**RESTKB: A Library of Commonsense Knowledge about Dining at a Restaurant**

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This paper presents a library of commonsense knowledge, RESTKB, developed in modular action language ALM and containing background knowledge relevant to the understanding of restaurant narratives, including stories that describe exceptions to the normal unfolding of such scenarios. We highlight features that KR languages must possess in order to be able to express pertinent knowledge, and expand action language ALM as needed. We show that encoding the knowledge base in ALM facilitates its piecewise construction and testing, and improves the generality and quality of the captured information, in comparison to an initial ASP encoding. The knowledge base was used in a system for reasoning about stereotypical activities, evaluated on the restaurant domain.

1 Introduction

In this paper, we introduce a library of general commonsense knowledge related to the restaurant domain, RESTKB, which is a result of our research on understanding narratives about stereotypical activities, including stories that describe exceptional scenarios. In previous work [33, 22, 32], we introduced a methodology for reasoning about such stories and demonstrated the advantages of using ASP [16] in implementing it. The knowledge in RESTKB was also originally written in ASP, but this encoding soon became difficult to manage and test. The next alternative was an action language, i.e., a high-level logic programming language dedicated to the representation of knowledge about actions and their effects [17]. Particularly appealing was a modular action language, ALM [21], that allows for the structuring and reuse of knowledge, and facilitates the gradual development and testing of knowledge modules. ALM’s semantics is described in terms of a translation into ASP{f} [2], an extension of ASP with non-Herbrand functions, which means that an ALM knowledge base can be seamlessly integrated into our ASP-based methodology for reasoning about stories involving stereotypical activities. However, ALM was not immediately suitable for our purpose, as its syntax did not provide means for specifying non-deterministic effects of actions, which was necessary for reasoning about exceptional scenarios that require diagnosis. To better manage the growing amount of encoded knowledge, we decided to expand ALM with the missing feature, which was facilitated by the close connection with ASP{f}.

Background knowledge bases are important for solving a variety of reasoning tasks, but they are even more important when dealing with narratives about stereotypical activities (e.g., dining at a restaurant, going to the doctor, etc.). Stories about stereotypical activities omit many more details about actions that take place, compared to other texts. These details are assumed to be filled in by the reader, based on a common understanding of how such activities should unfold. For instance, in Example 1 below, the fact that Nicole paid for her meal is not explicitly mentioned but assumed to have happened.
Example 1 (Normal Scenario, adapted from Mueller’s work [29]) Nicole went to a vegetarian restaurant. She ordered a lentil soup. The waitress put the soup on the table. Nicole enjoyed the soup. She left the restaurant.

Most importantly, our methodology is able to understand and explain exception scenarios like the one in Example 2, which could not be processed by previous approaches [29]. A suitable knowledge base should contain information that supports this type of reasoning.

Example 2 (Scenario Requiring Diagnosis) Nicole went to a vegetarian restaurant. She ordered lentil soup. The waitress brought her a miso soup instead. (Possible explanations include that the waitress or cook misunderstood the order.)

In particular, the knowledge in RESTKB supports reasoning about (a) normal restaurant scenarios; (b) scenarios in which something goes wrong (e.g., wrong dish/bill is brought to the customer); (c) scenarios in which the activity has to be suddenly stopped (e.g., the customer receives an urgent call and leaves); and (d) scenarios in which some of the customer’s subgoals are serendipitously achieved by someone else’s actions (e.g., someone pays for the customer’s bill). Exceptional scenarios of types (b)-(d) cannot be handled in a scalable way by previous approaches, including Mueller’s system.

We focus here on a knowledge base about the restaurant domain because a large number of actions occurring in dining episodes are general enough to be encountered in other domains (e.g., enter, go, request). We envision the modules created for the restaurant domain to be the foundation for a commonsense knowledge base created on top of linguistic resources, such as the verb ontology VerbNet [25, 24], and applicable to the task of general natural language understanding, as outlined by Lierler et al. [26]. Lierler et al. suggest coupling state-of-the-art natural language processing tools and resources with knowledge representation and reasoning (KR) techniques to demonstrate a deep understanding of the meaning of texts written in natural language.

The contributions of this paper are as follows:

• We demonstrate the benefits of using a higher-level logic programming language (an action language, specifically a modular one) to the creation of a restaurant library;
• We discuss key KR principles that we applied in creating the RESTKB, relevant to the creation of other libraries;
• We present the $ALM$ library RESTKB; and
• We demonstrate the use of RESTKB.

