Abstract

This paper describes a methodology for designing Question Answering systems that utilize an action language $\text{ALM}$ to allow inferences based on complex interactions of events described in texts. This methodology assumes the extension of the VERBNET lexicon with interpretable semantic annotations in $\text{ALM}$ and specifies the use of several other NLP resources to produce $\text{ALM}$ system descriptions for input discourses.

1 Introduction

In this paper, we propose a methodology for designing Question Answering (QA) systems that uses state-of-the-art techniques from the field of Natural Language Processing (NLP) complementing them with the latest advances from the field of Knowledge Representation and Reasoning (KRR).

The applicability of KRR for the design and implementation of QA systems was explored by Baral et al. (2004) who demonstrated the suitability of the KRR language Answer Set Prolog (ASP) (Gelfond and Lifschitz, 1991) for this purpose. Balduccini et al. (2008) continued this line of research and described a QA system with an intended wide coverage, based on KRR techniques and NLP tools. Todorova and Gelfond (2011; 2012) addressed the problem from a different angle. They focused on texts restricted to a controlled natural language tailored to motion verbs and concentrated on answering difficult questions requiring counting. Their knowledge base was written in a higher-level KRR language than ASP, a so-called action language called $\text{ALM}$ (Inclezan and Gelfond, 2016).

The system by Todorova and Gelfond processed multiple-sentence texts exemplified by

\begin{align*}
\text{Ann went to the room.} & \quad (1) \\
\text{Michael left the room.} & \quad (2)
\end{align*}

and derived inferences based on information in these sentences to answer questions such as

\begin{align*}
\text{Is Michael inside the room (at the end of the story)?} & \quad (3) \\
\text{Is Ann inside the room (at the end of the story)?} & \quad (4) \\
\text{Is the room empty (at the end of the story)?} & \quad (5)
\end{align*}

In the sequel, we refer to the text composed of sentences (1) and (2) as the MA discourse.

Our goal is to build upon the methodology outlined by Todorova and Gelfond by putting more emphasis on the organization of KRR libraries and the NLP stages of QA. We remove some of the constraints assumed by their system: we do not limit ourselves to the motion verbs and we avoid a commitment to a controlled language. Our long term goal is to have a methodology that encompasses texts containing a large collection of action verbs (go, give, put exemplify the class of action verbs). In this paper, we test the feasibility of such a proposal by allowing change of possession verbs such as grab, grasp, yank in addition to motion verbs. Consider a discourse that contains the sentence

\begin{align*}
\text{Michael grasped the suitcase.} & \quad (6)
\end{align*}
uttered between sentences (1) and (2). We name it the MAS discourse. We illustrate that a system developed according to our methodology is able to infer that at the time when Michael was grasping the suitcase, its location was the room — the location of Michael, and that the suitcase is no longer in the room at the end of the described scenario.

The main feature of our approach is the use of $\mathcal{ALM}$ as a language for encoding the meaning of action verbs (i.e., the effects and constraints for the execution of the actions they denote). In addition, we propose to extend an NLP resource about verbs, VERBNET (Kipper-Schuler, 2005; Palmer, 2006), with $\mathcal{ALM}$ based semantic annotations. Other logic formalisms have been used for other NLP tasks (e.g., Recognizing Textual Entailment (NIST, 2008)), but unlike $\mathcal{ALM}$ they cannot perform temporal reasoning (MacCartney and Manning, 2007; Harmeling, 2009) or reasoning by cases (Bos and Markert, 2005). This makes them less suitable for answering questions about discourses describing sequences of events.

The paper is structured as follows. Section 2 starts by introducing the KRR action language $\mathcal{ALM}$ by illustrating how a knowledge engineer can utilize this language to formalize the scenarios described by the MA and MAS discourses and query the respective formalization. In the process, generic modules that capture the knowledge about such actions/verbs as move, go, and grasp are developed. Section 3 focuses on the methods that will allow us to automatically produce $\mathcal{ALM}$ descriptions that capture information present in discourses of interest by utilizing the arsenal of modern NLP lexicons and tools including VERBNET, PROPBANK (Palmer et al., 2005; Palmer, 2005), SEMLINK (Bonial et al., 2013b,a), Ontonotes Sense Groupings (CLEAR, 2008), LTH (Johansson and Nugues, 2007b,a), and CORENLP (Manning et al., 2014). We end with conclusions and future work.

