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# Predicate Concepts and their Normal Form

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**Abstract.** This paper argues that a simple system of meaning relations drawn from words/lexical items in a natural language and framed in terms of syntax-free relations in linguistic texts can help ground linguistic predicates or concepts thereof in a number of meaning relations. These relations are constrained by the logical structures of linguistic meanings across sentence and discourse contexts. Significantly, such meaning relations are not defined over, or do not ride on, the syntactic structure of a given language. Nor do they (necessarily) turn on compositional relations for the computation of meaning values. This facilitates the formulation of meaning relations to be defined on the symbolic elements of a lexicon. This specific insight is carried over to the reduction of predicates or predicate concepts in natural language to the minimal form they can assume. This minimal form is formulated in terms of meaning relations in a manner that all complex predicates or predicate concepts can be reduced to a sort of *normal form* defined by meaning relations.

**Keywords.** Meaning relations, semantic representation, knowledge representation, normal form.

## 1 Introduction

The nature and form of linguistic meaning is such that it mainly rides on the syntax of natural language. One primary reason is that it is syntax that primarily determines the form semantics would assume in view of the arrangement of words in a language. Taken in this sense, syntax provides the form upon which semantic structures are constructed. But this need not be taken to mean that syntax exhibits everything that is required for the (re)construction of meanings from the meaning-bearing elements of linguistic expressions. For one thing, certain contextually determined meanings cannot be fully distilled and obtained from syntactic relations, compositional or otherwise. This is pivotal for AI research, especially in the area of semantic processing that is heavily dependent on various lexical resources such as WordNet, FrameNet, VerbNet etc. and also on the construction of semantic representations. For another, the meaning-bearing elements of linguistic expressions are not always as neatly arranged as they may be expected (as in parenthetical expressions such as 'These kids met, Amy tells me, a big tycoon yesterday').

This necessitates finding out subtle associations of meanings from the interpolated structures in discourse even though the relevant resources for scouting out the patterns may not be readily available. In a nutshell, this suggests a need for shallow processing of linguistic meaning which is what is becoming increasingly recognized.

Since speaker intentions, pragmatic contexts, situations, and real world settings apart from syntax contribute to the formation of linguistic meanings in a broad sense, it appears worthwhile to consider how semantic representations can be construed in terms of regularities and operations on them. The idea this paper advances is that meaning relations can be extracted from linguistic constructions in a manner that does not obey constraints of syntactic composition and yet they can define the normal form to which predicates or predicate concepts in natural language can be reduced. This reduction can help refine formal representations of natural language meaning in computational systems because predicates or predicate concepts in natural language (such as 'like', 'sleep', 'dance', 'rain' etc.) are often coarse-grained, whereas meaning relations are more granular.

A reduction of predicates or predicate concepts in natural language to meaning relations can facilitate the deployment of semantic structures in a bidirectional manner from coarse-grained predicate concepts to meaning relations and vice versa. Computational systems having predicate concepts (such as lexical resources) can be easily coded in terms of meaning relations. Also, computational systems utilizing such resources (say, a machine translation system) can easily translate meaning relations back into predicate concepts, whenever required. The relevant conception of meaning relations is such that they can be shown to be constrained by a certain uniform logical structure of linguistic meanings across sentences and discourse contexts (see [1, 2]). It is this pattern of uniformity that can help, at least to some extent, gain a purchase on what we take to be predicates or predicate concepts in a *minimalist* sense. The present proposal contains substantive differences when contrasted with other ways of representing meaning. Since this is beyond the scope of the current paper, readers are referred to [1] for extensive discussion. The next section will show how to conceive of meaning relations and their relationship to syntax.

The paper is organized as follows. First, section 2 outlines the formulation of meaning relations and their relationship with syntactic composition. The nature of meaning relations is explicated by making reference to appropriate notions of syntax and compositionality. In section 3 we describe the normal form of predicates or predicate concepts that can easily be amenable to computational representations of semantic structures from a coarse-grained format (natural language predicates or predicate concepts) to a granular format (meaning relations) and vice versa. In section 4, we integrate the insights from the previous sections and offer certain apposite concluding remarks. This section also provides directions for future work.

