DERIVING GLOBAL PARADIGM OPTIMIZATION IN JAPANESE VOICE FROM CONSTRAINT INTERACTION

SHIN-ICHIRO SANO
International Christian University

1 Introduction

In the grammatical category voice in Japanese, an overall change reorganizing the conjugation paradigm is currently underway. The process includes three variations: sa-Insertion, ra-Deletion and re-Insertion. This paper aims to construct a model of the change in light of Probabilistic OT (Boersma and Hayes 2001; Goldwater and Johnson 2003, among others), employing a large-scale corpus. The corpus employed is the Corpus of Spontaneous Japanese (Maekawa 2004, henceforth CSJ), which has rich annotations. First, I characterize the chronological change of the distribution of each phenomenon based on the observed data. Secondly, I formalize the changes in OT terms; in turn, I model and predict the change within the framework of Probabilistic OT. The results show that the gradient approximation of the ranking values of each constraint caused the emergence and the gradual increase of three innovative forms and that the overall change in voice can be explained by the interaction of a small set of constraints.

2 Background

In this section, I outline some key concepts of the present research. In Section 2.1, I describe three variations in Japanese voice marking. Section 2.2 introduces Maximum Entropy OT.

2.2 Variants

2.2.1 Sa-Insertion

Sa-Insertion is a variant of causative constructions in Japanese (Okada 2003; Sano 2011). Causatives in Japanese are formed by attaching causative suffixes to verb stems. Japanese verbs
are classified into two types, according to the stem-ending. One type is a consonant verb which ends in a consonant (e.g. nom- ‘drink’, ik-‘go’), and the other type is a vowel verb which ends in a vowel (e.g. tabe- ‘eat’, mi- ‘see’) (Bloch 1946); sa-Insertion is restricted to consonant verbs. The traditional variant of causatives for consonant verbs (henceforth, sa-TV), comprises the verb stem and the causative suffix –ase, yielding single causative constructions; on the other hand, sa-Insertion, which is the innovative variant, comprises the verb stem and the causative suffixes -as and -ase, yielding double causative constructions, as exemplified in (1).

(1) Happyoo-o owar-as-ase-te-itadakimasu.

presentation-ACC finish-CAUS-CAUS-TE-AUX.POL.NONP

‘Let me finish (my) presentation.’ (polite) (A04M0229)

Compared to sa-TV, sa-Insertion involves an extra causative suffix -as. This is the crucial difference between these two variants. Importantly, the meaning of sa-Insertion is honorific, rather than causative (Okada 2003).

2.2.2 Ra-Deletion

Ra-Deletion is a variation of potential constructions in Japanese (Matsuda 1993). Potentials in Japanese are formed by attaching the potential suffix -rare to verb stems. Ra-Deletion is restricted to vowel verbs. The traditional variant of potentials for vowel verbs (henceforth, ra-TV) comprises the verb stem and the potential suffix -rare; in contrast, ra-Deletion, which is the innovative variant, comprises verb stem and -re, which is a reduced form of the potential suffix -rare. I present below an example of ra-Deletion;

(2) Oishii mono-ga tabe-re-ru

delicious stuff-ACC eat-POT-NONP

‘(We) can eat delicious foods.’ (S00M0002)

Ra-Deletion is regarded as a segmental reduction within a single suffix, as the segments ra are deleted. Crucially, the meaning of ra-Deletion is restricted to potential, although the suffix -rare can have four meanings: potential, passive, honorific, or spontaneous.

2.2.3 Re-Insertion

Similar to ra-Deletion, re-Insertion is a variant of potential constructions in Japanese (Inoue and Yarimizu 2002). Re-Insertion is predominantly observed in consonant verbs. The traditional variant of potentials for consonant verbs (henceforth, re-TV) comprises the verb stem and the potential suffix -e, yielding single potential constructions; on the other hand, re-Insertion, which

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1 The alphanumeric character annotated to the end of each example (A04M0229) is the ‘speech ID’ that is used as the index of each speech. In each speech ID, a leading character ‘A’ indicates that a particular speech is classified into academic presentation speech (APS), ‘S’ simulated public speaking (SPS), ‘R’ readings, ‘D’ dialogs, or ‘M’ other. For the letter in the middle, ‘M’ indicates that the speaker of a particular speech is male, and ‘F’, female.
is the innovative variant, comprises the verb stem and the potential suffixes \(-e\) and \(-re\), yielding double potential constructions as shown below.

