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COMMUNICATION AND COGNITION: MULTIDISCIPLINARY PERSPECTIVES

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II

Syntax

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AN INFORMATION THEORETIC ACCOUNT OF KOREAN PASSIVE ALLOMORPHS

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Abstract. The morphological passive construction in Korean is derived from the concatenation of a lexically specified verb and one of the four allomorphs, -*i*-, -*hi*-, -*li*-, and -*ki*-. For example, the morphological passive form of *cha*- 'to kick' is *cha-i*- 'to be kicked', but not **cha-hi*-, **cha-li*-, or **cha-ki*-. There have been controversies over how to account for the selectional restriction of a lexically specified verb on the four allomorphs. I propose an account of the allomorphic alternation of the morphological passive construction in terms of information theory. Given a proper representation of the lexical passive verb and passive morpheme, correct selection of a passive allomorph can be induced by information capacity measured as entropy, a quantifiable measure of uncertainty. This approach to the morphological passive construction implies that a combination of linguistic representation and stochastic rule induction learning might be operative in the allomorphic realization of morphological passive construction in Korean. [1]

Keywords: Korean, morphological passive construction, passive allomorphs, Information Theory, entropy, information gain

Languages: Korean

This paper proposes an information theoretic account of allomorphic alternations in the Korean morphological passive construction (Shannon 1948; Quinlan 1986, 1990). There are two types of passive construction in Korean: one is a syntactic passive construction and the other is a morphological passive construction.[2]

The syntactic passive construction in (2) is derived from the active counterpart in (1). It consists of the form of 'verbal stem -{*e*, *a*}-*ci'*, where -*e*- and -*a*- are infinitive endings, and -*ci*- ('become') is an auxiliary verb.

(1)	John-i	Mary-lul	elkwul-ul	kuli-ess-ta.
	John-NOM	Mary-ACC	face-ACC	draw-PAST-DEC

'John drew Mary's face.'

(2)	Mary-ka	John-eyeuyhaese	elkwul-i/*ul	kuli-e-ci-ess-ta
	Mary-NOM	John-by	face-NOM/*ACC	draw-e-PASS-PAST-DEC

'Mary's face was drawn by John.'

1 Earlier versions of the present paper were presented at the MOT (Montreal-Ottawa-Toronto) Phonology Workshop (March 2010) and the Workshop on Korean Linguistics: In Honor of Chin-Woo Kim (May 2006) at the University of Illinois at Urbana-Champaign. I am grateful to Elizabeth Hume, Ivona Kucerova, Chin-Woo Kim, Jennifer Cole, James Yoon, Chilin Shih, and Richard Sproat for discussion.

2 Lexicalized passive forms also exist in Korean such as *macta* 'be hit' (cf. the active counterparts *chita* and *ttaylita* 'hit').

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The morphological passive construction exemplified in (3-6) is derived by concatenating a lexically specified verb and one of the four allomorphs, *-i-*, *-hi-*, *-li-*, and -ki-. Only one of the four allomorphs is allowed, depending on the type of the verb.

(3)	John-i	Mary-eykey	tali-ka/lul	cha-i/*hi/*li/*ki-ess-ta
	John-NOM	Mary-by	leg-NOM/ACC	kick-PASS-PAST-DEC
	'John was kicked in the leg by Mary.'			
(4)	Mary-ka	John-eykey	son-i/ul	cap-hi/*i/*li/*ki-ess-ta
	Mary-NOM	John-by	hand-NOM/ACC	catch-PASS-PAST-DEC
	'Mary was caught by the hand by John.'			
(5)	Mary-ka	kay-eykey	tali-ka/lul	mul-li/*i/*hi/*ki-ess-ta
	Mary-NOM	dog-by	leg-NOM/ACC	bite-PASS-PAST-DEC
	'Mary was bitten on the leg by a dog.'			
(6)	John-i	Mary-eykey	meli-ka/lul	kam-ki/*i/*hi/*li-ess-ta
	John-NOM	Mary-by	hair-NOM/ACC	wash-PASS-PAST-DEC
	'John had his hair washed by Mary.'			

Regarding the morphologically passive constructions, there have been different approaches that attempt to account for the selection of a proper passive allomorph by a lexically specified verb.