## 2 Meaning Relations and Syntactic Relations

At this juncture, we think it important to highlight that meanings from the meaning-bearing elements of linguistic expressions are those entities that may be realized by patterns of conceptualizations [3, 4] and internal mental constructions for conjoining predicates (see [5]). It may also be observed that the meaning-bearing elements of linguistic expressions partaking in the meaningful association of linguistic concepts can have inferential roles. This consideration applies independently of the exact type and nature of syntactic contributions to meaning, and thus the basic structural blocks of linguistic concepts evince patterns of inferential roles that are carried over to larger and larger associations of words and phrases [6, 7]. At this point, it may be noted that these inferential roles can be understood in terms of conceptual roles in a system of linguistic expressions that can be formally governed in a variety of associations of linguistic meanings (see for related discussion [8, 9]). Suffice it to say that conceptual associations of meanings are intimately tied to inferential roles. As The Norm Reduction Condition is formulated later in this section, this idea will become more explicit.

The idea that syntax does not carry all that is relevant to the (re)construction of meanings from the meaning-bearing elements of linguistic expressions can be perspicuous once one considers the very nature of meaningful associations of linguistic concepts. Not all viable meaningful associations of linguistic concepts are within the constraints of syntactic composition (comparative constructions, for instance, because the degree of comparison cannot be easily construed as part of the structural components of meaning).

Hence it may not be hard to see that meaningful associations of linguistic concepts need to be ascertained and recognized across boundaries, and beyond the constraints, of syntactic composition. Now it must be emphasized that the point is *not* to show that it is possible to replace standard compositional type-theoretic semantic structures with meaning relations, although that can be done for a large class of linguistic structures (see for discussion [2]). Rather, the point is that all meaningful associations of linguistic concepts are not, and perhaps need not be, compositionally structured, but they need to be accounted for in terms of a *logic* of associations of linguistic concepts. Since a number of meaningful associations of linguistic concepts abide by

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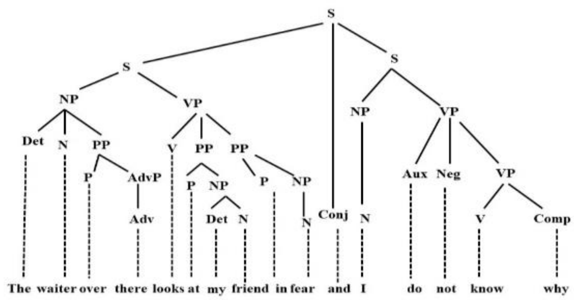


**Fig. 1.** The syntactic tree of *'The waiter over there looks at my friend in fear and I do not know why'*

compositionality and quite a good number of others do not, the exploration of non-typical sorts of meaningful associations of linguistic concepts is eminently desirable.

This consideration holds, regardless of whether syntactic structures are thought of in terms of richly articulated functional structures and structural displacements [10, 11], or in terms of phrase structure grammars [12, 4] or even in terms of categorial combinations constraining possible permutations of syntactic categories [13].

This becomes compellingly evident as one recognizes that the common empirical content of syntax relevant to certain conceptual associations of words may actually be invariant across varying conceptions of syntactic structures [14].

One may take, for example, the relation of a verb to its arguments (both internal and external) or the relation of a preposition to its complement. The specific relation concerned is invariant, no matter whether the relation is implemented via a binary combinatorial operation such as Merge [10] or via concatenation/unification [12, 4] or via functor-argument relations [15], or even via dependency relations [16, 17].

We may appeal to this *invariance* of syntactic relations with a view to showing how certain meaningful associations go beyond such syntactic relations. One illustrative example can help understand what is at issue.

We may consider the sentence 'The waiter over there looks at my friend in fear and I do not know why.' The compositional syntactic representation of this sentence in terms of basic phrase structure yields the following.

It is easy to notice that the tree diagram in Fig. 1 exhibits certain constraints of syntactic composition on the grouping of words. For instance, 'the waiter over there' as a noun phrase (NP) is related to 'looks at my friend in fear' as a verb phrase (VP) in terms of direct composition. But the same cannot be said about the relation between 'the waiter over there' and the verb phrase 'do not know why'. Similarly, the prepositional phrase 'over there' is in syntactic composition with the noun phrase 'the waiter' but not with the noun phrase 'my friend' or 'fear'. Furthermore, the noun phrase 'the waiter' is not in syntactic composition with either 'my friend' or 'fear'. But what tells us that this is the case?

