A Formalization of Metaphor Understanding in Situation Semantics

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Abstract

In this paper, we present a new theory which can account for understanding metaphorical expressions in a discourse. In order to deal with the information obtained from a metaphorical expression in a discourse, it is necessary that the part of semantics which deals with metaphor understanding should harmonize with the rest of semantics which deals with the ordinary discourse understanding. Accordingly we adopt the formalization based on situation semantics, in which by dealing with the interpretation of a metaphorical expression and the information in the expression separately the metaphor understanding is done according to the hearer's resource. That is, an actual meaning connoted by either a word or a phrase in a metaphorical expression may vary from its ordinary meaning. As a result, metaphorical expressions can convey some other new information. We would like to formulate this variation as a process of introducing new resources, namely, establishing correspondences between a source domain and a target domain. This theory can naturally explain metaphor understanding closely related to a discourse, such as the case that the information which the hearer obtains from a metaphorical expression depends on the context.

1 Introduction

Metaphor — one of rhetorical methods — is used not only in literary writings, but also in many conversations in our everyday life as effective means of communication[LJ80]. Therefore, metaphor understanding is one of the most important themes which we must deal with to have a sophisticated natural language understanding system. The metaphor understanding process has been discussed from various points of view by a number of researchers[TIT89, Ind87, GFS87].

It is the essence of metaphors that one thing or idea (we will call it α) is expressed by means of something else (β). For example, in a metaphorical phrase "A man like a wolf", "a man" corresponds to α and "a wolf" corresponds to β. In the rest of this paper, we will use the term *target* (or *target domain*) to refer to a thing α and *source*(*source domain*) to refer to β. According to the interaction theory of metaphors proposed by Black, an "implicative complex", which is a set of inferences that can be drawn about a domain, is associated with the domain. A metaphorical expression works by projecting an implicative complex of a source domain upon a target domain[Ind87]. There are a number of studies of the metaphor understanding based on this theory, in which such projections, or correspondences, are found by an analogical mapping[GFS87, Hol89, Ind87]. Most of these studies, however, deal only with understanding an isolated metaphorical sentence, and regard the metaphor understanding process just as establishing correspondences by some analogical mapping. Indeed the establishment of correspondences is the main part of the metaphor understanding process, but in order to deal with the information obtained from a metaphorical expression in a discourse, it is necessary that the part of semantics which deals with metaphor understanding should harmonize with the rest of semantics which deals with the ordinary discourse understanding. There are few researches based on such a viewpoint, that is, a framework which refers to the analysis of the metaphorical expression in a discourse[1].

[1] In the same viewpoint as ours, Hobbs deals with metaphor understanding in his stimulating paper[Hob90]. Especially, it should be noticed that he points out importance of the role of coherence relations in metaphor understanding. Hobbs' formalization of metaphor understanding, in which metaphor understanding process is described as axioms related to some metaphorical expression and inference based on the axioms, does not precisely deal with the difference between the

In this paper, in view of this point, we present a new theory which can account for understanding metaphorical expressions in a discourse. It is a typical case of the metaphor understanding in a discourse that the information which the hearer obtains from a metaphorical expression depends on the context in which the expression is uttered. For example, let us consider the following sentence:

With a new strategy, I attacked his position. (1)

This sentence can convey some different kind of information according to contexts in which it is embedded:

Case-1. A description about a war: The head of a winning state utters the sentence about the victory, referring to the head of the defeated state.

Case-2. A description about an argument: Someone utters the sentence about the argument in which he/she refuted his/her opponent.

A:"I argued with Mr.B about his theory last night." C:"How did it come out ?" (2)

Case-3. A description about a game: Someone utters the sentence about the result of the game (chess, go, etc.), referring to his opponent.

These connotations of the sentence (1), however, seem to share some common structure, rather than to be quite different from each other.

Generally speaking, the information in an expression may vary with hearer's circumstance, or *resource situations*, such as contexts, background knowledge, and so on. The context sensitivity like this can be explained by drawing a distinction between the interpretation of an utterance and the information in the utterance, which is one of the ideas in situation semantics[Bar89]. Accordingly we adopt the formalization based on situation semantics, in which by dealing with the interpretation of a metaphorical expression and the information in the expression separately the metaphor understanding is done according to the hearer's resource. That is, an actual meaning connoted by either a word or a phrase in a metaphorical expression may vary from its ordinary meaning. As a result, metaphorical expressions can convey some other new information. We would like to formulate this variation as a process of introducing new resources, namely, establishing correspondences between a source domain and a target domain, with which a hearer can project information about a source domain onto a target domain.

2 The Outline of Metaphor Understanding in Situation Semantics

In our theory, metaphor understanding consists of the following steps and semantic representations with which this metaphor understanding process are represented in terms of situation semantics[2]:

Step-1 Hear a fragment uf^i of an utterance and construct states of affairs corresponding to it by the convention of the language use. Then a described situation s^i_{uf} corresponding to uf^i is obtained.