2 The MA and MAS discourses formalized in $\mathcal{ALM}$

Action language $\mathcal{ALM}$ is a recent representative of KRR languages for modeling knowledge about domains in which changes are caused by the occurrence of actions. An important feature of $\mathcal{ALM}$ is its ability to capture the commonality of actions go and leave by defining them as instances of the same action class that we refer to as MOVE, and thus encode the relation that exists between the corresponding verbs.

We start by using $\mathcal{ALM}$ to formalize the domain behind the MA discourse. First, we use this example to illustrate the syntax and semantics of the language. Second, we demonstrate how the $\mathcal{ALM}$ framework can be used to perform inferences required to answer questions (3-5). The section concludes with the $\mathcal{ALM}$ formalization of the MAS discourse.

MA discourse via $\mathcal{ALM}$: There are several informative pieces in the MA discourse:
1. the discourse refers to actions of class MOVE through the use of verbs go and leave. This action class immediately brings about a set of axioms associated with it. For example, we are aware that it is impossible to move an object from a point if this object is not at this point.
2. three objects (entities, or instances) are introduced, to which we refer as ann, michael, and room; and two events (instances of actions): ann moves into room and michael moves out of room.
3. a sequence of event occurrences is given, i.e., first ann moves into room, and next, michael moves out of room.

Informative piece 1 or $\mathcal{ALM}$ module basic motion for modeling the MOVE action class: In Figure 1 (LHS), we show the $\mathcal{ALM}$ module called basic motion. This module is a general purpose description of knowledge/axioms about the MOVE action class. It describes how the location of objects is affected by occurrences of events of type MOVE.

Modules in $\mathcal{ALM}$ start with the declaration of sorts of objects relevant to the knowledge to be encoded. In basic motion, we distinguish between things and discrete points in space. We declare these two sorts as special cases of the pre-defined root sort of $\mathcal{ALM}$ called universe. We also declare a sort called agents, denoting entities capable to move by themselves, as a subsort of things. The knowledge engineer then proceeds to specify the relevant action classes for the domain in
module basic_motion
sort declarations
  things, points :: universe
agents :: things
move :: actions
attributes
  actor : agents
  origin, dest : points
function declarations
fluent
  basic
    loc_in : things * points -> booleans
axioms
  occurs(X) causes loc_in(A,D)
    if instance(X,move),
      actor(X)=A,
      dest(X)=D.
  occurs(X) causes -loc_in(A,O)
    if instance(X,move),
      actor(X)=A,
      origin(X)=O.
  impossible occurs(X) if instance(X,move),
    actor(X)=A,
    origin(X)=O,
    -loc_in(A,O).
  impossible occurs(X) if instance(X,move),
    actor(X)=A,
    dest(X)=D,
    loc_in(A,D).

module basic_motion_verbnet
sort declarations
  concrete :: universe
escape :: actions
attributes
  theme : concrete
  initial_location, destination : concrete
function declarations
fluent
  basic
    loc_in : concrete * concrete -> booleans
axioms
  occurs(X) causes loc_in(A,D)
    if instance(X,escape),
      theme(X)=A,
      destination(X)=D.
  occurs(X) causes -loc_in(A, O)
    if instance(X,escape),
      theme(X)=A,
      initial_location(X)=O.
  impossible occurs(X) if instance(X, escape),
    theme(X)=A,
    initial_location(X)=O,
    -loc_in(A, O).
  impossible occurs(X) if instance(X,escape),
    theme(X)=A,
    destination(X)=D,
    loc_in(A,D).

Figure 1: LHS: ALM module basic_motion capturing knowledge about action class MOVE; RHS: the same module restated using the VERBNET lexicon terminology.

question. In module basic_motion, action class move is declared as a special case of the pre-defined sort actions with three attributes (i.e., intrinsic properties): attribute actor ranging over the sort agents, and attributes origin and dest (destination) ranging over points.