In the remainder of the paper, we discuss related work and language $ALM$. We highlight desired features for high-level logic programming languages to support reasoning about (exceptional) stories involving stereotypical activities, and expand $ALM$ as needed. We present RESTKB and the key principles employed in creating it. We exemplify the use of the library on the restaurant domain, starting from natural language text.

2 Related Work

Mueller [29] studied restaurant texts and presented a system that could process stories about normal scenarios with a reasonable accuracy. His work was a continuation of research by Shank and Abelson [31] and represented a substantial improvement in terms of system capabilities compared to system SAM (Script Applier Mechanism) [11], due to the use of logic programming for reasoning purposes. Unfortunately, Mueller’s background knowledge base is proprietary and thus not available. Additionally, Mueller’s approach cannot handle exception scenarios of types (b)-(d), like the one in Example 2, because
it relies on the use of fixed scripts. This implies that his knowledge base lacks information needed to reason about, or explain, untypical scenarios.

A previous \(\mathcal{ALM}\) core library exists, COREALMLIB [20], derived from the Component Library [6] written in the language KM [10]. However, in our work with restaurant narratives we discovered that the collections of fluents and axioms in these two libraries are not rich enough to be useful for a deep understanding of restaurant narratives. Actions are denoted in natural language by action verbs. There are linguistic resources like VerbNet [25] that classify verbs and attempt to provide semantics for their meaning. However, these are only informal semantics (i.e., annotations) and are not useful in building reasoning systems.

A modular action language with similar goals to \(\mathcal{ALM}\)'s is MAD [27]. A MAD library of core concepts exists [14] but it requires substantial expansion to be applicable to the restaurant domain and it cannot be directly integrated in our ASP-based system for reasoning about stereotypical activities. Moreover, the reuse mechanism of MAD has the potential of requiring a higher number of modules than its \(\mathcal{ALM}\) correspondent and a deeper module hierarchy [19]. These are less desirable features from a software engineering point of view.

3 Action Language \(\mathcal{ALM}\)

Language \(\mathcal{ALM}\) [21] is a recent KR language for modeling dynamic domains. It is a modular action language that provides means for the structuring of knowledge into reusable classes and modules, which facilitates the knowledge engineering task, and the piecewise construction and testing of libraries and system descriptions. An \(\mathcal{ALM}\) module is a formal description of a specific piece of knowledge packaged as a unit, and consists of declarations of classes, functions, and axioms.

In \(\mathcal{ALM}\), the goal is to represent classes (sorts) of actions and objects in general terms (e.g., a move action class) instead of particular actions and objects (e.g., Nicole going to the table). Axioms written about a class are general and apply to all specific instances of the class. Moreover, classes have attributes that are optional instead of fixed parameters (e.g., a move action class has attributes origin and dest but any of these can be omitted from the definition of an instance of move). This facilitates the mapping of natural language stories into an \(\mathcal{ALM}\) logic form.

Here is an example of an \(\mathcal{ALM}\) action class declaration:

\[
\text{move} :: \text{actions} \\
\quad \text{attributes} \\
\quad \quad \text{actor} : \text{agents} \\
\quad \quad \text{origin}, \text{dest} : \text{points}
\]

This declares move as an action class with three attributes: actor of sort agents, and origin and dest of sort points. Fluents (and statics) are declared using a syntax similar to that of mathematical functions, for instance

\[
\text{at} : \text{things} \rightarrow \text{points}
\]

says that at, describing the location of things, maps things into points. Fluents, statics, and attributes are all (possibly partial) functions. Axioms describe the effects of actions and conditions for their execution. As an example, the axiom below states that the direct effect of the occurrence of an action of class move is that its actor will be at the destination.

\[
\text{occurs}(X) \quad \text{causes} \quad \text{at}(A) = D \quad \text{if} \quad \text{instance}(X, \text{move}), \quad \text{actor}(X) = A, \quad \text{dest}(X) = D.
\]

The next axiom states that an instance of move cannot be executed if its actor is already at the destination.

\[
\text{impossible} \quad \text{occurs}(X) \quad \text{if} \quad \text{instance}(X, \text{move}), \quad \text{actor}(X) = A, \quad \text{dest}(X) = D, \quad \text{at}(A) = D.
\]
An example of a definition of an action class instance is shown below. It represents Nicole’s action of going to a vegetarian restaurant (note that the origin is not specified):

```
e_1 \text{in move}
  \text{actor} = “Nicole”
  \text{dest} = “a vegetarian restaurant”
```

The semantics of \(\cal A\cal C\cal M\) is given via a translation into \(\text{ASP}\{f\}\) \(2\), e.g., the translation of the two \(\cal A\cal C\cal M\) axioms above looks as follows:

\[
\begin{align*}
at(A, I + 1) = D & \leftarrow \text{occurs}(X, I), \text{instance}(X, \text{move}), \text{actor}(X) = A, \text{dest}(X) = D. \\
\neg\text{occurs}(X, I) & \leftarrow \text{instance}(X, \text{move}), \text{actor}(X) = A, \text{dest}(X) = D, \text{at}(A, I) = D.
\end{align*}
\]

where \(I\) ranges over a new sort \text{step}, \(A\) ranges over \text{agents} and \(D\) over \text{points}. The translation also includes pre-defined rules like the Inertia Axioms for inertial fluents.