In this paper, I focus on the morphological passive construction and propose an alternative to the selection of passive allomorphs under the framework of Information Theory (Shannon 1948). Earlier approaches to the allomorphic alternation of the passive morpheme include:

(i) Derivation of the proper allomorph from an underlying form (C-W. Kim 1973; Bak 1982; Y.-S. Kim 1984)

(ii) Positing allomorphy rules under the framework of Lexical Phonology (Ahn 1985; Ahn 1996; cf. Kiparsky 1982, 1985)

(iii) An Optimality Theoretic account of the allomorphic alternation using constraint ranking (Ahn 1997; Kang 1997; cf. McCarthy & Prince 1993; Prince & Smolensky 1993)

(iv) Listing verb-allomorph pairs in the lexicon (Cho 1986)

There is a rather stark contrast between approaches (i-iii) and approach (iv). The first three approaches postulate rules or constraints, whereas the last approach requires every verb-allomorph pair to be listed in the lexicon. The existence of exceptional patterns is problematic for the rule or constraint-based approaches in (i-iii). In general, the stem-final syllable coda is the conditioning factor that is crucial to the selection of the allomorphs in Korean passive morphology. For example, Ahn (1996) claims that several allomorphy rules can predict most cases of lexical suffixation for passives. Below I give the distribution of each of the four allomorphs and the rules proposed in Ahn (1996) for the passive allomorph distribution:

The distribution of *-ki-* is formalized with the allomorph rule in (7):

(7) [PASS] → *ki* / [+CONS, -PLOSIVE, -LATERAL] + ___________

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The rule in (7) states that -*ki*- in Korean occurs after the stem-final -(l)m-, -n(h)-, -*s*-, -*t*-, and -*c*-. Examples include *kam-ki-ta* 'be wound', *salm-ki-ta* 'be boiled', *an-ki-ta* 'be hugged', and *s'is-ki-ta* 'be washed.'

The distribution of -*hi*- is formalized with the allomorph rule in (8):

(8) [PASS] → *hi* / [-CONT, -TENSE] + _____

In (8), -*hi*- is attached to a verb which ends with a consonant which can be aspirated, i.e., [-TENSE] (C.-W. Kim 1973). There are examples such as *mak-hi-ta* 'be blocked', *kat-hi-ta* 'be locked', and *p'op-hi-ta* 'be pulled out'.

The allomorph rule in (9) accounts for the distribution of -*li*-:

(9) [PASS] → *li* / [+LATERAL] + _____

In (9), -*li*- appears after a verbal stem which ends with an [*l*] on the phonetic level. That is, -*li*- always appears after an -*l*- but this *l* can be either an underlying or a derived form, e.g., *kal-li-ta* 'be ground', *nal-li-ta* 'be blown off', *t'ulh-li-ta* [*t'ullida*] 'be passed'.

Finally, the distribution of -*i*- is accounted for with the allomorph rule in (10):

(10) [PASS] → *i* elsewhere

The rule in (10) provides -*i*- in cases which are not covered by the allomorphy rules for -*ki*-, -*hi*-, and -*li*- suffixation. Examples include *k'i-i-ta* 'be inserted', *noh-i-ta* 'be locked', *k'a-i-ta* 'be cut', *halt^h-i-ta* 'be licked', and *təp^h-i-ta* 'be covered'

As noted in Ahn (1996), there are exceptions to this generalization: The environment of -*ki*- (i.e. the stem final -*t*- and -*c*-) overlaps with that of -*hi*-, as shown in (11) and (12). Despite the identical segments in the syllable coda of the verbal stem, different allomorphs are chosen (Ahn (1996)).

(11) *töt-ki-ta* 'be picked' *c'oc-ki-ta* 'be chased' *c'ic-ki-ta* 'be torn'

(12) *tat-hi-ta* 'be closed' *mεc-hi-ta* 'be tied'

Ahn (1996) states that it is necessary to list a few exceptional cases in the lexicon. Mere listing of the verb-allomorph pairs in the lexicon does not raise any problem with these exceptional patterns, but the listing approach suffers from lack of generalization.

1. AN INFORMATION THEORETIC ACCOUNT. I propose an Information-Theoretic account of the allomorphic alternation in the Korean morphological passive construction using such quantifiable measures as entropy, conditional entropy, information gain, and decision trees (Shannon 1948; Quinlan 1986, 1993). Given the proper representation of lexically-specified passive verbal stems and passive allomorphs, general rules which select a correct allomorph to a given passive verbal stem can be induced. Information capacity measured as entropy, conditional entropy and information gain (Shannon 1948; Quinlan 1986, 1993) is used to convert the observed patterns into rules via a decision tree using iterative decision criteria (Quinlan 1986). A measure of entropy calculated over observed data is used to capture the generalization which approaches (i-iii) are designed to capture, but also properly handle the seemingly

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exceptional patterns in (11) and (12). In the following, I will introduce the concepts of entropy, and information gain, respectively.