Step-2 By combining s^i_{uf} with the current context s^{i-1}_d, obtain a new situation s^{new}_d. In general, s^i_{uf} is included by s^{i-1}_d, that is, $s^{new}_d = s^{i-1}_d \trianglerighteq s^i_{uf}$. Then examine whether the situation s^{new}_d satisfies the following requirements:

1. Every relation in the situation s^{new}_d satisfies the appropriateness of its argument assignment.
2. The situation s^{new}_d is consistent.
3. All of constraints holding in the situation s^{new}_d are satisfied.

Step-3 If the requirements in Step-2 are satisfied, let the new context s^i_d be s^{new}_d and increase i by 1, then go to Step-1.

interpretation of a sentence including some metaphorical expression and the information conveyed by the sentence. It is important to clarify the difference for semantics of metaphorical expressions such as our example, which convey various different information according to contexts.

[2] *Situations* are parts of the world to which a *scheme of individuation* applies. The collection of all situations is partially ordered by the part-of relation $\trianglelefteq$. A situation s_1 is a part of a situation s_2 (that is, $s_1 \trianglelefteq s_2$) just in case every basic state of affairs that is a fact of s_1 is also a fact of s_2.

Step-4 Since the requirements in Step-2 are not satisfied at this point, introduce a new resource to cancel the inappropriateness and to obtain a meaningful interpretation. In metaphor understanding, as described later, the new resource is a set of constraints which represents the correspondence between the source domain and the target domain. Thus, the new situation s_r^i in which these constraints hold is regarded as a new resource situation. Now pay attention to states of affairs carried relative to the resource situation s_r^i by the described situation s_{uf}^i, which is a situation related to the source domain in this case. Since the situation $s_{uf}^{i,t}$ supporting these states of affairs corresponds to a situation related to the target domain, return to Step-2 after replacing the described situation s_{uf}^i with $s_{uf}^{i,t}$.

Not only in ordinary sentence understanding, but also in metaphor understanding, it does not seem to be plausible that the hearer begins to interpret a sentence just after he/she finished hearing all of the sentence. As described in Step-1, whenever the hearer hears/reads a fragment of an utterance such as a noun phrase, a verb (phrase), and so on, he/she must start to interpret the fragment under the current context made by the discourse.

It is Step-2 that is the process which integrates fragments of interpretation newly obtained with the current context. The way of the integration depends on the convention of the language being used. For example, the grammer of the language is one of the constraints which are effective within one sentence.

In Step-4, the described situation s_{uf}^i constitutes a part of the context about the source domain, which is going on in parallel with the main context. We call this context about the source domain the *parallel context* s_p^i. If there already exists a parallel context s_p^{i-1}, Step-2 is also applied to the parallel context and s_{uf}^i. When the requirements in Step-2 are satisfied, a new parallel context s_p^i, which consists of both s_p^{i-1} and s_{uf}^i, is made. In this case, the situation which includes both s_r^i and the resource situation which has already introduced for the parallel context s_p^{i-1} serves as a new resource situation.

3 The Details of Each Step

This section will give details of these steps roughly described in the previous section through the process of understanding the example sentence (1)

"With a new strategy, I attacked his position."

in the Case-2, in which a topic about an argument is described.

3.1 Construction of a Fragment of a Described Situation

As described in the previous section, we assume that whenever the hearer hears/reads a fragment of an utterance, he/she interprets the fragment to some extent. While how big the unit of fragments to be interpreted is depends on the language being used and his/her ability in the language use, it seems that the most primitive unit is the phrase, which is determined by the grammar of the language, such as a noun phrase and a verb phrase. Assuming that the phrase is the unit of an utterance fragment, the example sentence is regarded as the following sequence of four fragments:

[With a new strategy]$_{PP}$, [I]$_{NP}$ [attacked]$_{VT}$ [his position]$_{NP}$.

As the result of the constraint satisfaction such as the grammer of the language, the described situation s_{uf}^i corresponding to each fragment described above is obtained as follows[3]:

$$s_{uf}^1 \models \langle\langle with, object{:}ST, event{:}e_1\rangle\rangle \wedge \langle\langle new, object{:}ST\rangle\rangle \wedge \langle\langle strategy, object{:}ST\rangle\rangle \quad (3)$$

$$s_{uf}^2 \models \langle\langle speaker, agent{:}A\rangle\rangle \wedge \langle\langle agent, agent{:}A, event{:}e_2\rangle\rangle \quad (4)$$

$$s_{uf}^3 \models \langle\langle attack, object{:}P\rangle\rangle \quad (5)$$

$$s_{uf}^4 \models \langle\langle position, object{:}P\rangle\rangle \wedge \langle\langle own, agent{:}B, object{:}P\rangle\rangle \quad (6)$$