(3) Soko-de sum-e-re-tara
    there-LOC live-POT-POT-COND.PAST
    ‘If (I) can live there.’

Similar to \textit{sa}-Insertion, \textit{re}-Insertion contains an extra potential suffix \(-re\). In this sense, \textit{sa}-Insertion and \textit{re}-Insertion are regarded as examples of morpheme insertions. Importantly, the meaning of \textit{re}-Insertion is strong potential (Inoue and Yarimizu 2002).

2.2 Maximum Entropy OT

Maximum Entropy OT (Goldwater and Johnson 2003, among others; henceforth MaxEnt OT) is a log-linear model that calculates a probability distribution over the candidate set, where the strength of each constraint is represented as the parameter \textit{weight}. The probability of a candidate is proportional to the exponential of its Harmony score. The model searches for the least biased distribution that has the highest entropy. MaxEnt OT is accompanied by a learning algorithm: Stochastic Gradient Ascent (SGA), that is frequently used in machine learning. SGA estimates the weights of each constraint based on (i) the OT grammar that specifies input-output pairs, constraints and violation profiles, and (ii) the learning data (observed frequency distribution); SGA in turn generates the distribution of variants based on the model.

3 Summary of the Data

An exhaustive examination of CSJ brought forth a total of 13,375 innovative and traditional forms. The distribution of three variants is summarized in Table 1.\footnote{For more information about the procedure and the criteria for data extraction as well as the sociolinguistic properties of each variant, see Sano (2011).}

<table>
<thead>
<tr>
<th>Variant</th>
<th>Frequency</th>
<th>Variant</th>
<th>Frequency</th>
<th>Variant</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textit{sa}-Insertion</td>
<td>42</td>
<td>\textit{ra}-Deletion</td>
<td>543</td>
<td>\textit{re}-Insertion</td>
<td>20</td>
</tr>
<tr>
<td>\textit{sa}-TV</td>
<td>1,498</td>
<td>\textit{ra}-TV</td>
<td>7,615</td>
<td>\textit{re}-TV</td>
<td>3,657</td>
</tr>
</tbody>
</table>

| Rate of \textit{sa}-Insertion (%) | 2.73 | Rate of \textit{ra}-Deletion (%) | 6.66 | Rate of \textit{re}-Insertion (%) | 0.54 |

Among these three variants, \textit{ra}-Deletion is enormous in token frequency and the rate of \textit{ra}-Deletion is relatively high. This again shows that the change of \textit{ra}-Deletion is well under way. The token frequency of \textit{re}-Insertion, conversely, is remarkably small and the rate of \textit{re}-Insertion is quite low. The token frequency and the rate of \textit{sa}-Insertion are in between.

At this point, I illustrate chronological changes of the three variants in Figure 1, where rates for each variant are sorted according to the birth-year of the speakers (grouped every ten years).
As Figure 1 shows, the rate of ra-Deletion is consistently the highest, the rate of re-Insertion is the lowest, and the rate of sa-Insertion is intermediary, across every birth-year. In terms of the slopes of each approximated line, the rate of ra-Deletion shows a steep ascent; the rate of re-Insertion shows a smooth one; the rate of sa-Insertion takes an intermediate position.

On the assumptions that the change spreads gradually and that the rates of each innovative form reflect the degree of progression (the higher the rate of an innovative form, the more advanced the change), the order of the change of each variation would be as follows: ra-Deletion > sa-insertion > re-Insertion. This is consistent with the claims of previous studies: ra-Deletion was first observed at the end of the 19th century, sa-Insertion in 1947, and re-Insertion at the end of the 20th century (Matsuda 1993; Inoue and Yarimizu 2002; Sano 2011, among others).

4 Standard OT Analysis

As preliminaries to the probabilistic OT analysis, I first analyze each variant within the standard OT framework. The following four constraints play a crucial role in the evaluation: OCP (morph) and MAX-IO are against innovative forms, while ALLOCORR and PARCONTRAST are in favor of innovative forms. In this research, I assume that inputs consist of a verb stem and a set of morphemes that are to be phonologically spelled out in the output such as yar-ase or tabe-rare.

