The TRIPS Logical Form

The logical form language is an encoding of the semantic content of a sentence or text that can be mapped to a traditional knowledge representation only after contextual interpretation. It is roughly equivalent to a modal logic with underspecified scoping relationships. In addition, it is a "flat" representation, without the nested expressions one would see in a logic. The connection between the expressions is captured by the logical form variables, which serve as the links between different aspects of the formula.

In a typical application, the LF might pass through reference resolution to identify the intended referents of referring expressions, undergo some scope disambiguation to identify the intended order or quantifiers and operators. See Allen (1995) for an early discussion of our approach to logical form, and Manshadi et al. (2008) for an exploration of the LF as a underspecified constraint-based representation.

Another consideration is the support for robust parsing and interpretation. The LF is designed so that the correct representation of fragments extracted from an utterance will be identical in form to the same phrases if we had produced a full parse. The key technique that enables this is the use of a "flat" unscoped representations.

The word senses and semantic relations used in the logical form are specified by the TRIPS ontology. We have a browser for the LF ontology here.

The logical form of a sentence consists of a set of terms describing objects and relationships evoked by the utterance. One key term is speech act that was performed. For example, the term for the first noun phrase in logical form of

The man wants to eat it

is the term (THE m1 (:* ONT::MALE-PERSON W::MAN)). This expression shows most of the core elements that create a term. The first symbol, THE, is the **specifier**, and indicate that the NP is a definite reference. This information is critical for subsequent discourse processing and reference resolution. The second symbol, m1, is the **identifier**. This is a unique name that stands for this term. It will be used in other terms in the logical form (e.g., to indicate that m1 fills the EXPERIENCER role of the verb *want*, as well as acting as the discourse entity created in the discourse history and used for various purposes, especially in maintaining coreference chains. The third entity is the **ontology type** for the object. The types in the logical form maintain both the most specific class in the TRIPS ontology that describes the concept (i.e., *ONT::MALE-PERSON)* and also retains the stemmed lexical entry (i.e., W::MAN).

The remainder of a logical form term is a list of argument-value pairs that provide the links from the current term to other terms in the logical form. For example, the term for the event of wanting is

```
(F w1 (:* ONT::WANT W::WANT)
      :EXPERIENCER m1 :FORMAL e1
      :TENSE W::PRES))
```

This term involves the specifier "F", which indicates a propositional terms (i.e., defining a want event), the identifier as before, and the type (:* ONT::WANT W::WANT), and then a set of argument-value pairs including:

The EXPERIENCER role of the verb is *m1* (i.e., *the man)^,*

The FORMAL role of the verb in *e1 (the event of eating it)*

The TENSE argument is W::PRES, indicating the present tense of the verb.

Putting all this together, Table 1 shows the full set of terms for the sentence But the man wants to eat it.

Table 1: The Logical form of "But the man wants to eat it" as LF terms

(SPEECHACT s1 ONT::SA_TELL :CONTENT w1 :MOD b1)	s1 is a TELL speech act with content w1 and (discourse) modifier b1
(F w1 (:* ONT::WANT W::WANT) :EXPERIENCER m1 :FORMAL e1 :TENSE W::PRES))	w1 is a wanting relation between m1 and e1, that holds at a time indicated by the present tense
(THE m1 (:* ONT::MALE W::MAN))	m1 is some man identifiable in context
(PRO i1 (:* ONT::REFERENTIAL-SEM W::IT) :PROFORM W::IT)	i1 is a some object identifiable in context by pronoun "it"
(F e1 (:* ONT::CONSUME W::EAT) :AFFECTED i1 :AGENT m1))	e1 is an eating relation between m1 and p1
(F b1 (:* ONT::CONJUNCT W::BUT) :FIGURE s1))	s1 is related by a "but" relationship to previous context

It is often more convenient to view the logical form as a graph structure, especially for complex sentences. The set of terms define a graph where each node represents one identifier and is labelled with the ontology type. Arguments become arcs between nodes, as shown in Figure 1.

And, finally, for those familiar with AMR syntax, Figure 2 shows the same sentence in that format. You can have the webparser output any one of these formats for any sentence by simply using the interface options link.

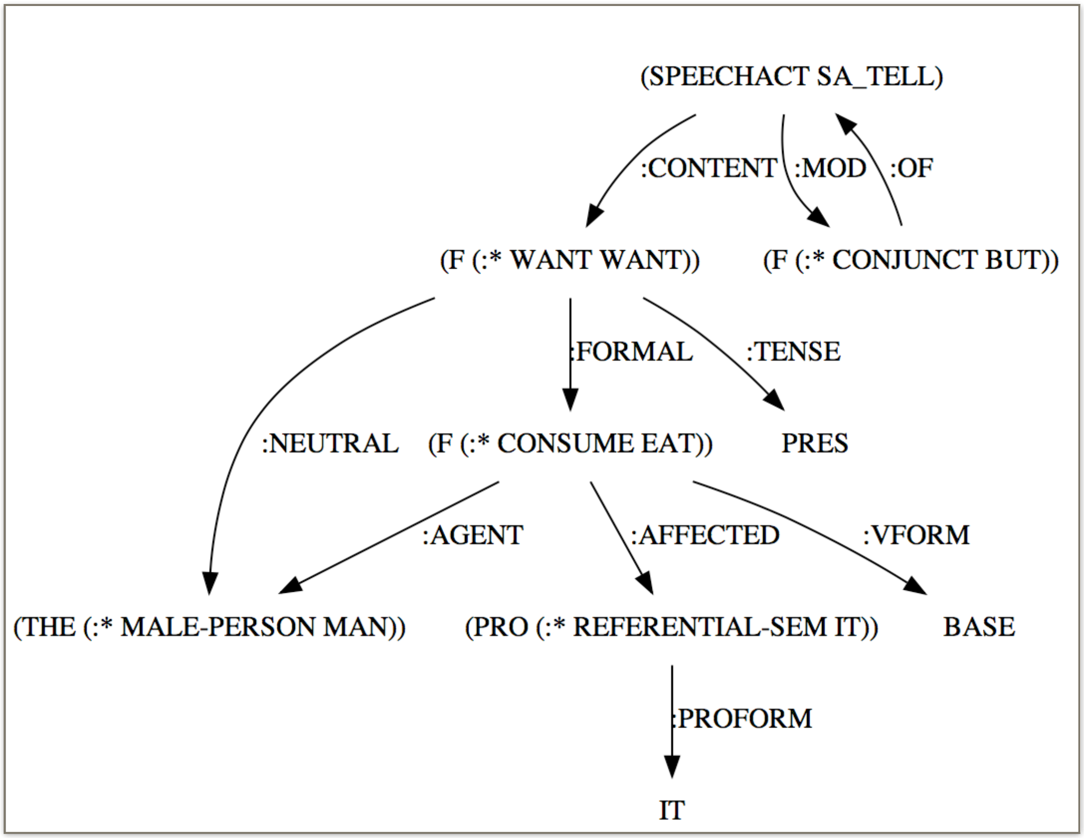

Figure 1: The Logical Form in Graphical Format

```
(ONT::V31997 / ONT::SA_TELL
              :CONTENT (ONT::V31840 / (:* ONT::WANT W::WANT)
                             :NEUTRAL (ONT::V31822 / (:* ONT::MALE-PERSON W::MAN))
                             :FORMAL (ONT::V31876 / (:* ONT::CONSUME W::EAT)
                                            :AGENT ONT::V31822
                                            :AFFECTED (ONT::V31881 / (:* ONT::REFERENTIAL-SEM W::IT)
                                                           :PROFORM ONT::IT)
                                            :VFORM ONT::BASE)
                             :TENSE ONT::PRES)
              :MOD (ONT::V31809 / (:* ONT::CONJUNCT W::BUT)
                             :OF ONT::V31997))
```

Figure 2: “But the man wants to eat it” in the AMR term format

1. Capturing Semantic Content

Summary of Building Blocks and Terms

The basic atoms of the logical form language consist of the following, each which will be described in more detail as we go along:

ATOMIC TYPES, atoms that denote classes of objects, be they physical objects, situations, abstractions, and so on (e.g., ONT::PERSON, ONT::SEND, ONT::NUMBER). These are organized into a hierarchy in the LF Ontology.