4 Desired Features in KR Languages

As we were building our knowledge base for the restaurant domain, we determined a set of features that KR languages (especially action languages) should possess to support the understanding of stories about stereotypical activities. We list here the identified features and justify their need.

1. An elegant solution to allowing optional attributes of actions (or action classes) instead of fixed parameters. In natural language, the arguments of verbs (also called thematic/semantic roles in linguistic terms) are often optional. For instance, we could encounter the verb “leave” either with a specified origin as in “She left the restaurant” (see Example 1) or without an explicit origin as in “She left.” An action language in which actions/ action classes have optional attributes would streamline the translation from natural language into the vocabulary of a knowledge base.

2. An ability to create concise representations for a large number of actions/ English verbs. Many actions are relevant to the understanding of stories about stereotypical activities, especially if multiple actors are involved as is the case with the restaurant domain. For restaurant scenarios we identified sixteen relevant actions in previous research \(22\) (thirteen in Mueller’s work). To facilitate the knowledge engineering task, action languages should allow a compact and speedy representation of a large number of actions that map into an even larger number of English verbs. Ideally, action languages would possess means for mimicking the way verbs are defined in natural language in terms of other, more basic verbs (e.g., \text{carry} defined as a special case of \text{move}), and the grouping of verbs via synonymy.

3. Means for representing partial fluents/ functions. In many dynamic domains including restaurant dining, items are created that did not exist before (e.g., a dish is prepared), or items are consumed. Fluents associated with these objects, such as location, should be undefined in states prior to the object coming into existence or after the object ceases to exist as is (e.g., it does not make sense to talk about the location of a dish before it is prepared).

4. Means for encoding non-deterministic effects of actions. This is particularly important for scenarios with exceptions, especially the ones that require explanations. For instance, in the story in Example 2, the possible explanation that the waitress misunderstood the order requires communication actions to be encoded as possibly having non-deterministic results under certain conditions. This would allow concluding that the waitress either understands the order to be for a lentil or a miso soup if there is interference.
4.1 \textit{ALM} and the Identified Features

The syntax and semantics of modular action language \textit{ALM} cover features 1–3 above. \textit{ALM} attributes (e.g., \textit{origin}, \textit{dest}) are optional in the sense that they may or may not be instantiated in an instance definition; thus feature 1 is satisfied. With respect to feature 2, \textit{ALM} has means for declaring classes of actions, and for declaring classes in terms of priorly defined classes. It can also structure information into modules of knowledge, consisting of declarations of sorts, functions, and axioms, which can be reused (imported) when building new modules, and can be independently tested. As for feature 3, \textit{ALM} fluents are by default partial functions, unless the keyword \texttt{total} precedes their declarations. In terms of semantics, functions are translated into non-Herbrand functions of ASP\{f\}, which can be partial. Additionally, for each function \textit{f}, \textit{ALM} provides a pre-defined function \texttt{dom}_f that is true if \textit{f} is defined for a given set of parameters and false otherwise. This allows specifying that a fluent becomes undefined as a result of some action occurring, as in the examples for feature 3 above.

Feature 4 required some changes to the syntax of \textit{ALM}. To illustrate this, we consider a request action class with attributes \textit{actor}, \textit{item} requested, and \textit{recipient} of the request. To handle miscommunication scenarios like the one in Example 2 the library should contain some rule stating that, if an \textit{interference} action occurs simultaneously, then a request has a non-deterministic effect in terms of what the \textit{actor} understands to be the requested \textit{item}. Specifically, we would like to encode this knowledge in \textit{ALM} via rules like:

\begin{align*}
\text{occurs}(X) & \quad \text{causes} \quad \text{informed}(R,T,A) \\
& \quad \text{if} \quad \text{instance}(X, \text{request}), \; \text{recipient}(X) = R, \; \text{item}(X) = T, \quad \text{actor}(X) = A, \; \neg \text{occurs(\textit{interference})}. \quad (1) \\
\text{occurs}(X) & \quad \text{causes} \quad 1\{\text{informed}(R,T1,A) : \text{instance}(T1, \text{things}), T1 \neq T\} \quad 1 \\
& \quad \text{if} \quad \text{instance}(X, \text{request}), \; \text{recipient}(X) = R, \; \text{item}(X) = T, \quad \text{actor}(X) = A, \; \text{occurs(\textit{interference})}. \quad (2)
\end{align*}