The answer comes straightforwardly from the form of syntactic compositions as explicitly displayed in the structuring of phrases and then their combination into a sentence. Semantic structures can be thought to ride on the way syntactic compositions work. This tells us that the waiter rather than the speaker looks at the speaker's friend since 'the waiter over there' (but *not* 'I') and the verb phrase 'looks at my friend in fear' are syntactically composed together. Significantly, certain otherwise valid combinations of linguistic concepts are clearly filtered out by the constraints of syntactic composition.

For example, 'the waiter' and the prepositional phrase 'in fear' are somehow conceptually related since it is the waiter who *is* in fear or in the state of fear and an *agent-emotional state* relation holds here. But this cannot be captured in terms of syntactic composition, as can be easily verified from the structure of the sentence in Fig. 1 above. Crucially, even if one argues that syntactic ambiguities may arise from the attachment of the prepositional phrase ‘in fear’ to the noun phrase ‘my friend’ (meaning that ‘’my friend’ is in fear), this in itself provides the evidence that the salient reading yielded by way of the higher attachment of the prepositional phrase ‘in fear’ to the verb displays no syntactically compositional relation between ‘the waiter’ and ‘in fear’. On this reading, the semantic composition between ‘looks at my friend’ and ‘in fear’ would not also yield the relevant meaning relation proposed. That is because the adjunction of ‘in fear’ to ‘looks at my friend’ and the semantic composition produce the characteristic function of the subset of those individuals looking

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at my friend whose members are just those who are in fear. This helps specify the set of those individuals who are looking at my friend and are also in fear, *but not* the exclusively special conceptual relation between ‘the waiter’ and the mental state described by ‘in fear’. The noun phrase ‘the waiter (over there)’ is definitely a member of this set, but the meaning relation between 'the waiter' and the prepositional phrase 'in fear' cannot be read off from the semantic composition of ‘looks at my friend’ and ‘in fear’, for the set of those individuals who are looking at my friend and are also in fear includes potentially many members other than ‘the waiter’.

Likewise, 'the waiter' and 'my friend' may be conceptually connected as an *experiencer-experienced* pair. Also, 'the waiter' is conceptually associated with 'at my friend' as the waiter as an agent is related to the directional/locative component of the meaning of 'at the speaker's friend'. But, once again, this is not ensured by the constraints of syntactic composition because 'at my friend' is composed with the verb directly and very indirectly with the noun phrase 'the waiter over there' as a whole (not specifically with 'the waiter'). Apart from that, a higher-order relation of a *reason-seeking state-situation* pair holds between 'do not know' and the relation constructed from 'the waiter' and 'in fear'.

This too cannot ride on syntactic composition holding between the verb 'know' and its sluiced clausal complement 'the waiter looks at my friend in fear', which, in itself, as a whole is syntactically composed. Therefore, there is no mistaking the conspicuous gap between syntactic composition-driven semantic structures/relations and conceptual associations that are not so grounded. The gap hides aspects of meaningful associations of linguistic concepts that are partly compositional and partly conceptual.

This suggests that meaningful associations of linguistic concepts may have a *dualistic* character: they may partake of functions formulated in terms of, say, lambda calculus on the one hand, and they may also be taken to be closely related to conceptual structures in theories of cognitive semantics on the other hand.

We now propose that linguistic meanings are constructed via combinations of lexical items and they can be characterized in terms of some relations iteratively and/or recursively defined on $\{Lex \cup R_1, \dots, R_k\}$, given that $R_1, \dots, R_k \subset Lex \times Lex \times \dots \times Lex$ where $k$ is an arbitrary number and the Cartesian product can be applied from one to an arbitrary number of times. Thus, relations defined on $\{Lex \cup R_1, \dots, R_k\}$ can form a new set with *Lex* (that is, $\{Lex \cup$ all relations defined on $\{Lex \cup R_1, \dots, R_k\}\}$ ) on which further relations can be defined and so on iteratively. All relations from $R_1, \dots, R_k$ to those constructed on more complex sets formed iteratively and/or recursively are meaning relations. Hence these infinitely many relations have the form $R_1, \dots, R_k, R_{k+1}, \dots, R_\infty$, where $R_{k+1}, \dots, R_\infty$ are higher-order relations. Thus, whatever $R_1, \dots, R_k$ are constructed on *Lex* form a union with *Lex* itself, and this can be repeated, if necessary.