Next, properties (fluents and statics) related to the domain are declared. Fluents are properties that may be changed by actions; they are divided in ALM into basic and defined. Basic fluents normally maintain their previous values, unless the occurrence of an event causes their value to change. Defined fluents allow one to specify properties in terms of other properties. Properties are modeled via functions in ALM using syntax similar to the mathematical notation for functions. In the basic_motion module, the property of interest is the location loc_in of things, which may be affected by the occurrence of actions of type move and is thus declared as a basic fluent. Per its specification, it is a function that maps pairs of things and points into the pre-defined sort booleans.

ALM modules conclude with axioms about described action classes and properties. The first two rules in the basic_motion module capture the direct effects of actions of sort move. In particular, the first axiom states that after an occurrence of an instance of move its actor will be located at the destination. The second axiom states that after an occurrence of a move event the actor will no longer be at the origin. We note that symbol “¬” is used to denote the classical negation symbol ¬. The last two statements describe when the action cannot be executed. In particular, the third and fourth axioms state that move cannot occur when the actor is not located at the specified origin, and when the actor is already at the destination, respectively.

Informative piece 2 or ALM system description for the MA discourse: In ALM, we describe a given domain via a system description that consists of a theory — modules organized into a hierarchy, and a structure — definitions of instances. A system description captures a transition diagram that characterizes the behavior of the given domain. Trajectories in a transition diagram correspond to possible evolutions or scenarios in the domain. We illustrate these concepts by means of the discourse_ma system description presented in Figure 2 (LHS), which corresponds to the MA discourse.
interpreted as a macro to denote that the ALM code describing “module basic_motion” has to be inserted in this place. The structure of discourse_ma declares instances ann, michael, and room so that the former two are of sort agents, whereas the latter is of sort points. The two events described in the MA discourse are represented as instances e1 and e2 of sort move. The actor of e1 is instance ann and its dest is room, while the actor of e2 is michael and its origin is room.

The system description discourse_ma defines the transition diagram T presented in Figure 3. It consists of four states labeled σ1⋯σ4, and five transitions labeled by actions e1, e2 that may take the dynamic system from one state to another. For example, the arc e1 between states σ2 and σ1 says that the occurrence of e1 may take the system from the former state to the latter. Note how action e1 cannot occur in state σ1 (due to the last axiom in basic_motion) and thus there is no arc in T going out of σ1 and labeled e1. The initial state of a system is associated with time step 0. Each arc in the transition diagram suggests an increment of a time step by one. A sequence τ1 = ⟨σ2, e1, σ1, e2, σ3⟩ constitutes a sample trajectory. This trajectory captures the following scenario: initially (time step 0), ann is not in room, whereas michael is in room; at time step 0, ann moves to (enters) room; at time step 1, michael moves from (leaves) room. A sequence τ2 = ⟨σ2, e2, σ1, e1, σ3⟩ exemplifies another trajectory of transition diagram T, whereas a sequence ⟨σ1, e1, σ2, e2, σ4⟩ is not a trajectory.

Informative Piece 3 or ALM histories: A particular domain scenario defines what we call a history (Gelfond and Khal, 2014) — a set of observations about fluents that hold in some states and events that happen at some states. Certain trajectories in the transition diagram encoded by a system description are compatible with a particular history, while others are not. We call the compatible trajectories models of a history. The MA discourse provides the following history: action e1 happens first (at time 0), then e2 happens (at time 1), which we abbreviate below

\[
\{hpd(e1, 0), hpd(e2, 1)\}.
\]  (7)

Given system description discourse_ma, trajectory τ1 is the only model of this history. Thus the initial state of the story conveyed by the MA discourse must be σ2 and the final one must be σ3.