ROLE NAMES, which can be thought of as "slots" in a frame, labeled arguments to a predicate, or functions from one object to another.

VARIABLES, written in lower case, x, y, c

LOGICAL OPERATORS, operators, such as ONT::AND and ONT::OR

TERM CONSTRUCTORS: ONT::THE, ONT::A, ONT::PRO, ONT::IMPRO, etc. as described below.

Terms in the LF all have the exact same format, namely

(<term constructor> <var-name> <type> [<role> <value>])*

where <*value*> can be:

A variable

A list of variables

2. Speech Acts

Utterances are represented at the top level by a surface speech act captures the literal or surface speech act of the utterance1. Using the example above with *But the man wants to eat it*, the top level form is defined as a surface speech act, which in this case is ONT::SA_TELL, the speech act that corresponds to most declarative sentences, i.e.,

(SPEECHACT V12 ONT::SA_TELL :CONTENT w1 :MOD b1)

The content w1 is defined by other terms. Discourse connectives such as but are treated as modifiers on the speech act. In this case, the term b1 defines the modifier as shown in Table 1.

Surface Acts

The surface speech acts are listed in Table 2, together with the slots that can occur with them. Most of these acts allow :CONTENT and :MOD slots. In few cases, other slots are possible. The associated roles (except for :MOD which can occur with any term) are listed for each act.

Discourse Adverbials

As mentioned above, the discourse adverbials relate the current utterance to the discourse context. Currently the parser does not analyze these into some deeper representation. Rather it just passes on a general classification (e.g., ONT::CONJUNCT) and the actual lexical forms for use in contextual interpretation. These connectors can affect many aspects of the analysis, including not only tense, but also the discourse act performed and what collaborative problem solving act is inferred. For example, the discourse adverbial “And” as in “Then it left” is treated as a modifier of type (:* ONT::CONJUNCT ONT::THEN) an the full LF for the speech act is

[1] Even when subsequently interpreted indirectly, the surface act influences the allowable forms of appropriate responses. For example, in response to the invitation *can you come to my party,* one can accept by saying *yes, i can*. But this acceptance would be inappropriate in response to the invitations *Please come to my party* or *Let me invite you to my party*. Each of these invitations would have a different surface act form. The fact that they are invitations is inferred by contextual interpretation.

Table 2: The Surface Speech Act Types

<table>
<tr><td>ONT::SA_Wh-Question :content :focus :mod</td><td>“Wh” questions</td><td colspan="2">Where is the knife? When? What?</td></tr>
<tr><td>ONT::SA_YN-Question :content :mod</td><td>Yes no question</td><td colspan="2">Is the knife in the kitchen?</td></tr>
<tr><td>ONT::SA_Request :content :mod</td><td>Imperative, typically a command</td><td colspan="2">Get the knife.</td></tr>
<tr><td rowspan="6">ONT::SA_Response :content :mod</td><td rowspan="6">Responses to yes-no questions</td><td>Content</td><td>Example</td></tr>
<tr><td>POS</td><td>Yes</td></tr>
<tr><td>NEG</td><td>No</td></tr>
<tr><td>UNSURE-POS</td><td>Maybe</td></tr>
<tr><td>UNSURE-NEG</td><td>I don’t think so</td></tr>
<tr><td>UNSURE</td><td>I don’t know</td></tr>
<tr><td>ONT::SA_Tell :content :mod</td><td>Assertions</td><td colspan="2">The knife is in the kitchen</td></tr>
<tr><td>ONT::SA_Identify</td><td>Noun phrase utterances</td><td colspan="2">The red one</td></tr>
<tr><td>ONT::SA_Evaluate :content</td><td>Acts that express an opinion about something</td><td colspan="2">Good, bad, excellent, OK, so-so, …</td></tr>
<tr><td>ONT::SA_Ack :content</td><td>Acts that acknowledge or confirm</td><td colspan="2">OK, uh-huh</td></tr>
<tr><td>ONT::SA_Request-comment :content</td><td>Acts that suggest an object or action</td><td colspan="2">How about coming to my party. What about a beer. How about Toronto.</td></tr>
<tr><td>ONT::SA_Greet :content</td><td>Greetings and Goodbyes</td><td colspan="2">Hello, Hi, Bye,</td></tr>
<tr><td>ONT::SA_Thank</td><td>Thanks</td><td colspan="2">Thanks, thank-you,</td></tr>
<tr><td>ONT::SA_Welcome</td><td>Responses to thanks</td><td colspan="2">You’re welcome, not at all</td></tr>
<tr><td>ONT::SA_Discourse-Manage</td><td>Acts that help manage the conversation, grounding, etc</td><td colspan="2">Just a second, oops, ...</td></tr>
</table>

(SPEECHACT V7263 ONT::SA_TELL :CONTENT V7035 :MOD V6997)

(F V7008 (:* ONT::CONJUNCT W::THEN) :FIGURE V7263)

Some of the general classes are shown in Table 3.

Table 3: Some discourse adverbials

ONT::CONJUNCT	And, and-then, so, but, …
ONT::SEQUENCE-POSITION	first, second, next, last, …
ONT::TOPIC-SIGNAL	by the way, anyways, …
ONT::POLITENESS	Please
ONT::DEGREE-OF-BELIEF	Hopefully, Actually, in fact, …
ONT::INTERJECTION	You know, I guess, …
ONT::QUALIFICATION	Probably, originally, eventually, …
ONT::ADDITIVE	Too, also, …
ONT::REASON	So that, because, since,
ONT::QUALIFICATION	Maybe, …

3. A Quick Overview of Basic Phrases

Simple Descriptions

Simple descriptions involve term constructors corresponding to definite and indefinite forms. For example:

the train -- (THE x (:* ONT::VEHICLE W::TRAIN))

the trains -- (THE-SET x (:* ONT::VEHICLE W::TRAIN))

a train -- (A x (:* ONT::VEHICLE W::TRAIN))

trains -- (INDEF-SET x (:* ONT::VEHICLE W::TRAIN))

Simple Events

The meaning of a clause is modeled as a relation between objects that are the arguments to the verb, and indicated by expressions using the formula constructor F. This is a neutral term that is used for any clause, whether it be main clauses, subordinates, complements, and so on. The use of the constructor F is determined by syntax rather than the semantic type of the event. The fact that a relation is claimed to represent the world would be captured in the speech act - the semantic formula describes the content of the sentence but makes no claim about the world. The event described in the sentence *A man loaded the cargo* would be:

(F l1 (:* ONT::FILL-CONTAINER W::LOAD) :AGENT m1 :AFFECTED c1)
(A m1 (:* ONT::MALE W::MAN))
(THE c1 (:* ONT::COMMODITY W::CARGO))

Note that events can occur in referring expressions as well. For instance, consider the following NP.

The loading of the cargo

(THE l1 (:* ONT::FILL-CONTAINER W::LOAD) :AFFECTED c1)
(THE c1 (:* ONT::COMMODITY W::CARGO))

Modifiers

The LF of adjectives such as "red" are not treated as role relations because they are time varying. A block might be red today, and green tomorrow. Furthermore, many adjectives take additional arguments and modifiers (as in "eager as a beaver", "ready to load"). Such propositions will use a named argument representation as we do with verbs. To attach a modifying phrase to a description, we use the :MOD role that takes a list of relation objects. For example:

The red truck

(THE v53 (:* ONT::LAND-VEHICLE W::TRUCK) :MOD v57)
(F v57 (:* ONT::RED W::RED) :FIGURE v53))

Typically, the single argument in unary relations is identified as the role :FIGURE, as with the LF for red above. For binary functional relations, the arguments are typically identified as :FIGURE and :GROUND. For example, spatial prepositions use such arguments, as seen in the example:

The truck in the city

(THE v27 (:* ONT::LAND-VEHICLE W::TRUCK) :LOCATION v20)
(F v20 (:* ONT::IN-LOC W::IN) :FIGURE v27 :GROUND v240)
(THE v240 (:* ONT::CITY W::CITY))

With this overview in hand, we can now look at various constructions in detail in the next few sections.