1.1. Entropy and conditional entropy as measures of uncertainty. As noted in Hall (2009), predictability of distribution is crucial in establishing phonological relations. Information Theory (Shannon 1948) provides quantifiable tools that enable us to measure the degree of predictability. That is, entropy is used as a measurement that quantifies predictability or uncertainty. The concept of entropy is not new and has long been recognized and used in the study of languages, including computational linguistics (Jurafsky & Martin 2000), historical linguistics (Juola 1998), psycholinguistics, e.g. word segmentation (Brent & Cartwright 1996), phonology (Hume 2008; Hall 2009), and morphology (Malouf & Ackerman 2010), among others[3]. When used in phonological relations, entropy can provide a way of formally describing and comparing even those phonological relationships which have been treated as "exceptions, ignored, relegated to alternative grammars, or otherwise seen as problematic for traditional descriptions of phonology." (Hall 2009)

Entropy is defined as the weighted average of uncertainty for all possible outcomes (x's) of a random variable (X), as in (13):

(13) $$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

In (13), ***p(x)*** is the probability that the outcome is ***x***, and ***–log p(x)*** is how uncertain we would be if the outcome were ***x*** (Malouf 2009). Entropy can be interpreted in a number of different ways (Malouf 2009): (i) the average number of bits required to store the value of ***X***; (ii) the average number of yes-or-no questions that one would have to ask to guess the value of ***X***; or (iii) the expected value of the surprisal for each possible value.

I will illustrate how to calculate and interpret the entropy of a binary event. If an event occurs with the probability of either ***1*** or ***0***, the entropy is at its minimum (i.e. ***0***), and thus the event is highly predictable. In other words, you are absolutely certain of the outcome of the event. If an event occurs with probability of ***0.5***, the entropy is at its maximum (i.e. ***1***), and thus the event is highly unpredictable. In other words, you are quite uncertain of the outcome of the event.

As a concrete example, let us consider the entropy in the Russian noun declension paradigm (14), which is taken from Malouf &Ackerman (2010).

[3] The most common use of entropy in phonology is nicely summarized in Hall (2009: p. 104): "Entropy is commonly used as a means of (1) determining the number of features or other units needed to convey a linguistic message, (2) measuring the relative work done by (i.e., the functional load of) different contrasts in a language, (3) conducting phonological classification for the purpose of automatic speech recognition, (4) learning phonological models, (5) quantifying the notion of phonological markedness and thus predicting certain phonological processes and changes, and (6) quantifying the choice between two sounds in a single phonological environment, rather than the choice among sounds in the entire set of phonological entities."

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Nom.pl.	Acc.pl.	Gen.pl.	Dat.pl.	Loc.pl.	Inst.pl.	
*del-**a***	*del-**a***	*del*	*del-am*	*del-ax*	*del-am'i*	'business'
*zavod-**i***	*zavod-**i***	*zavod-**ov***	*zavod-am*	*zavod-ax*	*zavod-am'i*	'factory'
*stran-**i***	*stran-**i***	*stran*	*stran-am*	*stran-ax*	*stran-am'i*	'country'
*gvozd'-**i***	*gvozd'-**i***	*gvozd'-**ej***	*gvozd'-am*	*gvozd'-ax*	*gvozd'-am'i*	'nail'

Table 1. Russian noun declension (adapted from Malouf & Ackerman (2010))

Some cells in the paradigm in Table 1 contain more than one suffix type, and other cells contain a single suffix. Information Entropy for each cell is given in (14-16), and the number of bits indicates degree of uncertainty associated with the suffixes in this paradigm:

(14) $$H(\text{Nom.pl.}) = H(\text{Acc.pl.}) = -(\frac{1}{4}\log_2\frac{1}{4} + \frac{3}{4}\log_2\frac{3}{4}) = 0.81 \text{ bit}$$

(15) $$H(\text{Dat.pl}) = H(\text{Loc.pl}) = H(\text{Inst.pl.}) = -(\frac{4}{4}\log_2\frac{4}{4}) = 0 \text{ bit}$$

(16) $$H(\text{Gen.pl.}) = -(\frac{2}{4}\log_2\frac{2}{4} + \frac{1}{4}\log_2\frac{1}{4} + \frac{1}{4}\log_2\frac{1}{4}) = 1.5 \text{ bits}$$

