Interpretation of Utterances based on Relevance Theory: Toward the Formalization of Implicature with the Maximal Relevance

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Abstract

This paper proposes an interpretation method of utterances using relevance theory. Sperber and Wilson have said that humans adopt the maximal relevance in interpretation of utterances. The maximal relevance has a high cognitive effect with low processing efforts. In relevance theory the meaning of utterances is divided into explicatures and implicatures. We study to formalize interpretations with the maximal relevance. We focus on implicatures and define process of deriving implicatures. In addition, we define the cognitive effect and the processing effort, and apply those to multi-objective optimization. We regard Pareto-optimal solutions as implicatures with the maximal relevance. We exemplify the validity of our method. Future work is an experiment using a method which combined this method with reported method.

1 Introduction

In daily conversation, human often use ambiguous expression to utter. For example, syntactic ambiguous expression, metaphor, irony, metonymy, euphemism, humor, etc. Interpretation of utterances with ambiguous expression has been investigated many times in the past.

In this paper, we propose an interpretation method of utterances, using relevance theory [1]. Relevance theory by Sperber and Wilson is the theory in pragmatics about how a hearer interprets a speaker's utterance. Sperber and Wilson have said, essentially, that humans adopt the maximal relevance in interpretation of utterances. That is applicable to not only interpretation of utterances but also general human cognition. The interpretation with the maximal relevance has a high cognitive effect with low processing efforts. A processing effort is accessibility of assumptions. A cognitive effect is produced by the interaction of given information and new information. In relevance theory, the meaning of an utterance is divided into explicatures and implicatures. Explicatures and implicatures are explicitly and implicitly communicated meaning, respectively.

We focus on implicatures and study to derive implicatures and calculate relevance. In order to calculate relevance, we formalize the cognitive effect (CE) and the processing effort (PE) of implicatures. We apply that CE and PE to multi-objective optimization, regarding Pareto-optimal solutions as interpretations with the maximal relevance.

The remainder of the paper is organized in the following way: in Section 2, we outline relevance theory. In Section 3, we present our method. In Section 4, we exemplify the validity.

2 Relevance theory

Relevance theory proposed by Sperber and Wilson is a pragmatic framework. It is based on Grice's principle. The goal of relevance theory is to explain how a hearer infers a speaker's meaning on the basis of the evidence provided.

Sperber and Wilson argued that there are two fundamentally different uses of language: descriptive use and interpretive use. Descriptive use is use of truth-conditional. Interpretive use is use of resemblance. Utterances are interpretively used to represent the thoughts of a speaker. That is, utterances are interpretations or interpretive expressions of the thoughts that the speaker wants to communicate. In interpretive use, emphasis is on how much a hearer faithfully reproduces the expression of thoughts of the speaker. Sperber and Wilson argued that interpretive use plays a fundamental role in the analysis of non-literal

utterances [2].

In general, communication has a stimulus to communicate something. A speaker attracts a hearer's attention by the stimulus, and distinctly shows the hearer that the speaker wants to communicate something. The stimulus which attracts the hearer's attention was called ostensive stimulus. Communication based on ostensive stimulus was called ostensive communication. The typical ostensive communication is a dialogue. Ostensive communication has an informative intention and a communicative intention. The informative intention is the intention to inform the hearer of something. The communicative intention is the intention to inform the hearer of one's informative intention. Relevance theory deals with ostensive communication [3].

2.1 The principle of relevance

Sperber and Wilson proposed two principles of relevance as follows:

> *Cognitive Principle of Relevance:*
> Human cognition tends to be geared to the maximisation of relevance.
>
> *Communicative Principle of Relevance:*
> Every act of ostensive communication communicates a presumption of its own optimal relevance.

