# Psycholinguistically Motivated Computational Models on the Organization and Processing of Morphologically Complex Words

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## Abstract

In this work we present psycholinguistically motivated computational models for the organization and processing of Bangla morphologically complex words in the mental lexicon. Our goal is to identify whether morphologically complex words are stored as a whole or are they organized along the morphological line. For this, we have conducted a series of psycholinguistic experiments to build up hypothesis on the possible organizational structure of the mental lexicon. Next, we develop computational models based on the collected dataset. We observed that derivationally suffixed Bangla words are in general decomposed during processing and compositionality between the stem and the suffix plays an important role in the decomposition process. We observed the same phenomena for Bangla verb sequences where experiments showed non-compositional verb sequences are in general stored as a whole in the ML and low traces of compositional verbs are found in the mental lexicon.

## 1 Introduction

*Mental lexicon* is the representation of the words in the human mind and their associations that help fast retrieval and comprehension (Aitchison, 1987). Words are known to be associated with each other in terms of, orthography, phonology, morphology and semantics. However, the precise nature of these relations is unknown.

An important issue that has been a subject of study for a long time is to identify the fundamental units in terms of which the mental lexicon is organized. That is, whether lexical representations in the mental lexicon are word based or are they organized along morphological lines. For example, whether a word such as "*unimaginable*" is stored in the mental lexicon as a whole word or do we break it up "*un-*" , "*imagine*" and "-*able*", understand the meaning of each of these constituent and then recombine the units to comprehend the whole word.

Such questions are typically answered by designing appropriate priming experiments (Marslen-Wilson et al., 1994) or other lexical decision tasks. The reaction time of the subjects for recognizing various lexical items under appropriate conditions reveals important facts about their organization in the brain. (See Sec. 2 for models of morphological organization and access and related experiments).

A clear understanding of the structure and the processing mechanism of the mental lexicon will further our knowledge of how the human brain processes language. Further, these linguistically important and interesting questions are also highly significant for computational linguistics (CL) and natural language processing (NLP) applications. Their computational significance arises from the issue of their storage in lexical resources like WordNet (Fellbaum, 1998) and raises the questions like, how to store morphologically complex words, in a lexical resource like WordNet keeping in mind the storage and access efficiency.

There is a rich literature on organization and lexical access of morphologically complex words where experiments have been conducted mainly for derivational suffixed words of English, Hebrew, Italian, French, Dutch, and few other languages (Marslen-Wilson et al., 2008; Frost et al., 1997; Grainger, et al., 1991; Drews and Zwitserlood, 1995). However, we do not know of any such investigations for Indian languages, which



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are morphologically richer than many of their Indo-European cousins. Moreover, Indian languages show some distinct phenomena like, compound and composite verbs for which no such investigations have been conducted yet. On the other hand, experiments indicate that mental representation and processing of morphologically complex words are not quite language independent (Taft, 2004). Therefore, the findings from experiments in one language cannot be generalized to all languages making it important to conduct similar experimentations in other languages.

This work aims to design cognitively motivated computational models that can explain the organization and processing of Bangla morphologically complex words in the mental lexicon. Presently we will concentrate on the following two aspects:

- **Organization and processing of Bangla Polymorphemic words:** our objective here is to determine whether the mental lexicon decomposes morphologically complex words into its constituent morphemes or does it represent the unanalyzed surface form of a word.
- **Organization and processing of Bangla compound verbs (CV):** compound verbs are the subject of much debate in linguistic theory. No consensus has been reached yet with respect to the issue that whether to consider them as unitary lexical units or are they syntactically assembled combinations of two independent lexical units. As linguistic arguments have so far not led to a consensus, we here use cognitive experiments to probe the brain signatures of verb-verb combinations and propose cognitive as well as computational models regarding the possible organization and processing of Bangla CVs in the mental lexicon (ML).

With respect to this, we apply the different priming and other lexical decision experiments, described in literature (Marslen-Wilson et al., 1994; Bentin, S. and Feldman, 1990) specifically for derivationally suffixed polymorphemic words and compound verbs of Bangla. Our cross-modal and masked priming experiment on Bangla derivationally suffixed words shows that morphological relatedness between lexical items triggers a significant priming effect, even when the forms are phonologically/orthographically unrelated. These observations are similar to those reported for English and indicate that derivationally suffixed words in Bangla are in general accessed through decomposition of the word into its constituent morphemes. Further, based on the experimental data we have developed a series of computational models that can be used to predict the decomposition of Bangla polymorphemic words. Our evaluation result shows that decomposition of a polymorphemic word depends on several factors like, frequency, productivity of the suffix and the compositionality between the stem and the suffix.

