A Logical Description of Metaphor Analysis

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Abstract

This paper aims to use logical techniques to describe how metaphors are analyzed. Metaphor analysis process functions as one of the most important strategies to uncover implied information in discourse understanding. A metaphor analysis logic system is developed and presented in terms of its definitions, axiomatic system, inference rules, properties, semantic interpretations and applications. The merits of the logic are that possible worlds are substituted with possible feature spaces compared with Local Frame Theory, and an understanding modal operator U_p, a relational symbol $\prec$ and a Gestalt rule are embodied. The most notable feature of the logic is that it takes into account subjective factors in the process of metaphor analysis.

1 Introduction

The cognitive nature of metaphor helps people to learn and describe new things. Metaphorical phenomena need to be analyzed in natural language processing because metaphor, to some extent, is the focus of the mind and center of language mechanism (Zhou,et al,2007).

We say that "A is B" is a metaphor if literally concept A is not equal to concept B, but A possesses some features of B or there are some similarities that both A and B share.

Consider the following examples.

(a) The lawyer is a fox.
(b) A car is a metal horse.

The topic of example (a) is a *lawyer* and the vehicle is a *fox*. Semantically the sentence is incorrect. But metaphorically the sentence is understandable. The metaphor is then resolved against a certain similarity between *lawyer* and *fox*, which is the hidden ground *sly*.

There are many formal theories in linguistics that describe attributes of metaphors (Shu, 2000). Comparison and Substitution View argues that metaphor is just the transition between words while later Richards and Black (1936) in their Interaction View upgraded word-transition to dynamic semantic interaction of topic and vehicle. Lakoff and Johnson put forward Conceptual Metaphor Theory (Lakoff and Johnson, 1980) which tells that metaphors like "Time is money" and "Thought is food" give rise to metaphors like "I am wasting my time", "I digested his thought" and etc.

This paper considers metaphor from logic aspect. Before representing the logic we first take a glance at the limits of current logics. Classical propositional logic or predicate logic has great limitations in explanation power because they cannot explain semantic problems in metaphors, for example they cannot tell the truth value of "metal horse" in example (b) and will semantically take "metal horse" or "a car is a post-horse" false. Researchers then introduced extra operators, such as modal operator to set up modal logic and epistemic logic. However, there is another problem—logic omniscience problem, that is $Bp \wedge B(p \rightarrow q) \rightarrow Bq$ allows people to deduce any knowledge (belief)

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embedded in already-known knowledge (belief), which is over-generalizing in reality. Levesque tries to resolve logic omniscience problem by extending the explanation power, distinguishing latent belief and obvious belief (Zhou, 2001), however, it is still logic-omniscient from the aspect of coherent logic.

The metaphor logic we aim to present should surpass the above limits. On the one hand, the metaphor logic should avoid the logic omniscience problem. Because according to people's cognitive nature there must be metaphors that have not been understood as long as people have not realized any relevant concepts at the present time. On the other hand, the logic is supposed to resolve semantic truth problems of metaphors. It needs to represent truth value of the literally-incorrect but pragmatically-feasible metaphors.

2 Metaphor Logic System

2.1 Language of Metaphor Logic System

To avoid redundant treatment of metaphor, we need a richer language that enables us to describe relations between topic and vehicle. Then we introduce possible feature spaces, a modal operator U_p and a relational symbol $\prec$ to explain metaphors.

Definition 1. ***Possible-feature spaces***

To avoid limits of classic logics, we make use of possible feature spaces to substitute possible worlds in Kripke model. A possible feature space is a set of features or propositions of concepts. An agent can hold some inconsistent beliefs, which depend on the local framework called the context of the epistemic state of the agent. Possible feature space is a framework in which we can easily discuss the truth problems of well-formed formulas.

Definition 2. ***The Language*** L^{met}

To indicate the metaphorical relation of a formula, the first-order language is augmented with a binary relational symbol '$\prec$'. Its left argument is a first-order formula and its right argument a formula of L^{met}.