[3] A relation R, and an appropriate assignment $\mathbf{a}$ of objects, determine two *basic states of affairs*, at most one of which is factual. We denote these states of affairs by $\langle\langle R, \mathbf{a}\rangle\rangle$ and $\langle\langle R, \mathbf{a}; -\rangle\rangle$. If appropriate objects $\mathbf{a}$ stand in the relation R, then the state of affair $\langle\langle R, \mathbf{a}\rangle\rangle$ is a fact. If, on the contrary, appropriate objects $\mathbf{a}$ do not stand in the relation R, then the state of affair $\langle\langle R, \mathbf{a}; -\rangle\rangle$ is a fact. We also denote a proposition that a state of affairs σ holds in a situation s by $s \models \sigma$.

where parameters e_1 and e_2 are events, that is, some situations. They are fixed up with some anchoring by linguistic convention, such as the English grammar. In this example, we assume the following relation:

$$s^1_{uf} \trianglerighteq e_1 = s^2_{uf} \trianglerighteq e_2 = s^3_{uf} \trianglerighteq s^4_{uf} \tag{7}$$

We also assume the following situation s^0_d as the initial context corresponding to the context (2):

$$s^0_d \models \langle\!\langle argue, agent{:}A, participant{:}B, object{:}TH \rangle\!\rangle \wedge \langle\!\langle theory, object{:}TH \rangle\!\rangle \wedge \langle\!\langle own, agent{:}B, object{:}TH \rangle\!\rangle \tag{8}$$

In the following subsections, we will show how the described situation s^1_{uf} is interpreted by Step-2, Step-3 and Step-4 in the process described above. For the limitation of space, we omit the explanation of the interpretation of s^2_{uf}, s^3_{uf} and s^4_{uf}.

3.2 Examining the Appropriateness of a Described Situation

According to Step-2, let us consider the situation s^{new}_d, that is, s^0_d under the condition:

$$s^1_{uf} \trianglelefteq s^0_d (= s^{new}_d) \tag{9}$$

This situation is a candidate for the context of s^2_{uf}. If only the condition (9) is imposed on s^{new}_d, the situation satisfies the requirements in Step-2. The hearer, however, usually uses some background knowledge to fill the lack of information, whenever he/she interprets an utterance fragment. For example, the typical situation supporting a state of affairs *argue*, and the knowledge that what state of affair is involved by the state of affair *strategy*, are derived from these background knowledge. In the following part of this subsection, first we show how to represent background knowledge, then we consider how s^{new}_d is interpreted with the background knowledge which we usually have in our mind.

3.2.1 Representing Background Knowledge

In this paper, by the term *resources* we mean some information which does not appear in utterances and can be used to interpret utterances by a hearer. We will pay attention particularly to the following resource, from which the hearer will be able to obtain useful information for metaphor understanding:

> The domain knowledge of a concept such as the typical context in which the concept is used

Since the speaker assumes that the hearer has sufficient knowledge about a source domain to retrieve some information intended by the speaker from an expression related to the source domain, the speaker may inform the hearer about something relevant to the current context, that is, the target domain intentionally by comparing the two domains. Therefore, in order to formulate metaphor understanding, it should be assumed that a hearer has some knowledge both of source and target domains to a certain extent. We treat this background knowledge as a situation type, that is, $[s \mid s \models \sigma]$, which somehow the hearer has[4]. Then an instance of a typical scenes actually used as a resource becomes the situation which is of this situation type, where parameters are anchored to fit individual situations.

We also define the type hierarchy in terms of the relation *subtype* in order to express the conceptual hierarchy as follows: R_1 *subtype* R_2 is true, if all assignments of the type R_1 are of the type R_2.

3.2.2 Interpretation with Background Knowledge

We suppose that the noun "strategy" recalls the situation type T_{war} to the hearer's mind as the background knowledge of the "war"[5]. Suppose also that T_{war} is the type of the situation which supports the following constraints about a strategy[6]:

$$\langle\!\langle \Rightarrow, \langle\!\langle strategy, object{:}x \rangle\!\rangle, \langle\!\langle method, object{:}x, event\text{-}type{:}ET_{use\ m.p.} \rangle\!\rangle \rangle\!\rangle \tag{10}$$

$$ET_{use\ m.p.} = [s \mid s \models \langle\!\langle use, agent{:}a_2, object{:}mp \rangle\!\rangle \wedge \langle\!\langle mil\text{-}power, object{:}mp \rangle\!\rangle] \tag{11}$$

[4] The *situation type* $[s \mid s \models \sigma]$ is the type of situation in which the state of affair σ holds.

[5] To do this, such a mechanism as the association is necessary in implementation.