4.1 Blocking of Double Causative/Potential

Sa-Insertion is a double causative containing two causative suffixes, while sa-TV is a single causative (Okada 2003). Traditionally, the double causative is not allowed in Japanese, and one of the causative suffixes is suppressed, yielding a single causative (Shibatani 1973). As a result, the double causative and single causative surface as identical forms: the single causative. Likewise, re-Insertion is a double potential containing two potential suffixes (Inoue and
Yarimizu 2002); in contrast, re-TV is a single potential. Based on these observations, I firstly introduce the constraint Obligatory Contour Principle (morph).\(^3\)

(4) OCP (morph):
No identical morphological categories are adjacent.

OCP (morph) blocks the occurrence of adjacent identical morphemes. I show how the double causative/potential is suppressed to a single causative/potential in terms of OCP (morph).\(^4\)

\[
\begin{array}{|l|l|}
\hline
\text{Input: /nom-as-ase/} & \text{OCP (morph)} \\
\hline
a. no.ma.sa.se & (sa-Insertion) !
\hline
\end{array}
\]

\[
\begin{array}{|l|l|}
\hline
\text{Input: /nom-e-re/} & \text{OCP (morph)} \\
\hline
a. no.me.re & (re-Insertion) !
\hline
\end{array}
\]

As shown in (5) and (6), both sa-Insertion (5a) and re-Insertion (6a) are blocked by OCP (morph), as these are double causative/potential forms containing two adjacent identical suffixes. Thus, OCP (morph) is shown to be against these two innovative forms.

### 4.2 Blocking of Segment Deletion

As I mentioned above, ra-Deletion is regarded as a segmental reduction of the potential suffix within a single morpheme, and accordingly MAX-IO comes into play.

(7) MAX-IO
Every segment in the I(nput) has a correspondent in the O(utput). (No deletion)

MAX-IO bars the deletion of segments. Here I show the evaluation of ra-Deletion in terms of MAX-IO. In (8), ra-Deletion, where the segments ra are deleted, is blocked by MAX-IO incurring two violations, showing that MAX-IO is against the innovative form.

\[
\begin{array}{|l|l|}
\hline
\text{Input: /tabe-rare/} & \text{MAX-IO} \\
\hline
a. tabe-re & (ra-Deletion) **!
\hline
\end{array}
\]

\[
\begin{array}{|l|l|}
\hline
\text{Input: /nom-as-ase/} & \text{MAX-IO} \\
\hline
a. no.ma.sa.se & (sa-Insertion) *
\hline
\end{array}
\]

\[
\begin{array}{|l|l|}
\hline
\text{Input: /nom-e-re/} & \text{MAX-IO} \\
\hline
a. no.me.re & (re-Insertion) *
\hline
\end{array}
\]

\[
\begin{array}{|l|l|}
\hline
\text{Input: /tabe-rare/} & \text{MAX-IO} \\
\hline
a. tabe-re & (ra-Deletion) **!
\hline
\end{array}
\]

---

\(^3\) The Obligatory Contour Principle (OCP), which bars consecutive identical features, was originally proposed by Leben (1973).

\(^4\) Although other constraints such as IDENT-IO, ONSET, NOCODA, and ALIGN-MORPH-L come into play in determining the phonological shapes of sa-Insertion, ra-Deletion, and re-Insertion in conformity with the CV structure of Japanese, I omit integrated evaluations with constraints of this kind due to limitations of space.
4.3 Analogical Leveling

Traditionally, the causative suffix and the potential suffix in Japanese show allomorphy: these suffixes undergo morphological alternations according to the verb types to which they attach, i.e. either consonant verbs or vowel verbs. Each innovative form plays a role in eliminating allomorphy via analogical leveling. To capture analogical leveling in OT terms, I introduce the constraint ALLOCORR. ALLOCORR is categorized as an OO-correspondence constraint (Benua 1997, among others), as it compares and evaluates multiple output forms in a single tableau, unlike the constraints in the IO family.