The tenets of this formulation have also been discussed in the context of semantic processing in AI systems [2]. An example can make this quite clearer. For instance, if we want to construct a meaning of the phrase ‘a beautifully painted picture of the river’ from the lexicon of English, the lexical items ‘a’, ‘beautifully’, ‘painted’, ‘picture’, 'of', 'the', and 'river' from *Lex* can be related to each other in terms of meaning relations involving the relevant lexical items[1]. Thus, one meaning relation obtains between ‘a’ and ‘picture’; a meaning relation between 'beautifully’ and ‘painted’; one *second-order* relation between the relation for 'beautifully’ and 'painted' put together and ‘picture’, and another between ‘a’ and a meaning relation for ‘beautifully painted picture’ or even 'beautifully painted picture of the river' (because ‘beautifully painted picture’ or 'beautifully painted picture of the river' is already formed by a first-order meaning relation). It may be observed that meaning relations and their identification do not involve, or depend on, the manner in which syntactic relations and also semantic compositions are defined on

[1] Note that this notion of relation is distinct from relations constructed in model-theoretic syntax, for nodes in a tree (such as precedence or dominance relations) and also for categories such as NP (Noun Phrase), VP (Verb Phrase), S (Sentence) etc. that are characterized as properties of nodes (see [20] for discussion). In the present context, the relations $R_1, \dots, R_k, R_{k+1}, \dots, R_\infty$ cover many *dimensions* that characterize linguistic structures (such as string adjacency, dominance, precedence, and *parent-of* relations etc.).

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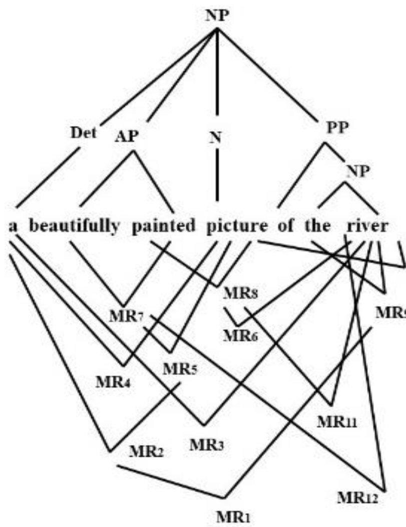


**Fig. 2.** The Distinction between Syntactic Compositional Structures and Meaning Relations ($MR_1 ... MR_{12}$): while $MR_7$, $MR_8$, $MR_5$, $MR_2$, $MR_1$, $MR_9$ can be derived in terms of relevant functions of syntactic composition, other MRs cannot

hierarchical relations of linguistic structures. However, some meaning relations may well correspond to those that can be defined on lexical items as determined by syntactic compositions.

For example, one could imagine a meaning relation between ‘a’ and ‘river’ that does not form any syntactically defined constituent in the given phrase, or even comes from the way syntactic composition combines the given words. Likewise, 'painted' and 'river' can form a meaning relation of a property-object pair, which is not governed by the syntactic composition of the prepositional phrase (PP) 'of the river' and the noun head 'picture'.

Note that if the Montague-type notion of compositionality as a homomorphism between syntactic and semantic operations is applied [18, 19], it would not be possible to derive such meaning relations from the homomorphism as these relations are outside the scope of the homomorphism concerned.

If a direct way of composing such meaning relations from the available syntactic relations is warranted, this becomes a more pressing issue. In any case, the differences between semantic values constructed from standard syntactic relations and meaning relations should be evident. Fig. 2 below clearly shows the difference between hierarchical structures of syntactic composition and meaning relations that are not (necessarily) compositional.

At this point, it is important to figure out how meaning relations can be constrained. That is, there has to be a way in terms of which licit meaning relations can be filtered in and illicit meaning relations can be filtered out. One way in which this can be achieved is to construe meaning relations as *filler-gap* relations such that one item in R is the filler and another is the gap. Thus, given $R_i = \{(x_1, y_1), \dots, (x_n, y_n)\}$ either x or y can be the filler and the other item is the gap.

For instance, if we consider the case of ‘a beautifully painted picture of the river’, which was our example described above, 'a' exhibits a gap (in requiring something to be nominally specified) that can be filled in by 'picture'. In contrast, a meaning relation cannot be formed with 'a' and 'beautifully', precisely because while 'a' contains a gap, 'beautifully' is not a filler as it requires an adjectival predicate and hence is itself a gap.