[6] A positive constraint $\Rightarrow$ is defined as follows. If $s_0 \models \langle\!\langle \Rightarrow, \sigma(\vec{x}), \tau(\vec{x}) \rangle\!\rangle$ then for every situation $s \trianglelefteq s_0$ and every anchor $f : \vec{x} \rightarrow Obj(s)$ such that $s \models \sigma(f)$, there is a situation s' such that $s' \models \tau(f)$. A negative constraint $\perp$ is also defined as follows. If $s_0 \models \langle\!\langle \perp, \sigma(\vec{x}), \tau(\vec{x}) \rangle\!\rangle$ and there is a situation $s \trianglelefteq s_0$ and an anchor f such that $s \models \sigma(f)$, then there is no situation s' such that $s' \models \tau(f)$.

For the initial context s_d^0, we also suppose that the verb "argue" recalls the type T_{argue} of the situation, in which the following states of affairs hold, as the background knowledge of the "argue":

$$\langle\langle argue, agent{:}a, participant{:}p, object{:}x\rangle\rangle \wedge \langle\langle use, agent{:}a, object{:}y\rangle\rangle \wedge \langle\langle reasoning, object{:}y\rangle\rangle \tag{12}$$

Moreover, we suppose that T_{misc} is the situation type which represents the miscellaneous background knowledge and a situation of T_{misc} supports the following constraints:

$$\langle\langle \Rightarrow, \langle\langle with, object{:}x, event{:}e\rangle\rangle \wedge \langle\langle method, object{:}x, event\text{-}type{:}et\rangle\rangle, \langle\langle et, e\rangle\rangle\rangle\rangle \tag{13}$$

$$\langle\langle \bot, \langle\langle mil\text{-}power, object{:}y\rangle\rangle, \langle\langle reasoning, object{:}y\rangle\rangle\rangle\rangle \tag{14}$$

The state of affairs (13) represents the constraint about the case that the preposition "with" occurs with a "method". The state of affairs (14) represents the constraint about the conceptual structure.

Now, let us apply the background knowledge described above to s_d^{new} such that (9), that is, assume the following conditions:

$$s_d^{new}{:}T_{argue} \tag{15}$$

$$s_d^{new}{:}T_{war} \tag{16}$$

$$s_d^{new}{:}T_{misc} \tag{17}$$

The proposition (15) leads to:

$$s_d^{new} \models \langle\langle argue, agent{:}A, participant{:}B, object{:}TH\rangle\rangle \wedge \langle\langle use, agent{:}A, object{:}y\rangle\rangle \wedge \langle\langle reasoning, object{:}y\rangle\rangle \tag{18}$$

where we assume that the state of affair *argue* supported by s_d^{new} was merged with one in T_{argue}.

On the other hand, for (16) and (17) imply that the constraints (10) and (13) hold in s_d^{new}, there exists the situation s'_d and the situation e_1 is obtained as follows:

$$s'_d \models \langle\langle method, object{:}ST, event\text{-}type{:}ET_{use\ m.p.}\rangle\rangle \tag{19}$$

$$e_1(= s_{uf}^2 \trianglelefteq s_{uf}^1) \models \langle\langle use, agent{:}a_2, object{:}mp\rangle\rangle \wedge \langle\langle mil\text{-}power, object{:}mp\rangle\rangle \tag{20}$$

In (20), it seems to be natural that we presume the state of affair *use* in (18) is merged with one in (20), because $agent{:}a_2$ should be anchored to $agent{:}A$ in (18) owing to the coherence of discourse. For this presumption leads to:

$$s_d^{new} \models \langle\langle reasoning, y\rangle\rangle \wedge \langle\langle mil\text{-}power, y\rangle\rangle \tag{21}$$

it is clear that the situation s_d^{new} violates the constraint (14). Since the requirement 3 of Step-2 is not satisfied, to assume the condition (9), that is, $s_{uf}^1 \trianglelefteq s_d^0$ has turned out to be false. Therefore s_{uf}^1 constitutes the parallel context s_p^1, that is, $s_p^1 = s_{uf}^1$.

Generaly speaking, there exists some inappropriateness about the content in metaphorical expressions. What a pair of domains is compared with in a metaphor understanding is shown by the background knowledge recalled using associations. In the example, the initial context s_d^0 and the new described situation s_{uf}^1 recall the background knowledge T_{argue} of an argument and the background knowledge T_{war} of a war respectively. This means that the target domain is the "argument", and the source domain is the "war". Finally we obtain the following conditions as the result of Step-2:

$$s_d^0 \neq s_{uf}^1 \tag{22}$$

$$s_d^0{:}T_{argue} \wedge s_d^0{:}T_{misc} \tag{23}$$

$$s_{uf}^1{:}T_{war} \wedge s_{uf}^1{:}T_{misc} \tag{24}$$

That is, the new described situation s_{uf}^1 constitutes a parallel context which is not equal to the main context s_d^0. The main context s_d^0 and the described situation s_{uf}^1 are the situations related to an argument and a war, respectively.