4. Noun Phrases in More Detail

There is a fair range of term constructors needed to handle the variety of noun phrases that occur. The ones defined so far are shown in Table 4. Here we discuss the major classes of noun phrases and how they map into the logical forms.

Names

Names are treated as definite descriptions. A special role NAME-OF relates the object to its specified name. For instance, we have

John

(THE x ONT::PERSON :NAME-OF (W::JOHN))

The NAME-OF slot is a list to accommodate multi-word names such as "The New York Times":

The New York Times:

(THE x ONT::PUBLICATION :NAME-OF (W::THE W::NEW W::YORK W::TIMES))

Although rare, this form can include modifiers as well, as in the phrase,

The other John

(THE x ONT::PERSON :NAME-OF (John) :MOD f1)
(F f1 (:* ONT::IDENTITY OTHER) :FIGURE x)

Pronouns

Pronominal forms use the term constructor PRO. We also have a specially defined type in the ontology, ONT::REFERENTIAL-SEM, that includes all types of objects that can be typically referred to (objects, events, some abstract objects). Pronoun LFs uses a special role called PROFORM that indicates information relevant for how the expression relates to the context. In general, the value of this slot is simply the lexical form of the pronoun that was used. For example, the pronoun *it* would have the LF

(PRO x (:* ONT::REFERENTIAL-SEM W::IT) :PROFORM W::IT)

The pronoun *he* would have the LF

(PRO x (:* ONT::MALE-PERSON W::HE) :PROFORM W::HE)

Plural pronouns such as *them* would be as:

(PRO-SET x (:* ONT::REFERENTIAL-SEM W::THEM) :PROFORM W::THEM)

Table 4: The Term Constructors

ONT::THE	a definite singular form (we expect to be able to resolve it from context)
ONT::THE-SET	Definite plural form (we expect to identify a set of objects from context)
ONT::A	an indefinite form (we expect it to be introducing new object into context)
ONT::INDEF-SET	Indefinite plural (we expect to introduce a set of objects into the context)
ONT::SM	Indefinite mass-term, loosely meaning “some quantity of”
ONT::PRO	a pronoun form (we expect it to be resolved in local context
ONT::PRO-SET	a plural pronoun (we expect it to be resolved in local context)
ONT::IMPRO	an implicit anaphoric form (i.e., it is implicit in the text but does not appear; we expect it to be resolved from local context
ONT::IMPRO-SET	implicit anaphoric form to a set of individuals that we expect to be resolvable from local context.
ONT::BARE	NPs that have no specifier and are typically ambiguous between generic, kind, mass, and indefinite interpretations
ONT::QUANTIFIER	Universally quantified constructions (e.g., each truck, every item)
ONT::WH-TERM	“wh” terms as in questions (e.g., which trucks), and complements to verbs like *know* (e.g., *I know <u>where they hid</u>)*

Cardinality Constraints on plurals

With plurals, most modifiers apply to each individual in the set, except for cardinality which refers to the size of the set. The cardinality of sets is captured in the role :SIZE. Other modifiers are attached in the MOD feature, and they point back to the variable identifying the set. (Note if you were mapping to extensional logic interpretation, we’d need another variable ranging over the elements of the set. The TRIPS LF does not commit to such an interpretation).

The three red trains --

(THE-SET x (:* ONT::VEHICLE W::TRAIN) :MOD v1 :SIZE 3)
(F v1 (:* ONT::COLOR_VAL W::RED) :FIGURE x)

Quantifiers

The TRIPS logical form divides quantifiers into two classes. The first are the true quantifiers, which involve some form of universal iteration over a set of objects, such as *each* and *every*, and have singular agreement in English (e.g., *each dog*, not **each dogs*). The second are the cardinality quantifiers, such as *most*, *some, a few, many,* and have plural agreement. The latter are

Table 5: Quantified count expressions

<table>
<tr><th>Construction</th><th>Logical Form</th><th>Other quantifiers</th></tr>
<tr><td>Each man</td><td>(QUANTIFIER v1 (:* ONT::MALE W::MAN) :QUAN ONT::EACH)</td><td>Every
No</td></tr>
<tr><td>Each of the men</td><td>(QUANTIFIER v1 (:* ONT::MALE W::MAN) :QUAN ONT::EACH :REFSET v2)
(THE-SET v1 (:* ONT::MALE W::MAN))</td><td>None
All</td></tr>
<tr><td>All men</td><td>(QUANTIFIER v1 (:* ONT::MALE W::MAN) :QUAN ONT::UNIVERSAL)</td><td>No</td></tr>
<tr><td>Some men</td><td>(INDEF-SET v1 (:* ONT::MALE W::MAN) :SIZE ONT::SOME)</td><td rowspan="2">A few
Many
Most
Several</td></tr>
<tr><td>Some of the men</td><td>(INDEF-SET v1 (:* ONT::MALE W::MAN) :SIZE ONT::SOME :REFSET v2)
(THE-SET v2 (:* ONT::MALE W::MAN))</td></tr>
<tr><td>Five men</td><td>(INDEF-SET v1 (:* ONT::MALE W::MAN) :SIZE v2)
(THE v2 ONT::NUMBER :VALUE 5)</td><td rowspan="2">At least six
More than eight
Around four</td></tr>
<tr><td>Seven of the men</td><td>(INDEF-SET v1 (:* ONT::MALE W::MAN) :SIZE v2 :REFSET v3)
(THE v2 ONT::NUMBER :VALUE 7)
(THE-SET v3 (:* ONT::MALE W::MAN))</td></tr>
</table>

treated as relations defining the modified set in terms of another (possibly implicit set). Note that explicit existential quantifiers do not exist in our LF, they are either indefinites (e.g., *I had a dog)*, or arise from expletive constructions (e.g., *there are five cars)*. Expletive constructions such as *it is raining* and *there are five cars* do not have an explicit quantifier in the logical form. Rather the interpretation is capture by a existence predicate, EXISTS, which is a sense of the verb *be* (see Section 5).

True Quantifiers

These use the constructor ONT::QUANTIFIER but take an extra feature QUAN that identifies the specific quantifier used.

Each man ---

(QUANTIFIER v1 (:* ONT::MALE W::MAN) :QUAN ONT::EACH)

When the domain of quantification is explicitly indicated, it is captured with a :REFSET relation, as in

Each of the men ---

(QUANTIFIER v1 (:* ONT::MALE W::MAN) :QUAN ONT::EACH :REFSET v2)
(THE-SET v2 (:* ONT::MALE W::MAN))

Cardinality Quantifiers

Cardinality quantifiers produce a logical form that defines a set in terms of some other (possibly implicit) set of objects. The REFSET feature specifies the “reference set” from which the objects are drawn, and the SIZE feature identifies the size of the subset drawn from the reference set. For example, the LF for the phrase *most of the men* would have :SIZE most and :REFSET being the men, e.g.,

Most of the men ----

(INDEF-SET x (:* ONT::MALE W::MAN) :SIZE ONT::MOST :REFSET V33)
(THE-SET V33 (:* ONT::MALE W::MAN))

Mass Terms

Mass terms, such as "sand", have different properties than count nouns such as "truck". Whereas the LF type associated with truck, ONT::TRUCK, can be viewed as a predicate that is true of any object that is a truck, it is not clear what the predicate ONT::SAND is true of. A common approach is to view ONT::SAND as being true of some quantity of sand. We'll take this view for the sake of motivation, but note the logical form doesn't not constrain what final semantics one might give after contextual interpretation. The indefinite form for mass terms refers to amounts of substances, and we use the term constructor ONT::SM, the mass form of the quantifier *some*. The definite description "The sand" refers to some delineable object that consists of sand, such the beach we are talking about. Note because of this treatment, you have to consider the interpretation of the predicate in order to distinguish count and mass interpretations for definite descriptions.

the water (i.e., a specific delineable amount of water identifiable in context)

(THE v1 (:* ONT::WATER W::WATER))

some beer (i.e., an indefinite quantity of beer)

(SM v2 (:* ONT::FOOD ONT::BEER))

The explicit quantity can also be specified, as in

three gallons of water

(SM v1 (:* ONT::WATER W::WATER) :QUANTITY v2)
(A v2 (:* ONT::QUANTITY F::VOLUME-SCALE)
:SCALE ONT::VOLUME-SCALE
:UNIT (:* ONT::VOLUME-MEASURE-UNIT ONT::GALLON)
:AMOUNT v3)
(A v3 ONT::NUMBER :VALUE 3)

The phrase *the three gallons of water* would have the same LF except that the term constructor would be ONT::THE instead of ONT::SM. More details on quantity expressions are given later.