(9) ALLOCORR (Allomorph Correspondence, Ito and Mester 2004):
Morphs in a relation of allomorphy are identical.

ALLOCORR evaluates identity between forms within paradigms with respect to segments, and it requires allomorphs to take identical form. First, I show the evaluation of sa-Insertion.5

<table>
<thead>
<tr>
<th>Candidate paradigms for /nom-/ and /tabe-/</th>
<th>ALLOCORR</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. consonant verb: no.ma.sa.se</td>
<td>(sa-Insertion)</td>
</tr>
<tr>
<td>vowel verb: ta.be.sa.se</td>
<td>(sa-TV)</td>
</tr>
<tr>
<td>b. consonant verb: no.ma.se</td>
<td>(sa-TV)</td>
</tr>
<tr>
<td>vowel verb: ta.be.sa.se</td>
<td>***!</td>
</tr>
</tbody>
</table>

Paradigm (a), which includes sa-Insertion, shows no allomorphy: both the consonant verb and the vowel verb uniformly take the causative suffix -sase, while paradigm (b), which consists exclusively of sa-TV, shows the allomorphy: the consonant verb takes -se, while the vowel verb takes -sase, and three segments do not have identical segments as their counterparts, resulting in three violations of ALLOCORR. Thus, sa-Insertion is more compatible with ALLOCORR.

<table>
<thead>
<tr>
<th>Candidate paradigms for /nom-/ and /tabe-/</th>
<th>ALLOCORR</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. consonant verb: no.me</td>
<td>(ra-Deletion)</td>
</tr>
<tr>
<td>vowel verb: ta.be.re</td>
<td>(ra-TV)</td>
</tr>
<tr>
<td>b. consonant verb: no.me</td>
<td>(ra-TV)</td>
</tr>
<tr>
<td>vowel verb: ta.be.ra.re</td>
<td>****!</td>
</tr>
</tbody>
</table>

Next, I illustrate the evaluation of ra-Deletion. In (11), paradigm (a), which includes ra-Deletion, shows less allomorphy: the vowel verb takes -re; on the other hand, the consonant verb does not, and two segments do not have identical segments as their counterparts, resulting in two violations of ALLOCORR. In contrast, paradigm (b), which consists exclusively of ra-TV, shows the allomorphy: the vowel verb takes -rare, while the consonant verb does not, and four segments do not have identical segments as their counterparts, resulting in two violations of ALLOCORR. Thus, ra-Deletion is also shown to be more compatible with ALLOCORR.

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5 In what follows, I conduct the evaluation by ALLOCORR assuming that an initial vowel of the causative/potential suffix for consonant verbs is incorporated into the end of the preceding verb stem (nucleus of the final syllable) in conformity with the phonological structure of Japanese (CV), based on the claim of Inoue (2003).
Finally, I show the evaluation of re-Insertion. In paradigm (a), which includes re-Insertion, both the consonant verb and the vowel verb uniformly take the potential suffix -re, showing no allomorphy, while paradigm (b), which consists exclusively of re-TV, shows the allomorphy: the vowel verb takes -re, while the consonant verb does not, and two segments do not have identical segments as their counterparts, resulting in two violations of ALLOCORR. Thus, re-Insertion is again more compatible with ALLOCORR.6

![Candidate paradigms for /nom-/ and /tabe-/](table)

<table>
<thead>
<tr>
<th>a. consonant verb: no.me.re</th>
<th>(re-Insertion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>vowel verb: ta.be.re</td>
<td>(ra-Deletion)</td>
</tr>
<tr>
<td>b. consonant verb: no.me</td>
<td>(re-TV)</td>
</tr>
</tbody>
</table>
| vowel verb: ta.be.re     | (ra-Deletion)  **!

In summary, in each evaluation, paradigms with innovative forms show no allomorphy or less allomorphy; all the innovative forms are more compatible with ALLOCORR.

### 4.4 Reduction of Functional Load

Along with analogical leveling, each innovative form has another function in language change: innovative forms contribute to the reduction of functional load.7 Here, PARCONTRAST comes into play. PARCONTRAST is also categorized as an OO-correspondence constraint.

(13) PARCONTRAST (Paradigm Contrast, Ito and Mester 2004)

The cells of a paradigm are pair-wise phonologically distinct.