The organization of the paper is as follows: Sec. 2 presents related works; Sec. 3 describes experiment design and procedure; Sec. 4 presents the processing of CVs; and finally, Sec. 5 concludes the paper by presenting the future direction of the work.

## 2 Related Works

### 2.1 Representation of polymorphemic words

Over the last few decades many studies have attempted to understand the representation and processing of morphologically complex words in the brain for various languages. Most of the studies are designed to support one of the two mutually exclusive paradigms: the *full-listing* and the *morphemic* model. The *full-listing model* claims that polymorphic words are represented as a whole in the human mental lexicon (Bradley, 1980; Butterworth, 1983). On the other hand, *morphemic model* argues that morphologically complex words are decomposed and represented in terms of the smaller morphemic units. The affixes are stripped away from the root form, which in turn are used to access the mental lexicon (Taft and Forster, 1975; Taft, 1981; MacKay, 1978). Intermediate to these two paradigms is the *partial decomposition model* that argues that different types of morphological forms are processed separately. For instance, the derived morphological forms are believed to be represented as a whole, whereas the representation of the inflected forms follows the morphemic model (Caramazza et al., 1988).

Traditionally, *priming experiments* have been used to study the effects of morphology in language processing. *Priming* is a process that results in increase in speed or accuracy of response to a stimulus, called the *target*, based on the occurrence of a prior exposure of another stimulus, called the *prime* (Tulving et al., 1982). Here, subjects are exposed to a prime word for a short duration, and are subsequently shown a target word. The prime and target words may be morphologically, phonologically or semantically related. An analysis of the effect of the reaction time of subjects reveals the actual organization and representation of the lexicon at the relevant level. See Pulvermüller (2002) for a detailed account of such phenomena.

It has been argued that frequency of a word influences the speed of lexical processing and thus, can serve as a diagnostic tool to observe the nature and organization of lexical representations. (Taft, 1975) with his experiment on English inflected words, argued that lexical decision responses of polymorphemic words depends upon the base word frequency. Similar observation for surface word frequency was also observed by (Bertram et al., 2000;Bradley, 1980;Burani et al., 1987;Burani et al., 1984;Schreuder et al., 1997; Taft 1975;Taft, 2004) where it has been claimed that words having low surface frequency tends to decompose. Later, Baayen(2000) proposed the dual processing race model that proposes that a specific morphologically complex form is accessed via its parts if the frequency of that word is above a certain threshold of frequency, then the direct route will win, and the word will be accessed as a whole. If it is below that same threshold of frequency, the parsing route will win, and the word will be accessed via its parts.

### 2.2 Representation of Compound Verbs

A compound verb (CV) consists of a sequence of two verbs (V1 and V2) acting as a single verb and expresses a single expression of meaning. For example, in the sentence

রুটিগুলো খেলে ফেলো (/ruTigulo kheYe phela/) "bread-plural-the eat and drop-pres. Imp"

"Eat the breads"

the verb sequence "খেলে ফেলো (eat drop)" is an example of CV. Compound verbs are a special phenomena that are abundantly found in Indo-European languages like Indian languages.

A plethora of works has been done to provide linguistic explanations on the formation of such word, yet none so far has led to any consensus. Hook (1981) considers the second verb V2 as an aspectual complex comparable to the auxiliaries. Butt (1993) argues CV formations in Hindi and Urdu are either morphological or syntactical and their formation take place at the argument structure. Bashir (1993) tried to construct a semantic analysis based on "prepared" and "unprepared mind". Similar findings have been proposed by Pandharipande (1993) that points out V1 and V2 are paired on the basis of their semantic compatibility, which is subject to syntactic constraints. Paul (2004) tried to represent Bangla CVs in terms of HPSG formalism. She proposes that the selection of a V2 by a V1 is determined at the semantic level because the two verbs will unify if and only if they are semantically compatible. Since none of the linguistic formalism could satisfactorily explain the unique phenomena of CV formation, we here for the first time drew our attention towards psycholinguistic and neurolinguistic studies to model the processing of verb-verb combinations in the ML and compare these responses with that of the existing models.