It is exceedingly necessary to point out that gaps on this view are more general than those currently recognized in linguistic theory. Crucially, gaps on the present conception include arguments, complements, and also predicates including verbs or relations that are formed via filler-gap links. In a nutshell, any meanings relation must have a filler and a gap related in some way. It is thus easy to recognize the relevant asymmetry intrinsic to the relationship established between a gap and a filler.

For this reason, logical precision is desirable. Therefore, we can suppose that the construction of any arbitrary meaning relation $R_i$ must result in the reduction of the cardinality (or norm) of the set characterizing the gap element or the filler element. This can be stated as The Norm Reduction Condition for Meaning Relations:

Given an arbitrary meaning relation $R_i$, which is asymmetric by definition, if $(x, y) \in R_i$ in which x and y are either the filler and the gap, or the gap and the filler, the cardinality or norm of the set characterizing x or y must be reduced when it is introduced into an *n-tuple* of $R_i$, that is, when it becomes part of $(x, y) \in R_i$ in the present case.

A firm logical basis for the norm reduction condition formulated above can be secured by recognizing the 'persistence' of information preserved across meaning relations constructed from an array of lexical ítems participating in a given construction. A gap plays a special logical role with reference to the filler in a given meaning relation. The underlying idea is simply that when a filler and a gap build a meaning relation the cardinality or *norm* of the product of the relevant formation is reduced with respect to that of either the filler or the gap.

Thus, for instance, 'picture' denotes a set of pictures and when 'a' and 'picture' form a meaning relation across a discontinuous distance of syntactic composition, the product as a set ('a' and 'picture' forming a meaning relation specifies a singleton set) has a cardinality reduced with respect to that of 'picture'.

The words 'a' and 'beautifully' cannot form a meaning relation, precisely because both 'a' and 'beautifully' are gaps, and even though 'beautifully' specifies a set of ways or manners in which something can be beautiful, there is no linguistically available sense in which 'a', if combined with 'beautifully', forms a whole that reduces the cardinality of 'beautifully'.

That is so because 'a' does not specify a manner of being (beautiful) from among certain choices but does the job specification from among a set of entities. Likewise, the meaning relation (as a representation-object pair) constructed via the association of 'painted picture' and 'river' helps reduce the cardinality of the set characterizing 'painted picture' (which is just a set of painted pictures) because the set of painted pictures *as representations* of rivers must be a smaller set than the set of all possible painted pictures.

However, in case of expressions such as 'alleged incidents' or ‘fake banknotes’ the situation is different. The privative modifier ‘fake’ or 'alleged' does not seem to reduce the cardinality of the set of banknotes or incidents. Be that as it may, the extensions of linguistic expressions of nonexistent entities such as 'fake guns' or 'imaginary creatures' can be recalibrated and so re-conceptualized with those of the entities that exist via *the principle of non-vacuity* demanding that the positive and negative extensions of a predicate be interpreted in a non-vacuous manner [21].

Besides, it is also plausible that the fit between the gap and the filler can be *fuzzy*, especially when idiomatic expressions encode meaning relations.

For instance, in idioms such as 'beat around the bush' or 'kick the bucket', the words 'beat' and 'around' and 'bush', or the words 'kick' and 'bucket' can form a meaning relation, but here the fit is weaker for the appropriate meaning relation to be constructed than the fit holding for the literal meaning. In such cases, the words have to form a template and then enter into a meaning relation, somewhat along the line of formulation like this: {'beat-around-the-bush', ('beat', 'around', 'bush')} or {'kick-the-bucket', ('kick', 'bucket')}. Equipped with the idea of meaning relations as the basis of minimal building blocks of semantic structures, we can now go on to explicate the normal form of predicate concepts.

## 3 The Normal Form of Predicate Concepts

We are now ready to explicate the reduction of predicates or predicate concepts in natural language to meaning relations as formulated in section 2 above. Predicates in natural language come in several sorts of adicity. Thus, we have 1-place predicates such as 'sleep', 'dance', 'cough' etc., 2-place predicates such as 'kill', 'feel', 'hold', 'throw' etc. and 3-place predicates such as 'give', 'put', 'hand' etc. Prepositions, nouns, adjectives etc. can also act as predicates if they take arguments.