Relevance is a potential property not only of utterances and other observable phenomena, but of thoughts, memories and conclusions of inferences. Any external stimulus or internal representation which provides an input to cognitive processes is relevant to an individual. Cognitive principle of relevance describes that human's cognitive resource tends to process an input which is the most relevant in available inputs. Communicative principle of relevance describes that the ostensive stimulus has optimal relevance with no exceptions. Sperber and Wilson defined presumption of optimal relevance as follows:

> *Presumption of Optimal Relevance:*
> (a) The ostensive stimulus is relevant enough for it to be worth the addressee's effort to process it.
> (b) The ostensive stimulus is the most relevant one compatible with the communicator's abilities and preferences.

According to these principles, the hearer, who received the speaker's ostensive stimulus, expects presumption of optimal relevance. Then the hearer starts inferring in order to get the interpretation of the maximal relevance.

Relevance is not just an all-or-none matter but a matter of degree. Relevance is assessed in terms of the cognitive effect and the processing effort. The maximal relevance has a high cognitive effect with low processing efforts.

The cognitive effect is a modification of a cognitive environment by the interaction of the new information with existing assumptions. The cognitive environment of an individual is a set of assumptions that are manifest to him. The modification of the cognitive environment has three types: contextual implication, strengthening of existing assumptions, and contradiction and elimination of existing assumptions.

The first modification of the cognitive environment is addition of contextual implications to the cognitive environment. The contextual implication is a conclusion deducible from the input and the context, which is new information. Consider the following example:

(1) X: Do you like cats?
Y: I don't like any animals.
a. Cats are animals.
b. Y doesn't like cats.

In understanding Y's utterance, X has an assumption (1a) which was included in his cognitive environment, and X deduces a contextual implication (1b). X's cognitive environment is modified by addition of the contextual implication (1b) to X's cognitive environment.

The second modification of the cognitive environment is strengthening of existing assumptions, by providing further evidence. Consider the following example:

(2) a. If Y is afraid of cats, Y doesn't like cats.

b. Y is afraid of cats.

(2a) and (2b) are added to (1) as new information. X deduces (1b) from (2a) and (2b). (1b) is an existing assumption, not a contextual implication. (1b) is strengthened by new information (2).

The third modification of the cognitive environment is elimination of existing assumptions that appear to be false. If new information and an existing assumption are contradiction, weak one is eliminated. Consider the following example:

(3) a. If Y has cats, Y likes cats.
b. Y has a cat.
c. Y likes cats.

(3) is added to (1) as new information. X deduces a contextual implication (3c) from (3a) and (3b), but (3c) contradicts the (1b). If (1b) is weaker than (3c), (1b) is eliminated. On the other hand, if (3c) is weaker than (1b), (3c) is eliminated.

Each assumption has a confirmation value, which is degree of confidence. Modification of the confirmation value yields the cognitive effect. In the case of addition of contextual implication, the confirmation value is provided. In the case of strengthening of existing assumptions, the confirmation value of an existing assumption increases. In the case of elimination of existing assumptions, the confirmation value of an eliminated assumption is lost.

Processing effort is determined by three main factors [4] as follows:

(a) The complexity of the utterance: the more complex the utterance the greater the processing effort.
(b) The size of the context: the larger the context, the greater the processing effort.
(c) The accessibility of the context: the less accessible the context, the greater the processing effort.

The accessibility has two characteristics as follows:

(a) One is that recently accessed assumptions are more accessible than assumptions not recently accessed.
(b) Another is that assumptions frequently accessed are more accessible than assumptions infrequently accessed.

2.2 The meaning of an utterance

According to the relevance-theoretic account, the meaning of an utterance is divided into explicatures and implicatures. These definitions are as follows:

(I) An assumption communicated by an utterance U is EXPLICIT [hence an "explicature"] if and only if it is a development of a logical form encoded by U.
(II) An assumption communicated by U which is not explicit is IMPLICIT [hence an "implicature"].

Explicatures are derived by disambiguation, saturation, free enrichment, and ad hoc concept construction. Implicatures are derived by inference. Implicatures come in two sorts: implicated premises and implicated conclusions. Implicated premises are a subset of the contextual assumptions used in processing the utterance. Implicated conclusions are a subset of its contextual implications. Explicatures and implicatures are derived in parallel [6].