3.3 Introducing New Resources to Get Meaningful Information

In the previous subsection, we examined the inappropriateness which might occur when a described situation is combined with the hearer's circumstances. In metaphor understanding, however, the clue

is what kinds of information is carried by an utterance and is combined with the context to make a new context. But, as described in the previous subsection, the hearer's background knowledge of both a war and an argument is insufficient for information which contributes to the main context to be able to obtained from s^1_{uf}. Therefore, it can be presumed that the hearer should introduce some new resource to get meaningful information.

Including the interaction theory mentioned in the section 1, a number of studies suggest that the correspondence is important. As the consequence we come up with having the following supposition:

> First, the hearer introduces some correspondence between a source domain and a target domain as a new resource. Then, according to this resource, he/she converts information, that is, he/she converts some states of affairs in the source domain into the corresponding states of affairs in the target domain[7].

3.3.1 A Description of Correspondences between a Target Domain and a Source Domain

In this section, we will show what correspondences we should deal with and how to express them. Since a source domain and a target domain are generally distinct from each other, in a strict sense we should treat correspondences between the schemes of individuation for each situation in order to express correspondences between the situations. However, since it is important for metaphor understanding what kinds of information about the target domain are obtained from descriptions about the source domain, the following constraints are sufficient to express correspondences between the source domain and the target domain:

$$\langle\!\langle \Rightarrow, \langle\!\langle r_{source}, \vec{x}; p_s \rangle\!\rangle, \langle\!\langle r_{target}, \vec{y}; p_t \rangle\!\rangle \rangle\!\rangle \tag{25}$$

where s_{target} and s_{source} are the situations related to the target domain and the source domain respectively, and $r_{target} \in Rel_{s_{target}}$, $r_{source} \in Rel_{s_{source}}$.

3.3.2 How to Obtain Correspondences

How can we obtain the constraints which represent the correspondence between the source domain and the target domain ? General metaphors[LJ80] are an important concept relevant to this question. Lakoff points out that a metaphorical expression in a certain text is an instance of a general metaphor. For instance, the example sentence can be regarded as an instance of the general metaphor "ARGUMENT IS WAR". At first sight, it seems to be sufficient for metaphor understanding to prepare all of correspondences obtained from all of general metaphors. However, for metaphorical expression can be and moreover might be extended flexibly by the speaker according to the context, it seems to be difficult that we prepare universal set of correspondences. If so, how can we get correspondences, which should be set up according to the context ? In the next section, we show that some heuristics can give us some useful correspondences.

3.3.3 Heuristics for Analogical Mapping in Metaphor Understanding

Basically, there may be many possible correspondences between two domains. However, it seems that we use some heuristics to establish correspondences which can be used to retrieve some useful information from metaphorical utterances during our interpretation process. Let us enumerate some heuristics useful for metaphor understanding[8]:

H1 Coherence of information
There are no incoherent situations when constraints, representing correspondences, are applied.

H2 Similarity between corresponding states of affairs
This heuristic is based upon our assumption that it is difficult even also for human in metaphor understanding to find correspondences between two domains containing no pairs of states of affairs closely related to each other. On this assumption, we expect that some corresponding pairs of states of affairs may be found easily.

H2.1 Make correspondences between the same states of affairs in two domains as far as possible.

[7] From now on, let the terms "source domain" and "target domain" mean also situations related to a source domain and a target domain, respectively.

[8] Some measure, that is, some evaluating functions for application of heuristics may be required for the efficient search of a plausible correspondence.

H2.1.1 Especially, when a state of affairs $\sigma = \langle\langle r, \vec{x}; p\rangle\rangle$ holding in the source domain does not appear in the target domain, check whether the state of affairs can be used in the target domain, that is, checking whether the assignments to the argument roles of the state of affairs are appropriate in the target domain. If the condition is satisfied, the following constraint becomes one of the assumption: $\langle\langle \Rightarrow, \sigma, \sigma\rangle\rangle$.

H2.2 Make correspondences between *similar* states of affairs in two domains as far as possible, when the heuristic H2.1 is not applicable. Similarity among relations is defined in terms of the relation *subtype*, by which the type hierarchy is defined.

H2.2.1 If in the target domain the assignment is not appropriate for the state of affairs σ obtained by applying the heuristic H2.1.1, generalize the relation r by obtaining a super type r_{sup} such that $\sigma' = \langle\langle r_{sup}, \vec{x}; p\rangle\rangle \& r$ *subtype* r_{sup} from the type hierarchy and check whether the assignment is appropriate for this super type. If the condition is satisfied, the following constraint becomes one of the assumption: $\langle\langle \Rightarrow, \langle\langle r, \vec{x}; p\rangle\rangle, \langle\langle r_{sup}, \vec{x}; p\rangle\rangle\rangle\rangle$. This generalization, however, gives us a weaker assumption.

