Enhancing Learning with Primitive-Decomposed Cognitive Representations

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Abstract

This paper proposes work that applies insights from meaning representation systems for in-depth natural language understanding to representations for self-supervised learning systems, which show promise in developing complex, deeply-nested symbolic structures through self-motivated exploration of their environments. The core of the representation system transforms language inputs into language-free structures that are complex combinations of conceptual primitives, forming a substrate for human-like understanding and common-sense reasoning. We focus on decomposing representations of expectation, intention, planning, and decision-making which are essential to a self-motivated learner. These meaning representations may enhance learning by enabling a rich array of mappings between new experiences and structures stored in short-term and long-term memory. We also argue that learning can be further enhanced when language interaction itself is an integral part of the environment in which the self-supervised learning agent is embedded.

Keywords: Self-supervised learning; natural language understanding; conceptual primitives; conceptual representations

1. Introduction

Machine learning research has recently shown dramatic improvements in performance on natural language processing tasks such as machine translation, information retrieval, and question answering by feeding large corpora of natural language into neural networks. However, work on adversarial examples demonstrates that these systems may only be exploiting surface-level patterns in training datasets to get high scores on the tests instead of actually understanding language (Jia and Liang, 2017; Zhang et al., 2020). In contrast, this position paper proposes work that applies insights from meaning representation systems for in-depth natural language understanding to representations for self-supervised learning systems, which have shown promise in developing complex, deeply-nested symbolic structures through self-motivated exploration of their environments. The core of the representation system transforms language inputs into language-free structures that are complex combinations of conceptual primitives, forming a substrate for human-like understanding, non-linguistic cognition, and common-sense reasoning.

We present preliminary ideas on the enhancement of a theoretical framework for in-depth understanding of natural language expressions that describe types of motivational and anticipatory thinking which are fundamental to self-motivated learning systems. The theory, Schank's Conceptual Dependency (CD; Schank, 1972, 1975), decomposes natural language into complex combinations of simple conceptual primitives representing physical

and mental acts and events; this representation is designed to confront the problem of linguistic variation—the fact that there are so many ways of expressing the same thing—by translating language into a non-linguistic conceptual "base". The conceptual primitive decomposition system has abstract primitives representing intelligent agents' interactions with their physical environment, as well as primitives representing memory and cognitive states that are needed to decompose concepts related to motivation, communication, planning, anticipatory reasoning, and theory of mind.

To provoke thought on the primitive decomposition of concepts related to prospective actions and motivation, we construct a number of CD structures that employ a primitive called MBUILD, which can be used in combination with other CD structures to represent acts of thinking in their great variety. We present standard relations between each conceptual structure and its English language gloss, and then mechanically generate a number of paraphrases of the glosses as a way to determine how an automated natural language understanding system based on the theory would understand the different expressions as meaning the same thing. We closely examine the paraphrases to determine whether they make sense and correspond to the spirit of the conceptual structure from which they were generated, and, when they do not, to see how they suggest ways in which the representation system could be improved for representing the imagery of motivation and anticipatory thinking.

2. Primitive Decomposition Systems

Primitive decomposition systems (Schank, 1972; Jackendoff, 1983; Wilks and Fass, 1992; Wierzbicka, 1996) have been employed by cognitive scientists, linguists, and artificial intelligence researchers because they represent canonical forms of meaning and thus reduce linguistic ambiguity in a variety of research contexts. Among primitive decomposition systems, a particularly compelling kind are those that work to represent a "inner language" of thought (Winston, 2012a,b) that is different and separate from natural language and represents mental models (Johnson-Laird, 1983) and mental imagery (Sadoski and Paivio, 2001). Recent work has explored how primitive decomposition systems may be scaled efficiently through crowdsourcing (Macbeth and Grandic, 2017) and used for knowledge representation (Macbeth, 2017), sentiment analysis (Cambria et al., 2018), and validating the output of neural perception systems (Gilpin et al., 2018).