Each implicature has strength. Consider the following example of a strong implicature:

(4) X: Would you drive a Mercedes?
Y: I wouldn't drive any expensive car.
a. Y wouldn't drive any expensive car.
b. A Mercedes is an expensive car.
c. Y wouldn't drive a Mercedes.

(4a) is an explicature which was derived by saturation, (4b) is an implicated premise, and (4c) is an implicated conclusion. In this conversation, Y did not answer X directly. However, Y gives X immediate access to X's encyclopedic information about expensive cars, the information in (4b). If X retrieves assumption (4b) from X's memory and adds to X's context, X would derive the contextual implication (4c). Hence, X assumes that Y does not drive a Mercedes. (4b) and (4c) are strong implicatures.

Y's utterance in (4) gives X access to X's encyclopedic information about expensive cars.

Hence it would be reasonable for X to add premises (5a) and (6a), and derive conclusions (5b) and (6b). Or X could construct some premise such as (7a), and derive conclusion (7b).

(5) a. A Rolls-Royce is an expensive car.
b. Y wouldn't drive a Rolls-Royce.
(6) a. A Cadillac is an expensive car.
b. Y wouldn't drive a Cadillac.
(7) a. If *x* would not drive expensive cars, then *x* disapproves of displays of wealth.
b. Y disapproves of displays of wealth.

It is clear that (5-7) are not what Y wanted to communicate. Because Y does not force X to use (5-7). Hence, (5-7) are weak implicatures, which X chose freely from a wider range of context. Using such weak implicature is the X's sole responsibility. Distinction between strong implicatures and weak implicatures is whether the hearer supplied premises along an encouragement given by the speaker. It seems that the encouragement given by the speaker is included in the speaker's utterance.

Consider another example of the weak implicature:

(8) His ink is pale.
(9) a. He has the character of a man who would use pale ink.
b. His writing lacks contrasts.
c. There is something weak in his writing.
d. He does not put his whole heart into his work.

In the case of an interpretation consistent with the principle of relevance composed of various implicatures, the result of deduction is also the weak implicature. (8) did not require deriving specific implicatures. There are not strong implicatures. A hearer searches weak implicatures (9) from extensive context in order to interpret the meaning of (8). In this case, hearer's confidence is less strong than the case (4).

3 Methods

Relevance theory has not applied enough in the computer science field yet. Our goal is to formalize relevance theory for an interpretation method of utterances. In [6] we have reported a method of interpretation for explicatures. In this paper, we propose a method to model the relevance of implicatures.

3.1 Process of deriving implicatures

Implicatures are supplied wholly by inference. Typical inference consists of deduction and induction. According to the relevance-theoretic account, the human deductive device has access only to the following elimination rules. Let *P* and *Q* denote assumptions.

And-elimination
(a) *Input*: (*P* and *Q*)
Output: *P*
(b) *Input*: (*P* and *Q*)
Output: *Q*

Modus ponendo ponens
Input: (i) *P*
(ii) (If *P* then *Q*)
Output: *Q*

Modus tollendo ponens
(a) *Input*: (i) (*P* or *Q*)
(ii) (not *P*)
Output: *Q*
(b) *Input*: (i) (*P* or *Q*)
(ii) (not *Q*)
Output: *P*

Implicatures come in two sorts: implicated premises and implicated conclusions. Implicated premises are premises of deduction, and implicated conclusions are conclusions of deduction. We show a process of deriving implicatures. This process consists of two sub processes: first, retrieval of implicated premises existing in a memory; second, deduction of implicated conclusions from implicated premises which were retrieved.

We define implicated premise formats as follows:

(a) IF-THEN rule: 'IF *P* then *Q*,' where *P* and *Q* are propositional forms or assumption schemata.
(b) ISA relationship: '*A* is *B*,' where *A* and *B* are words or phrases or propositional forms or a

variable (when one is the variable, other is never the variable) or assumption schemata.

Examples are as follows:

(10) a. If it is winter, then it is cold.
b. If *x* has cats, then *x* like cats.
c. Cats are animals.
d. '*x* is awake' is '*x* is not sleeping.'