H2.2.2 If the heuristic H2.2.1 is applicable, examine subtypes r_{sub} of the relation r_{sup} obtained by applying H2.2.1 such that $\sigma'' = \langle\langle r_{sub}, \vec{x}; p\rangle\rangle \& r_{sub}$ *subtype* r_{sup}. If the assignment is appropriate for one of the subtypes, r_{sub}, the following constraint becomes one of the assumption: $\langle\langle \Rightarrow, \langle\langle r, \vec{x}; p\rangle\rangle, \langle\langle r_{sub}, \vec{x}; p\rangle\rangle\rangle\rangle$. This assumption is stronger than the result of H2.2.1.

H3 Coherence of objects in two domains

Each object in one domain corresponds to an object in another domain according to correspondences between relations. There must be no incoherence in these correspondences between objects.

H4 Isomorphism of constraints

Make correspondences which preserve the isomorphism of constraints in two domains. For example, suppose the following causal relations hold in the target domain and a source domain respectively.

$$\langle\langle \Rightarrow, A_{target}, B_{target}\rangle\rangle,\ \langle\langle \Rightarrow, A_{source}, B_{source}\rangle\rangle$$

It seems to be natural to assume that the consequence B_{target} corresponds with the consequence B_{source}, if it is known that the premise A_{target} corresponds to A_{source}, and vice versa.

H4.1 Strengthening the definition of constraints

Since the definition of the positive constraint, which is described in the section 3.2.2, is weaker than the implication of the predicate logic, we cannot combine several constraints into a new constraint. Therefore, the heuristic H4, which depends on the isomorphism of constraints, not always work well. In order to cope with this, we introduce the heuristic which strengthens the definition of the positive constraint only while the heuristic H4 is applied to make some correspondences. The strengthening is achieved by the following two restrictions.

- The situation s' which supports the state of affairs τ, which is carried relative to a constraint, should be a part of the situation s_0, which supports the constraint. That is, add the condition $s' \trianglelefteq s_0$ to the definition of the positive constraint.
- This definition should be bidirectional. Replace "if" in the definition of the positive constraint with "if-and-only-if".

These may correspond to the plausible restriction on the domain of consideration, with which we usually do not have to examine unrelated matters.

These restrictions contribute to the derivation of some relations as follows, which can be used in H4, rather than, to finding quite new constraints[9].

Transitivity	$s \models \langle\langle \Rightarrow, \sigma, \sigma'\rangle\rangle \wedge \langle\langle \Rightarrow, \sigma', \sigma''\rangle\rangle \rightsquigarrow s \models \langle\langle \Rightarrow, \sigma, \sigma''\rangle\rangle$
Monotonicity	$s \models \langle\langle \Rightarrow, \sigma, \sigma'\rangle\rangle \rightsquigarrow s \models \langle\langle \Rightarrow, \sigma \wedge \sigma'', \sigma'\rangle\rangle$
Conjoining of consequence	$s \models \langle\langle \Rightarrow, \sigma, \sigma'\rangle\rangle \wedge \langle\langle \Rightarrow, \sigma, \sigma''\rangle\rangle \rightsquigarrow s \models \langle\langle \Rightarrow, \sigma, \sigma' \wedge \sigma''\rangle\rangle$
Disjoining of consequence	$s \models \langle\langle \Rightarrow, \sigma, \sigma' \wedge \sigma''\rangle\rangle \rightsquigarrow s \models \langle\langle \Rightarrow, \sigma, \sigma'\rangle\rangle \wedge \langle\langle \Rightarrow, \sigma, \sigma''\rangle\rangle$
Weakening	$s \models \langle\langle \Rightarrow, \sigma, \sigma'\rangle\rangle \rightsquigarrow s \models \langle\langle \Rightarrow, \sigma \wedge \sigma'', \sigma' \wedge \sigma''\rangle\rangle$

where $\rightsquigarrow$ means that assuming the restriction described above, the right hand side is derived from the left hand side logically.

[9] The size of search spaces for finding quite new constraints based on these restrictions is often very large.

3.3.4 Computing Correspondences

In our approach, computing correspondences is equivalent to applying the heuristics described in the last section. Therefore the computational process is expressed as the order of the application of each heuristic. From the viewpoint of computing correspondences, the heuristics are classified into two groups, one group which generate hypotheses of correspondence (H2,H4) and another group which impose restrictions on generating hypotheses (H1,H3). While to clarify the process of the application of the heuristics we should study it furthermore, empirically, in many cases, the correspondences can be computed by applying the heuristics repeatedly in the following order:

1. H2.1 (H2.1.1)
2. H3 and H1
3. H4 or H2.2
4. H3 and H1

Note that from the viewpoint of the computational complexity, the generator heuristics tend to be applied in order of computational simplicity.