Allomorphic relations between verbal stems and passive allomorphs can best be modeled using conditional entropy. Conditional entropy is the uncertainty in one random variable on average (i.e. ***Y***), given the knowledge of another random variable (i.e. ***X***), as defined in (17):

(17) $$H(Y \mid X) = -\sum_{x \in X} P(x) \sum_{y \in Y} P(y \mid x) \log_2 (y \mid x)$$

Once again let us consider the example from the Russian noun declension in Table 1. If we know that the suffix indicating the nom.pl. is *–a*, then we know with certainty that the null suffix indicates gen.pl. The calculated conditional entropy of ***0*** bit in (18) fits our intuition:

(18) $$H(\text{gen.pl.} \mid \text{nom.pl.} = -\text{a}) = -(\frac{1}{1}\log_2\frac{1}{1}) = 0 \text{ bit}$$

Conditional entropy can be applied to modeling the Korean morphological passive construction. In particular, I argue that the conditional entropy value of the four allomorphs can be calculated, based on the type of stem-final syllable coda. This is based on the assumption that if the stem-final syllable coda plays a crucial role in selecting passive allomorphs, we would expect very low conditional entropy values.

2. Information theoretic modeling of Korean passive allomorphs.

2.1. Data and feature representation. Data used in this experiment are taken from Ahn (1996), who compiled the list based on three Korean dictionaries. A total of 148 morphological passive items are used in this experiment. Table 2 illustrates the feature representation: onset, nucleus, and coda of the final syllable in the passive verbal stem are hand-coded, along with the target attribute of 4 types of passive allomorphs.

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Stem-final Syllable			Passive
Onset	Nucleus	Coda	
k’	a	k	**i**
k	ε	ø	**i**
p	o	k’	**i**
k	ə	t	**hi**
p’	o	p	**hi**
k	a	l	**li**
k’	ö	l	**li**
c’	o	c	**ki**
c’	i	c	**ki**
t’	ö	t	**ki**
t	a	m	**ki**
…	…	…	…

Table 2. Example of feature representation (ø is used for empty slots in the syllable.)

Based on the feature representation in Table 2, the conditional entropy for each verbal stem for an allomorph is calculated. The conditional entropy calculation for each allomorph is done starting from the verb final segment and then moving to the preceding segments in the stem. When the conditional entropy of the final segment in the verbal stem is not ***0***, a decision is made to split the data into smaller sets, and a new entropy value is calculated by moving to the preceding column in the feature matrix. This approach to the morphological passive construction assumes that a combination of linguistic representation, such as syllable structure, and stochastic rule induction learning will be operating together in realizing allomorphs in the Korean morphological passive construction.

Table 3 shows the conditional entropy of the stem-final syllable coda conditioned by four types of passive allomorphs. When entropy approaches zero, the outcome is highly certain. As entropy increases, the uncertainty increases as well.

Coda	Allomorph	Frequency	Probability	Entropy
p	hi	12	0.0810	0.0
t	hi or ki	6	0.0405	**0.6500**
c	hi or ki	5	0.0337	**0.9709**
k	hi	8	0.0540	0.0
s	ki	2	0.0135	0.0
h	ki	2	0.0135	0.0
k’	ki	7	0.0472	0.0
ph	i	2	0.0135	0.0
th	i	1	0.0067	0.0
l	li	56	0.3783	0.0
m	ki	3	0.0202	0.0
n	ki	1	0.0067	0.0
nc	ki	1	0.0067	0.0
nh	ki	1	0.0067	0.0
lp	hi	2	0.0135	0.0
lk	hi	4	0.0270	0.0
lth	hi	1	0.0067	0.0
lm	ki	2	0.0135	0.0

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Coda	Allomorph	Frequency	Probability	Entropy
lh	li	2	0.0135	0.0
ø	i	30	0.2027	0.0

Table 3. Allomorph conditional entropy with frequency, probability for stem-final coda

In Table 3, the conditional entropy value in the syllable coda of the verbal stem appears to be informative, since most codas have zero entropy values. It is also evident that uncertainty occurs when the coda of the stem-final syllable is either -*t* or -*c*, as the two non-zero entropy values illustrate.

Table 4 shows the calculated measures of average conditional entropy based on the position in the last syllable. Again, most passive allomorphs are associated undoubtedly on the basis of the coda of the stem-final syllable.