Such rules are not in the syntax of \textit{ALM} because \textit{occurs} expressions are not allowed in the body of dynamic causal laws, though they are allowed in executability conditions (see (1)), and choice elements\footnote{Intuitively, choice elements are syntactic instruments that allow a compact way of describing multiple possibilities/models.} are not allowed in the heads of rules (see (2)). Dynamic causal laws of \textit{ALM} have the syntax:

\[ \text{occurs}(a) \quad \text{causes} \quad f(\bar{x}) = o \text{ if } \text{instance}(a,c), \; \text{cond} \]

where \textit{a} and \textit{o} are variables or constants, \textit{f} is a basic (i.e., inertial) fluent, \textit{c} is the class \textit{actions} or a subclass of it, and \textit{cond} is a collection of literals. The law says that an occurrence of an action \textit{a} of the class \textit{c} in a state satisfying property \textit{cond} causes the value of \textit{f(\bar{x})} to become \textit{o} in any resulting state.

We change the syntax of \textit{ALM} to now allow \textit{cond} to contain expressions of the form \textit{occurs(t)} or \textit{\neg occurs(t)} where \textit{t} is a variable or an object constant of the sort \textit{actions}. We also allow the head of dynamic rules \textit{f(\bar{x}) = o} to be replaced by a choice element in GRINGO syntax (as in (2)), where the choice must concern a basic (i.e., inertial) fluent. This implies no changes to the semantics of \textit{ALM} (i.e., the translation into ASP\{f\} and definition of a transition) because the existing definition of the translation already specifies how \textit{occurs} expressions should be processed, given that they may appear in the body of executability conditions, and GRINGO-style choice elements are part of the language of ASP\{f\}.

An additional refinement of \textit{ALM} is related to one of the KR principles discussed in the next section. The original version of \textit{ALM} does not allow overloaded attributes, meaning the same attribute name declared in different classes. However, it would be convenient to reuse the same attribute name (e.g.,
actor) in several action classes. We relax the initial constraint by adding the following definition of a valid attribute and requiring that all attributes in a system description must be valid.

**Definition 1 (Valid Attribute)** An attribute \( a \) is valid if

1. there is at most one declaration of \( a \) per class and
2. each axiom containing an attribute literal of the form \( a(X,\bar{x}) = o \) or \( a(X,\bar{x}) \neq o \), where \( X \) is a variable, \( \bar{x} \) is a (possibly empty) collection of variables/ constants, and \( o \) is a variable/ constant, must also contain an atom of the form \( \text{instance}(X,c) \) where \( c \) is a class.

With the new requirement, if both action classes move and request have an attribute actor, an axiom of the form:

\[
\text{head if } \text{instance}(X,\text{request}), \text{actor}(X) = o.
\]

would be valid, but the same rule without an atom of the type \( \text{instance}(X,s) \) would not.

### 5 The RESTKB Library

In building our library for the restaurant domain, we were guided by the following key KR principles that we believe to be important for the creation of other libraries, possibly in other KR or action languages as well:

I. **A shallow action class inheritance hierarchy and module dependency hierarchy.**

   Research on object-oriented software maintainability indicates that an inheritance depth of three is optimal \[12\].

II. **Introduce new attributes as low as possible in the action class hierarchy.**

   In contrast, in the Component Library \[6\] the superclass for all action classes contains all possible attributes (thematic roles) that any action (verb) may have. As needed, action classes are then specified not to contain a given attribute or to have a restricted attribute range. We believe that this approach makes it difficult for people using the library to identify the names and range of attributes of a given action class, which may require looking into the top class. With the principle we propose, attribute information will reside locally with the action class and will be easier to find.

III. **Reduce the overall number of attribute names.**

   The idea would be to reuse attribute names whenever possible. For instance, actor would be a common attribute for multiple action classes. Note that the original version of \(\text{ALM}\) required different names for attributes of different action classes (e.g., mover, grasper). To accommodate this principle, we relaxed the definition of a valid attribute declaration in the previous section, under the conditions specified in Definition\[1\].

IV. **Restrict attributes of an action class to necessary ones.**

   This will improve the readability of action classes. By necessary we mean attributes that are commonly used in conjunction with a given action class or appear in axioms. For instance, we recommend not introducing an attribute instrument in action class prepare (some food) if instrument does not appear in any of the axioms.