Note that many mass terms, like *beer*, can be coerced into other forms, like objects (as in a bottle of beer). Currently, we use the indefinite count specifiers for these expressions.

a beer

(A y (:* ONT::FOOD ONT::BEER))

beers

(INDEF-SET y (:* LF ::FOOD ONT::BEER))

Finally, mass terms may occur without any determiner and generally act as some type of predicate or kind. Rather than committing to a specific interpretation, we encode such forms using the constructor ONT::BARE, leaving the interpretation for discourse processing.

water

(BARE v1 (:* ONT::WATER W::WATER))

Table 6: Roles related to quantities and amounts

Role	Usage
:QUAN	Identifies quantifier (ONT::EACH, ONT::EVERY, ONT::NONE, ONT::UNIVERSAL) in a true quantification expression
:SIZE	The cardinality of a set of objects (points to either a number or a qualitative amount e.g., ONT::SOME, ONT::MANY, ONT::A-FEW, …)
:QUANTITY	the amount of stuff in a mass term, either in quantitive terms (e.g., three pounds) or qualitative (e.g., much)
:AMOUNT	Used in QUANTITY expressions in combination with units (e.g., the *three* in three pounds)

It is also possible to convert most countable objects into a mass term, introducing a new semantic relation :REFOBJECT. Here's an example:

Much of the truck

(SM v1 (:* ONT::LAND-VEHICLE W::TRUCK) :QUANTITY ONT::MUCH
:REFOBJECT v2)
(THE v2 (:* ONT::LAND-VEHICLE W::TRUCK))

There are a number of roles to do with quantities and amounts that were discussed in this section and are easy to confuse. These are summarized in Table 6.

Quantities and Containers

Quantities can also be specified in terms of containers, such as *bagful* and *truckload*. The root forms of these terms can also sometimes be used as quantities. For example, a *bag of potatoes* is ambiguous between a quantity of potatoes, as in *I ate a bag of potatoes last week*, and a bag containing potatoes, as in *I lifted the bag of potatoes*. These interpretations have distinct logical forms as follows:

A bag of potatoes (quantity interpretation)

(INDEF-SET m1 (:* ONT::VEGETABLE W::POTATO) :SIZE q1)
(A q1 ONT::QUANTITY
:SCALE ONT::VOLUME
:UNIT (:* ONT::BAG W::BAG)
:NUMBER 1)

A bag of potatoes (container interpretation)

(A b1 (:* ONT::BAG W::BAG) :CONTENTS p1)
(INDEF-SET p1 (:* ONT::VEGETABLE W::POTATO))

Other Bare Terms

There is a small set of nouns in English that do not require a determiner, yet are not interpreted like bare mass NPs, such as *I was happy in school,* and *Would you come to lunch*. These terms seem to refer to culturally defined events, and vary from dialect to dialect. Depending on their use, these may refer the to temporal/spatial objects defined by an activity (e.g., A*t school we can't speak freely*). We use the BARE term constructor for these as well, leaving these complications for later interpretation:

I laughed at school

(F g1 ONT::LAUGH :AGENT i1 :LOCATION loc1)
(PRO i1 ONT::PERSON :PROFORM I)
(F loc1 (:* ONT::AT-LOC AT) :FIGURE g1 :GROUND s1)
(BARE s1 ONT::SCHOOL)

WH Terms

Wh-terms such as where, when, how, and so on play a central role in questions, and also appear in the complements of verbs like know, as in *I know where the truck is*.

For questions, the wh-terms appear in the LF using the WH-TERM constructor. For example

What's the plan

(SPEECHACT V12087 ONT::SA_WH-QUESTION :FOCUS V14 :CONTENT V18)
(F V18 (:* ONT::IN-RELATION W::BE) :NEUTRAL1 V11 :NEUTRAL V14
:TENSE W::PRES))
(THE V11 (:* ONT::PLANNING W::PLAN))
(WH-TERM V14 ONT::REFERENTIAL-SEM :PROFORM W::WHAT)

For some wh-terms, like where, when and how, the question LF is captured with both a modifying relation and a wh-term. Thus “Where can we treat him” has an LF that is equivalent to “At what location can we treat him”.

Where was he seen?

(SPEECHACT V11 ONT::SA_WH-QUESTION :FOCUS V1 :CONTENT V2)
(WH-TERM V1 ONT::REFERENTIAL-SEM :PROFORM W::WHERE)
(F V2 (:* ONT::ACTIVE-PERCEPTION W::SEE) :NEUTRAL V3 :MOD V4)
:TENSE W::PAST :PASSIVE +))
(PRO V3 (:* ONT::PERSON W::HE) :PROFORM W::HE)
(F V4 (:* ONT::WH-LOCATION W::WHERE) :FIGURE V2 :GROUND V1)

WH-NP’s as Complements

When wh-terms are used as complements to verbs like know or find out, we treat them as wh-terms descriptions with a special role, :SUCHTHAT; for example,

I know what arrived.

(F V21028 (:* ONT::FAMILIAR W::KNOW) :FORMAL V2 :NEUTRAL V5)
(WH-TERM V2 (:* ONT::REFERENTIAL-SEM W::WHAT)
:PROFORM W::WHAT :SUCHTHAT V6)
(F V6 (:* ONT::ARRIVE W::ARRIVE) :AFFECTED V2)
(PRO V5 (:* ONT::PERSON W::I) :PROFORM W::I)

Show me where the car stopped.

(F V23438 (:* ONT::SHOW W::SHOW) :AFFECTED V1 :FORMAL V7 :AGENT V9)
(WH-TERM V7 (:* ONT::SPATIAL-LOC W::WHERE) :SUCHTHAT V2)
(F V2 (:* ONT::STOP-MOVE W::STOP) :AFFECTED V3)
(THE V3 (:* ONT::LAND-VEHICLE W::CAR))
(PRO V1 ONT::PERSON :PROFORM W::ME)
(IMPRO V9 ONT::PERSON :PROFORM W::*YOU*)

Possessives

The possessive construction is captured in the logical form using a role relation :ASSOC-POSS, which denotes abstract possession. The exact relations between the possessor and possessed, say ownership, or control, or proximity, can only be determined by contextual interpretation.

The man's cat

(THE V1 (:* ONT::NON-HUMAN-ANIMAL W::CAT) :ASSOC-POSS V2)
(THE V2 (:* ONT::MALE MAN))

Demonstratives

Demonstratives are treated as definite descriptions and the lexical item is placed in the PROFORM relation as done with pronouns. This allows reference resolution processes to have strategies specific for each word. For example

These trucks

(THE-SET x (:* ONT::LAND-VEHICLE W::TRUCK) :PROFORM ONT::THESE)

That truck

(THE x (:* ONT::LAND-VEHICLE W::TRUCK) :PROFORM ONT::THAT)

One

One used as a head noun indicates no restriction on the LF type, and *one* is placed in the :PROFORM to enable special referential processing.