For instance, prepositions such as 'in', 'on' etc. require two arguments--an entity (X) and another entity (Y) *on* which X can be. A noun such as 'incident' requires only one argument, that is, the entity which is an incident, whereas 'destruction' will require two (the agent of the destruction and the entity destroyed) because it is a de-verbalized noun. Likewise, adjectives such as 'happy', 'excited' etc. require two arguments--the agent who is happy and the entity about which the agent is happy or excited.

We can now relate this concept of predicates to their rendering in conceptual functions. Jackendoff [4] has developed a theory of conceptual semantics within the general framework of cognitive semantics.

A wide range of facts about meanings are captured in the theory. In this approach, the mind cannot relate to the world on its own; rather, some level of structure within the cognitive substrate has to do the job. It is *conceptual structure* (CS) that allows us to connect to the world via some sort of projection of the outer world within the mind. Hence CS is a mental structure that encodes the world as human beings conceptualize it [4, 22].

Significantly, CS is independent of syntax but connected to it by an interface that has interface rules, which consist of words, among other things. These interface rules connect CSs to syntactic and phonological structures. CS, in virtue of being an independent level of thought and reasoning, builds structures in a combinatorial manner out of conceptually distinct ontological categories such as THING, PLACE, DIRECTION, TIME, ACTION, STATE, EVENT, SITUATION, PROPERTY, MANNER and PATH. Combinatorial structures that are built out of such categories encode category membership, predicate-argument structure and so forth. Crucially, any predicate in natural language can be designated or rendered in terms of conceptual functions (F) that can assume several forms. Some basic conceptual functions are BE, STAY, GO, CAUSE, TO, IN whose functional structures are provided below:

BE: <(X, Y), STATE>
[*BE maps (X, Y) to a state*]

STAY: <(X, Y), EVENT>
[*STAY maps (X, Y) to an event*]

GO: <(OBJECT, PATH), STATE>
[*GO maps (OBJECT, PATH) to an event*]

CAUSE:<(OBJECT, OBJECT, EVENT),EVENT>
or <(OBJECT, EVENT), EVENT> (1)

[*CAUSE maps either (OBJECT, OBJECT, EVENT) or (OBJECT, EVENT) to an event*]

INCH: <STATE, EVENT>
[*INCH maps a state to an event*]

TO: <X, PATH>
[*TO maps an X to a path*]

IN: <X, PLACE>
[*IN maps an X to a place*].

Besides, other lexical items than those provided above can be captured in terms of the basic conceptual functions listed above and/or their own entries. These representations are thus supposed to be the conceptual correlates of the linguistic structures concerned.

For instance, the sentence 'A professor wants a huge library' can be captured in the CS in the following fashion (by means of 'want' itself and some other conceptual functions designated by the words used in the sentence):

$[_{Event}$ WANT **(**$_{object}$ PROFESSOR, $_{object}$ LIBRARY **(**$_{property}$ HUGE**) )**]. (2)

But the sentence 'Ron is in town' is captured in the CS in terms of BE and some other conceptual functions listed in (1):

$[_{State}$ BE **(**$_{Object}$ RON, $_{Place}$ IN ($_{Thing}$ TOWN) **)**]. (3)

Equipped with the understanding of predicate concepts in terms of conceptual functions, we may now explicate the normal form of predicate concepts in terms of meaning relations.

First of all, we may establish the equivalence between conceptual functions and their rendering in predicate logic. This is stated in (4) below:

$$F(<T1, T2,...>) \equiv P(T1, ..., Ti), \quad (4)$$

here '≡' denotes a special equivalence sign; F is a conceptual function and P is a natural language predicate (mathematically realized as a relation). T1, T2... are the relevant arguments/terms of the corresponding F or P. Further, *i* in $T_i$ is an arbitrary number which is ≤3 since the upper bound on all natural language predicates is 3 (only core arguments or theta roles as opposed to *adjuncts* of predicates are considered here).