Briefly, PARCONTRAST requires one-to-one correspondence between form and meaning. Firstly, I present the evaluation of sa-Insertion in (14). As mentioned above, the meaning of sa-Insertion is honorific, rather than causative (Okada 2003).

In paradigm (a), the meanings ‘causative’ and ‘honorific’ take distinct forms: ‘causative’ takes no.ma.se (sa-TV), while ‘honorific’ takes no.ma.sa.se (sa-Insertion), satisfying one-to-one correspondence between form and meaning. On the other hand, in paradigm (b), ‘causative’ and ‘honorific’ take the identical form; in other words, no.ma.se (sa-TV) carries two meanings, and one-to-one correspondence is not satisfied. Thus, paradigm (a), which includes sa-Insertion, satisfies one-to-one correspondence, and reduces the amount of functional load. Sa-Insertion is shown to be more compatible with PARCONTRAST.

<table>
<thead>
<tr>
<th>Candidate paradigms for /nom-/</th>
<th>PARCONTRAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. no.me.re</td>
<td></td>
</tr>
</tbody>
</table>
| b. no.ma.se                  |             **!

6 Based on the fact that the change of ra-Deletion is followed by the change of re-Insertion, I assume that the potential form for vowel verbs is ra-Deletion as in tabe-re instead of ra-TV as in tabe-rare.

7 Throughout this paper, I use the term “functional load” to refer to the amount of function/meaning which a certain morpheme carries, unlike the way the term is traditionally used in phonology.
Next, I show the evaluation of ra-Deletion in (15). The meaning of ra-Deletion is restricted to potential, although the suffix rare can have four meanings: potential, passive, honorific, or spontaneous. In paradigm (a), ‘passive’, ‘honorific’, and ‘spontaneous’ take ta.be.ra.re (ra-TV), while ‘passive’ takes ta.be.re (ra-Deletion); the functional load of rare decreases, as it carries only three meanings, and one-to-one correspondence is satisfied with respect to ‘potential’. On the other hand, in paradigm (b) four meanings take the identical form ta.be.ra.re. In other words, ta.be.ra.re carries four meanings. Paradigm (a), which includes ra-Deletion, is closer to one-to-one correspondence, and reduces the amount of functional load. Thus, we can argue that ra-Insertion is more compatible with PARCONTRAST.

(15)

<table>
<thead>
<tr>
<th>Candidate paradigms for /tabe-/</th>
<th>PARCONTRAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. passive, honorific, spontaneous:</td>
<td>(ra-TV)</td>
</tr>
<tr>
<td>ta.be.ra.re</td>
<td>ta.be.re</td>
</tr>
</tbody>
</table>
| b. passive, honorific, spontaneous, potential: | ta.be.ra.re | (ra-TV) | *

Finally, I show the evaluation of re-Insertion in (16). The meaning of re-Insertion is strong potential (Inoue and Yarimizu 2002). Paradigm (a) satisfies one-to-one correspondence, as ‘potential’ takes no.me (re-TV), while ‘strong potential’ takes no.me.re (re-Insertion); on the other hand, paradigm (b) does not satisfy one-to-one correspondence, as ‘potential’ and ‘strong potential’ take the identical form no.me. Paradigm (a), which includes re-Insertion, satisfies one-to-one correspondence, and reduces the amount of functional load. Thus, re-Insertion is also more compatible with PARCONTRAST.

(16)

<table>
<thead>
<tr>
<th>Candidate paradigms for /nom-/</th>
<th>PARCONTRAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. potential:</td>
<td>no.me</td>
</tr>
<tr>
<td>strong potential:</td>
<td>no.me.re</td>
</tr>
</tbody>
</table>
| b. potential, strong potential: | no.me | (re-TV) | *

In summary, paradigms with innovative forms reduce the amount of functional load, and accordingly, innovative forms are more compatible with PARCONTRAST.

5 Probabilistic OT Analysis

In this section, I conduct the probabilistic OT analysis. I assume that the chronological change of the distribution of innovative forms can be attributed to the gradient approximation of the weights of four constraints.
I implement the analysis by means of the Maximum Entropy model in Praat (Boersma and Weenink 1992-2008). As shown in Table 2, I classified the observed distribution into three birth-year periods: 1915-39, 1940-59, and after 1960.