## 3 The Proposed Approaches

### 3.1 The psycholinguistic experiments

We apply two different priming experiments namely, the cross modal priming and masked priming experiment discussed in (Forster and Davis, 1984; Rastle et al., 2000;Marslen-Wilson et al., 1994; Marslen-Wilson et al., 2008) for Bangla morphologically complex words. Here, the prime is morphologically derived form of the target presented auditorily (for cross modal priming) or visually (for masked priming). The subjects were asked to make a lexical decision whether the given target is a valid word in that language. The same target word is again probed but with a different audio or visual probe called the control word. The control shows no relationship with the target. For example, baYaska (aged) and baYasa (age) is a prime-target pair, for which the corresponding control-target pair could be naYana (eye) and baYasa (age).

Similar to (Marslen-Wilson et al., 2008) the masked priming has been conducted for three different SOA (Stimulus Onset Asynchrony), 48ms, 72ms and 120ms. The SOA is measured as the amount of time between the start the first stimulus till the start of the next stimulus.

| Class | Example |
|---|---|
| M+S+O+ | nibAsa(residence)-nibAsi(resident) |
| M+S+O- | mitra(friend) - maitri (friendship) |
| M'+S-O+ | Ama(Mango)- AmadAni (import) |
| M-S+O- | jantu(Animal)- bAgha (Tiger) |
| M-S-O+ | ghaDi(watch)-ghaDiYAla (crocodile) |

**Table 1: Dataset for the experiment, + implies related, and - implies unrelated.**

There were 500 prime-target and control-target pairs classified into five classes. Depending on the class, the prime is related to the target either in terms of morphology, semantics, orthography and/or Phonology (See Table 1).

The experiments were conducted on 24 highly educated native Bangla speakers. Nineteen of them have a graduate degree and five hold a post graduate degree. The age of the subjects varies between 22 to 35 years.

**Results:** The RTs with extreme values and incorrect decisions were excluded from the data. The data has been analyzed using two ways ANOVA with three factors: priming (prime and control), conditions (five classes) and prime durations (three different SOA). We observe strong priming effects ($p<0.05$) when the target word is morphologically derived and has a recognizable suffix, semantically and orthographically related with respect to the prime; no priming effects are observed when the prime and target words are orthographically related but share no morphological or semantic relationship; although not statistically significant ($p>0.07$), but weak priming is observed for prime target pairs that are only semantically related. We see no significant difference between the prime and control RTs for other classes.

We also looked at the RTs for each of the 500 target words. We observe that maximum priming occurs for words in [M+S+O+](69%), some priming is evident in [M+S+O-](51%) and [M'+S-O+](48%), but for most of the words in [M-S+O-](86%) and [M-S-O+](92%) no priming effect was observed.

### 3.2 Frequency Distribution Models of Morphological Processing

From the above results we saw that not all polymorphemic words tend to decompose during processing, thus we need to further investigate the processing phenomena of Bangla derived words. One notable means is to identify whether the stem or suffix frequency is involved in the processing stage of that word. For this, we apply different frequency based models to the Bangla polymorphemic words and try to evaluate their performance by comparing their predicted results with the result obtained through the priming experiment.

**Model-1: Base and Surface word frequency effect-** It states that the probability of decomposition of a Bangla polymorphemic word depends upon the frequency of its base word. Thus, if the stem frequency of a polymorphemic word crosses a given threshold value, then the word will decomposed into its constituent morpheme. Similar claim has been made for surface word frequency model where decomposition depends upon the frequency of the surface word itself. We have evaluated both the models with the 500 words used in the priming experiments discussed above. We have achieved an accuracy of 62% and 49% respectively for base and surface word frequency models.

**Model-2: Combining the base and surface word frequency-** In a pursuit towards an extended model, we combine model 1 and 2 together. We took the log frequencies of both the base and the derived words and plotted the best-fit regression curve over the given dataset.

The evaluation of this model over the same set of 500 target words returns an accuracy of 68% which is better than the base and surface word frequency models. However, the proposed model still fails to predict processing of around 32% of words. This led us to further enhance the model. For this, we analyze the role of suffixes in morphological processing.

