Born To Be Gradient
Predicting Exceptions of Compound Tensing in Korean

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How to deal with exceptionality?

- **Compound Tensing (CT)** in Korean unexpectedly fails to apply to certain Noun-Noun compounds (Jun 2001; Zuraw 2011; Ito 2014; Kim 2016).
- Should this exceptionality be dealt with the grammar or through lexicalization?

Gradient Symbolic Representation

- I argue for an account in terms of **Gradient Symbolic Representations** (GSR; Smolensky and Goldrick, 2016, Rosen 2016).
- The intrinsic property of GSR captures the **nature of gradient inclination for CT**, which is impossible with other systems.

Learnability

- An **error-driven algorithm** also shows that the scalar activities are learnable.
Data
Korean has a three-way distinction in terms of laryngeal contrast in obstruents

(1)

(a) /pul/ → [pul] ‘fire’
(b) /pʰul/ → [pʰul] ‘grass’
(c) /pʼul/ → [pʼul] ‘horn’
Korean has a three-way distinction in terms of laryngeal contrast in obstruents

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(a) /pul/ → [pul] ‘fire’
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(c) /p’ul/ → [p’ul] ‘horn’
Compound Tensing

- **Compound Tensing (CT)**:
  When a compound consist of two nouns, $W_A$ and $W_B$, initial plain obstruents of $W_B$s undergo junctural processes including *obstruent tensification*.

\[(2)\]

(a) /hɛ/ + /pi/ → [hɛ.p’i] post Vowel
(b) /kail/ + /pi/ → [ka.il.p’i] post Lateral
(c) /pom/ + /pi/ → [pom.p’i] post Nasal
(d) /pok/ + /pi/ → [pok.p’i] post obstruent
## Exceptionality

- 23% noun-noun compounds exceptionally does not undergo CT in a random fashion  

(3)

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The compound tensing exhibit continuum of **gradient preferences** depending on **both the conjuncts** $W^A, W^B$ in the compound.

(4)

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Gradient Pattern of Tensing

(6) Gradient patterns for compounding tensing

\[ W_A \]

(a) \(k'\text{oc}^h\)  
(b) \(h\epsilon\)  
(c) pipim  
(d) \(k^h\text{or}\)  
(e) \(k\epsilon\)  

\[ W_B \]

(f) \(\text{kap}\)  
(g) \(\text{kalu}\)  
(h) \(\text{pap}\)  
(i) \(\text{kuksu}\)  
(j) \(\text{toti}\)

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Compound Tensing

No Compound Tensing
(6) Gradient patterns for compounding tensing

\[ W_A \]
(a) k’oc\textsuperscript{h}
(b) hε
(c) pipim
(d) k\textsuperscript{h}o\textsuperscript{rj}
(e) kε

\[ W_B \]
(f) kap
(g) kalu
(h) pap
(i) kuksu
(j) toti

---

Compound Tensing

---

No Compound Tensing
(6) Gradient patterns for compounding tensing

\[ W_A \]

(a) k'oc^h
(b) he
(c) pipim
(d) k^h_01\]
(e) k\varepsilon

\[ W_B \]

(f) kap
(g) kalu
(h) pap
(i) kuksu
(j) toti

Compound Tensing

No Compound Tensing
There is no way in standard rule-based (Chomsky and Halle, 1968) or Optimality theory frameworks (Prince and Smolensky, 1993) where features are binary or privative, to give a word a feature that will determine its precise degree of preference for CT.
Proposal
Symbols in a linguistic representation can have **different activities**:

‘Symbols are discrete but their degree of presence in a given linguistic representation is continuously gradient’  
(Smolensky and Goldrick, 2016, 2)

- (Continuous) Numerical strength from 0 to 1 can be associated to input

- Output elements are all fully active (1) as discrete forms
The underlying structure is grammatically computed inside Harmonic Grammar (Legendre et al. 1990)

It can predict lexical exceptions:

- Elements in the underlying representation of a morpheme can be too weak to undergo/trigger a certain process

- Elements associated with different activity can be strong enough to undergo/trigger the same process
I suggest that each edge of nouns in Korean may have *floating feature* \([\text{cg}]\) (Zoll 1996) with *gradient activity* in the underlying structures (Rosen 2016, 2018).

\[(7)\]

\[
\begin{array}{c}
\ldots \quad \bullet \\
| \\
\text{m} & \text{[cg]}^A_{0.4} & \text{[cg]}^B_{0.2} & \text{k} \\
| \\
\ldots \\
\end{array}
\]
- CT occurs by the **coalescence** of two stem-specific, partially activated floating \([cg]\) features and **docking** to the root node

\[(8)\]

\[
\begin{array}{c}
\cdots \\
\vdots \\
m \\
\end{array}
\begin{array}{c}
\vdots \\
\cdots \\
p \\
\end{array}
\begin{array}{c}
\text{[cg]}_{A,B}^{1} \\
\end{array}
\]
- Only when the additive combination of these features $[cg]^A, [cg]^B$ exceeds some threshold $\Sigma$ does tensing occur.

\[(9)\] A hierarchy of 5-level of activation values for compounding tensing

<table>
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<th>$[cg]_A / [cg]_B$</th>
<th>0</th>
<th>1</th>
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<tr>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>$\times$</td>
<td>$\checkmark$</td>
</tr>
<tr>
<td>$1$</td>
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Only when the additive combination of these features \([cg]^A,^B\) exceeds some threshold \(\Sigma\) does tensing occur.

\[
\begin{array}{c|ccccc}
[\text{cg}]_A / [\text{cg}]_B & 0 & \cdots & \cdots & \cdots & 1 \\
\hline
\times & \times & \times & \times & \checkmark \\
\times & \times & \times & \checkmark & \checkmark \\
\times & \times & \checkmark & \checkmark & \checkmark \\
\times & \checkmark & \checkmark & \checkmark & \checkmark \\
\checkmark & \checkmark & \checkmark & \checkmark & \checkmark \\
\end{array}
\]
Constraints

- **Max[cg]**: Input must have output correspondents. It **rewards** underlying activity that makes it to the surface.
  - i.e., the more strength the feature bears, the more rewards it induces when it realizes

- **Ident[cg]**: The specification for the feature [cg] of an input segment must be preserved in its output correspondent.
  - i.e., it **penalizes** the feature change

- **Uniformity[cg]**: No feature [cg] in the output has multiple correspondents in the input.
  - i.e., ‘No coalescence’
This analysis accounts for the gradient nature of CT.