V. **Place opposite concepts in the same module.**

   This applies to action classes with opposite effects (e.g., enter and leave), fluents that are (almost) opposites (e.g., standing and sitting), and opposite axioms.

VI. **Limit the number of conditions in the body of dynamic causal laws.**

   Instead of increasing the number of conditions in dynamic causal laws, delegate as many conditions as possible to executability conditions for a separation of purposes of axiom types.
We applied these KR principles in building RESTKB. The library declares 30 classes out of which nineteen are action classes; seventeen inertial fluents; and 95 axioms. Classes (and the pertinent fluents and axioms) are grouped into seven modules based on their common theme. Module names and the dependencies between them are shown in Figure 1. All of the modules in RESTKB except RESTAURANT are general enough to be useful in modeling other domains. Specifically, in preliminary work on the “going to the doctor” stereotypical activity, we determined that modules MOTION and COMMUNICATION would be relevant and could be imported from this library (e.g., the patient goes from the reception area to the exam room; the patient communicates with the receptionist/doctor). The classes and inertial fluents in each module are shown in Table 1. Note that universe and actions are built-in classes of ALM, and additional defined fluents of ALM (i.e., defined in terms of other fluents) are present in some of the modules.

![Figure 1: Module Dependency Hierarchy in RESTKB](image)

| Module       | Contents                                      | subclasses of | subclasses of |
|--------------|-----------------------------------------------|---------------|---------------|
| ROOT         | Classes: agents, things, points, areas        | universe      | persons       |
|              | persons                                       | subclass of   | agents        |
|              | Fluents: at, in                               |               |               |
| MOTION       | Classes: move, enter, leave, lead_to          | subclasses of | actions       |
|              | Fluents: open                                 |               |               |
| BODILY_MOTION| Classes: sit, stand_up                        | subclasses of | actions       |
|              | Fluents: sitting, standing, seating_exists    |               |               |
| GRASPING_RELEASING | grasp, release | subclasses of | actions       |
|              | Fluents: put_on                              |               | release       |
|              |                                               |               |               |
| COMMUNICATION| Classes: communicate, interference            | subclasses of | actions       |
|              | greet, request                               |               | communicate   |
|              | Fluents: greeted_by, informed                 |               |               |
| EATING       | Classes: foods                               | subclass of   | things        |
|              | eat, prepare                                 |               | actions       |
|              | Fluents: satiated, food_prepared_by          |               |               |
| RESTAURANT   | Classes: customers, waiters, cooks            | subclasses of | persons       |
|              | bills                                         |               | subclass of   |
|              | restaurants                                   |               | things        |
|              | read_menu, pay, becomes_unavailable order     |               | subclass of   |
|              |                                               |               | areas         |
|              | Fluents: available, served, has_read_menu,    |               | subclass of   |
|              | bill_generated_for, paid                      |               | request       |
Modules contain between 2 and 9 classes out of which 0–5 are action classes; 1–5 inertial fluents; and 0–50 axioms. The average numbers per module are: 4 classes out of which 3 action classes; 2 inertial fluents; and 13 axioms. The depth of the class hierarchy is three.

We compared R\textsc{EST}KB with our initial ASP encoding and found the following advantages for the \textsc{ALM} library:

- **More concise.** About 20 of the axioms in the original ASP encoding did not need to be represented in the \textsc{ALM} version. This is a result of \textsc{ALM}’s power to define subclass relations (e.g., \textit{order} is a subclass of \textit{request}) leading to axiom reuse, and to declare \textit{functional} fluents (i.e., fluents with a unique value, like \textit{at}, for which specifying a non-boolean range in \textsc{ALM} automatically implies that the value is unique).

- **Higher quality.** \textsc{ALM} axioms follow principle VI listed at the beginning of this section, while the initial ASP encoding did not. Also, \textsc{REST}KB contains 10\% new relevant axioms that were missing from the ASP version, as well as two new action classes and two new fluents. Some of these were relevant specifically to the restaurant domain, but others were added to increase the generality of the solution and allow modules to be suitable for other domains.

- **More manageable and easier to test,** as the knowledge is divided into modules. The library (available at \url{https://tinyurl.com/yan3qam5}) was tested via integration in a system for reasoning about stereotypical activities [22], where the ASP translation of \textsc{REST}KB replaced the initial ASP knowledge base. A collection of 20 restaurant stories was used in the evaluation, and the \textsc{REST}KB-based system performed as well as the original.