$\alpha ::= P(x_{1...}x_n) \mid \neg\alpha \mid \alpha \wedge \beta \mid \alpha \rightarrow \beta \mid \alpha \vee \beta \mid \forall x\alpha \mid \exists x\alpha \mid \alpha \prec \beta$

A modal operator U is also introduced to describe the understanding state of α. Together with possible space p, $U_p\alpha$ is a well-formed formula which means the agent understands formula α in possible feature space p.

Definition 3. ***Truth conditions***

Truth value of formula $\alpha \prec \beta$ is defined as follows:

$v(\alpha \prec \beta)=1$ denotes it is true that α is the same as β.

$v(\alpha \prec \beta)=0$ denotes it is false that α is the same as β.

Any other values between 0 and 1 are excluded. If α and β share some features then we say $\alpha \prec \beta$ is true under the features. When adding modal operator U_p, Truth Value of formula $U_p(\alpha \prec \beta)=1$ means in possible feature space p the agent understands or accepts that the metaphoric counterparts α and β are as the same.

2.2 Axiomatic System

1. Standard tautologies in predicate logic.
2. AU1: $U_p(\alpha \rightarrow \alpha)$

   AU2: $U_p\alpha \rightarrow \sim U_p \sim \alpha$ (If understand α then do not reject α.)

   AU3: $U_p(\alpha \rightarrow \beta) \rightarrow (U_p\alpha \rightarrow \sim U_p \sim \beta)$ (If understand $\alpha \rightarrow \beta$ and α then do not reject β.)

To avoid confusion we omit quantifiers $\forall$ and $\exists$ here.

2.3 Axiomatic Inference Rules

According to axiomatic system, the inference rules are as follows:

R0: Substitution Rule

If ε is a variable in well-formed formula α which is proved true in axiomatic system (written as $\vdash \alpha$) and β is an arbitrary well-formed formula, then α' arising by substituting each ε in α with β is also proved true (written as $\vdash \alpha'$).

R1: Separation Rule

If $\vdash \alpha$ and $\vdash \alpha \rightarrow \beta$, then $\vdash \beta$.

R2: Understanding rule

If $\vdash \alpha \rightarrow \beta$, then $\vdash U_{p'}\alpha \rightarrow U_{p'}\beta$, where possible-feature space p' is the largest coherent possible-feature space in $\overline{S}$. ($\overline{S}$ is a set of various possible feature spaces.)

R3: Contraction Rule

If $\vdash \sim U_p \sim \alpha$, then existing a $p' \subset p$ that $\vdash U_{p'}\alpha$.

R4: Gestalt Rule

$\vdash (U_p\alpha \wedge U_{p'}\beta) \rightarrow U_{p''}(\alpha \prec \beta)$, $p'' \subset (p \cap p')$

A visible interpretation of R4 is if the agent understands α in space p and also understands β in space p', then in space p'', a subset of the interaction of p and p', the agent understands that α is the same as β.

R4 is embodied to describe metaphors. Without Gestalt rule the logic system is similar to Levesque's logic system. We can get $(U_p\alpha \wedge U_{p'}\beta) \rightarrow \sim U_{p''} \sim (\alpha \wedge \beta)$ where space p'' is the largest coherent possible-feature space in $\overline{S}$. $\sim U_{p''} \sim$ here means in space p'', there is at least one proposition not rejected (either understood as true or understood without any truth value). This is equal to "aware" in FH logic system.

When we introduce formula $(U_p\alpha \wedge U_{p'}\beta) \rightarrow U_{p''}(\alpha \prec \beta)$, FH system becomes a particular case of our logic system. Because if we adjust the accessibility of spaces p, p' and p'', then $(\alpha \prec \beta)$ comes to be $(\alpha \wedge \beta)$. Therefore our logic is more applicable in interpreting metaphors.