Conceptual Dependency (Schank, 1972, 1975) is a primitive decomposition theory that works to decompose language into complex combinations of the eleven conceptual primitives shown in Table 1. Figure 1 shows an example of a primitive decomposition of the sentence "Lisa kicked the ball to the fence" in CD, into a combination of three physical primitive acts, a MOVE, a PROPEL, and a PTRANS representing Lisa moving her foot toward the ball, applying a force to the ball, and thus transferring the ball to a new location. The primitive acts are connected by a double arrow (marked "p" for past tense) to the actor performing them (Lisa) and they are connected to each other by "instrumental" links to represent that one act was performed as a part of achieving another. Specifically, the instrumental link from the PROPEL to the PTRANS represents that the PROPEL act was performed as part of achieving the PTRANS, while the instrumental link from the MOVE to the PROPEL represents that the MOVE act was performed as part of achieving the PROPEL.

CD Physical Primitives		CD Non-Physical Primitives	
PTRANS	To physically transfer an object from one location to another. Ex: "go" is a PTRANS by the actor of himself.	ATRANS	To transfer possession of an object from source to recipient. Ex: "give" is an ATRANS to someone else, "take" is an ATRANS to yourself, "buy" is two ATRANSes ...
PROPEL	To apply a force to an object. Ex: "push" is a PROPEL, "throw" is a PROPEL through air.	MTRANS	To transfer information within one person or between people. Ex: "tell" is an MTRANS between people.
MOVE	To move a body part. Ex: the usual means (instrument) of PROPELing is MOVEing one hand.	MBUILD	To create new mental information from old. Ex: "decide", "think about".
GRASP	To grasp an object. Ex: "hold" and "grab" are GRASPs. Usually a GRASP must be ended in order to "throw."	ATTEND	To focus a sense organ on a sensation. Ex: "look at" is ATTEND eye, "hear" is ATTEND ear.
INGEST	To ingest an object. Ex: "drink" is INGEST liquid, "breathe" is INGEST air.	SPEAK	To make noise. Ex: "tell" is an MTRANS by means of SPEAKing words.
EXPEL	To force an object from inside the body to outside the body. Ex: "spit," "excrete."		

Table 1: The eleven primitives of Conceptual Dependency (CD) divided into groups of physical and non-physical primitives. Adapted from Schank et al. (1975).

A natural language understanding system that decomposes the meaning into this form (or a similar one) would be able to map this sentence, or paraphrases of the same idea, such as "Lisa moved her foot to the ball and hit it to the fence", onto the same meaning structure. One major motivation for using primitive decomposition is that it offers depth of understanding; it provides a substrate for the rich associations between natural language expressions and a non-linguistic conceptual representation, as well as between the conceptual representation of natural language and complex knowledge structures for the reasoning processes that support understanding.

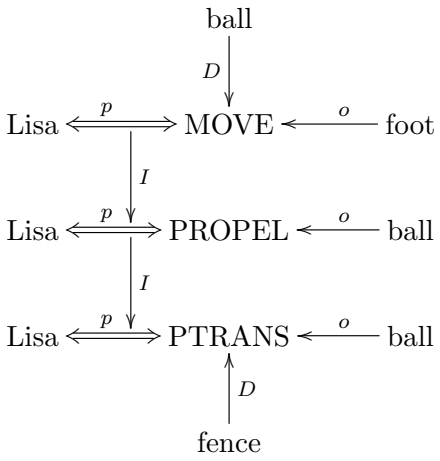

Figure 1: A CD decomposition of the sentence "Lisa kicked the ball to the fence." CD (Schank, 1972) decomposes the kicking act into a combination the primitive acts PTRANS, MOVE, and PROPEL. Double arrows indicate the actor performing the primitive act. Single arrows marked "o", "D", and "I" indicate the object, the directional case, and the instrument case, respectively. The "p" above the double arrow represents that the time of the conceptualization is previous to the time of the utterance.

3. MBUILD Conceptualizations

In addition to six primitives representing physical actions and events, CD has five primitives representing social interaction, perception, and thought. In particular, the MBUILD primitive represents the mental act in which a person manipulates some number of conceptualizations that are already in memory and creates a new conceptualization. Because of this, in MBUILD CD diagrams, the objective case to MBUILD is represented with multiple arrows: several "from" arrows pointing from the existing conceptualizations, and a "to" arrow pointing toward the conceptualization that was created. A pair of MBUILD CD conceptualizations are shown in Figure 2.