(10a, b) are IF-THEN rule formats, (10c, d) are ISA relationship formats.

We define selection rules of implicated premises and derivation processes of implicated conclusions. An implicated conclusion is deduced from an implicated premise and a literal meaning or an explicature or an implicated conclusion which was deduced previously. It seems that retrieval cues of the strong implicated premises are included in the speaker's utterance. Let P_0 denote the literal meaning or the explicature or the implicated conclusion, which was deduced previously.

(a) IF-THEN rule

(i) *P* is the propositional form: when P_0 corresponded to the antecedent *P*, or P_0 was an analytic implication of *P*, the consequent *Q* is the implicated conclusion.

Consider the following example:

(11) X: Shall we play tennis?
Y: It's raining.
a. If it's raining then it's not a good idea to play tennis.
b. It's not a good idea to play tennis.

(11a) is an implicated premise. Y's utterance corresponds to the antecedent of (11a). Hence the consequent of (11a) is an implicated conclusion (11b).

(ii) *P* is the assumption schema: when *P* was able to be unified with P_0, the consequent *Q* is the implicated conclusion.

Consider the following example:

(12) X: Do you like cats?
Y: I have a cat.
a. Y has a cat.
b. If *x* has cats, then *x* like cats.
c. If Y has cats, then Y likes cats.
d. Y like cats.

(12a) is an explicature of Y's utterance. (12b) is an assumption schema which was retrieved from X's memory. If *x* gets unified with Y, an implicated premise (12c) is formed. (12d) is an implicated conclusion derived from (12a) and (12c).

(b) ISA relationship (*A* is *B*)

(i) *A* (*B*) is the word or the phrase: when a word or phrase which is included in P_0 matched to *A* (*B*), or it was the analytic implication of *A* (*B*), new P_0 which changed it into *B* (*A*) is the implicated conclusion.

For example, the explicature of Y's utterance in (1) is 'Y doesn't like cats' is explicature was derived by saturation. 'Any animals', included in the explicature of Y's utterance and is the analytic implication of 'animals'. New assumption which changed 'animals' into 'cats' is the implicated conclusion (1b).

(ii) *A* (*B*) is the propositional form: when P_0 matched to *A* (*B*), *B* (*A*) is the implicated conclusion.

(iii) *A* is the variable and *B* is a word or the phrase: if a word or phrase which is included in P_0 matched to *B*, or it was the analytic implication of *B*, then new P_0 which changed the word or phrase into *A*, which is unified, is the implicated conclusion.

Consider the following example:

(13) X: Have you read Z's book?
Y: I don't read any autobiography.
a. Y doesn't read any autobiography.
b. *x* is an autobiography.
c. Z's book is an autobiography.
d. Y doesn't read Z's book.

(13a) is an explicature of Y's utterance, (13b) is an

assumption schema which was retrieved from X's memory, (13c) is an implicated premise which X formed based on (13b), and (13d) is an implicated conclusion derived from (13a) and (13c).

(iv) A (B) is the assumption schema: when A (B) was able to be unified with P_0, B (A) is the implicated conclusion.

3.2 Formalization of relevance

In this section, we formalize the degree of relevance. Relevance is a matter of degree, and depends on the cognitive effect and the processing effort. There is trade-off between the cognitive effect and the processing effort. First, we discuss clues to define the relevance of implicatures. Next, we define the cognitive effect and the processing effort, and apply those to multi-objective optimization.

First, we discuss clues to define the relevance of implicatures. The implicated conclusion deduced from specific implicated premises is strong. In the case of implicated premises accessed from extensive context, the implicated conclusion is weak. In short, the strength of implicated conclusions depends on the strength of implicated premises. The strong implicature has specific implicated premises and implicated conclusions which are deduced from specific implicated premises. On the other hand, the weak implicature is implicated premises accessed from extensive context and implicated conclusions deduced from them.