In our system, formulae like $U_p\alpha \rightarrow \alpha$ or $U_p \sim \alpha \rightarrow \sim \alpha$ will not be deduced. Because when we say that a metaphor is true we mean it is true for the agent who understands it. We do not mean the metaphor is absolutely true in the world but only subjectively true. As a result whether or how a metaphor is understood is limited in an agent's certain cognitive spaces.

3 Properties of the Metaphor Logic System

The metaphor logic system has five main properties:

1. Each possible feature space is logically coherent. There is no possible-feature space in which both α and $\sim\alpha$ are true. As a result formula $\sim (U_p\alpha \wedge U_p \sim \alpha)$ is satisfiable.

2. The logic system has avoided logic-omniscient problem because $\{U_p\alpha, U_p(\alpha \rightarrow \beta), \sim U_p\beta\}$ is satisfiable. If the agent does not realize any propositions or predicates about β in space p he will not understand β. So the logic system is restricted to a suitable explanation power.

3. $\sim U_p(\alpha \vee \sim \alpha)$ is satisfiable. Thus if the agent does not realize any propositions or predicates about α in space p then the agent will not understand $(\alpha \vee \sim \alpha)$. To be more explicit, the set of tautologies is not closed. This property also shows that there are metaphors whose meaning are not easy to pin down.

4. In Levesque's logic system nesting is not allowed. In our metaphor logic system α and p can be nested. This property is coherent to people's cognitive ability to understand new metaphors from known ones.

5. To an identical metaphor, different agents may deduce different interpretations. Subjective factors are integrated in this logic system. Different corpus will produce different possible feature spaces which realize different cognitive states.

4 Semantic Interpretations and Applications

In this section we apply the metaphor logic system to interpret metaphoric phenomena in language. Processing rules are designed to treat five most common types of metaphors for the purpose of natural language processing.

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4.1 Axiomatic Inference Rules

Before applying this logic to represent metaphors, Gestalt rule R4 $\vdash (U_p\alpha \wedge U_{p'}\beta) \rightarrow U_{p''}(\alpha \prec \beta)$ should first be specified. Formulae α and β should be refined because the combination of space p, p' and p'' is influenced by parts of speech of α and β. Parts of speech of α and β here are restricted to nouns, transitive verbs, intransitive verbs, modifier and etc.

Rules for sentence processing are as follows:

NU1: Metaphor markers like "is", "as⋯as", "like" and the like are ignored when processing sentences. Only nominal formulas before and after the markers are Gestaltized.

NU2: Entities have the priority of collocating with verbal predicates or modifiers.

NU3: Terms of possible feature space p in $U_p\alpha$ are ordered linearly. Each term can be any of the following three types: entity, relation (attribute, strong relation) or root metaphor (e.g. time $\prec$ money). All the terms are represented as weighted sequences in possible feature spaces.

4.2 Semantic Interpretation and Processing Rules

1. As for "α is β" metaphors where α and β are nouns, the processing rules are:

Rn31: $U_p\alpha \wedge U_{p'}\beta \Rightarrow U_{p''}(\alpha \prec \beta)$

Where the intersection of space p and p' is not empty and p'' denotes the interaction.

Rn32: As for formula $U_p\alpha \wedge U_{p'}\beta$, if $U_p\alpha$ becomes true when extracting some terms in p' into p, then add the terms to p.

Rn33: As for formula $U_p\alpha \wedge U_{p'}\beta$, if the intersection of space p and p' is empty, then search for the historical records of p. If formulae like $U_p(m \prec n)$ are found where n is a term in p', then the attribute m in p and n in p' can be Gestaltized. This rule is to make two inaccessible spaces accessible.