MBUILD is meant as a representation of natural language surface forms such as "to think about/of," "to decide," and "to consider," among many others. The conceptualizations that are manipulated and created by an MBUILD act are also represented in CD[1]. The *f* marking the double arrow for the MOVE conceptualization created by MBUILD represents that the MOVE is conceived to happen sometime in the future from the time of the MBUILD act. This is meant to mean that the MOVE is a decision or plan to perform the act if the actor of the MBUILD is the same as the actor of the MOVE. More generally, if the actors are not

1. In Schank (1975), the MBUILD conceptualizations all have a "recipient" case indicating the locations of source and destination conceptualizations in long-term memory and the "conscious processor" (short-term memory). These have been left out of the diagrams shown here for simplicity.

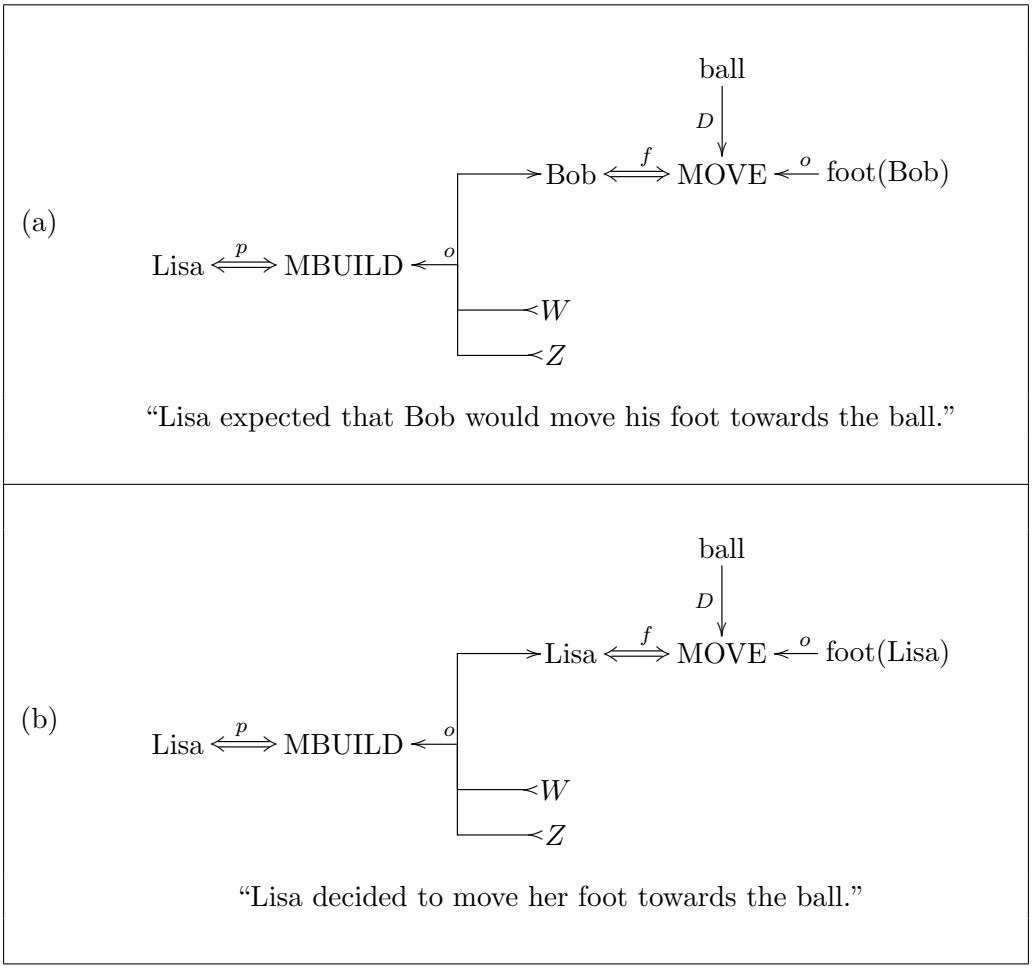

Figure 2: Two Conceptual Dependency conceptualizations using the MBUILD primitive with their English glosses. MBUILD represents the act of creating a new conceptualization inside the mind of the actor based on existing conceptualizations. MBUILD is generally meant to represent surface language forms like "to think about" and others representing thinking and reasoning. The object case to MBUILD is represented by multiple arrows marked with an 'o': two "from" arrows pointing from the existing "source" conceptualizations (in this case, W and Z, which are not specified), and a "to" arrow pointing toward the conceptualization that was created. The f marking the double arrow for the MOVE represents that the MOVE is conceived to happen sometime in the future from the time of the MBUILD act. In cases when the created conceptualization is in the future, it represents "to predict" or "to expect" (a), while in cases when the actor of the MBUILD and the created conceptualization are the same, it represents "to decide" and similar constructions (b). Adapted from Schank (1975).

the same, the conceptualization stands for some act or event that the actor of the MBUILD expects to happen in the future, but that they are not performing themselves.

Figure 2(a) shows an MBUILD act by Lisa in which the product conceptualization is a MOVE act where Bob is MOVEing his foot towards a ball. In this case the English glosses are "Lisa expected that Bob would move his foot towards the ball", or "Lisa thought that Bob would move his foot towards the ball." The source conceptualizations are not specified and are simply given as W and Z. The second diagram, Figure 2(b), shows an MBUILD act by Lisa in which the product conceptualization is a MOVE act where Lisa is MOVEing her foot towards a ball. Because the actors of the MBUILD and of the created conceptualization, MOVE, are the same, it has the English gloss "Lisa decided to move her foot towards the ball" in CD theory (Schank, 1975).