Answering questions (3-5): Model τ1 of history (7) allows us to answer questions (3-5). The final
Figure 4: (a) ALM module defining action grasp; (b) System description for the MAS discourse.

state $\sigma_3$ of the trajectory $\tau_1$ contains literal $-\text{loc\_in(michael, room)}$, which translates into the answer no to question (3). State $\sigma_3$ contains $\text{loc\_in(ann, room)}$ that translates into answer yes to question (4). Presence of $\text{loc\_in(ann, room)}$ in state $\sigma_3$ translates into answer no to question (5).

Similarly, we can answer other questions: Is Michael inside the room at the beginning of the story? Is Ann inside the room at the beginning of the story? Were Ann and Michael in the room together at some point? How many people were in the room when Ann walked in? The initial state $\sigma_2$ of model $\tau_1$ supports the answers yes and no to the first and the second questions, respectively. The positive answer to the third question is endorsed by the intermediate state $\sigma_1$ of $\tau_1$. Initial state $\sigma_2$ encodes the situation preceding Ann walking into the room. It supports the answer at least one to the last question.

Automatically computing models of a history: Given the ALM system description and the history that correspond to a discourse in question, the task of computing models of this history relative to the system description can be automated. First, the system description is translated into a logic program under answer set semantics using the transformation defined by Inclezan and Gelfond (2016). Second, the history and a predefined module for temporal projection (Gelfond and Khal, 2014) are added to the produced logic program. Answer sets of the resulting program can be computed using an off-the-shelf ASP{f} solver CLINGO{f} available at http://www.mbal.tk/clingof/. Each answer set corresponds to a model of the given history. A prototype translator from ALM system descriptions and histories to logic programs is available at http://tinyurl.com/z6n9fmx.

MAS discourse via ALM: In order to model the MAS discourse, an ALM module that formalizes knowledge about actions of type GRASP is required. Figure 4 (a) presents a module called grasping that serves this purpose. It is adapted from (Inclezan and Gelfond, 2016), where it was used to illustrate the methodology of creating modular representations in ALM by encoding a classical Monkey and Bananas problem from the field of reasoning about actions and change. The first line of module grasping specifies the reuse of sorts and/or functions explicitly declared in module basic\_motion. Specifically, this module reuses the fluent loc\_in since the location of agents and things conditions what GRASP actions can be executed.
**ALM system description for the MAS discourse:** The system description for the MAS discourse, `discourse_mas`, is presented in Figure 4 (b). Its theory starts with an import statement for module grasping. Given that grasping depends on module basic_motion, the meaning of this ALM statement is that contents of both modules are copied into the theory of `discourse_mas`. Hence, within this system description we can instantiate events that are of type grasp or move. The fact that action classes grasp and move are interconnected in the definition of module grasping allows a knowledge engineer to model nontrivial interdependencies between actions. For example, an instance of action grasp causes its agent to hold a grasped object. Module grasping also encodes the knowledge that if an agent holds an object then the locations of the agent and object must be the same. These restrictions allow one to deduce that, when an instance of an action move occurs while the agent holds some object, then this object changes its location just as the agent does. The structure of the `discourse_mas` system description is defined similarly to that of `discourse_ma`.

History \{hpd(e1,0), hpd(ea,1), hpd(e2,2)\} records the events described in discourse MAS. In all models of this history relative to `discourse_mas` (i) the location of entity suitcase is the same as that of entity michael (namely, entity room) before action instance e2 occurs; (ii) after event ea occurs michael is holding suitcase in all subsequent states; and (iii) after event e2 occurs michael is holding suitcase, and both michael and suitcase are not in room. All of these observations correspond to our expectations given the MAS discourse. Indeed, we infer that the suitcase is no longer in the room at the end of the story. Similarly, when Michael grasped the suitcase, its location was the same as the location of Michael, i.e., the room.

3 Automatic construction of ALM system descriptions from discourses

In the previous section we illustrated how a knowledge engineer may encode the information carried within the MA and MAS discourses in ALM. We then discussed how these ALM formalizations can be used to automatically reason about these discourses. In this section, we present a proposal for automating the process of creating an ALM system description for an English discourse by relying on modern NLP tools such as LTH, CORENLP and existing lexical resources including Ontonotes Sense Groupings, VERBNET, PROPBANK, and SEMLINK. We stress the steps that have to be performed and how NLP tools and resources are to be used in those steps. The MA discourse is a running example in this section.