2. As for "$\beta\,\alpha$" metaphors where α is a noun and β is a modifier (a noun or an adjective), the processing rules are:

Ra31: If $U_p\alpha \wedge U_{p'}\beta$, then $U_{p''}(\alpha[\beta])$ where $\alpha[\beta]$ does not denote first-order logic or higher-order logic. Take the phrase "strong horse" for example. α is the horse and β is strong. Proposition "horse[strong]" denotes "strong horse". Actually, if $p = p' = p''$, and $U_p\beta \wedge U_p\alpha \rightarrow \sim U_p \sim(\beta \wedge \alpha)$, then $\alpha \wedge \beta$ is realized as $\alpha[\beta]$. If β is the modifier of α and $U_\beta\alpha$ is true, then some modifications will be made to spaces p, p' and p''. If $p'' \subset (p \cap p')$, then $U_p\beta \wedge U_{p'}\alpha \rightarrow U_{p''}(\alpha[\beta])$. If β can be added to space p'', then $p'' = p \cup \{\beta, U_{px}(\alpha \prec \gamma)$.

If no formulae like $U_{px}(\alpha \prec \gamma)$ are found in historical records, compare $U_{p''}(\alpha[\beta])$ with other words and expressions and do rule Rn31 to see whether β can be added to other spaces. If not, then $U_{p''}(\alpha[\beta])$ is false and the collocation of α and β is not a metaphoric but an incorrect collocation.

3. As for "$\alpha\,\beta$" metaphors where α is a noun and β is an intransitive verb, the processing rules are:

Rv31: As for formula $U_p\alpha \wedge U_{p'}\beta(x)$ where β is an intransitive verb and x is the agent of action β, if the interaction of set p and p' is not empty, then we get $U_{p''}((\alpha = x) \wedge \beta(x))$ where p'' is derived by adding $\{\beta\}$ into the interaction.

Rv32: As for formula $U_p\alpha \wedge U_{p'}\beta(x)$, if the interaction of set p and p' is empty, then search for the historic records to check whether there is a Gestalt rule $U_{px}\alpha \prec \gamma$ and whether $U_\gamma\beta$ is true. If so, then we get $U_{p''}((\alpha = x) \wedge \beta(x))$, $p'' = p \cup \{\beta, U_{px}(\alpha \prec \gamma)$. A visual explanation is that in γ's space p'', the agent considers that α doing the action β is understandable.

If no Gestalt rule $U_{px}\alpha \prec \gamma$ is found, the conclusion comes to be that the collocation of α and β is incorrect.

4. As for "$\alpha\,\beta$" metaphors where α is a noun and β is a transitive verb, the processing rules are:

Rv33: As for formula $U_p\alpha \wedge U_{p'}\beta(x,y)$ where β is a transitive verb and x is the agent and y is the patient, if the interaction of set p and p' is not empty, then we get $U_{p''}((\alpha = x) \wedge \beta(x,y))$ where p'' is derived by adding $\{\beta\}$ into the interaction.

Rv34: As for formula $U_p\alpha \wedge U_{p'}\beta(x)$, if the interaction of set p and p' is empty, then search for the historic records to check whether there is a Gestalt rule $U_{px}\alpha \prec \gamma$ and $U_\gamma\beta$ is true. If so, then we get $U_{p''}((\alpha = x) \wedge \beta(x,y))$, $p'' = p \cup \{\beta, U_{px}(\alpha \prec \gamma)$. A visual explanation is that in γ's space p'', the agent consider that α doing the action β is understandable.

5. As for "α β" metaphors where α is a transitive verb and β is a noun, the processing rules are:

Rv35: As for formula $U_p\alpha(x,y) \wedge U_{p'}\beta$ where α is a transitive verb and x is the agent and y is the patient, if the interaction of p and p' is not empty, then we get $U_{p''}(\alpha(x,y) \wedge (\beta = y))$ where p'' is derived by adding $\{\beta\}$ into the interaction.

Rv36: As for formula $U_p\alpha(x,y) \wedge U_{p'}\beta$, if the interaction of p and p' is empty, then search for the historical records to check whether there is a Gestalt rule $U_{px}\alpha \prec \gamma$ and whether $U_\gamma\beta$ is true. If so, then we get $U_{p''}(\alpha(x,y) \wedge (\beta = y))$, $where\ p'' = p \cup \{\beta, U_{px}(\alpha \prec \gamma)$. In γ's space p'', the agent considers that action α acts on β is understandable. If no Gestalt rule $U_{px}\alpha \prec \gamma$ is found or $U_\gamma\beta$ is false, then $\alpha \wedge \beta$ is considered to be an incorrect collocation.