Figure 3 shows another pair of MBUILD CD conceptualizations. In Figure 3(a), the MOVE act is given as the source conceptualization, and no conceptualization is given as the product. This is meant to mean that the actor is performing some conceptual manipulation based on the sources, but has not yet completed the thinking process to produce any conceptualization as output. This conceptualization has the English glosses "Lisa considered moving her foot towards the ball", and "Lisa thought about moving her foot towards the ball".

Finally, in Figure 3(b) the diagram has a section that is identical to that in Figure 2(b); it is an MBUILD act by Lisa in which the product conceptualization is a MOVE act in the future where Lisa is MOVEing her foot towards a ball. But it also has another component representing Lisa MOVEing her foot towards a ball that is not an object of the MBUILD and is separate from it. This MOVE is connected to the MBUILD via a "result" causal link, shown as a triple arrow marked "r" between the double arrows of the MOVE and MBUILD. This link denotes that the MOVE act was caused by the MBUILD, and expresses that Lisa consciously thought of the act of moving her foot before doing it and that conceptualizing the MOVE is what caused Lisa to perform it. This conceptualization carries the gloss "Lisa intentionally moved her foot towards the ball" (Schank et al., 1972)[2].

4. Examining Paraphrases

A close examination of the decomposed conceptual structures and proposed natural language glosses is a frequently used method for determining the suitability of the primitive decomposition system (see, for example, Schank et al., 1972, and Schank, 1975). By constructing conceptual structures and generating glosses and paraphrases for those structures, one can determine how well and in what ways the language-free conceptual structures correspond to those that human minds generate when understanding the same texts.

First, we may try using the most general glosses for MBUILD, such as "to think", to generate paraphrases. For Figures 2(a) and (b), the paraphrases "Lisa thought that Bob would move his foot toward the ball" and "Lisa thought that she would move her foot toward the ball" seem appropriate. For Figure 3(a) we realize that "to think about" is a more appropriate form than "to think that" to express the processing of the input

2. The decomposition of intentionality and volition-related expressions from Schank et al. (1972) uses a CD primitive called CONC, "which refers to the primitive act of conceptualization". CONC does not appear in later presentations of CD, so we have changed it to an MBUILD to conform with Schank (1975).