### 6 Tools for Library Use

To facilitate the use of the \textsc{REST}KB library in natural language understanding tasks, we created two tables that can be searched for relevant \textsc{REST}KB knowledge. A first table connects action classes and fluents to word senses from WordNet [15], as done in previous work on commonsense libraries [20]. WordNet is a large lexical database for the English language. It groups nouns, verbs, adjectives, and adverbs into “sets of cognitive synonyms, each expressing a distinct concept.” In our first table, word senses from WordNet 3.1\footnote{\url{http://wordnetweb.princeton.edu/perl/webwn}} represent the search keys. In Table 2, we show parts of this table for the action classes and fluents from module \textit{MOTION} of \textsc{REST}KB. Note, for example, that WordNet senses \textit{go}\#1, \textit{locomote}\#1, and \textit{travel}\#1 are synonyms (i.e., they have the same definition), and therefore searching by any of these terms leads to the same \textsc{REST}KB action class, \textit{move}.

Additionally, we connect action classes to verb classes from the verb ontology VerbNet [25] and predicates from PropBank [30], following the approach suggested by Lierler et al. [26]. VerbNet\footnote{\url{https://uvi.colorado.edu/}} is a verb lexicon that categorizes English verbs based on their syntactico-semantic behavior in sentences. VerbNet classes may contain several verbs. For instance, the verb class \textit{ESCAPE-51.1-1} contains among others \textit{verb go}; one of its subclasses, \textit{ESCAPE-51.1-1-2}, contains verb \textit{enter}. Note that \textsc{REST}KB also contains an action class \textit{enter} that is a subclass of \textit{move} (the matching action class for \textit{verb go} of VerbNet). As seen in Table 3, not all English verbs have a clear mapping into a VerbNet class (e.g., the verb \textit{release} as in “letting go of an object” corresponding to our action class \textit{release} may be mapped into class \textit{LET-64.2}, but this is not completely clear; the verb \textit{interfere} corresponding to our action class \textit{interference} is not linked to any VerbNet class yet.) PropBank\footnote{\url{http://verbs.colorado.edu/~mpalmer/projects/ace.html}} is a linguistic resource that provides information on
Table 2: Searching library contents by WordNet 3.1 verbs (motion verbs)

| WordNet 3.1 Verb [WordNet Synonyms] | RESTKB Action Class |
|-------------------------------------|---------------------|
| go#1 [locomote#1, travel#1]        | move                |
| Definition: change location; move, travel, or proceed, also metaphorically |
| enter#1 [come in#1, get in#1, get into#2, go in#1, go into#1, move into#1] | enter               |
| Definition: to come or go into     |
| leave#1 [go away#2, go forth#1]    | leave               |
| Definition: go away from a place   |
| leave#5 [exit#1, get out#1, go out#1, go out#1] | leave               |
| Definition: move out of or depart from |
| lead#1 [conduct#4, direct#5, guide#2, take#3] | lead to             |
| Definition: take somebody somewhere |

the semantic roles (i.e., arguments) associated with different verbs (i.e., predicate-argument relations). The PropBank predicates listed in Table [5] have sense information associated with them coming from Ontonotes Sense Groupings. For instance, the suffix 01 in go.01 indicates that Ontonotes associates this PropBank predicate with sense 1 of verb go. This second table can be searched by VerbNet verb class or PropBank predicate.

Table 3: Searching library contents by VerbNet verb classes and PropBank predicates

| VerbNet Verb Class | PropBank Predicate | RESTKB Action Class | RESTKB Module       |
|--------------------|--------------------|---------------------|---------------------|
| ESCAPE-51.1-51.1   | go.01, go.02       | move                | MOTION              |
| ESCAPE-51.1-51.1-2 | enter.01           | enter               |                     |
| ESCAPE-51.1-51.1-1 | leave.01, leave.04 | leave               |                     |
| ACCOMPANY-51.7     | lead.01            | lead_to             |                     |
| ASSUMING_POSITION-50| sit.01             | sit                 | BODILY_MOTION       |
| ASSUMING_POSITION-50| stand.01           | stand_up            |                     |
| HOLD-15.1-1        | grasp.01           | grasp               | GRASPINGRELEASEING  |
| LET-64.2 (?)       | release.01         | release             |                     |
| PUT-9.1-2          | put.01             | put                 |                     |
| TRANSFER_MESG-37.1 | communicate.01     | communicate         | COMMUNICATION       |
| JUDGMENT-33.1-1    | interfere.01       | interference        |                     |
| BEG-58.2           | greet.01           | greet               |                     |
|                  | request.01         | request             |                     |
| EAT-39.1-1         | eat.01             | eat                 | EATING              |
| PREPARING-26.3-1   | prepare.01         | prepare             |                     |
| PAY-68.1           | pay.01             | pay                 | RESTAURANT          |
| GET-13.5-1         | order.02           | order               |                     |