4.3 Examples Using the Processing Rules

The processing rules can be applied to several types of metaphors. In the following we will show how these rules work through several specific examples.

Terms in each possible feature space are derived from a certain corpus (e.g. Wordnet (Fellbaum, 1998) in English and Hownet (Dong, 1998) in Chinese).

A is B metaphors

Example 1 *A lawyer is a fox.*

$U_{\{court,\ crime,\ case,\ sly\}} lawyer \wedge is \wedge U_{\{forest, sly, doubtful, rabbit\}} fox$

$\Rightarrow U_{\{sly\}} lawyer \prec fox$

The interpretation is that under the ground of sly a lawyer is the same as a fox.

Example 2 *A car is a metal horse.*

$U_{\{traffic, road, direction, rapidness\}} car \wedge is \wedge U_{\{metal\}} iron$

$\wedge U_{\{rapidness, battlefield\}} horse$

$\Rightarrow U_{\{U_{\{rapidness\}} horse \prec car, rapidness\}} car \prec horse[iron]$

In space $U_{\{U_{\{rapidness\}} horse \prec car, rapidness\}}(car \prec horse[iron])$, there is a formula $horse \prec car$ in which horse is to considered to be highly analogous to term $U_{\{traffic, road, direction, rapidness\}} car$. So term $U_{\{rapidness\}} horse \prec car$ can be added into the space of $U_{\{traccif, road, direction, rapidness\}} car$.

Verbal metaphors

In verbal Metaphors the relations of verb and its collocated nouns are metaphorical.

Example 3 *The flower sings.*

$U_{\{tender,\ beautiful\}} flower \wedge U_{\{person, band, act\}} \sin g(x) \quad \Rightarrow$

$U_{\{U_{\{beautiful\}}(flower \prec person\}, tender, beautiful\}}(flower = x) \wedge \sin g(x)$

Action: Rv32+historiic record $U_{\{beautiful\}}(flower \prec perpon)$

Example 4 *Deposit time.*

Using the root metaphor Time is money.

$U_{\{money\}} deposit(x,y) \wedge U_{\{valuable, time, U_{px} time \prec money\}} time$

$\Rightarrow U_{\{U_{px} time \prec money\}} deposit(x,y) \wedge (time = y)$

Following this, the word deposit can be used to describe time.

5 Discussions and Future Work

Nowadays modern logic and artificial intelligence are increasingly integrated. More powerful logics (Steinhart, 2001; Zhang, 2003; Huang, 2005) are designed to deal with complex human thoughts. The logic system for metaphor analysis is just designed to describe the cognitive nature of natural language.

In the metaphor logic system, possible worlds are substituted with possible feature spaces. A modal operator U_p is introduced to denote the fact that in possible feature space p α is acceptable or understandable. A relational symbol $\prec$ is also introduced to represent metaphoric relation. $\alpha \prec \beta$ known as Gestalt rule denotes α is analogous to β. These embedded strategies are proved to have resolved the truth value and logic omniscience problems.

The main novelty of this logic is it takes into account subjective factors. It argues that whether a metaphor is understood or how the truth value of a metaphor is valued lies on the agent concerned.

Different people come up with different interpretations. Different subjective states of agents are realized by possible feature spaces derived from different corpus. Thus the metaphor logic system is consistent to the working of human mind.

Several processing rules are also designed to deal with different kinds of metaphors for the purpose of natural language processing. However it is inadequate to use a single logic system to interpret all kinds of metaphoric phenomena owing to the rich expressive power of natural language and cognitive nature of human beings. For that matter, a rational classification system of metaphors needs to worked out to guide further research on analyzing and interpreting process of metaphors.

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