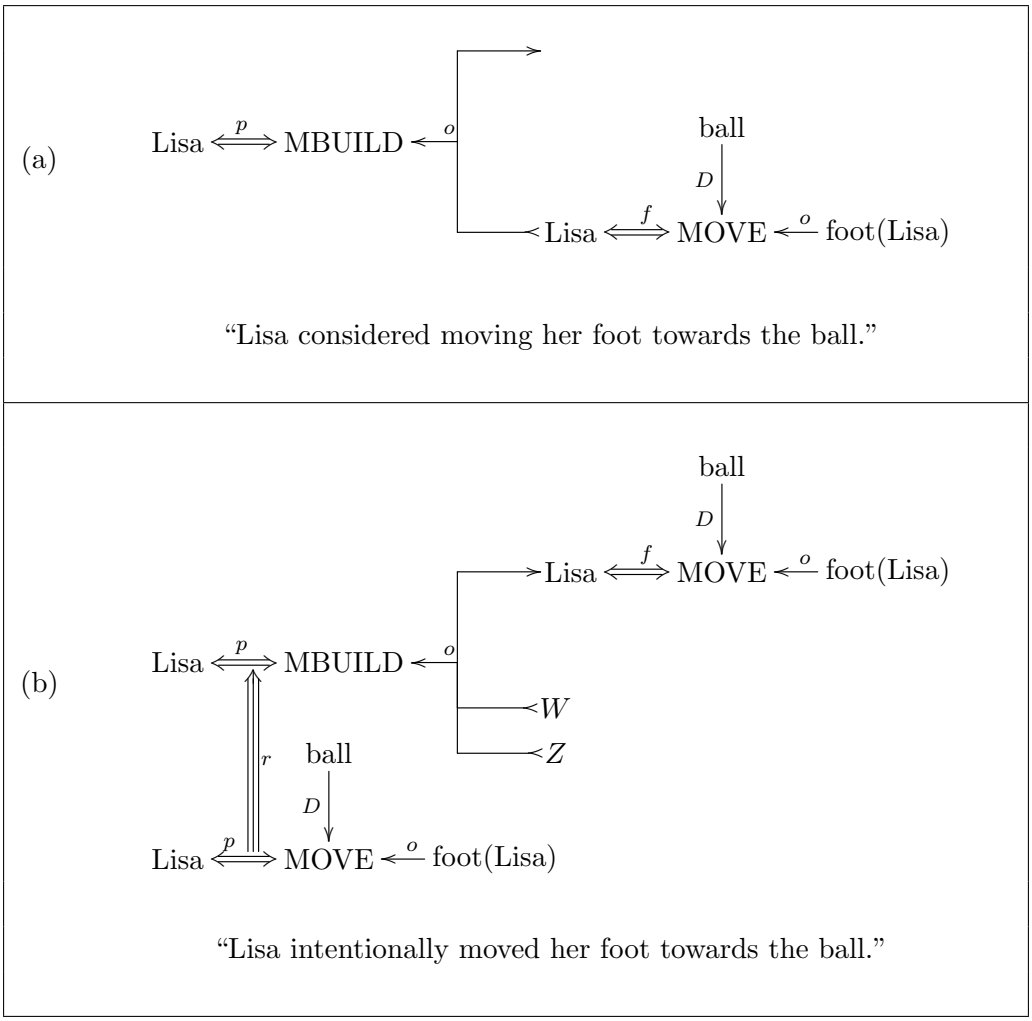

Figure 3: Two more Conceptual Dependency conceptualizations using the MBUILD primitive with their English glosses. When a source conceptualization is specified, it can be used in constructions involving "to consider", or "to think about", as is the case with the MOVE conceptualization in (a). In (a), the output conceptualization is blank, indicating that none was produced by the MBUILD process. In (b), the triple arrow marked "r" between the MOVE and MBUILD conceptualizations is a causal link, meaning that the MBUILD caused the MOVE. This kind of construction is used to represent volitional premeditated acts, expressed in the gloss in the adverb "intentionally". Adapted from Schank et al. (1972) and Schank (1975).

conceptualization to an MBUILD, and get "Lisa thought about moving her foot towards the ball".