A $T_i$ can itself be a predicate. WANT(T1, T2) would be the equivalent to **want**(T1, T2). But BE(T1, T2) would be equivalent to **is**(T1, T2)--the predicates marked in bold are expressions in predicate logic. Even though a predicate logic expression of 'open' is rendered in CS in terms of CAUSE, the predicate logic arguments of 'open' and BE (somewhat like CAUSE(T1, T2, BE(T2, open)), this will be translated into **open**(T1, T2)--where CAUSE and BE are normalized to T1 and T2 because 'open' requires only two arguments in natural language. We state the normalizing principle for this in (5) below:

$$F(<T1, T2,...>) \dashrightarrow F\otimes F^{+}. \qquad (5)$$

Here, $F^{+}$ as a regular expression denotes one or more conceptual functions, and $F\otimes F^{+}$ denotes the functional combination of F with $F^{+}$. The symbol $\otimes$ may also be interpreted in terms of the tensor product of all Fs regarded as vectors. In any event, this is immaterial for us at the moment. Thus, we have the following:

$$F\otimes F^{+} \equiv P(T1, ..., Ti). \qquad (6)$$

If this is so, we can now easily formulate the normal form for (6) in terms of meaning relations. This is stated in (7) below:

$$F\otimes F^{+} \equiv P(T1, ..., Ti) \dashrightarrow MR^{*}\oplus MR. \qquad (7)$$

Here, $F\otimes F^{+} \equiv P(T1, ..., Ti)$ is rewritten as the concatenation of 0 or more meaning relations (MR) with 1 or more meaning relations. MR* is required for non-compositional meaning relations in sentences/clauses. If the value of MR* is 0, then $MR^{*}\oplus MR^{+} = MR^{+}$. Thus, if our earlier sentence 'A professor wants a huge library' is represented as WANT(professor(+definite), library(-definite) (huge) ) ≡ **want**(a professor, a huge library), then it is to be normalized to $MR^{3}\oplus MR^{4}$, where MR1(MR2, MR3), MR2(a, professor), MR3(a, MR4), and MR4(huge, library). The non-compositional relations would be MR5(professor, MR3), MR6(professor, MR4), and MR7(professor, library). Before we proceed further, a proof of (7), when interpreted as a theorem, can be furnished.

**Proof:** The only situation in which (7) does not hold is when $F\otimes F^{+} \equiv P(T1, ..., Ti)$ is rewritten as no existent meaning relation. That is, $F\otimes F^{+} \equiv P(T1, ..., Ti)$ is mapped onto no relevant meaning relation: $F\otimes F^{+} \equiv P(T1, ..., Ti) \dashrightarrow MR^{0}$. If this holds, it follows that the combination of some conceptual functions (that is, $F\otimes F^{+}$) yields no viable meaning relation. Clearly, this is contradictory, given (4), in that a conceptual function, or any combination of conceptual functions, is an instantiation of some natural language predicate(s).

If so, that predicate is also an instantiation of a meaning relation in requiring at bare mínimum an argument (a filler). Thus, on the one hand, it is at least true that $F\otimes F^{+} \equiv P(T1, ..., Ti)$ )--> $MR^{1}$, but one the other hand, our initial assumption tells us that $F\otimes F^{+} \equiv P(T1, ..., Ti)$ )--> $MR^{0}$. This is a contradiction. Therefore, it must be the case that $F\otimes F^{+} \equiv P(T1, ..., Ti) \dashrightarrow MR^{*}\oplus MR^{+}$.

Significantly, it may be noted here that any MR can itself be normalized to the following formulation:

$$MR \dashrightarrow LI^{2} \text{ or } MR \dashrightarrow (LI^{+})|MR^{+}. \qquad (8)$$

Here, $LI^{2}$ represents lexical items (LI) of length 2, and $(LI^{+})|MR^{+}$ designates the optional presence of 1 or more lexical items along with 1 or more MRs. The symbol '|' indicates the neutrality of direction--the optional $LI^{+}$ can be either on the right or on the left of $MR^{+}$. If we turn Fig. 2 upside down, it is easy to recognize that any MR can be reduced to an array of lexical ítems and/or other meaning relations along the line articulated in (8) above. In this sense, any MR in (7) can be further normalized to (8). A proof of (8) may now be formulated below so as to place both (7) and (8) on firmer footing.

**Proof:** Let's assume that $MR \dashrightarrow LI^{1}$. If this holds, any meaning relation to be established has to be reflexive and will also turn out to be symmetric, given that we can have $MR(LI_k, LI_k) \leftrightarrow MR(LI_k, LI_k)$, when, for example, $LI_k$ is the only lexical item involved. Given the Norm Reduction Condition in section 2, it is clear that any MR is asymmetric. Then it is nothing but a contradiction that $MR \dashrightarrow LI^{1}$.

