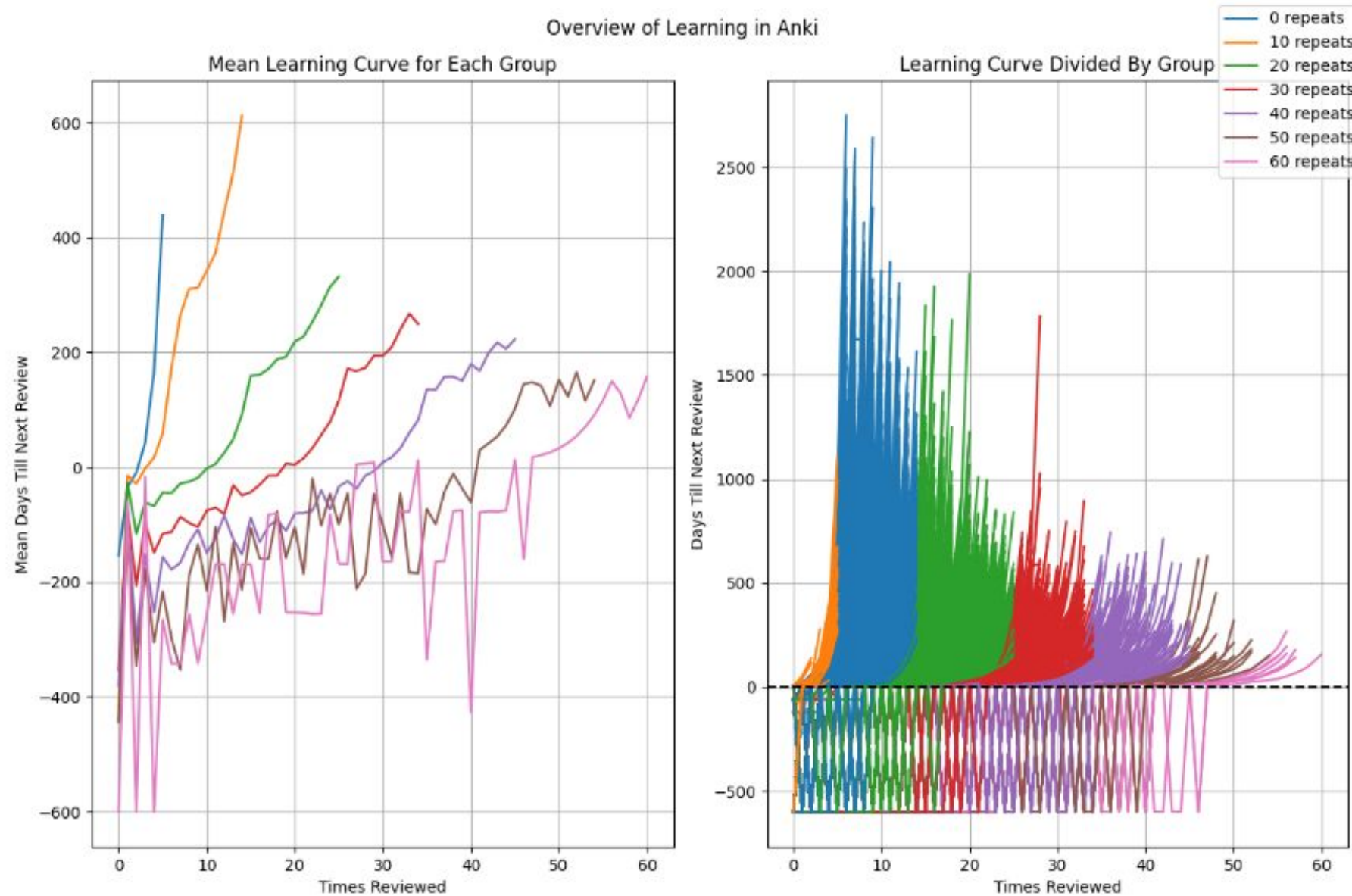
Figure 3: Duolingo Session Overview

Figure 4: Duolingo Session and History Comparison

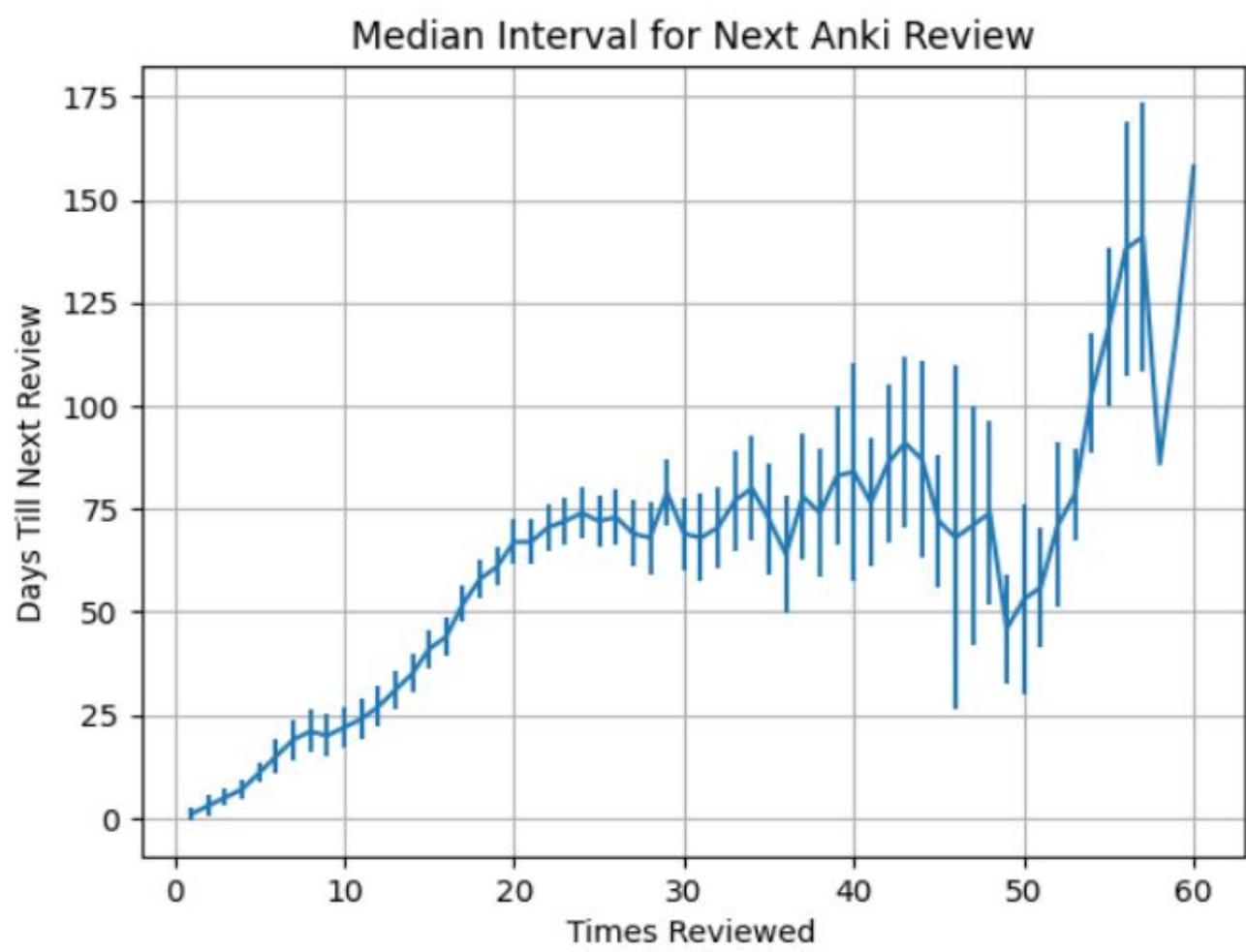
The graph on the left shows a positive relationship between the frequency a word has been seen and the frequency it was recalled correctly in a single session. Essentially, the more times a word has been seen, the more likely the user will recall it correctly. The graph on the right compares spaced repetition's efficacy within individual sessions and across all sessions (history). Due to the increased scale of history, the x axis was compressed giving the graph an exponential curve. The data suggests that spaced repetition also works well across sessions, successfully increasing the time delay before the next review.

When investigating whether spaced repetition was more effective for learning some languages than others, the data suggested that spaced repetition works equally well across languages. Similarly, looking at the top six most common parts of speech like nouns and verbs, spaced repetition worked equally well regardless of the part of speech being studied.

### ANKI RESULTS



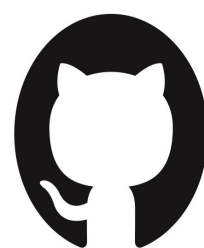
The left graph shows the average learning curve for seven different categories of cards, while the right graph shows the learning curve of individual cards. -600 is the default value for a card to be reviewed in the same day, which drew the average learning curves below zero. Orange and blue cards were very easy to learn and quickly reached large review intervals, while purple, brown, and pink were more difficult to learn and were scheduled for review more frequently.



When looking at the median interval for the next Anki review, spaced repetition seems to be consistently effective for review intervals less than 75 days. Beyond this, or for cards that have been reviewed more than 30 or 40 times, it is less predictable whether the recall of the word will be effective. This trend suggests that spaced repetition is effective for smaller review intervals, but less effective for larger intervals.

### CONCLUSION

This research serves as a light introduction to the efficacy of Spaced Repetition in language learning apps, and should be used as a foundation for further research. Future studies may consider analyzing more than one anki deck or getting more recent data from duolingo to draw stronger conclusions.



<https://github.com/SpyChicken00/A-Computational-Approach-to-Language-Learning-Models>