Gentner[GFS87, Bur86] proposed the *systematicity condition* as a general condition on the mapping process in analogy. This condition is essentially that "relations are more likely to be imported into the target domain if they belong to a system of coherent, mutually constraining relationships the others of which are mapped". This is the standpoint in which the heuristic H4 is regarded important. While H4 deals with higher order relations, that is, constraints like Gentner's method, our method differs from hers in the point that the heuristic also uses isomorphism of constraints to generate new correspondences. Indurkhya[Ind87] proposed a mapping called *T-MAP* and a model of metaphors and analogies based on it. T-MAP is a general mapping schema according to the coherence of a target domain and newly mapped relations. Since this method does not use the information about a relation like the heuristic H2 to get a clue of correspondences, there exists the problem of the computational complexity. Burstein[Bur86] also refers to non-identical mappings, which Gentner's theory cannot deal with. While this non-identical mappings corresponds to the heuristic H2, in his method, H2.2.2 is restricted to generating only "brother" of the relation in the source domain.

3.3.5 An Example of Establishing Correspondences

Let us examine correspondences for the example sentence. As described in the section 2, the described situation s^1_{uf} forms a certain part of the parallel context s^1_p in parallel with the main context s_d. Therefore correspondences we should obtain are those that connect states of affairs which hold in s^1_{uf} to states of affairs which meet the requirements of Step-2 in the context s^0_d relative to the conditions (22), (23) and (24).

First let us spell out the states of affairs which hold in s^1_{uf} under the condition (24). The states of affairs which hold in s^1_{uf} are given in (3). By applying the constraints in T_{misc} to s^1_{uf}, it is derived that there exists a situation s'_d such that (20). Now, supposing that s'_d is also used as a part of the parallel context, the condition $s'_d \trianglelefteq s^1_{uf}$ should be satisfied. Under the condition, states of affairs holding in s^1_{uf} are as follows:

$$s^1_{uf} \models \langle\langle with, object{:}ST, event{:}e_1\rangle\rangle \wedge \quad (26)$$

$$\langle\langle strategy, object{:}ST\rangle\rangle \wedge \quad (27)$$

$$\langle\langle method, object{:}ST, event\text{-}type{:}ET_{use\ m.p.}\rangle\rangle \quad (28)$$

$$e_1(\trianglelefteq s^1_{uf}) \models \langle\langle use, agent{:}A, object{:}mp\rangle\rangle \wedge \quad (29)$$

$$\langle\langle mil\text{-}power, object{:}mp\rangle\rangle \quad (30)$$

Let us construct the constraints which connect the states of affairs (26),...,(30) to the states of affairs which may hold in the target domain. For the state of affairs (29), the following constraint is obtained by the heuristic H2.1, which generates correspondences related to the states of affairs which can be used also in the target domain:

$$C^1_{w\to a} = \{\langle\langle\Rightarrow, \langle\langle use, agent{:}A, object{:}mp\rangle\rangle, \langle\langle use, agent{:}A, object{:}y\rangle\rangle\rangle\rangle\} \quad (31)$$

To the states of affairs (26),(27), (28) and (30), however, the heuristic H2.1 cannot be applied, since they cannot be used in the target domain[10]. For the state of affair (30), the correspondence is obtained by

[10] Because (30) violates the constraint (14), (26) and (28) lead to (30) with (13), and (27) leads to (28) with (10).

comparing s^1_{uf} with the main context s^0_d under the correspondences (39) and (31). Under the condition (23) the main context s^0_d is as follows:

$$\begin{aligned} s^0_d \quad \models \quad & \langle\langle argue, agent{:}A, participant{:}B, object{:}TH\rangle\rangle \wedge \langle\langle theory, TH\rangle\rangle \wedge \\ & \langle\langle own, agent{:}B, object{:}TH\rangle\rangle \wedge \langle\langle use, agent{:}A, object{:}y\rangle\rangle \wedge \langle\langle reasoning, object{:}y\rangle\rangle \end{aligned} \tag{32}$$

Since the parameter mp in the source domain is connected to the parameter y in the target domain by (31), by applying the heuristic H3, the following constraint is obtained:

$$C^2_{w\to a} \quad = \quad \{\langle\langle \Rightarrow, \langle\langle mil\text{-}power, object{:}mp\rangle\rangle, \langle\langle reasoning, object{:}y\rangle\rangle\rangle\rangle\} \tag{33}$$

Since the relation *method* itself can be used also in the target domain, for the state of affair (28) the correspondence constraint is obtained by translating the situation type, which is in the argument of the state of affair and is related to the source domain, into the situation type related to the target domain. Since the correspondence constraints (31) and (33) are applied to the any situation s, such that $s{:}ET_{use\ m.p.}$, related to the target domain, it is derived that there exists a situation s' such that $s'{:}ET_{use\ reas}$ for every situation s, where

$$ET_{use\ reas} \quad = \quad [s \mid s \models \langle\langle use, agent{:}y, object{:}reas\rangle\rangle \wedge \langle\langle reasoning, object{:}reas\rangle\rangle] \tag{34}$$