On the other hand, $MR \dashrightarrow (LI^{+})|MR^{+}$ can be false exactly when the value of MR on the right-hand side (RHS) is $MR^{0}$ rather than $MR^{+}$, that is, no viable MR is involved on the right-hand side, since $LI^{+}$ is optional anyway. If so, an MR is rewritten as no existent MR.

Given the proof of (7), this is a contradiction, precisely because the MR on the left-hand side (LHS) of $MR \dashrightarrow (LI^{+})|MR^{+}$ involves at least a relation, whereas no relation can be found on the right-hand side. Therefore, it must be true that $MR \dashrightarrow LI^{2}$ or $MR \dashrightarrow (LI^{+})|MR^{+}$.

With this in place, another example can be provided now to illustrate the significance of (7) in a better way. Let's take the example 'Jon thinks he falls'. This sentence can be first represented as THINK(Jon, FALL(x)) ≡ **thinks**(Jon, ^**Falls**(x))--where it may be the case that x=Jon in a certain context and ^**Falls**(x) designates an embedded predicate with its arguments. This can be reduced to $MR^{3}\oplus MR^{3}$. In this case, MR1(Jon, MR2), MR2(thinks, MR3), MR3(he, falls).

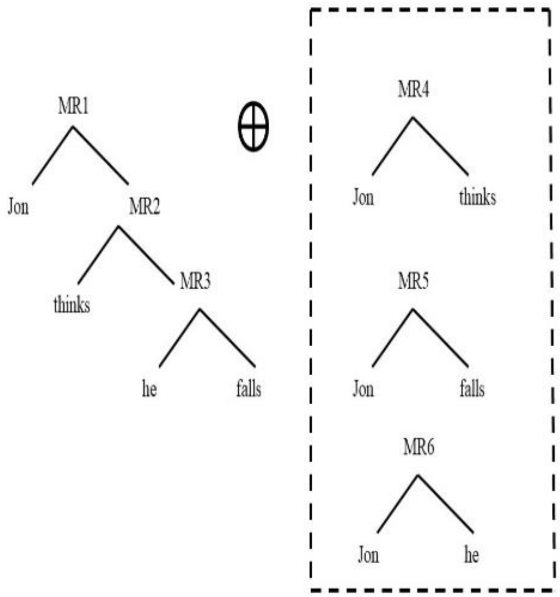


**Fig. 3.** The division of MRs in MR*⊕MR⁺ for our example sentence 'Jon thinks he falls'

The non-compositional relations are MR4(Jon, thinks), MR5(Jon, falls), and MR6(Jon, he). It is clear that (7) ensures that predicate concepts are easily coded in terms of meaning relations, and then meaning relations are back-coded into predicate concepts.

The representations of predicate concepts can also be made in terms of the non-recursive predicates in Minimal Recursion Semantics [23] so that the elementary predicates can be easily recognized in the back-coding of meaning relations into predicate concepts. This is just a possibility that we leave open for further reflections.

In this way, all predicate concepts can be reduced to a concatenation of some meaning relations. The concatenated form of meaning relations can be translated back into predicate concepts typically by removing MR* from $MR^*\oplus MR^+$. This is shown in Fig. 3 below by means of the dashed lines for the non-compositional relations.

The compositional relations, in contrast, can easily lend themselves to being converted into $F\otimes F^+$ or P(T1, ..., Ti).

This is shown for our example sentence 'Jon thinks he falls'.

## 4 Concluding Remarks

We have shown the normal form of predicate concepts. The normal form represents the minimal form of all predicate concepts in natural language. Apart from having mathematical implications, this formulation can be potentially important for natural language processing tasks in computational processing of natural language.

Computational systems having predicate concepts (such as WordNet or VerbNet) can have semantic representations that can be easily coded in terms of meaning relations. This ease in conversion can smoothen the use of semantic resources because the construction of meaning relations does not require heavy resources as it is done on the surface structure of sentences/clauses.

This has the added advantage that machine translation in resource-poor languages can possibly use the conversion of meaning relations into predicate concepts by way of the normal form and then back into meaning relations, whenever required. We leave it open for further investigation.

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