Paraphrasing the conceptualization in Figure 3(b), we can represent the causal link with "to cause" or "because" and form "Lisa moved her foot towards the ball because she thought that she would move her foot towards the ball", and "Lisa's thinking that she would move her foot towards the ball caused her to move her foot towards the ball." More briefly, these could be "Lisa moved her foot towards the ball because she thought she would", and "Lisa's thinking that she would move her foot towards the ball caused her to do it". We can also paraphrase Figure 3(b) using "to decide" since the MBUILD part of the conceptualization matches that in Figure 2(b). This gives us "Lisa moved her foot towards the ball because she decided to", and "Lisa's deciding that she would move her foot towards the ball caused her to do it."

Next, we can attempt to apply "to expect", which is part of the gloss of Figure 2(a) to other diagrams, since they all have MBUILDs in which the built conceptualization is in the future with respect to the MBUILD act. This gives us "Lisa expected that she would move her foot towards the ball", or perhaps "Lisa expected to move her foot towards the ball" for Figure 2(b). For Figure 3(b) this gives us "Lisa moved her foot towards the ball because she expected to", and "Lisa's expectation that she would move her foot towards the ball caused her to do it."

In examining these paraphrases, the verb "to think" seems to apply well across all of the CD diagrams we composed, although we needed to be careful about phrasing with "that" and "about". Many of the "to expect" sentences seem odd since expectation is usually associated with events and acts that are not within someone's direct control. However, they are still understandable, which may indicate that the decomposition is accurate and that the weirdness of the paraphrases is only due to conventions in the use of "to expect" and related verbs.

However, the causal link used in Figure 3(b) to represent intentionality in acts did not seem to work well when we expressed it linguistically using "because" and "to cause". It seems somewhat odd to say that Lisa's thinking about or deciding that she would move her foot is what "caused" her to do it. It could be that we have chosen the wrong linguistic expression of this kind of link in this case. It seems clear that intentionality in an act involved some kind of conceptualization of the act before performing it, but it may be that a "causal" link is the wrong kind of link to choose to connect the two acts, or that more needs to be added to the conceptualization.

5. Conclusion

The preliminary work presented in this paper is focused on enhancing a meaning representation theory for systems that perform in-depth understanding of natural language expressions of anticipatory thinking. We examined a number of conceptual structures that employ the CD primitive MBUILD, which is meant to represent acts of thinking in a non-linguistic conceptual "base". Future work on the specific thread of exploration presented herein will examine causal links between MBUILD and other acts to represent volition and intention.

It is also important to consider how surface forms such as the words "goal" and "plan" map onto this representation. MBUILD allows for input source conceptualizations for rep-

resenting "to consider" and "to think about", but clearly the act of planning and the surface form "to plan" are different and more specific. This exploration suggests that there may be ways to improve aspects of the CD primitive decomposition system that represent natural language expressions of expectation, intention, planning, and decision making by expanding, reducing, or modifying the conceptual primitives (e.g. MBUILD) and connectives used to compose the structures. However, larger more sophisticated "script" structures (Schank and Abelson, 1977) based on these primitives may also prove to be capable of capturing the complexity of these concepts.

Another area of future interest is to attempt to map these structures onto belief-desire-intention (BDI) models (Bratman, 1987) for intelligent agents. Also, the primitive decomposition uses a time designation to represent things happening in the future, and things in the future naturally represent expectations and intentions, but this may not always be the case, since it is possible to conceptualize future events that are not expected or planned—particularly events that are to be avoided.

More generally, however, we intend to apply insights from these systems to future generations of self-supervised learning systems. Future research in this area focuses on how the meaning representation may enhance self-supervised learning, and how episodic memories that self-supervised learning systems encode in the representation form a corpus of knowledge structures that may be a foundation for reasoning. If it is true that learning occurs on the margins of what an agent already knows, representing knowledge structures in this primitive-decomposed form will enhance learning by enabling a rich array of mappings between new experiences and structures in short-term and long-term memory. We also argue that learning can be further enhanced when language interaction itself is embedded in the environment, for example, via communication with a parent or teacher agent, allowing the system to form a foundation for in-depth understanding of language by grounding it in the knowledge structures created in the self-supervised world exploration.

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