**Model-3: Degree of Affixation and Suffix Productivity:** we examine whether the regression analysis between base and derived frequency of Bangla words varies between suffixes and how these variations affect morphological decomposition. With respect to this, we try to compute the degree of affixation between the suffix and the base word. For this, we perform regression analysis on sixteen different Bangla suffixes with varying degree of type and token frequencies. For each suffix, we choose 100 different derived words. We observe that those suffixes having high value of intercept are forming derived words whose base frequencies are substantially high as compared to their derived forms. Moreover we also observe that high intercept value for a given suffix indicates higher inclination towards decomposition.

Next, we try to analyze the role of suffix type/token ratio and compare them with the base/derived frequency ratio model. This has been done by regression analysis between the suffix type-token ratios with the base-surface frequency ratio.

We further tried to observe the role of suffix productivity in morphological processing. For this, we computed the three components of productivity P, P* and V as discussed in (Hay and Plag, 2004). P is the “conditioned degree of productivity” and is the probability that we are encountering a word with an affix and it is representing a new type. P* is the “hapaxed-conditioned degree of productivity”. It expresses the probability that when an entirely new word is encountered it will contain the suffix. V is the "type frequency". Finally, we computed the productivity of a suffix through its P, P* and V values. We found that decomposition of Bangla polymorphemic word is directly proportional to the productivity of the suffix. Therefore, words that are composed of productive suffixes (P value ranges between 0.6 and 0.9) like "-oYAlA", "-giri", "-tba" and "-panA" are highly decomposable than low productive suffixes like "-Ani", "-lA", "-k", and "-tama". The evaluation of the proposed model returns an accuracy of 76% which comes to be 8% better than the preceding models.

**Combining Model-2 and Model-3:** One important observation that can be made from the above results is that, model-3 performs best in determining the true negative values. It also possesses a high recall value of (85%) but having a low precision of (50%). In other words, the model can predict those words for which decomposition will not take place. On the other hand, results of Model-2 posses a high precision of 70%. Thus, we argue that combining the above two models can better predict the decomposition of Bangla polymorphemic words. Hence, we combine the two models together and finally achieved an overall accuracy of 80% with a precision of 87% and a recall of 78%. This surpasses the performance of the other models discussed earlier. However, around 22% of the test words were wrongly classified which the model fails to justify. Thus, a more rigorous set of experiments and data analysis are required to predict access mechanisms of such Bangla polymorphemic words.

### 3.3 Stem-Suffix Compositionality

Compositionality refers to the fact that meaning of a complex expression is inferred from the meaning of its constituents. Therefore, the cost of retrieving a word from the secondary memory is directly proportional to the cost of retrieving the individual parts (i.e the stem and the suffix). Thus, following the work of (Milin et al., 2009) we define the compositionality of a morphologically complex word ($W_e$) as:

$$C(W_e)= {}_1H(W_e)+ {}_2H(e)+ {}_3H(W|e)+ {}_4H(e|W)$$

Where, H(x) is entropy of an expression x, H(W|e) is the conditional entropy between the stem W and suffix e and is the proportionality factor whose value is computed through regression analysis.

Next, we tried to compute the compositionality of the stem and suffixes in terms of relative entropy D(W||e) and Point wise mutual information (PMI). The relative entropy is the measure of the distance between the probability distribution of the stem W and the suffix e. The PMI measures the amount of information that one random variable (the stem) contains about the other (the suffix).

We have compared the above three techniques with the actual reaction time data collected through the priming and lexical decision experiment. We observed that all the three information theoretic models perform much better than the frequency based models discussed in the earlier section, for predicting the decomposability of Bangla polymorphemic words. However, we think it is still premature to claim anything concrete at this stage of our work. We believe much more rigorous experiments are needed to be performed in order to validate our proposed models. Further, the present paper does not consider factors related to age of acquisition, and word familiarity effects that plays important role in the processing of morphologically complex words. Moreover, it is also very interesting to see how stacking of multiple suffixes in a word are processed by the human brain.