The red one

(THE x (:* ONT::REFERENTIAL-SEM W::ONE) :MOD c1 :PROFORM ONE)
(F c1 (:* ONT::RED W::RED) :SCALE ONT::COLOR-SCALE :FIGURE x)

5. Enumerated Constructions

Conjunctions and other enumeration constructions are pervasive in English and almost any type of constituent can be conjoined: noun phrases, as in *John and Mary arrived*, N1 constituents, as in *The dos and cat arrived*, adjective constructions as in *He was happy and excited*, adverbs, as in *he sat in the corner and out of the way*, verbs, as in *he cooked and ate a pizza*. In addition, besides conjunction and disjunction, phrases may itemize exceptions and qualifications, as in *The dog and cat, but not the horse, ate the meat* and *He was hungry but satisfied*. This section considers the logical forms for these range of constructions.

Enumerated Noun Constructions

Conjoined noun phrases require the construction of a set of objects. A set is constructed for the conjoined phrase that uses the special roles :SEQUENCE*n* to list the items involved. For example.

Dogs and cats

```
(INDEF-SET v44 ONT::NONHUMAN-ANIMAL
        :OPERATOR ONT::AND
        :SEQUENCE v40
        :SEQUENCE1 v46))
(INDEF-SET v40 (:* ONT::NONHUMAN-ANIMAL W::DOG))
(INDEF-SET v46 (:* ONT::NONHUMAN-ANIMAL W::CAT))
```

Neither dogs nor cats

```
(QUANTIFIER v1 ONT::NONHUMAN-ANIMAL
        :OPERATOR ONT::NONE-OF
        :SEQUENCE v2
        :SEQUENCE1 v3)
(INDEF-SET v2 (:* ONT::NONHUMAN-ANIMAL W::DOG))
(INDEF-SET v3 (:* ONT::NONHUMAN-ANIMAL W::CAT))
```

Either the dog or the cat

```
(A v1 ONT::NONHUMAN-ANIMAL
        :OPERATOR ONT::ONE-OF
        :SEQUENCE v2
        :SEQUENCE1 v3)
(THE v2 (:* ONT::NONHUMAN-ANIMAL W::DOG))
(THE v3 (:* ONT::NONHUMAN-ANIMAL W::CAT))
```

Enumerations may also include exclusions as well, such as *Dogs and cats but not horses*. The exclusions are indicated using a new role :EXCEPT as follows:

Dogs and cats but not horses

```
(INDEF-SET v44 ONT::NONHUMAN-ANIMAL
        :OPERATOR ONT::AND
        :SEQUENCE v40
        :SEQUENCE1 v46
        :EXCEPT v47))
(INDEF-SET v40 (:* ONT::NONHUMAN-ANIMAL W::DOG))
(INDEF-SET v46 (:* ONT::NONHUMAN-ANIMAL W::CAT))
(INDEF-SET v47 (:* ONT::NONHUMAN-ANIMAL W::HORSE))
```

Enumerated Adjective and Adverbial Modifiers

Adjectives and adverbs may be conjoined and qualified. The simple conjunctions resemble the noun constructions and use the :SEQUENCE roles.

He was hungry and happy

(F p1 (*: ONT::HAVE-PROPERTY W::BE) :NEUTRAL he1 :FORMAL p2)
(F p2 ONT::AND
:OPERATOR ONT::AND
:SEQUENCE p3
:SEQUENCE1 p4)
(F p3 (:* ONT::HUNGRY W::HUNGRY) :FIGURE he1)
(F p4 (:* ONT::EUPHORIC W::HAPPY) :FIGURE he1)

However, the conjunction *but* for properties identifies a qualification on the claim, not a negation as with noun phrase enumerations. As a result, we link these with a relation called :QUALIFICATION.

He was hungry but happy

(F p1 (*: ONT::HAVE-PROPERTY W::BE) :NEUTRAL he1 :FORMAL p2)
(F p2 (:* ONT::HUNGRY W::HUNGRY) :FIGURE he1 :QUALIFICATION p3)
(F p3 ONT::BUT :FIGURE p2 :GROUND p4)
(F p4 (:* ONT::EUPHORIC W::HAPPY) :FIGURE he1)

He sat in the corner but not by the porch

(F p1 (*: ONT::BODY-MOVEMENT-PLACE W::SIT) :AGENT he1 :LOCATION p2)
(F p2 (:* ONT::IN-LOC W::IN) :FIGURE p1 :GROUND c1 :QUALIFICATION p3)
(THE c1 (:* ONT::CORNER W::CORNER))
(F p3 ONT::BUT :FIGURE p2 :GROUND p4)
(F p4 (:* ONT::ADJACENT W::NEAR) :FIGURE p1 :GROUND p2 :NEG n1)
(THE p2 (:* ONT::MANUFACTURED-OBJECT W::PORCH))
(F n1 (:* ONT::NEG W::NOT) :FIGURE p4)

Enumerated Verb Constructions

<<*to do*>>

5. Event Nominalizations

While events are typically evoked by a sentence that describes them, there are other ways to refer to events or parts of events in language. This section described some of these phenomena and how they are realized in the logical form.

Gerunds and Nominalizations

Most verbs support forms that make various noun phrases. When a specifier is explicit we build the obvious form. For example

The investigation of the crime

(THE l1 (:* ONT::SCRUTINY W::INVESTIGATION) :NEUTRAL c2)
(THE c2 (:* ONT::ACTIVITY W::CRIME))

Identical in form except for the constructor to the verbal form:

They investigated the crime

(F l1 (:* ONT::SCRUTINY W::INVESTIGATION) :AGENT p1 :NEUTRAL c2)
(PRO-SET p1 (:* ONT::REFERENTIAL-SEM W::THEY) :PROFORM W::THEY)
(THE c2 (:* ONT::ACTIVITY W::CRIME))

Gerunds are treated similarly. For example:

The burning of the city

(THE d1 (:* ONT::BURN W::BURN) :AFFECTED c1)
(THE c1 ONT::CITY)

Bare gerunds, which might refer to events or to kinds of activities, retain the ONT::BARE constructor, leaving disambiguation to contextual processing

Burning the city was fun

(F e1 (:* ONT::HAVE-PROPERTY W::BE) :NEUTRAL b1 :FORMAL p1)
(BARE b1 (:* ONT::BURN W::BURN) :AFFECTED c1)
(THE c1 ONT::CITY)
(F p1 (:* ONT::ENTERTAINMENT-VAL W::FUN) :FIGURE b1)

6. Modifiers and Scale Expressions

A large number of predicates in English are conceptually organized around a notion of scales or domains. For example, the adjectives *hot, cold, tepid, lukewarm, cool,* and *warm* all identify values on the TEMPERATURE scale. In addition, some scales support measurement options in terms of units (e.g., degrees for temperature, feet for height, etc). In particular, we have the following types of words related to scales:

Scale names, nouns such as *temperature* and *height*, all subclasses of ONT::DOMAIN

Scale value properties, adjectives and adverbs such as *hot* and *tall,* all subclasses of ONT::PROPERTY-VAL. Semantically these predicates are true of objects that have a scale value within some range of the scale they are associated with.

Units, nouns such as *degree* and *inch*, all subclasses of ONT::UNIT, which quantify the values on a particular scales.

The logical form attempts to organize these concepts around the central notion of scale.

As an example, Figure 3 shows some aspects of the ONT::HEIGHT scale. The height scale supports a quantitative measurement in several different systems. In the figure we see examples of measurements in *feet* and in *meters*. Adjectives such as *short* and *tall* are true of ranges on the scale, and relative to a some, often implicitly specified reference subscale (the *standard*). For instance, a short building is almost surely taller than a tall person. Individuals are mapped to values on a scale using a general location relation ONT:AT-LOC relative to a scale. In Figure 1, we see that PERSON1 is short, PERSON3 is tall, and PERSON2 is neither short nor tall. Comparison operators compare object values relative to a scale. We see that PERSON2 is taller than PERSON1, though neither of them are *tall!*

Table 7 summarizes the set of semantic roles that are used with scale-based adjectives, where the predicate is shown in italics and the argument is underlined.

Now we can look at the actual logical forms for scale-based modifiers.