	Onset	Nucleus	Coda
Conditional Entropy	1.3291	1.5274	0.0591

Table 4. Conditional entropy average values for stem-final syllable positions input feature

Because of the uncertainty in cases where the stem-final syllable coda is either -*t* or -*c*, we need to consider other syllable positions to find out whether the other positions will help resolve the ambiguity regarding the selection of the passive allomorphs. A general method exists that chooses the least uncertain feature value from the input feature matrix. This method is called **information gain** (Quinlan 1986). The formula for computing the information gain is given in (20):

(20) $$\text{Gain}(X,A) = H(X) - \sum_{v \in A} \frac{|X_V|}{|X|} H(X_V)$$

Information gain is computed as the difference between degrees of uncertainty in the whole features and the weighted summation of degrees of uncertainty in the subset features. The weight is based on the number of records for each attribute value.

Table 5 shows the computed values of information gain from the input feature matrix, together with average entropy and conditional entropy:

	Onset	Nucleus	Coda
Entropy	1.8434	1.8434	1.8434
Conditional Entropy	1.3291	1.5274	0.0591
Information Gain	0.5143	0.3159	**1.7842**

Table 5. Average entropy, conditional entropy, and information gain of the input feature matrix of the Korean morphological passive construction.

The stem-final syllable coda reveals the lowest value of conditional entropy and the highest value of information gain.

As noted above, despite the highest degree of information gain in the stem-final syllable coda, a certain degree of uncertainty still exists when the coda is either -*t*- or -*c*-. Tables 6 and 7 present the full list of all possible morphological passive forms when the stem-final syllable coda is -*t*-, and when the stem-final syllable coda is -*c*-, respectively. We use these data to calculate what the uncertainty (or entropy) value would be when the coda is -*t*- or -*c*-.

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Onset	Nucleus	Coda	Passive
p	a	t	**hi**
t	a	t	**hi**
k	a	t	**hi**
k’	ə	t	**hi**
m	u	t	**hi**
t	ö	t	**ki**

Table 6. Possible morphological passive forms when the coda is -t-

Onset	Nucleus	Coda	Passive
k’	o	c	**hi**
t	i	c	**hi**
c’	o	c	**ki**
s’	i	c	**ki**
c’	i	c	**ki**

Table 7. Possible morphological passive forms when the coda is -c-

When the coda is -*t*- or -*c*-, one of the remaining feature vectors, i.e., either nucleus or onset, is expected to produce the lowest entropy value. Iterative decision criteria will be used to select a feature vector with the lowest entropy value. As shown in Table 8, it turns out that when the syllable coda is -*t*-, the nucleus gives rise to the lowest entropy of ***0***. Thus, no further disambiguation is needed.

Nucleus	Frequency	Probability	Entropy
a	3	0.6	0.9182
u	2	0.4	1.0
ö	1	0.166	0.0
ə	1	0.166	0.0

Table 8. Entropy of stem-final syllable nucleus when the stem-final syllable coda is -t-

When the syllable coda is -*c*-, the syllable nucleus is not informative enough, as shown in Table 9. Therefore, when the syllable coda is -*c*-, it is necessary to consider the entropy value of the syllable onset, as in Table 10.

Nucleus	Frequency	Probability	Entropy
i	3	0.6	0.9182
o	2	0.4	1.0

Table 9. Entropy of stem-final syllable nucleus when the stem-final syllable coda is -c-

Table 10 shows that the entropy values in the syllable onset can be used to settle down the ambiguity between -*hi*- and -*ki*-.

Onset	Frequency	Probability	Entropy
t	1	0.2	0.0
c’	2	0.4	0.0
k’	1	0.2	0.0
s’	1	0.2	0.0

Table 10. Entropy of stem-final syllable onset when the stem-final syllable coda is -c-

3. CONCLUSION. I have described the morphological passive construction in Korean and presented two broadly defined previous approaches for explaining its al-

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lomorphy. One type of approach derives the passive allomorphs through rules or constraints, while the other approach lists all the allomorphs and stem pairs in the lexicon. These two approaches suffer from the existence of exceptional patterns, i.e. a lack of generality. The approach taken in this paper utilizes quantifiable measures such as entropy, conditional entropy, information gain, and a recursive rule induction mechanism. These quantified measures successfully induce a general pattern that earlier rule or constraint-based approaches attempted but failed to capture (e.g. C.-W. Kim 1973, Ahn 1985, Ahn 1997). Furthermore, by extending the local context from the stem-final syllable coda to other syllable positions in the verbal stem (i.e. syllable nucleus and syllable onset), the approach can also account for the seemingly exceptional patterns. Thus, rule induction through quantifiable measures is used effectively in understanding the full scope of the passive allomorphic alternation in Korean.

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