Logical Form of Hierarchical Relation on Verbs and Extracting it from Definition Sentences in a Japanese Dictionary

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ABSTRACT

We are studying how to extract hierarchical relation on verbs from definition sentences in a Japanese dictionary. The hierarchical relation on verbs has been dealt with as a binary relation on verbs, but it should be dealt with as logical relation on predicates. We will define the logical form of the hierarchical relation on verbs and then discuss which part of the syntactic structure of the definition sentence represents that relation. We will call the main predicate verb in this part the definition verb. Furthermore we will describe how to semiautomatically select the proper meaning of the definition verb and the proper correspondence between cases of an entry verb and the definition verb in order to extract the hierarchical relation as logical relation.

1 Introduction

The syntactic processing has been playing the main role in a natural language processing system. But we have come to know that we can't construct a practical system with only this processing and that the semantic processing is necessary for it. Inference plays an important role in the semantic processing, we therefore need a large knowledge base about meaning of words and we must treat it as logical relation.

Hierarchical relation between words is inevitable and transitive, and it is a important relation in the large knowledge base. Because inevitable relation holds at any time and the reliability of conclusions inferred from it doesn't fall down and transitive relation can be described efficiently.

There were some researches on extracting the hierarchical relation between words from definition sentences in a ordinary dictionary[1][2][3][4]. But they treated it as only binary relation between words. Verbs correspond to n-ary predicates on entities and we therefore must describe the correspondence between the variables (that is case or syntactic role) of a subordinate verb and ones of its superordinate verb. But this correspondence can't be described if the relation is treated as binary relation between words.

We will propose how to extract the hierarchical relation with a logical form on verbs from definition sentences in a Japanese dictionary. Firstly, we will define the logical form of the hierarchical relation on verbs and then discuss which part of the syntactic structure of the definition sentence represents that relation. We will call the main predicate verb in this part the definition verb. Secondly, we will describe how to semiautomatically select the proper meaning of the definition verb and the proper correspondence between the variables of an entry verb and ones of the definition verb. Lastly, we will report about the result of a experiment to extract the
hierarchical relation from the machine readable dictionary IPAL.

A verb will be corresponded to the n-ary predicate according to a pattern of cases (syntactic roles). Considering the polysemy of verbs, each meaning of a single verb must correspond to the distinct predicate. For example, "愛する" (love) as first meaning is used with the form of "x₁がx₂を愛する" (x₁ love x₂) and corresponds to ‘愛する₁(x₁, x₂)’.

Furthermore, we will not deal with intensional verbs in this paper.

2 Logical Form of Hierarchical Relation on Verbs

Verbs correspond to predicates on entities. If \( V^L(\eta_1, \ldots, \eta_n) \) is the subordinate predicate of \( V^U(\xi_1, \ldots, \xi_m) \), both predicates have the same arity (i.e., \( m = n \)), there is a one-to-one correspondence \( \psi \) from \( \{1, \ldots, n\} \) to \( \{1, \ldots, n\} \), and if \( V^L(\xi_1, \ldots, \xi_m) \) is true, \( V^U(\xi_\psi(1), \ldots, \xi_\psi(n)) \) is also true at the same time. That is,

\[
\forall x \left[V^L(x) \supseteq V^U(x) \right],
\]
where boldface \( x \) stands for a tuple of variables. Strictly speaking, the logical form of the hierarchical relation on verbs is (1).

For example, "飲む₁" is the subordinate verb of "飲む₁". To describe this logically,

\[
\forall x_1 x_2 \left[\text{飲む₁}(x_1, x_2) \supseteq \text{飲む₁}(x_1, x_2) \right],
\]
where '飲む₁(η₁, η₂)' means that η₁ drink η₂ and '飲む₁(η₁, η₂)' means that η₁ take η₂.

But there are \( V^L \) and \( V^U \) such that some arguments in \( V^L(\eta_1, \ldots, \eta_m) \) don't correspond to any arguments in \( V^U(\xi_1, \ldots, \xi_m) \) or some in \( V^U(\xi_1, \ldots, \xi_m) \) don't correspond to any arguments in \( V^L(\eta_1, \ldots, \eta_m) \), although \( V^L \) is a subordinate verb of \( V^U \). In this case, we conclude that the predicate denoted by \( \exists y V^L(x, y) \) is a subordinate one of the predicate denoted by \( \exists z V^U(x, z) \). Therefore, by generalizing (1), we get

\[
\forall x \left[\exists y V^L(x, y) \supseteq \exists z V^U(x, z) \right],
\]
that is,

\[
\forall x y \exists z \left[V^L(x, y) \supseteq V^U(x, z) \right].
\]

We expand (2) further to restrict the domain of \( z \), and define the logical form of the hierarchical relation on verbs as follows.