**Stage 1 or Entity and relation extraction:** The goal of this stage is to take an English discourse as an input and produce a so-called discourse representation structure (DRS) — a basic building block of Discourse Representation Theory (Kamp and Reyle, 1993). Figure 5 presents a DRS for the MA discourse. The top part of this DRS enumerates all of the entities, called discourse referents, that take part in the captured discourse (namely, r1, r2, and r3) as well as referents denoting events that the discourse describes (namely, e1 and e2). The bottom part of the DRS captures conditions on the entities and events that follow from the discourse. The events are encoded in Neo-Davidsonian style.

| r1 | r2 | r3 | e1 | e2 |
|------------------------------|------------------|------------------|------------------|------------------|
| entity(r1) entity(r2) entity(r3) | property(r1,ann) property(r2,room) property(r3,michael) | event(e1) event(e2) | eventType(e1,go.01) eventTime(e1,0) eventArgument(e1,a1,r1) eventArgument(e1,a4,r2) | eventType(e2,leave.01) eventTime(e2,1) eventArgument(e2,a0,r3) eventArgument(e2,a1,r2) |

Figure 5: Discourse representation structure for the MA discourse

To produce a DRS as exemplified, the first proposed step is to process discourse sentences using the LTH semantic role labeler. For sentences (1) and (2) of the MA discourse, LTH produces the output:

[A1 Ann] [V (go.01) went] [A4 to the room]  
[A0 Michael] [V (leave.01) left] [A1 the room]
The examples above are annotated using the rolesets/labels of the predicates \texttt{go.01} and \texttt{leave.01} as defined in frame schemas of PROPBank (version 1.7), where the suffix \texttt{01} indicates that Ontonotes Sense Groupings associates these predicates with senses 1 of verbs \texttt{go} and \texttt{leave}:

\texttt{go.01: motion}
\begin{itemize}
  \item A1: entity in motion/goer
  \item A2: extend
  \item A3: start point
  \item A4: end point
  \item \texttt{AM-LOC}: medium
  \item \texttt{AM-DIR}: direction (usually up or down)
\end{itemize}

\texttt{leave.01: move away from}
\begin{itemize}
  \item A0: entity leaving
  \item A1: place left
  \item A3: attribute/secondary predication
\end{itemize}

In the second step, we propose to process a given discourse using the Stanford \texttt{coreNLP} system. Among other NLP tasks, the \texttt{coreNLP} system can perform mention detection and coreference resolution. Given the \texttt{MA} discourse it is able to detect that there are three entities in the discourse: \textit{Michael}, \textit{Ann}, and \textit{the room}, and that expressions \textit{the room} in sentences (1) and (2) refer to the same entity.

In the third step, the output of systems \texttt{LTH} and \texttt{coreNLP} is combined to produce a DRS for the given input. Based on the output of \texttt{coreNLP}, entities \texttt{r1}, \texttt{r2}, and \texttt{r3} that have a property of being \texttt{ann}, \texttt{room}, and \texttt{michael}, respectively, are added to the DRS. Similarly, events \texttt{e1} and \texttt{e2} are known to be of type \texttt{go.01} and \texttt{leave.01}, respectively, based on the output of \texttt{LTH}. Relation \texttt{eventArgument} is populated by using the role labels assigned by \texttt{LTH}. The time step for the events (encoded by \texttt{eventTime}) is provided based on chronological order of events mentioned in the discourse, which coincides with default readings of sentences (we disregard for now markers such as \texttt{before}, \texttt{after}).

**Related NLP systems:** System \texttt{BOXER} (Bos, 2008) is an open-domain NLP tool that, given a discourse constructs a respective DRS. However, the discourse representation structures constructed by \texttt{BOXER} omit ordering of events in the discourse (i.e., contain no counterpart to "eventTime" in Figure 5), as well as details on the roles played by event arguments. Also, named entity recognition and coreference resolution components of \texttt{coreNLP} perform better than \texttt{BOXER}.