We suppose the following constraint, for s' can be regarded as a situation related to the target domain:

$$\begin{aligned} C^3_{w\to a} \quad = \quad & \{\langle\langle \Rightarrow, \langle\langle method, object{:}ST, event\text{-}type{:}ET_{use\ m.p.}\rangle\rangle, \\ & \langle\langle method, object{:}ST, event\text{-}type{:}ET_{use\ reas}\rangle\rangle\rangle\rangle\} \end{aligned} \tag{35}$$

Lastly we examine the case of the state of affairs (27). It seems to be natural that we assume the following constraint about the "logic" holds in a situation s which is of the situation type T_{argue} about the "argument".

$$\langle\langle \Rightarrow, \langle\langle logic, object{:}x\rangle\rangle, \langle\langle method, object{:}x, event\text{-}type{:}ET_{use\ reas}\rangle\rangle\rangle\rangle \tag{36}$$

Now, applying the heuristic H4 to the constraints (10) and (36), the following correspondence constraint are obtained:

$$C^4_{w\to a} \quad = \quad \{\langle\langle \Rightarrow, \langle\langle strategy, object{:}ST\rangle\rangle, \langle\langle logic, object{:}ST\rangle\rangle\rangle\rangle\} \tag{37}$$

We have obtained all constraints which connect each state of affairs holding in s^1_{uf} to a state of affairs related to the target domain "argument".

3.4 Metaphor Understanding with Resources Related to Correspondences

The resource situation s^1_r in Step-4 becomes the situation which supports the constraints $C^1_{w\to a}, \ldots, C^4_{w\to a}$ in the previous subsection. In order to apply these constraints to e_1, suppose the condition $s^1_r = s^1_{uf}$. Then it is derived that there exists the following situation e^t_1:

$$e^t_1 \quad \models \quad \langle\langle use, agent{:}A, object{:}y\rangle\rangle \wedge \langle\langle reasoning, object{:}y\rangle\rangle \tag{38}$$

Because e_1 corresponds to e^t_1, the following constraint is obtained:

$$C^5_{w\to a} \quad = \quad \{\langle\langle \Rightarrow, \langle\langle with, object{:}ST, event{:}e_1\rangle\rangle, \langle\langle with, object{:}ST, event{:}e^t_1\rangle\rangle\rangle, \} \tag{39}$$

This constraint is also included by s^1_r. Then it is derived that there exists the following situation $s^{1,t}_{uf}$:

$$s^{1,t}_{uf}(\trianglerighteq e^t_1) \quad \models \quad \langle\langle with, agent{:}A, object{:}ST\rangle\rangle \wedge \langle\langle logic, object{:}ST\rangle\rangle \wedge \langle\langle method, object{:}ST, event\text{-}type{:}ET_{use\ reas}\rangle\rangle$$

This situation corresponds to a described situation related to the target domain. Return to Step-2 after replacing the described situation s^1_{uf} with $s^{1,t}_{uf}$. Then all requirements in Step-2 are satisfied under the condition $s^{1,t}_{uf} \trianglelefteq s^0_d$. Therefore $s^{1,t}_{uf}$ forms part of the new main context s^1_d such that $s^1_d = s^0_d \trianglerighteq s^{1,t}_{uf}$. Generally speaking, the semantic representation of metaphor understanding can be formulated as the following constituents:

- A described situation s^i_{uf} related to the source domain, that is , a part of the parallel context

- An application of the background knowledge of the source domain s^i_{uf}:T_{source}
- A resource situation s^i_r which supports constraints representing the correspondence
- A described situation $s^{i,t}_{uf}$ related to the target domain, which satisfies the conditions: $s^i_r = s^i_{uf}$, $s^i_{uf} \Vdash_{s^i_r} \sigma$, $s^{i,t}_{uf} \models \sigma$.
- The condition, which represents the construction of a new context: $s^i_d = s^{i-1}_d \trianglerighteq s^{i,t}_{uf}$.
- An application of the background knowledge of the target domain s^i_d:T_{target}

4 Conclusion

In this paper, we give a formal description of metaphor understanding in terms of situation semantics. In this formulation, we propose the model in which the hearer introduces correspondences between a target domain and a source domain as a new resource to obtain useful information about the target domain in terms of source domain. We expect that this formal description of metaphor understanding may serve as a guide to natural language understanding systems which can understand discourses with metaphors.

From the viewpoint of a computational model, our model is not perfect. Since we have concentrated upon a formal description in this paper, we have not mentioned how to search a plausible correspondence. The concrete method of how to search a plausible correspondence will be developed in our future work. (As related works of plausible search in metaphor understanding, several methods have been proposed[TIT89, Ind87].)

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