Definition 1 \( v^L \) is a subordinate verb of \( v^U \), if for some \( N \)

\[
\forall x y \exists z \left[V^L(x, y) \supseteq N(z) \land V^U(x, z) \right],
\]
where boldface \( N \) stands for a tuple of predicate letters and \( N(z) \) means \( N_1(z_1) \land \cdots \land N_n(z_n) \).

A small letter, such as \( n, v, \) and \( v^L \), stands for a linguistic expression and a capital letter, such as \( N, V, \) and \( V^L \), stands for the predicate symbol corresponding to the linguistic expression represented by its small letter.

For example, "飲む₁" is a subordinate verb of "飲む₁" because the following formula holds,

\[
\forall x y z \left[\text{飲む₁}(x, y) \supseteq \text{飲む₁}(x, z) \right],
\]
where

- \( \text{飲む₁}(\eta₁, \eta₂) \) : η₂ is irrigated by η₁,
- \( \text{水分}(\eta) \) : η is moisture,
- \( \text{帯びる₁}(\eta₁, \eta₂) \) : η₁ take on η₂.

3 Extraction

3.1 Extracting the Hierarchical Expression in a Definition Sentence

Definition 2 The relation between an entry verb \( v^e \) and its definition sentence \( s \) is

\[
\forall x \left[\exists y V^e(x, y) \equiv \exists z S(x, z) \right].
\]

For example, the definition sentence for "飲む₁" (drink) is "飲物を摂取する₁" (to take a drink) and the definition sentence for "飲む₁" is "水分をたっぷりと帯びる₁" (to take on moisture fully). We get

\footnote{Syntactic role is represented by means of a postposition, such as "が" and "を", in Japanese.}

\footnote{For convenience, we will omit the number of the meaning of an entry verb.}
where

\[
\forall x_1 x_2 \text{飲む}_1(x_1, x_2) \equiv \\
\text{飲物}_2(x_2) \land \text{摂取する}_1(x_1, x_2),
\]

\[
\forall z \exists y \text{渋う}_1(y, z) \equiv \\
\exists z \text{水分}_2(z) \land \text{たっぷりと待る}_1(x, z),
\]

We call the main predicate verb of a definition sentence the definition verb. If the definition sentence of a entry verb \(v^e\) corresponds to \(N(\eta) \land V^d(\eta)\), then we can easily derive the hierarchical relation between \(v^e\) and its definition verb \(v^d\) from Definition 2. In this paragraph, we assume that the meaning of the definition verb has been selected correctly and we will omit the number of the meaning of definition verbs. How to select it will be given in 3.2.

A definition sentence does not always correspond to the logical form as (3). But if we can get the sentence \(s^d\) which is a part of the definition sentence \(s\) and corresponds to the logical form as (3) and \(S \supset S^d\), then we can also derive the hierarchical relation between the entry verb and the definition verb. We call \(s^d\) the hierarchical expression in a definition sentence (HED).

Definition 3 We get rid of modifiers out of a simple sentence \(s\). We call the rest of \(s\) the kernel sentence \(s^k\) of \(s\).

Since there isn’t a expression corresponding to a universal quantifier in the definition sentence of a verb, we can conclude the following characteristic.

Characteristic 1 If \(s^k\) is the kernel sentence of a simple sentence \(s\), then \(S \supset S^k\) and the logical form of \(S^k\) is (3).

For example, the kernel sentence of “体の痛みを一時的に消す” (to kill a pain in the body temporarily) is “痛みを消す” (to kill a pain) and its logical form is

\[
\text{痛み}_2 \land \text{消す}_1(\eta_1, \eta_2),
\]

and the following formula holds,

\[
\forall \eta_1 \eta_2 \eta_3 [S(\eta_1, \eta_2, \eta_3) \supset \\
\text{痛み}_2 \land \text{消す}_1(\eta_1, \eta_2)],
\]

where \(S(\eta_1, \eta_2, \eta_3)\) is the formula corresponding to “体の痛みを一時的に消す” and means that \(\eta_2\) is a pain, \(\eta_3\) is a body, and \(\eta_1\) kill \(\eta_2\) in \(\eta_3\) temporally. ‘痛み (\(\eta\))’ means that \(\eta\) is a pain. ‘消す (\(\eta_1, \eta_2\))’ means that \(\eta_1\) kill \(\eta_2\).