**Stage 2 or From discourse to an \texttt{ALM} system description or via \texttt{PROPBank} to \texttt{VERBNet} to \texttt{ALM}:** The next question that we tackle is how to map entities, properties, and history present in a given DRS into the vocabulary of \texttt{ALM} modules that capture axioms about the actions denoted by verbs occurring in this DRS? For the \texttt{MA} discourse, this question translates into \textit{how do we transition from the DRS in Figure 5 to an ALM scenario composed of a system description in Figure 2 and history (7)?}

In order to produce a system description and a history from a DRS, first we have to link two distinct \texttt{PROPBank} predicates \texttt{go.01} and \texttt{leave.01} to the same \texttt{ALM} action class \texttt{MOVE}. Second, we ought to map the semantic roles prescribed by \texttt{PROPBank} for these predicates to the arguments of action class \texttt{MOVE} as prescribed by the \texttt{basic_motion} module. Third, we have to link the entities mentioned in the given DRS in Figure 5 with the instances that compose the structure of the system description capturing this discourse. We will illustrate how these steps result in an \texttt{ALM} system description \texttt{discourse_ma_verbnnet} presented in Figure 2 (RHS). It is easy to see that to a large extent the new system description is a syntactic modification of the \texttt{discourse_ma} system description in Figure 2 (LHS) that has been designed earlier to process the \texttt{MA} discourse. The \texttt{discourse_ma_verbnnet} system description can be used in the same manner to answer questions about this discourse. Next, we present details on components required to automate the construction of this system description.

**\texttt{VERBNet} Lexicon:** We start by focusing on the first two of the described tasks: mapping \texttt{PROPBank} predicates \texttt{go.01} and \texttt{leave.01} and their arguments into instances of the \texttt{ALM} action class \texttt{MOVE} and its attributes. We argue that it is possible to carry out such mappings in a systematic manner using theories developed by linguists pertaining to verb semantics. Levin (1993) proposed the grouping of verbs into classes based on their syntactico-semantic behavior in sentences. Verb lexicon \texttt{VERBNet} is organized into verb classes that extend and refine these by Levin. For instance, \texttt{VERBNet} class \texttt{ESCAPE-51.1} contains among others verbs \texttt{go} and \texttt{return}. A direct subclass of \texttt{ESCAPE-51.1} named \texttt{ESCAPE-51.1-1} contains verb \texttt{leave}. Any subclass of a class in \texttt{VERBNet} inherits all of the features of its parent class, but also contains its specific entries. In addition to capturing the grouping information of the verbs, \texttt{VERBNet} provides the ontology of core thematic roles associated with each group.
Four (thematic) roles are identified with the classes ESCAPE-51.1 and 51.1-1: \textit{theme}, \textit{initial}, \textit{location}, \textit{destination}, and \textit{trajectory}. Condition \textit{concrete} represents (selectional) \textit{restriction} that the arguments of the verbs of this class should satisfy to form semantically coherent sentences. Intuitively, in sentence (1) an entity corresponding to \textit{Ann} serves the role \textit{theme}, while an entity corresponding to \textit{the room} serves the role \textit{destination}. Both of these entities are of \textit{concrete} kind/sort. Kipper-Schuler, Section 3.1.4 (2005) describes semantic annotations provided within \textsc{VerbNet} for each class. However, unlike \textsc{ALM} descriptions, these do not have formal semantics and are not computer interpretable in prescribed manner.

The \textsc{ALM} declaration of action class \textsc{move} in Figure 1 (LHS) echoes the information present in \textsc{VerbNet}. We see how attribute \textit{actor} of \textsc{move} is declared of sort \textit{agents}, whereas \textit{origin} and \textit{dest} are declared of sort \textit{points}. Intuitively, attribute names such as \textit{actor}, \textit{origin}, and \textit{dest} serve the role of thematic roles \textit{theme}, \textit{initial}, \textit{location}, and \textit{destination}, respectively. Sorts \textit{agents} and \textit{points} echo selectional restrictions and are designated to be of \textit{concrete} kind by \textsc{VerbNet}. Figure 1 (RHS) presents the restatement of the \textsc{basic motion} module in (LHS) of the same figure using \textsc{VerbNet} terminology and named \textsc{basic motion verbnet}. It differs from (LHS) by different name choices. The only non-syntactic change appears in sort declarations, where the (RHS) module defines a less specific sort hierarchy. We envision an extended \textsc{VerbNet} that is augmented with \textsc{ALM} modules (such as \textsc{basic motion verbnet}), which provide \textsc{ALM}-based semantic annotations for its verb classes.