Table 2: Observed distributions of three variants

<table>
<thead>
<tr>
<th></th>
<th>1915-39</th>
<th>1940-59</th>
<th>1960-69</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>sa</em>-Insertion</td>
<td>2</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td><em>sa</em>-TV</td>
<td>149</td>
<td>428</td>
<td>842</td>
</tr>
<tr>
<td><em>ra</em>-Deletion</td>
<td>23</td>
<td>128</td>
<td>391</td>
</tr>
<tr>
<td><em>ra</em>-TV</td>
<td>350</td>
<td>1,644</td>
<td>5,573</td>
</tr>
<tr>
<td><em>re</em>-Insertion</td>
<td>1</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td><em>re</em>-TV</td>
<td>205</td>
<td>858</td>
<td>2,560</td>
</tr>
</tbody>
</table>

Based on the observed frequency distribution, I estimated the weights of each constraint in three time periods, and derived the chronological transition of the weights of constraints. The result is shown below.

Table 3: Observed distributions of three variants

<table>
<thead>
<tr>
<th></th>
<th>1915-39</th>
<th>1940-59</th>
<th>1960-69</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCP (morph)</td>
<td>103.083</td>
<td>103.017</td>
<td>102.863</td>
</tr>
<tr>
<td>MAX-IO</td>
<td>100.675</td>
<td>100.551</td>
<td>100.669</td>
</tr>
<tr>
<td>ALLOCORR</td>
<td>89.402</td>
<td>89.849</td>
<td>90.074</td>
</tr>
<tr>
<td>PARCONTRAST</td>
<td>96.242</td>
<td>96.433</td>
<td>96.468</td>
</tr>
</tbody>
</table>

Specifically, the weights of OCP (morph) and of MAX-IO are gradually decreasing; on the other hand, those of ALLOCORR and of PARCONTRAST are increasing. Thus, the constraints are getting closer along the time-line, showing that the gradient approximation of the weights of each constraint caused the emergence and gradual increase of innovative forms.

Based on the estimated model, the program further generates the predicted distribution. I show the frequency distribution predicted by the program.

Table 4: Predicted distributions of three variants

<table>
<thead>
<tr>
<th></th>
<th>1915-39</th>
<th>1940-59</th>
<th>1960-69</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>sa</em>-Insertion</td>
<td>2</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td><em>sa</em>-TV</td>
<td>149</td>
<td>429</td>
<td>850</td>
</tr>
<tr>
<td><em>ra</em>-Deletion</td>
<td>23</td>
<td>125</td>
<td>396</td>
</tr>
<tr>
<td><em>ra</em>-TV</td>
<td>350</td>
<td>1,647</td>
<td>5,568</td>
</tr>
<tr>
<td><em>re</em>-Insertion</td>
<td>1</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td><em>re</em>-TV</td>
<td>205</td>
<td>856</td>
<td>2,549</td>
</tr>
</tbody>
</table>

---

8 I set the representative parameters in learning as follows: Decision strategy, Exponential Maximum Entropy; Initial ranking, 100; Evaluation noise, 2.0; Ranking strategy, symmetric all; Initial plasticity, 1.0; Replications per plasticity, 100,000.
The predicted distribution in Table 4 is consistent with the observed distribution in Table 2. If the OT grammar is inadequate, the prediction would never match the observed data. Therefore, we can argue that the OT analysis and the estimated model are adequate.

6 Conclusion

In this paper, I modeled the ongoing morphological changes in voice in Japanese in terms of Probabilistic OT, based on corpus data. Maximum Entropy analysis detected the chronological transition of the weights of each constraint, showing that the gradient approximation of the ranking values caused the emergence and the gradual increase of three innovative forms. The OT analysis and the estimated model were shown to be adequate by the close matching between the observed distribution and the predicted distribution. I propose that the mechanisms of these changes can be reduced in principle to the dynamic interaction of the small set of constraints: OCP (morph), MAX-IO, ALLOCORR and PARCONTRAST.

References


9 The results of the chi-square goodness of fit test are not significant (p < 0.05), and it follows that the distributions (observed and predicted) are equivalent.