There is a sentence \(s\) which satisfies the following characteristic.

Characteristic 2 A sentence \(s\) includes a sentence \(s'\) and \(S \supset S'\).

If the definition sentence \(s\) of a verb is complex, then \(s\) satisfies Characteristic 2 and \(s'\) is its main clause. For example, the main clause of the sentence “何かが何かするように付着する” (something adheres to X as it covers X) is “何かが付着する” (something adheres to), and it corresponds to the following formula,

\[
\text{何か}_1 (\eta_1) \land \text{付着する}_1(\eta_1, \eta_2),
\]

and the following formula holds,

\[
\forall \eta_1 \eta_2 [S(\eta_1, \eta_2) \supset \\
\text{何か}_1 (\eta_1) \land \text{付着する}_1(\eta_1, \eta_2)],
\]

where \(S(\eta_1, \eta_2)\) is the formula corresponding to “何かが何かするように付着する” and means that something \(\eta_1\) adhere to \(\eta_2\) as \(\eta_1\) covers \(\eta_2\), ‘何か (\(\eta\))’ means that \(\eta\) is something, and ‘付着する (\(\eta_1, \eta_2\))’ means that \(\eta_1\) adhere to \(\eta_2\).

Meaning of the compound sentence \(s\), in which two sentences \((s_1, s_2)\) are connected by a conjunction corresponding to ‘and’ in English, is either ‘\(S_1 \land S_2\)’ or ‘after \(S_1\), \(S_2\)’. Therefore, an operator needs to decide the relation between \(s_1\) and \(s_2\). In the former case, \(s\) satisfies Characteristic 2 and \(s'\) can be both \(s_1\) and \(s_2\). For example, a sentence “何かを投げて勢いよく接触させる” (to throw something and have it touched...
hard) consists of two sentences. One is "何かを投げる" (to throw something), the other is "勢いよく触れる" (to have it touched hard), and two sentences correspond to following formulae respectively,

:\begin{align*}
\forall \eta_1 \eta_2 \eta_3 [ S(\eta_1, \eta_2, \eta_3) \supset \\
\text{何か (}\eta_2\text{) \& 投げる (}\eta_1, \eta_2\text{)],}
\end{align*}

\begin{align*}
\forall \eta_1 \eta_2 \eta_3 [ S(\eta_1, \eta_2, \eta_3) \supset \\
\text{勢いよく触れる (}\eta_1, \eta_2, \eta_3\text{)],}
\end{align*}

where \( S(\eta_1, \eta_2, \eta_3) \) is the formula corresponding to "何かを投げる・勢いよく触れる" and means that \( \eta_1 \) throw \( \eta_2 \) and have \( \eta_2 \) touched hard to \( \eta_3 \). "何か (}\eta)" means that \( \eta \) is something. "投げる (}\eta_1, \eta_2\" means that \( \eta_1 \) throw \( \eta_2 \). "勢いよく触れる (}\eta_1, \eta_2, \eta_3\)" means that \( \eta_1 \) have \( \eta_2 \) touched hard to \( \eta_3 \).

And two sentences are simultaneous. So following formulae hold,

\begin{align*}
\forall \eta_1 \eta_2 \eta_3 [ S(\eta_1, \eta_2, \eta_3) \supset \\
\text{何か (}\eta_2\text{) \& 投げる (}\eta_1, \eta_2\text{),}
\end{align*}

\begin{align*}
\forall \eta_1 \eta_2 \eta_3 [ S(\eta_1, \eta_2, \eta_3) \supset \\
\text{勢いよく触れる (}\eta_1, \eta_2, \eta_3\text{)],}
\end{align*}

where \( S(\eta_1, \eta_2, \eta_3) \) is the formula corresponding to "何かを投げる・勢いよく触れる" and means that \( \eta_1 \) throw \( \eta_2 \) and have \( \eta_2 \) touched hard to \( \eta_3 \). "何か (}\eta)" means that \( \eta \) is something. "投げる (}\eta_1, \eta_2\" means that \( \eta_1 \) throw \( \eta_2 \). "勢いよく触れる (}\eta_1, \eta_2, \eta_3\)" means that \( \eta_1 \) have \( \eta_2 \) touched hard to \( \eta_3 \).