Then, the \textsc{VerbNet} lexicon can serve as a lookup table for finding relevant action classes and \textsc{ALM} modules while processing discourses. We believe that the creation of an extended \textsc{VerbNet} will be an important contribution to both the NLP and KRR communities.

The \textsc{Semlink} Project: The last step to address is how to translate information about entities and events in a DRS into the \textsc{ALM} system description capturing a given discourse. Here, the missing piece of the puzzle is the \textsc{Semlink} project (Bonial et al., 2013b) that links together \textsc{PropBank} and \textsc{VerbNet}.

For instance, \textsc{Semlink} contains an entry suggesting that (i) the predicate \textsc{leave.01} is part of verb class 51.1-1 (a child of the class ESCAPE-15.1) (ii) the argument \textsc{A0} of predicate \textsc{leave.01} is mapped to role \textit{theme} of verb class 51.1-1, and (iii) the argument \textsc{A1} of predicate \textsc{leave.01} is mapped to role \textit{initial location} of class 51.1-1. These mappings are sufficient for devising a translation from information in the DRS in Figure 5 about event \textsc{e2} into the respective part of the structure of the \textsc{ALM} system description present in Figure 2 (RHS). Thus an event of type \textsc{leave.01} can be seen as an event of type ESCAPE-51.1 and in turn as an instance of action \textsc{move}, which is captured by \textsc{escape in the basic motion verbnet} module presented in Figure 1 (RHS). Note that this also implies that module \textsc{basic motion verbnet} should be imported into the theory of this constructed system description. Similarly, \textsc{Semlink} contains a mapping for predicate \textsc{go.01} of \textsc{PropBank} to a respective class in \textsc{VerbNet}. Yet, argument \textsc{A4} of \textsc{go.01} and role \textit{destination} in \textsc{VerbNet} is missing in this mapping. Thus, \textsc{Semlink} has to be augmented to accommodate the mapping from \textsc{A4} to \textit{destination}. Nevertheless, \textsc{Semlink} provides a solid foundation for the \textsc{PropBank-VerbNet} connection.

4 Conclusions and Future Work

We proposed a methodology for building a QA system that uses KRR techniques related to the representation of actions. We focused on answering questions that require the specification of knowledge about actions. We argued that annotating the verb lexicon \textsc{VerbNet} with such knowledge specifications in the KRR language of \textsc{ALM} will allow us to utilize a variety of NLP tools. We showed that the use of multiple NLP resources provides us with the means to extract information from an input discourse sufficient to “populate” a respective \textsc{ALM} system description and history that in turn can be used to draw nontrivial inferences about the discourse in question. In the immediate future, we will evaluate our method on a collection of texts from project bAbI (Weston et al., 2016; Facebook Research, 2016) containing motion and change of possession verbs. In a long term, we plan to expand the \textsc{VerbNet} annotations to include other types of English verbs.
References

Balduccini, M., C. Baral, and Y. Lierler (2008). Knowledge Representation and Question Answering. In F. van Harmelen, V. Lifschitz, and B. Porter (Eds.), Handbook of Knowledge Representation, pp. 779–820. Elsevier.

Baral, C., M. Gelfond, and R. Scherl (2004). Using Answer Set Programming to Answer Complex Queries. In Workshop on Pragmatics of Question Answering at HLT-NAAC2004.

Bonial, C., K. Stowe, and M. Palmer (2013a). SemLink. https://verbs.colorado.edu/semlink/ [Accessed: 2017].