The strength of implicatures has the following relations with the processing effort, the cognitive effect and relevance:

(a) The strong implicature is more accessible than the weak one. In other words, the processing effort of the strong one is less than the weak one.
(b) The degree of the cognitive effect depends on how much a confirmation value of assumptions increased:
  - In the contextual implication, when the implicature with high confirmation value was deduced, the cognitive effect is high.
  - In strengthening of existing assumptions, when a confirmation value was much increased, the cognitive effect is high.

From (a) and (b), we add a supposition as follows:

(c) The strong implicature is more relevant than the weak one: the strong implicature has high cognitive effect with low processing efforts.

On the basis of those relations, we define the cognitive effect and the processing effort. The degree of the cognitive effect depends on a confirmation value of an implicated conclusion. The confirmation value of the implicated conclusion depends on two things: (1) confirmation values of premises used by deduction; (2) the degree of resemblance between an implicated conclusion the hearer deduced and explicit responses that a speaker would have wanted to communicate. With regard to (2), it seems that one of the role of inference is recovery of implicitly conveyed. Hence, the implicated conclusion with a strong resemblance should have high cognitive effect.

We define a calculation of the confirmation value. Let P_0 denote the literal meaning or the explicature or the implicated conclusion, which was deduced previously. Let IP and IC denote respectively the implicated premise and the implicated conclusion which is a contextual implication. Let CV(x) denote the confirmation value of x. The calculation of CV applied Conjunctive Rules of MYCIN's certainty factor [7]. CV(IC) is calculated by the following formula:

$$\mathrm{CV}(IC) = \mathrm{CV}(P_0) \times \mathrm{CV}(IP)$$

Here, CV ranges from 0 to 1. If CV(x) = 0, x is not an assumption existing in cognitive environment. The more CV increases, the more the confidence of x becomes strong.

If deduction is repeated many times, the confirmation value decreases.

(14) a. P_0
  b. (If P_0 then P_1)
  c. P_1
  d. (If P_1 then P_2)
  e. P_2
  f. (If P_2 then P_3)
  g. P_3

(14a) is an assumption, (14b) is an implicated premise, and (14c) is an implicated conclusion derived from (14a) and (14b). (14d) is an implicated premise, and (14e) is an implicated conclusion derived from (14c) and (14d). (14f) is an implicated premise, and (14g) is an implicated conclusion derived from (14e) and (14f). The confirmation value of P_1, P_2 and P_3 is calculated respectively as follows:

$$\begin{aligned}\mathrm{CV}(P_1) &= \mathrm{CV}(P_0)\times\mathrm{CV}(IP)\\ &= 0.8\times 0.8\\ &= 0.64\\ \mathrm{CV}(P_2) &= \mathrm{CV}(P_1)\times\mathrm{CV}(IP)\\ &= 0.64\times 0.8\\ &= 0.512\\ \mathrm{CV}(P_3) &= \mathrm{CV}(P_2)\times\mathrm{CV}(IP)\\ &= 0.512\times 0.8\\ &= 0.4096\end{aligned}$$

Here, we assume that the confirmation value of P_0 and all implicated premises (IP) is 0.8. If n is large, $\mathrm{CV}(P_n) \approx 0$. However, humans often conclude a relevant implicature, even though deduction is repeated many times. A hearer supposes explicit responses that a speaker would have wanted to communicate. If an implicated conclusion is similar to one of explicit responses, the implicated conclusion would be relevant. That is, by comparing the implicated conclusion with explicit responses, the degree of resemblance is provided.

Consider (4)-(7) again. X asks Y whether Y would drive a Mercedes. X supposes that (1) “Y would drive a Mercedes” and (2) “Y would not drive a Mercedes”. They are direct responses X supposes. We think that they are included in X's cognitive environment. X retrieves implicated premises (4b), (5a), (6a) and (7a). Then X deduces implicated conclusions (4c), (5b), (6b) and (7b). (4c) corresponds to one of direct responses in implicated conclusions. By modus tollendo ponens, the direct response (1) is eliminated and the direct response (2) is strengthened. The confirmation value of (4c) is greater than that of other implicated conclusions.