To apply Characteristic 2 repeatedly, we conclude that there is a definition sentence \( s \) which include a simple sentence \( s' \) and \( S \supset S' \) and that the kernel sentence of \( s' \) is \( \text{HED} \). For example, the sentence \( s "あるものをまっすぐにするためにその物の両端を持って両方向に力を加える" (to hold both ends of something and apply force to both sides in order to make it straight) is complex. It therefore satisfies Characteristic 2 and \( S \supset S_1 \), where \( s_1 \) is its main clause "その物の両端を持って両方向に力を加える" (to hold both ends of something and apply force to both sides). \( s_1 \) is a compound sentence and is composed of \( s_2 "その物の両端を持つ" (to hold both ends of something) and \( s_3 "両方向に力を加える" (to apply force to both sides) and two sentence is simultaneous. \( S_1 \) therefore satisfies Characteristic 2 and \( S_1 \supset S_2 \) and \( S_1 \supset S_3 \). Therefore, \( S \supset S_2 \) and \( S \supset S_3 \). Because \( s_2 \) and \( s_3 \) are simple sentences, the kernel sentences of \( s_2 \) and \( s_3 \) are \( \text{HEDs} \). When the definition sentence is simple, its kernel sentence is \( \text{HED} \).

If we decide the proper meaning of the definition verb and the proper correspondence from cases of \( v^e \) to cases of \( v^d \) correctly, we conclude

\begin{align*}
\forall x y \exists z [ v^e(x, y) \supset \\
N_z(x) \wedge N_z(x) \wedge V^d(x, z)].
\end{align*}

We can get a hierarchical relation between \( v^e \) and \( v^d \) as follows from (4),

\begin{align*}
\forall x y \exists z [ v^e(x, y) \supset N_z(x) \wedge V^d(x, z)].
\end{align*}

3.2 Necessary Condition and Heuristic

In this paragraph we supposed that an entry verb \( v^e \) has \( \text{HED} \).

What we call the selectional restriction has been used to narrow down candidates for syntactic structure in the syntactic processing. It is the restriction about the semantic category of a noun phrase which a certain verb can take as a certain case. The semantic category has been called the semantic marker or semantic primitive. For example, semantic categories of the subjective noun phrase and the objective noun phrase for the verb "飲む"(drink) must be 'animal' and 'liquid' respectively. We use this information to semiautomatically select the proper meaning of \( v^d \) and the proper correspondence from cases of \( v^e \) to cases of \( v^d \). The information is mentioned in the Japanese dictionary we used for the experiment of extraction.

The restriction that if a verb \( v_k \) can take a noun phrase with a case \( c \) the semantic category of the noun phrase is \( D \) is expressed logically as follows,

\begin{align*}
\forall x [v_k(x) \supset D(x_1)],
\end{align*}

where \( x_1 \) is the argument corresponding to the case \( c \), and \( k \) is the meaning number of \( v \). We call \( D \) in (5) the domain for \( c \) of \( v_k \). For example, \( v_{hi}(\text{飲む}_1, \eta_2) \supset \text{animal}(\eta_1) \wedge \text{liquid}(\eta_2) \),

where "飲む (}\eta_1, \eta_2\)" means that \( \eta_1 \) drink \( \eta_2 \).

If the semantic category of a noun \( n \) is \( D \),

\begin{align*}
\forall x [N(x) \supset D(x_1)].
\end{align*}

We call \( D \) in (6) the domain for \( n \).

If the \( k \)-th meaning is proper as \( v^d \) in the definition sentence of \( v^e \) and the correspondence from \( i \)-th case of \( v^e \) to \( j \)-th case of \( v^d \) is correct, then the following formula holds,
Assumption 1 We assume $\exists x V(x)$ is true for each verb $v$ and $\exists x N(x)$ is true for each noun $n$.

We conclude

$$\exists x [D^* (x) \land D^n (x) \land D^d (x)]$$

from $\exists x V^e (x)$ (Assumption 1) and (7), where

$$\forall \eta [V^e (\ldots, \eta, \ldots) \supset N^e (\eta)],$$

$$\forall \eta [V_k^d (\ldots, \eta, \ldots) \supset N^d (\eta)],$$

$$\forall \eta [N(\eta) \supset D^n (\eta)].$$

We establish (8) as the necessary condition in which the correspondence is valid. We check (8) with $\exists x N(x)$ (Assumption 1) and the relation between domain predicates.