Bonial, C., K. Stowe, and M. Palmer (2013b). Renewing and revising semlink. In Proceedings of The GenLex Workshop on Linked Data in Linguistics.

Bos, J. (2008). Wide-coverage semantic analysis with boxer. In Proceedings of the 2008 Conference on Semantics in Text Processing, STEP ’08, Stroudsburg, PA, USA, pp. 277–286. Association for Computational Linguistics.

Bos, J. and K. Markert (2005). Recognising textual entailment with logical inference. In Proceedings of the Conference on Human Language Technology and Empirical Methods in Natural Language Processing, HLT ’05, Stroudsburg, PA, USA, pp. 628–635. Association for Computational Linguistics.

CLEAR (2008). Ontonotes Sense Groups. http://clear.colorado.edu/compsem/index.php?page=lexicalresources&sub=ontonotes [Accessed: 2017].

Facebook Research (2016). bAbI. https://research.fb.com/downloads/babi/ [Accessed: 2017].

Gelfond, M. and Y. Khal (2014). Knowledge Representation, Reasoning, and the Design of Intelligent Agents: The Answer-Set Programming Approach. Cambridge University Press.

Gelfond, M. and V. Lifschitz (1991). Classical Negation in Logic Programs and Disjunctive Databases. New Generation Computing 9(3/4), 365–386.

Harmeling, S. (2009, October). Inferring textual entailment with a probabilistically sound calculus*. Nat. Lang. Eng. 15(4), 459–477.

Inclezan, D. and M. Gelfond (2016). Modular action language. TPLP 16(2), 189–235.

Johansson, R. and P. Nugues (2007a). Language Technology at LTH. http://nlp.cs.lth.se/ [Accessed: 2017].

Johansson, R. and P. Nugues (2007b, June). Lth: Semantic structure extraction using nonprojective dependency trees. In Proceedings of the Fourth International Workshop on Semantic Evaluations (SemEval-2007), Prague, Czech Republic, pp. 227–230. Association for Computational Linguistics.

Kamp, H. and U. Reyle (1993). From discourse to logic, Volume 1,2. Kluwer.

Kipper-Schuler, K. (2005). VerbNet: A Broad-Coverage, Comprehensive Verb Lexicon. Ph. D. thesis, University of Pennsylvania.

Levin, B. (1993). English verb classes and alternations: a preliminary investigation. University Of Chicago Press.

MacCartney, B. and C. D. Manning (2007). Natural logic for textual inference. In Proceedings of the ACL-PAASCAL Workshop on Textual Entailment and Paraphrasing, RTE ’07, Stroudsburg, PA, USA, pp. 193–200. Association for Computational Linguistics.
Manning, C. D., M. Surdeanu, J. Bauer, J. Finkel, S. J. Bethard, and D. McClosky (2014). *Stanford CoreNLP: a suite of core NLP tools*. http://stanfordnlp.github.io/CoreNLP/ [Accessed: 2017].

NIST (2008). Past RTE data. https://tac.nist.gov/data/RTE/index.html [Accessed: 2017].

Palmer, M. (2005). *Proposition Bank*. http://verbs.colorado.edu/~mpalmer/projects/ace.html [Accessed: 2017].

Palmer, M. (2006). *VerbNet*. https://verbs.colorado.edu/~mpalmer/projects/verbnet.html [Accessed: 2017].

Palmer, M., D. Gildea, and P. Kingsbury (2005, March). The proposition bank: An annotated corpus of semantic roles. *Computational Linguistics 31*(1), 71–106.

Todorova, Y. (2011). *Answering questions about dynamic domains from natural language using ASP*. Ph. D. thesis, Texas Tech University.

Todorova, Y. and M. Gelfond (2012). Toward Question Answering in Travel Domains. In *Correct Reasoning*, pp. 311–326.

Weston, J., A. Bordes, S. Chopra, A. M. Rush, B. van Merriënboer, A. Joulin, and T. Mikolo (2016). *Towards AI-Complete Question Answering: A Set of Prerequisite Toy Tasks*. https://arxiv.org/pdf/1502.05698.pdf [Accessed: 2017].