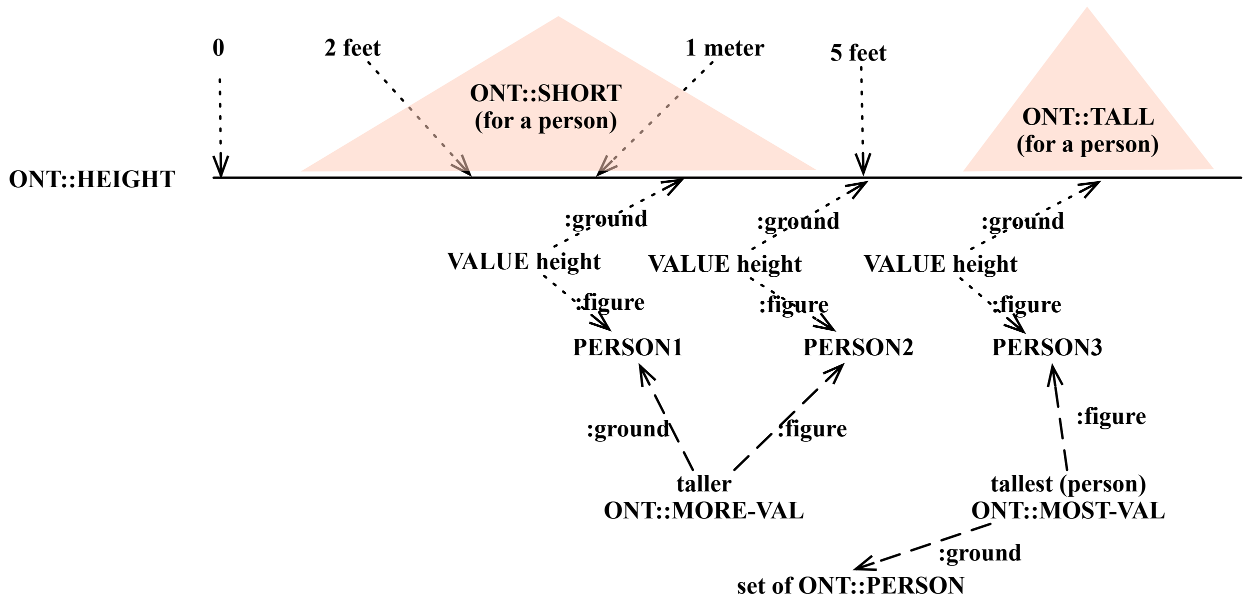

Figure 3: The HEIGHT Scale

Table 7: The Semantic Roles for Scalar Predicates

Role	Definition	Example (argument is underlined)
FIGURE	the argument that is being characterized with respect to other objects (the GROUND), a scale, or an relative sub scale (the STANDARD),	The *red* block The block is *red*. The *larger* dog The *tallest* building
GROUND	the argument related to the FIGURE	The building *closer* to the river
COMPAR	An explicit object with which the FIGURE is being compared	My dog is *larger* than your dog The building *closer* to the river than that
REFSET	A explicit set of objects of which the FIGURE belongs	She is the *tallest* of the girls in the class The *larger* of the animals died.
SCALE	The scale on which a predication is based (typically implicit in the predicate)	It is *hotter* in temperature It is *hot* spice-wise
STANDARD	a relative subscale defined by a predicate, ranging from fairly simple (e.g., tall for a dog, the standard is the height subscale associated with dogs) to complex (e.g., short to reach the shelf defined a standard that is a subscale of heights where someone could reach the shelf.	It is *hot enough* for taking a walk The shelf is *too high* to reach The ladder is *a bit short* to reach the shelf He is *large* for a dog He is *old* to be in third grade
EXTENT	The amount by which the figure differs from the ground in a comparison operation	It is 6 inches *longer* than the shelf
DEGREE	A qualitative measure of value on a scale	He is very *tall*

Simple adjectives are treated as predicates modifying an object with the addition of a SCALE value (if known). The main argument of the predicate fills the FIGURE role. Here is an example:

The tall man --

```
(THE C1 (:* ONT::MAN W::MAN) :MOD m1)
(F m1  (:* ONT::TALL-VAL W::TALL)
        :FIGURE C1
        :SCALE ONT::HEIGHT-SCALE)
```

Adjectives that involve relationships with other objects use FIGURE and GROUND, as in

The man close to the corner--

```
(THE M1 (:* ONT::MAN W::MAN) :MOD m1)
(F m1  (:* ONT::NEAR W::CLOSE)
        :FIGURE M1
        :GROUND C2
        :SCALE ONT::DISTANCE-SCALE)
(THE C2 (:* ONT::CORNER W::CORNER)
```

Of course, a property like tall or expensive is relative to what the standard value of an object might be, not an absolute scale. For instance a $100 car is cheap, but a $100 burger is expensive. While the standard is often implicit, it can be made explicit with modifiers as in *It is expensive for a hamburger*. This standard of measurement is called STANDARD, the thing that the modified object is compared with. Thus we have the following logical form:

(It is) expensive for a hamburger --

```
(F m1 (:* ONT::EXPENSIVE W::EXPENSIVE)
        :FIGURE c1
        :SCALE ONT::COST-SCALE
        :STANDARD  h1)
(KIND h1 (:* ONT::FAST-FOOD W::HAMBURGER))
```

Adjectives can also be used to identify quantitive value on a scale. In this case it serves to identify the scale only, and does not have its normal value as a range of values on the scale. Thus, if you say *it is 2 feet tall*, you are not saying that it is tall. This construction uses the predicate ONT::AT-SCALE-VALUE, which is the generalized notion asserting something as at a location on a scale. AT-SCALE-VALUE has the roles FIGURE and GROUND. So we have

(It is) 3 foot tall --

```
(F f1  ONT::AT-SCALE-VALUE
        :FIGURE i1
        :SCALE (:* ONT::HEIGHT W::TALL)
        :GROUND v1)
(A v1 ONT::QUANTITY :UNIT (:* ONT::FOOT W::FOOT)  :AMOUNT 3)
```

Note that not all predicates can readily be used to identify their scale. For instance, the sentence *he is 4 foot short* is awkward and is understandable only as some sort of pun or joke.

Adjectives also invoke their scale in questions, as in

How tall is he? --

(SPEECHACT sa1 ONT::QUESTION :content b1 :FOCUS v1)
(F b1 (:*: ONT::HAVE-PROPERTY :neutral p1 :formal p1)
(F p1 ONT::AT-SCALE-VALUE
    :FIGURE i1
    :SCALE ONT::HEIGHT
    :DEGREE v1)
(WH-TERM v1 ONT::DEGREE :SUCHTHAT p1)

The comparative and superlative forms of adjectives involve comparisons based on the scale associated with the core adjective, but not related to its actual value. Thus, while *cheap* is an adjective that identifies a range on the ONT::COST-SCALE, *cheaper* relates two objects on the ONT::COST-SCALE scale, neither of which might be cheap, and *cheapest* identifies an object with the minimum cost in a set of objects. Note that *expensive* could refer to a value on the same scale, ONT::COST-SCALE, where the superlative, *most expensive*, refers to the object with the maximum value on this scale. The logical form captures these distinctions using a general ordering and maximizing/minimizing relation types. As described above, the comparatives and superlatives use two roles: The FIGURE role identifies the object being compared and the GROUND role identifies the object, or set of objects, that the figure is being compared too. The GROUND is often implicit, e.g., *the cheaper computer* and must be identified in context, e.g.,

The cheaper computer --

(THE c1 (:* ONT::COMPUTER W::COMPUTER) :MOD m1)
(F m1 ONT::MORE-VAL
    :SCALE (:* ONT::CHEAPNESS W::CHEAP)
    :FIGURE c1)

If the object that is being compared with is explicit, we use a COMPAR role, as in

A computer cheaper than that one

(A c1 (:* ONT::COMPUTER W::COMPUTER) :MOD m1)
(F m1 ONT::LESS-VAL
    :SCALE (:* ONT:CHEAPNESS W::CHEAP)
    :FIGURE c1
    :COMPAR c2)
(THE c2 (:* ONT::COMPUTER W::ONE) :PROFORM W::THAT)

Note that the ontology encodes relationships between the scales, and that some scales are oriented int the opposite direction of others. For instance, the CHEAPNESS scale is a subscale of the COST-VALUE scale but is oriented in the negative direction (i.e., more cheap means less cost, nd less cheap means more expensive). We do not capture this distinction in the logical form or the parser, and leave it for reasoning with the ontology.