Necessary Condition If the $k$-th meaning is proper as $v^d$ in the definition sentence of $v^e$ and the correspondence from $i$-th case of $v^e$ to $j$-th case of $v^d$ is correct, then

$$\exists x [D^* (x) \land D^n (x) \land D^d (x)],$$

where $D^*$ is the domain for $i$-th case of $v^e$ and $D^d$ is one for $j$-th case of $v^d_k$ and the noun of $j$-th case of $v^d_k$ in the definition sentence is $n$ and the domain for $n$ is $D^n$.

The meaning of an entry verb $v^e$ is defined by using the definition verb $v^d$. Then, the less the number of the variables appearing either only in $v^e$ or only in $v^d$ (i.e. (size of tuple $y$) + (size of tuple $x$) in the formula (4)), the more $v^d$ restricts the meaning of $v^e$. An editor of a dictionary would select such a definition verb. We therefore establish the following heuristic.

Heuristic The less the number of the variables appearing either only in $v^e$ or only in $v^d$, the more we have chance of correct selection for meaning of $v^d$ and the correspondence of the variables.

3.3 Example of Extraction

In this paragraph the method how to extract the hierarchical relation on verbs will be introduced. We suppose following definitions about "愛する" and "持つ".

愛する
I [(human) (human) を持つ] とする気持ちを持つ.(to experience a strong feeling of fondness)

持つ
II [(human) (human) を持つ] を持つ.(to have something with one’s hand)

III [(all_entities) の抽象] 何らかの属性を有する.(to have some property or equipment)

@ means that “愛する” is used with the form of “$np_1$ と $np_2$ を愛する” and the semantic category of $np_1$ and $np_2$ must have ‘human’. We get the following knowledge about domain of words.

$$\forall \eta [\text{愛する}_1(\eta_1, \eta_2) \supset \text{human}(\eta_1) \land \text{human}(\eta_2)],$$

$$\forall \eta [\text{持つ}_1(\eta_1, \eta_2, \eta_3) \supset [\text{human}(\eta_1) \land \text{hand}(\eta_2) \land \text{concrete}(\eta_3)]],$$

$$\forall \eta [\text{持つ}_2(\eta_1, \eta_2, \eta_3) \supset [\text{human}(\eta_1) \land \text{human}(\eta_2) \land \text{mental}(\eta_3)]],$$

$$\forall \eta [\text{持つ}_3(\eta_1, \eta_2) \supset \text{all_entities}(\eta_1) \land \text{abstract}(\eta_2)],$$

$$\forall \eta [\text{気持ち} (\eta) \supset \text{mental}(\eta)].$$

‘all_entities’ expresses the set of all entities. We suppose the following relation between domain predicates,

$$\forall \eta [\text{human}(\eta) \lor \text{hand}(\eta) \supset \text{concrete}(\eta)],$$

$$\forall \eta [\text{mental}(\eta) \supset \text{abstract}(\eta)],$$

$$\forall \eta [\text{concrete}(\eta) \lor \text{abstract}(\eta) \supset \text{all_entities}(\eta)],$$

$$\neg \exists \eta [\text{concrete}(\eta) \land \text{abstract}(\eta)],$$

$$\neg \exists \eta [\text{human}(\eta) \land \text{hand}(\eta)].$$

We parse the definition sentence “とても好きだという気持ちを持つ” for the entry verb “愛す.
We have defined the logical form of the hierarchical relation on verbs and have described how to extract it from definition sentences in a Japanese dictionary.

The method described in this paper is for a Japanese dictionary, but it can be applied to other languages dictionary, too.
Reference

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Appendix

A.1 Example of Contents of IPAL

Appendix

A.2 A Example of Extracted Relations

\[ \forall x (x_1, x_2) \in \text{organization}(x_2), \]

where ‘政府’ means ‘government’. We used the above informations.

\[ \forall x \in \text{organization}(x_1) \]

from these informations. Japanese words following \( \text{名} \) are example of \( \text{NP} \). We can get the domain for nouns from these informations. For example, we can get

\[ \forall x \in \text{organization}(x_1) \]

A.2 A Example of Extracted Relations

\[ \forall x \in \text{organization}(x_1) \]

where ‘政府’ means ‘government’. We used the above informations.