## 4 Organization and Processing of Compound Verbs in the Mental Lexicon

Compound verbs, as discussed above, are special type of verb sequences consisting of two or more verbs acting as a single verb and express a single expression of meaning. The verb V1 is known as pole and V2 is called as vector. For example, "ওঠে পড়া" (*getting up*) is a compound verb where individual words do not entirely reflects the meaning of the whole expression. However, not all V1+V2 combinations are CVs. For example, expressions like, "নিয়ে যাও"(*take and then go*) and " ফিরে আসো" (*return back*) are the examples of verb sequences where meaning of the whole expression can be derived from the meaning of the individual component and thus, these verb sequences are not considered as CV. The key question linguists are trying to identify for a long time and debating a lot is whether to consider CVs as a single lexical units or consider them as two separate units. Since linguistic rules fails to explain the process, we for the first time tried to perform cognitive experiments to understand the organization and processing of such verb sequences in the human mind. A clear understanding about these phenomena may help us to classify or extract actual CVs from other verb sequences. In order to do so, presently we have applied three different techniques to collect user data. In the first technique, we annotated 4500 V1+V2 sequences, along with their example sentences, using a group of three linguists (the expert subjects). We asked the experts to classify the verb sequences into three classes namely, *CV*, *not a CV* and *not sure*. Each linguist has received 2000 verb pairs along with their respective example sentences. Out of this, 1500 verb sequences are unique to each of them and rest 500 are overlapping. We measure the inter annotator agreement using the Fleiss Kappa (Fleiss et al., 1981) measure (κ) where the agreement lies around 0.79. Next, out of the 500 common verb sequences that were annotated by all the three linguists, we randomly choose 300 V1+V2 pairs and presented them to 36 native Bangla speakers. We ask each subjects to give a compositionality score of each verb sequences under 1-10 point scale, 10 being highly compositional and 1 for noncompositional. We found an agreement of κ=0.69 among the subjects. We also observe a continuum of compositionality score among the verb sequences. This reflects that it is difficult to classify Bangla verb sequences discretely into the classes of *CV* and *not a CV*. We then, compare the compositionality score with that of the expert user's annotation. We found a significant correlation between the expert annotation and the compositionality score. We observe verb sequences that are annotated as CVs (like, খেয়ে ফেল )করে নে ,ওঠে পড় ,have got low compositionality score (average score ranges between 1-4) on the other hand high compositional values are in general tagged as *not a cv* (নিয়ে যা (*come and get*), ফিরে আয় (*return back*), তুলে রেখেছি (*kept*), গড়িয়ে পড়ল (*roll on floor*)). This reflects that verb sequences which are not CV shows high degree of compositionality. In other words non CV verbs can directly interpret from their constituent verbs. This leads us to the possibility that compositional verb sequences requires individual verbs to be recognized separately and thus the time to recognize such expressions must be greater than the non-compositional verbs which maps to a single expression of meaning. In order to validate such claim we perform a lexical decision experiment using 32 native Bangla speakers with 92 different verb sequences. We followed the same experimental procedure as discussed in (Taft, 2004) for English polymorphemic words. However, rather than derived words, the subjects were shown a verb sequence and asked whether they recognize them as a valid combination. The reaction time (RT) of each subject is recorded. Our preliminarily observation from the RT analysis shows that as per our claim, RT of verb sequences having high compositionality value is significantly higher than the RTs for low or non-compositional verbs. This proves our hypothesis that Bangla compound verbs that show less compositionality are stored as a hole in the mental lexicon and thus follows the full-listing model whereas compositional verb phrases are individually parsed. However, we do believe that our experiment is composed of a very small set of data and it is premature to conclude anything concrete based only on the current experimental results.

## 5 Future Directions

In the next phase of our work we will focus on the following aspects of Bangla morphologically complex words:

**The Word Familiarity Effect:** Here, our aim is to study the role of familiarity of a word during its processing. We define the familiarity of a word in terms of corpus frequency, Age of acquisition, the level of language exposure of a person, and RT of the word etc.

**Role of suffix types in morphological decomposition:** For native Bangla speakers which morphological suffixes are internalized and which are just learnt in school, but never internalized. We can compare the representation of Native, Sanskrit derived and foreign suffixes in Bangla words.

**Computational models of organization and processing of Bangla compound verbs:** presently we have performed some small set of experiments to study processing of compound verbs in the mental lexicon. In the next phase of our work we will extend the existing experiments and also apply some more techniques like, crowd sourcing and language games to collect more relevant RT and compositionality data. Finally, based on the collected data we will develop computational models that can explain the possible organizational structure and processing mechanism of morphologically complex Bangla words in the mental lexicon.

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