Objects can also be compared to actual values on the scale rather than to another object. In this case the ground is explicitly specified as a the value on the scale.

A computer cheaper than $1000 --

(THE c1 (:* ONT::COMPUTER W::COMPUTER) :MOD m1)
(F m1 ONT::LESS-VAL

:SCALE (:* ONT::COST-SCALE W::CHEAP)
:FIGURE c1
:COMPAR d2)
(A d2 (:* ONT::QUANTITY ONT::MONEY-SCALE) :UNIT ONT::DOLLAR
‘ :AMOUNT 1000)

Comparatives can also include the extent to which something is higher or lower on a scale, as in the following:

A computer $1000 cheaper than that one --

(THE c1 (:* ONT::COMPUTER W::COMPUTER) :MOD m1)
(F m1 ONT::MORE-VAL
:SCALE (:* ONT::CHEAPNESS W::CHEAP)
:FIGURE c1
:COMPAR c2
:EXTENT d2)
(A d2 ONT::QUANTITY :SCALE ONT::MONEY-SCALE :UNIT ONT::DOLLAR
:AMOUNT 1000)
(THE c2 (:* ONT::COMPUTER W::ONE) :PROFORM W::THAT)

The GROUND can also be elliptical event, as in *He is taller than I am*.

The superlative construction is handled similarly, but selects an object based on the relationship from a set. For this we use the REFSET role also used with quantifiers. The REFSET can be implicit or explicit:

The most expensive computer --

(THE c1 (:* ONT::COMPUTER W::COMPUTER) :MOD m1)
(F m1 ONT::MAX-VAL
:SCALE (:* ONT::COST-SCALE W::EXPENSIVE)
:FIGURE c1)

The least expensive of the computers --

(THE c1 (:* ONT::COMPUTER W::COMPUTER) :MOD m1)
(F m1 ONT::MIN-VAL
:SCALE (:* ONT::COST-SCALE W::EXPENSIVE)
:FIGURE c1
:REFSET d1)
(THE-SET d1 (:* ONT::COMPUTER W::COMPUTER))

There are other constructs that relate an objects value on a scale to a standard that is defined by the ability to do an action. For instance, *It is cheap enough to buy* means that the object is priced inexpensively enough that it can be bought. We get a similar logical form of the similar construct involving the adverbial *so*:

He was so hot he couldn’t run:

(F b1 (:* ONT::HAVE-PROPERTY W:BE) :NEUTRAL h1 :FORMAL p1)
(PRO h1 (:* ONT::MALE-PERSON W::HE) :PROFORM W::HE)
(F p1 ONT::SO-MUCH-THAT
    :FIGURE h1
    :STANDARD p2
    :SCALE (:* ONT::TEMPERATURE W::HOT))
(F pr (:* ONT::MOVE-RAPIDLY W::RUN) :AGENT h1 :NEGATION +
    :MODALITY (:* ONT::CONDITIONAL W::COULD))

These complex terms can also modify nouns (or verbs) as an adjective(or adverb), as in *He has enough money to buy a ticket*, with the logical form

He has enough money to buy a ticket:

(F b1 (:* ONT::HAVE W:HAVE) :NEUTRAL h1 :NEUTRAL1 m1)
(PRO h1 (:* ONT::MALE-PERSON W::HE) :PROFORM W::HE)
(SM m1 (:* ONT::MONEY W::MONEY) :MOD p1)
(F p1 ONT::ADEQUATE
    :FIGURE h1
    :STANDARD b1)
(F b1 (:* ONT::PURCHASE W::BUY) :AGENT h1 :AFFECTED c1)
(A c1 (:* ONT::COMPUTER W::COMPUTER)

Table 8 summarizes the key predicates involved in these complex constructions.

Table 8: Predicates of Comparison

Type	Predicates	Ground	Definition	Example
Comparative	**ONT::MORE-VAL ONT::LESS-VAL**	another object/ event of same type as figure	the figure is higher (or lower) on the scale than the ground	I am **taller than you** He ran **faster** than Sue did Can you do it **more quickly** He is **less happy** now
Comparative or equal	**ONT::AS-MUCH-AS**	another object/ event of the same type as the figure	the figure is at least as high on the scale as the ground	Dogs are as friendly as cats The women ran as fast as the men did
Superlative	**ONT::MAX-VAL ONT::MIN-VAL**	a set of objects/ events	the figure has the highest (or lowest) value on the scale	I bought the **most expensive** computer He ran the **most** during practice It was the **least desirable** seat
Excessive	**ONT::TOO-MUCH**	a purpose that requires some maximal level on a scale	The figure is above the level (on a scale) needed for some purpose	It was **too hot** to go outside She ran **too fast** to be caught There we **too many** people for a party There are **too many** people in the coffee shop
Assetive	**ONT::ADEQUATE**	a purpose that requires some level on a scale	The figure allows the purpose as it is above the minimum scale value required	Mary is **smart enough** to accept the offer There weren't **enough** men at the dance She ran **fast enough** to get away
Threshold	**ONT::SO-MUCH-THAT**	a purpose that requires some level on a scale	The figure (unexpectedly?) allows a purpose as it is above a minimum threshold required on the scale	She was **so hungry** she ate my shoe She ran **so quickly** that she won the race

7. Time, Numbers, and Locations

Temporal Objects

Temporal expressions fall into two categories, those describing particular times according to some clock system (e.g., the time of day), and those describing durations of time (e.g., the length of a movie). Here we describe the first use, reference to temporal "locations". Temporal durations are handled in the next section as an example of quantity terms.

Clock-times are often underspecified and require contextual processing. We say Saturday but don't mention which Saturday is meant, or 3 PM without mentioning the day. These terms serve to constrain the range of possible times that could be intended, and contextual interpretation would identify the intended one. These are classified in the ontology as ONT::TIME-LOC, which has slots for type of clock-time attribute, as shown in Table 9.

Here are some examples:

Monday July 4

```
(THE V3 ONT::TIME-LOC
        :DAY 4
        :MONTH  (:* ONT::MONTH-NAME JULY)
        :DAY-OF-WEEK (:* ONT::DAY-NAME MONDAY)))
```

Five PM

```
(THE V7039 ONT::TIME-LOC
        :AM-PM (:* ONT::TIME-OBJECT W::PM)
        :HOUR 5)
```

Table 9: The slots of ONT::TIME-LOC

Slot Name	Ontology Type of value	Typical values	Example text
:YEAR	ONT::NUMBER	2004, 2010	2010, Two thousand ten
:MONTH	ONT::MONTH-NAME	ONT::JULY	July
:DAY	ONT::NUMBER	1,..., 31	July **4th**
:DOW	ONT::DAY-NAME	ONT::MONDAY, ONT::TUESDAY	Monday, Tuesday
:AM-PM	ONT::TIME-OBJECT	ONT::AM, ONT::PM, ONT::MORNING	AM, A.M., morning, evening
:HOUR	ONT:::NUMBER	1,..., 12	1,..., 12, one, ...,twelve
:MINUTE	ONT::NUMBER	1,...,59	5:**30**, 6:**45**
:CENTURY	ONT::NUMBER	1,2,...	The third century
:ERA	ONT::ERA	ONT::AD, ONT::BC	3rd Century **BC**
:PHASE	ONT::STAGE-VAL	ONT::MID, ONT::EARLY, ONT::LATE	**Mid**-July

Numbers

Numbers are the most basic quantity terms. Below we will deal with other quantity terms that expressed quantities in terms of units and measures. The LF of an expression like five is not simple an atom such as 5 because we need to handle modifiers, as in at least five, a few hundred, and not more than seven. These express constraints on values and can appear almost anywhere a simple number may. The system simplifies purely numeric expressions into conventional form, as in the following examples.