The Harmony of the representation $\tau$ is:

$$H(r) = 1 \cdot C_{\text{Max}[cg]}(r) - 0.6 \cdot C_{\text{Ident}[cg]}(r) - 0.1 \cdot C_{\text{Uniformity}[cg]}(r)$$

The candidate with maximal harmony in its candidate set is the optimal output.


**Optimization : Compound Tensing**

\[ W_A : /\text{pipim}/ - \tau : 0.4, \ W_B : /\text{pap}/ - \tau : 0.4 \]

(11) \( T_1. \text{pipim} + \text{pap} \rightarrow [\pi.\text{pim.p'ap}] \)

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<th>( \text{Max} ) ([c.g])</th>
<th>( w = 100 )</th>
<th>( \text{Ident} ) ([c.g])</th>
<th>( w = -60 )</th>
<th>( \text{Uniformity} ) ([c.g])</th>
<th>( w = -10 )</th>
<th>( H )</th>
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<td>( \ldots )</td>
<td>( \text{[cg]}_0^{x} )</td>
<td>( \text{[cg]}_0^{y} )</td>
<td>( \ldots )</td>
<td>( \text{m} )</td>
<td>( \text{p} )</td>
<td>( \text{0} )</td>
</tr>
<tr>
<td>O_2 :</td>
<td>( \ldots )</td>
<td>( \text{[cg]}_1^{x,y} )</td>
<td>( \ldots )</td>
<td>( \text{m} )</td>
<td>( \text{p} )</td>
<td>( 0.4+0.4 )</td>
<td>( \text{1} )</td>
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- The sum of additive feature \([cg]\) from two conjuncts are **strong enough** to undergo CT
**Optimization : No Compound Tensing**

\[ W_A : /\text{pipim}/ - \tau : 0.4, \ W_B : /\text{kuksu}/ - \tau : 0.2 \]

(12) \[ T_2, \text{pipim} + \text{kuksu} \rightarrow [\text{pi.pim.kuk.s’u}] \]

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| (0.4+0.2) | 1 | 1 | \(-10\) |

- The total sum of the feature \([\text{cg}]\) of ‘pipim’ and ‘kuksu’ is **too weak** to undergo tensification.
Why Gradience?

Not only do words that occur as the second conjunct of a compound exhibit gradient preferences for [cg], but the first conjunct in the compound also arguably exhibits the same kind of gradient preference for triggering tensing in the word that follows it.
The error-driven learning algorithm

(13) An Architecture of Convolutional Neural Network
The error-driven learning algorithm

**Step 1: Initialization**

1. A learning algorithm was trained through Convolutional Neural Network (Mikolov et al. 2013)
   - It consists of 2 hidden and 1 softmax layers

2. Activation levels for $[cg]$ of the $W^A$ s and $W^B$s were initialized at 0.5

3. Constraints MAX and IDENT were initialized with unit values

4. UNIFORMITY and LINEARITY have fixed values

5. The threshold levels for the sum values of $[cg]$ for compounds were set at 0.7
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Step 2 : Iteration

1. The compounds \([W^A + W^B]\) are evaluated on each iteration to check whether each gross effect of CT is correctly derived;
   - will get a reward +10 if the correct pattern is derived,
   - will get a penalty -5 if the wrong pattern is derived

2. When two coalescing activations [cg] require adjusting,
   - It randomly refills the both values of [cg] by either decrementing or incrementing them (a stepsize of 0.05)
   - MAX and IDENT adjust their weights slightly adjusted through a simulated-annealing process (De Vicente et al. 2003) \(^1\)

Step 3 : Convergence

- After 16533 iterations (i.e., when the algorithm can predict all the training set data of CT corretly) the training of this learning was converged.

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1. with a decaying temperature \(T\) and random Gaussian noise \(N\) with \(m = 0\) and \(s.d. = 0.05\)
Results

### Results

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<table>
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<tbody>
<tr>
<td>Average of iterations</td>
<td>32</td>
</tr>
<tr>
<td>Final Value of $Max$</td>
<td>1.121</td>
</tr>
<tr>
<td>Final Value of $Ident$</td>
<td>0.69</td>
</tr>
<tr>
<td>The number of activation levels for $W^A$</td>
<td>5</td>
</tr>
<tr>
<td>The number of activation levels for $W^B$</td>
<td>5</td>
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Conclusion
1. This **GSR analysis** can predict all the patterns of exceptional non-undergoer of Compound Tensing successfully without any redundancy rules.

2. The intrinsic property of GSR enables the elements to bear a scalar strength and to **capture the lexical exception of alternation** in the same context.

3. Although the distinction is not visible on the surface, there are reasons to believe that obstruents in Korean has diverse patterns of different underlying structures with a **gradiently active feature** [cg].

4. The learning algorithm also supports that this scaler grammar is **learnable**.
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References II

- Smolensky, Paul & Matthew Goldrick (2016). Gradient symbolic representations in grammar: The case of French Liaison. ROA 1286