7 Application: Restaurant Stories

We used RESTKB as the background commonsense knowledge base for a question answering system dedicated to restaurant scenarios of the type defined in the Section 1. Our system can answer

[http://clear.colorado.edu/compsem/index.php?page=lexicalresources&sub=ontonotes]
questions of the following types:

- \textit{query\_yes\_no}(A) – Did action \textit{A} occur?
- \textit{query\_when}(A) – When did action \textit{A} occur?
- \textit{query\_where}(P, \textit{A}) – Where was person \textit{P} when action \textit{A} happened?
- \textit{query\_who}(A) – Who performed action \textit{A}?
- \textit{query\_who\_whom}(A) – Who performed action \textit{A} and to whom?
- \textit{query\_what}(F, \textit{A}) – What was the value of fluent \textit{F} when action \textit{A} happened?
- \textit{query\_goal}(P, \textit{A}) – What goal was \textit{P} trying to achieve when action \textit{A} happened?
- \textit{query\_intended}(P, \textit{A}) – What was \textit{P}’s intended activity when action \textit{A} happened?

where \textit{A} is a physical action. In the spirit of Muller’s work \cite{29}, we recently expanded our system with an ASP module that can generate a number of queries for each input text, such that the answers to these queries are not explicitly stated in the text \cite{32}.

In previous work \cite{22}, we exemplified how the information in the input text can be connected to axioms in the knowledge base, which was originally written in ASP. In this section, we will show that encoding the knowledge base in \textsc{ALM} actually facilitates the process of connecting the natural language in the input text to axioms in the \textsc{ALM} knowledge base in a way that can be automated. As before, we use the approach outlined by Lierler \textit{et al.} \cite{26}, which relies on a variety of state-of-the-art NLP tools. We illustrate this process on Example 1.

As a first step, the input text would be fed into a number of NLP tools that perform parsing, semantic role labeling, mention detection, and coreference resolution. We learned that we can obtain more complete information by using several tools instead of just one \cite{26}. The output of the LTH semantic role labeler, shown in Figure 2(a), indicates what verbs were identified in the text, including their Ontonotes Sense Groupings (e.g., \textit{go.01}) and their semantic roles/ arguments (e.g., \textit{goer}), which are annotated by LTH with PropBank labels (e.g., \textit{A1}). Note that the same semantic role label can mean different things for different verbs. The PropBank semantic role labels and their meanings for the relevant verbs in Example 1 are shown in Table 4. The output produced by the CoreNLP system, shown in Figure 2(b), includes mention detection and coreference resolution. This output correctly indicates, for example, that pronoun “she” in sentences 2 and 5 refers to “Nicole,” who is mentioned in sentences 1 and 4.

Table 4: PropBank semantic roles

| go.01 | order.02 | put.01 | leave.01 |
|-------|----------|--------|----------|
| (motion) | (request to be delivered) | (location) | (depart) |

\textbf{A1}: \textit{entity in motion/goer}

A0: \textit{orderer}
A1: \textit{thing ordered}
A3: \textit{benefactive, ordered-for}

\textbf{A2}: \textit{extent}
A0: \textit{puter}
A1: \textit{thing put}

\textbf{A3}: \textit{start point}
A2: \textit{where put}

\textbf{A4}: \textit{end point, end state of A1}
A2: \textit{destination}

(Semantic roles that have a correspondent in the matching action classes of \textsc{REST}KB are shown in bold.)

Given this input, our goal is to produce a logic form representation of the input text that allows us to use axioms in \textsc{REST}KB to reason and answer queries about the text. This logic form should contain facts defining objects named in the text as instances of relevant \textsc{REST}KB sorts, and observations about the occurrences of action instances explicitly mentioned in the text. In other words, we need to connect the output of the NLP tools shown above to the vocabulary of \textsc{REST}KB. In Lierler \textit{et al.}’s approach, this

\footnotesize{http://barbar.cs.lth.se:8081/parse}
\footnotesize{http://nlp.stanford.edu:8080/corenlp/}
is done via an intermediary step that constructs a so called Discourse Representation Structure (DRS) [23]. Due to space limitations, we skip this step here (see [26, 22] for details).