We redefine the calculation of the confirmation value. If IC corresponds to one of the direct responses which a hearer supposes or IC was an analytic implication of that,

$$\mathrm{CV}(IC) = \frac{\mathrm{CV}(P_0)\times\mathrm{CV}(IP)+1}{2}$$

elsewhere,

$$\mathrm{CV}(IC) = \mathrm{CV}(P_0)\times\mathrm{CV}(IP)$$

We define the degree of the cognitive effect as follows: in the case of contextual implication,

$$\mathrm{CE} = \mathrm{CV}(x_i)$$

in the case of strengthening,

$$\mathrm{CE} = \alpha(\mathrm{CV}(x_i) - \mathrm{CV}(x_j))$$

where x_i is an implicated conclusion as a contextual implication. x_j is an existing assumption and this propositional form is same as x_i. α is a parameter that emphasizes either the contextual implication or strengthening.

The degree of the processing effort depends on accessibility of implicated premises. We regard the processing effort as a summation of costs of implicated premises, and define the cost of an implicated premise a_i. The cost is based on two characteristics of the accessibility:

$$\mathrm{cost}(a_i) = \min\left[m\alpha, \frac{\beta}{n+1}\right]$$

where $m\alpha$ is a cost of an assumption accessed when a hearer interpreted speaker's utterance before m times. $\beta/(n+1)$ is a cost of an assumption accessed n times in the past. α and β are arbitrary constants. Definition of the processing effort is as follows:

$$\mathrm{PE} = \sum \mathrm{cost}(a_i)$$

Relevance is a matter of degree, and depends on the cognitive effect and the processing effort. There is trade-off between the cognitive effect and the processing effort. We apply those to multi-objective optimization.

Multi-objective optimization is an approach

which allows balancing among many different functions. An optimum solution set which is balanced is called Pareto-optimal solutions. There is no dominant strategy in Pareto-optimal solutions. We regard Pareto-optimal solutions as implicatures with the maximal relevance. Definition is as follows:

$$\max \mathrm{CE}(x_i),\ \ \min \mathrm{PE}(x_i) \quad \text{s.t.}\ x_i \in F$$

where x_i is an implicated conclusion, F is set of all implicated conclusions possible.

4 Example

In this section, we derive implicatures, calculate relevance defined in Section 3, and exemplify the validity of our method.

Consider following dialogue. X makes his first utterance to Y after dinner.

(15) X: Would you like a cup of coffee?
Y: It keeps me awake.

Suppose that Y must get up early for next day's morning work. X retrieves and deduces the following assumptions.

(16) a. Y must get up early next morning. (1.0)
b. Coffee keeps Y awake after dinner. (0.9)
c. If coffee keeps Y awake awhile after dinner, then Y would not be able to go to bed early tonight. (0.8)
d. Y would not be able to go to bed early tonight.
e. If Y would not be able to go to bed early tonight, then Y would not be able to get up early next morning. (0.8)
f. Y would not be able to get up early next morning.
g. If Y would not be able to get up early next morning, then Y should not drink a cup of coffee. (0.8)
h. Y should not drink a cup of coffee.

Values in parentheses are confirmation values we suppose. (16a) is a fact about Y. (16b) is the explicature (E) which was derived by saturation and free enrichment. (16c, e, g) are implicated premises (IP). (16d), (16f) and (16h) are implicated conclusions (IC) which was deduced from (16b, c), (16d, e) and (16f, g), respectively. They are contextual implications. They are deduced as follows:

$$(16b)+(16c)\rightarrow(16d)$$
$$(16d)+(16e)\rightarrow(16f)$$
$$\Leftrightarrow(16b)+(16c)+(16e)\rightarrow(16f)$$
$$(16f)+(16g)\rightarrow(16h)$$
$$\Leftrightarrow(16b)+(16c)+(16e)+(16g)\rightarrow(16h)$$

The confirmation value of (16d), (16f) and (16h) are calculated respectively as follows:

$$\begin{aligned}\mathrm{CV}(IC_d) &= \mathrm{CV}(E_b)\times\mathrm{CV}(IP_c)\\ &= 0.9\times 0.8\\ &= 0.72\\ \mathrm{CV}(IC_f) &= \mathrm{CV}(IC_d)\times\mathrm{CV}(IP_e)\\ &= 0.72\times 0.8\\ &= 0.576\\ \mathrm{CV}(IC_h) &= \mathrm{CV}(IC_f)\times\mathrm{CV}(IP_g)\\ &= 0.576\times 0.8\\ &= 0.4608\end{aligned}$$

where E_b is (16b), IP_c is (16c), IC_d is (16d), IP_e is (16e), IC_f is (16f), IP_g is (16g) and IC_h is (16h).

Suppose that X is aware of (17). They are direct responses to X's question.

(17) a. Y would like a cup of coffee. (0.5)
b. Y would not like a cup of coffee. (0.5)

(16h) is most similar to (17b) among (16d, f, h). Hence, the confirmation value of (16h) is recalculated as follows:

$$\begin{aligned}\mathrm{CV}(IC_h) &= \frac{\mathrm{CV}(IC_f)\times\mathrm{CV}(IP_g)+1}{2}\\ &= \frac{0.576\times 0.8+1}{2}\\ &= 0.7304\end{aligned}$$

(16d), (16f) and (16h) are contextual implication. Hence, each cognitive effect is as follows:

$$\mathrm{CE}(IC_d) = 0.72$$
$$\mathrm{CE}(IC_f) = 0.576$$
$$\mathrm{CE}(IC_h) = 0.7304$$

Next we calculate the processing effort. Here we assume that the dialogue (15) is begun by X's utterance. That is, the X's utterance is 1st utterance in the conversation. Therefore, we disregard $m\alpha$ which is included in definition of cost(a_i). That is, cost(a_i) = $\beta/(n+1)$. Additionally, we assume that all premises (16b, c, e, g) were retrieved with same frequency. In $\beta/(n+1)$, n and β denote frequency and arbitrary constant respectively. In this example $\beta/(n+1)$ is constant because n is same value for all premises. Hence the value of PE is the number of retrieved premises.

In order to deduce (16d), (16b, c) were retrieved. Hence, the processing effort of (16d) is as follows:

$$\mathrm{PE}(IC_d) = \frac{2\beta}{n+1}$$

Similarly, in order to deduce (16f) and (16f), (16b, c, e) and (16b, c, e, g) were respectively retrieved. Hence, processing efforts of (16d) and (16h) are as follows:

$$PE(IC_f) = \frac{3\beta}{n+1}$$
$$PE(IC_h) = \frac{4\beta}{n+1}$$

Fig. 1 shows the degree of the cognitive effect and processing effort. Both CE and PE of (16d) are better than those of (16f). Thus, (16d) dominates (16f). PE of (16d) is better than that of (16h). However, CE of (16h) is better than that of (16d). Thus, (16d) and (16h) are Pareto-optimal solutions. They are implicatures with the maximal relevance.

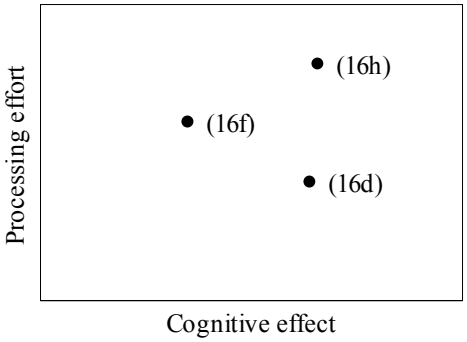

Fig. 1 Result.

5 Conclusion

In this paper, we presented a method to model the relevance of implicatures. First, we defined a process of deriving implicatures. And we formalized the cognitive effect and the processing effort, and applied them to multi-objective optimization. The validity of our method was exemplified.

In future work, we will observe various cases about implications, experiment and evaluate our method. Additionally, we intend to experiment with a method which combined this paper with [6].

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