To achieve our goal, Table 3 (which enables searching RESTKB by PropBank verbs) needs to be expanded with a matching of PropBank semantic roles to attributes of action classes of RESTKB. Table 5 indicates the mappings necessary to process the text in Example 1. For instance, semantic role labels A1, A3, A4 of the verb *go*.01 match the attributes *actor*, *origin*, and *dest*, respectively, of action class *move* of module *MOTION* in RESTKB. Note that this matching is not perfect, as some PropBank verbs have additional semantic roles with respect to their RESTKB correspondent (e.g., *order*.02 in PropBank has the semantic role “A2: benefactive, ordered-for” that does not have a correspondent in the action class *order* of RESTKB).

### Table 5: Mapping of PropBank semantic roles to RESTKB attributes

| PropBank Semantic Role | RESTKB Attribute | PropBank Semantic Role | RESTKB Attribute |
|------------------------|------------------|------------------------|------------------|
| go.01                  | move             | order.02               | order            |
| A1: entity in motion/goer | actor           | A0: orderer            | actor            |
| A3: start point        | origin           | A1: thing ordered      | item             |
| A4: end point, end state of A1 | dest          | A2: source             | recipient         |
| put.01                 | put_on           | leave.01               | leave            |
| A0: putter             | actor            | A0: entity in motion   | actor            |
| A1: thing put          | object           | A1: starting point     | origin            |
| A2: where put          | on               |                        |                  |

Using the output of LTH and CoreNLP shown in Figure 2 together with the matching provided in Table 5 the following action instances could be automatically produced:
For instance, to produce $e_1$ the system would analyze the LTH output shown in Figure 2(a) and identify 
concept as the verb in the first sentence. It would then search Table 3 with key 
go.01 to find the matching action class from RESTKB, move. The system would also detect the semantic role labels in the LTH output, A1 and A4, and the text entities they correspond to, “Nicole” and “a vegetarian restaurant.” By searching Table 5 with keys A1 and A4, the system would identify the attributes actor and dest of move, respectively, and connect them to the appropriate text entities.

After generating action instances, the system would then produce facts about the occurrence of these action instances, as required by the logic form encoding of the text expected by our methodology for processing restaurant stories, i.e., 
\{ st_hpd($e_1$,true,0), st_hpd($e_2$,true,1), st_hpd($e_3$,true,2), st_hpd($e_4$,true,3) \}, saying that $e_1$ was the first event explicitly mentioned to have occurred in the story, $e_2$ was the second one, etc. The logic form will in turn trigger the appropriate axioms from RESTKB, for instance axioms (1) and 2) about request actions, as $e_2$ is an instance of action class order, which is a subclass of request.

In contrast, when using the original ASP background knowledge base, the process of producing a logic form could not be easily automated; instead, one rule had to be written for each action class of the knowledge base, as shown in the example below [22]:

$st_hpd(go(Actor,Dest).true,S) ← event(Ev),eventType(Ev,go.01),
eventArgs(Ev,a1,EActor),property(EActor,Actor),
eventArgs(Ev,a4,EDest),property(EDest,Dest).$

Being able to automate the process of translating the input text into a logic form according to Lierler et al.’s proof-of-concept is a substantial improvement. The automation of this process is an important research question in itself with its own hurdles. The output of NLP tools is not always accurate or complete, and thus requires added logic for remediation. As an example, sense order.02 (“request to be delivered”) is a better match for verb “order” as used in Example 1 than the sense order.01 (“impelled action”) identified by the LTH system. Also, sort information for the entities appearing in a text can be inferred from the semantic roles they instantiate in verbs, but usually this information is not as specific as the information produced by hand.

8 Conclusions

We have presented an ALM library of commonsense knowledge about restaurants, RESTKB. We have identified features that KR languages should possess to support reasoning about narratives describing stereotypical activities, including exceptional scenarios, and expanded ALM as needed. We have shown

\begin{verbatim}
e_1 in move
    actor = “Nicole”
    dest = “a vegetarian restaurant”
e_2 in order
    actor = “Nicole”
    item = “a lentil soup”
e_3 in put_on
    actor = “the waitress”
    object = “a lentil soup”
    on = “the table”
e_4 in leave
    actor = “Nicole”
\end{verbatim}
that the $\text{ALM}$ encoding is more compact, manageable, easier to test, and of a higher quality than an original ASP encoding. The knowledge base was integrated in a prototype system for reasoning about stereotypical activities, evaluated on restaurant stories.

In previous work [26], we outlined a process for scaling the creation of a vast $\text{ALM}$ library that can serve as a background knowledge base for reasoning about a larger number of stereotypical activities. Our idea is to create $\text{ALM}$ representations of the most frequent classes of action verbs in English and utilize existing linguistic resources in this process (e.g., verb ontology VerbNet). $\text{ALM}$’s features that support the reuse of knowledge will speed up this process and facilitate the testing of the resulting library.

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