Five *dogs*

(INDEF-SET x (:* ONT::NON-HUMAN-ANIMAL DOG) :SIZE v1)
(A v1 ONT::NUMBER :VALUE 5)

At least five *dogs*

(INDEF-SET x (:* ONT::NON-HUMUM-ANIMAL DOG) :SIZE v1)
(A v1 ONT::NUMBER :MOD v2)
(F v2 (:* ONT::QMODIFIER W::MIN) :FIGURE v1 :GROUND v3)
(A v3 ONT::NUMBER :VALUE 5)

Approximately five *dogs*

(INDEF-SET x (:* ONT::NON-HUMUM-ANIMAL DOG) :SIZE v1)
(A v1 ONT::NUMBER :MOD v2)
(F v2 (:* ONT::QMODIFIER W::APPROXIMATE) :FIGURE v1 :GROUND v3)
(A v3 ONT::NUMBER :VALUE 5)

Numeric expressions that involve units, like hundred, thousand, etc, have an LF that uses the mathematical representation. Thus we have expressions like the following

Five hundred

(A v1 ONT::NUMBER :VALUE 500)

Two thousand three hundred and five

(A v1 ONT::NUMBER :VALUE 2305)

However, for vague number expressions we have to retain the units explicitly, as in

Several hundred

(A v1 (:* ONT::NUMBER-UNIT W::HUNDRED) :AMOUNT v2)
(A v2 ONT::NUMBER :VALUE W::SEVERAL)

Quantity Terms

There are many expressions of measurement in language, that combine a numerical quantity and some unit on a scale. This includes expressions such as three miles, many liters, several hours, eight days, and so on. These generally map to expressions of type QUANTITY, as in

Three miles

(A v1 ONT::QUANTITY

:SCALE ONT::LENGTH-SCALE
:UNIT (:* ONT::LENGTH-UNIT W::MILE) :AMOUNT v2)
(A v2 ONT::NUMBER :VALUE 3)

Several pounds

(A v1 ONT::QUANTITY
:SCALE ONT::WEIGHT-SCALE
:UNIT (:* ONT::WEIGHT-UNIT W::POUND) :AMOUNT ONT::SEVERAL)

At least ten dollars

(A v1 ONT::QUANTITY
:SCALE ONT::MONEY-SCALE
:UNIT (:* ONT::MONEY-UNIT W::DOLLAR) :AMOUNT v2)
(A v2 ONT::NUMBER :MOD v3)
(F v3 (:* ONT::QMODIFIER W::MIN) :FIGURE v2 :GROUND v4)
(A v4 ONT::NUMBER :VALUE 10)

As described earlier, such quantity terms can then be used like quantity quantifiers, as in the following:

Several ounces of meat

(SM m1 (:* ONT::MEAT W::MEAT) :QUANTITY q1)
(A q1 (A v1 ONT::QUANTITY
:SCALE ONT::WEIGHT-SCALE
:UNIT (:* ONT::WEIGHT-UNIT W::OUNCE) :AMOUNT ONT::SEVERAL)

9. Other Aspects of Verbs

Tense, Aspect and Modality

There is information expressed in the lexical and structural forms that identify tense, aspect and modality, that have not yet been discussed in the logical form language. All this information is important for contextual interpretation, and is encoded in special roles as shown in Table 10.

Some examples of full logical forms follow:

I had not seen the ice

(F v0 (:* ONT::ACTIVE-PERCEPTION W::SEE) :AFFECTED v1 :NEUTRAL v2
:TENSE PAST :PERF + :NEGATION +)))
(PRO v1 (:* ONT::PERSON W::I) :PROFORM W::I)
(THE v2 (:* ONT::SUBSTANCE W::ICE))

I should have gone

(F v1 (:* ONT::MOVE W::GO) :AGENT v2 :TENSE W::PRES :MODALITY (:*
ONT::SHOULD W::SHOULD) :PERF +))
(PRO v2 (:* ONT::PERSON W::I) :PROFORM W::I)

I can't see it

Table 10: The Tense/Modality/Aspect Features

Feature	Values	Realization	Example
:NEGATION	+/-	Not	I don't like ...
:TENSE	:PRES	Present tense	I like ...
	:PAST	Past tense	I liked ...
	:FUT	Future construction	I will like ...
:PROGR	+/-	Progressive	I am liking ...
:PERF	+/-	Perfective	I had liked ...
:PASSIVE	+/-	Passive	I was liked
:MODALITY	ONT::ABILITY	Can auxiliary	I can run
	ONT::DO	do	I did run
	ONT::MUST	must	I must run
	ONT::SHOULD	should	I should run
	ONT::FUTURE	will, shall	I will run
	ONT::POSSIBILITY	may, might	I might run
	ONT::CONDITIONAL	could, would	I could run
	ONT::GOING-TO	going to, gonna	I'm going to run

(F v1 (:* ONT::ACTIVE-PERCEPTION SEE) :AFFECTED v1 :NEUTRAL v2
  :TENSE PRES :MODALITY (:* ONT::ABILITY W::CAN :NEGATION +))
(PRO v1 (:* ONT::PERSON W::I) :PROFORM W::I)
(PRO v2 (:* ONT::REFERENTIAL-SEM W::IT) :PROFORM W::IT)

Elided Forms

Because we treat auxiliaries as augmentations to main verbs, we need a special treatment for elided forms. We introduce a special LF for the elided verb phrase. This would serve as a signal to

I can't

(F V6 ONT::ELLIPSIS :AGENT V2
    :TENSE PRES :MODALITY (:* ONT::ABILITY W::CAN)
    :NEGATION +)))

Appendix A: Semantic Roles

The TRIPS ontology has a fixed set of semantic roles that are critical for defining the ontology and the structure of verbal forms. Rather than viewing semantic roles as merely signaling different argument positions for predicates, the semantic roles have inferential import in their own right. In addition, the TRIPS ontology makes a key distinction between what we call **core roles**, those that identify various ways objects may relate to a core event, such as AGENT, AFFECTED, etc, and the various other relations that are actually treated as prepositional/adverbial meanings, such as RESULT, LOC, METHOD, and so on. Note also that a predciate may take multiple arguments with the same role name. In this case, they are distinguished by having an index, e.g., AGENT, AGENT1, where the order indicates the prominence in the sentence.

Core Argument Roles			
Role	***Definition***	***Intuitive tests***	***examples***
AGENT	Entity that plays a causal or initiating role as part of the event meaning	1) X is an AGENT if the event can be paraphrased as *X caused Y to Z*. 2) X is an agent if X is undergoing some process distinct from the event that is cotemporally causing the event	The boy told a story The hammer broke the window The storm destroyed the house
AFFECTED	(non-causing) Entity that is changed over the course of the event in some way	X is an AFFECTED entity if it is changed as a result of the event (e.g., it changes location as it is pushed, ice changed gradually to water as it melts.	He carried the package The ice melted The ball hit the wall
AFFECTED-RESULT	(non-causing) Entity that is undergoes a change at the end of the event.	The change that is a result of the event happens at the end of the event. Adding *almost* to the sentence entails the object was not changed (in the way entailed by the event) E.g., *He almost loaded the truck* entails the truck is not loaded.	He loaded the truck with oranges We baked a cake
NEUTRAL	Acausal argument, neither causing nor changed by the event, but which has existence	Arguments in the neutral role must be objects (abstract or concrete) that can be created - e.g., a *picture can be created (I drew a picture), as well as a party (I threw a party), and a story (I wrote a story)*. In these sentences, they would be the AFFECTED role. See exampled for use in neutral role. Note: by their very nature, most stative uses of verbs have a NEUTRAL argument.	I told him a story We entered the room I enjoyed the party
EXPERIENCER	A specialization of NEUTRAL role in events of cognition and perception	The *EXPERIENCER* role is special case of the *NEUTRAL* role for sentient entities involved in (stative) events of cognition and perception. It is only used with stative verbs.	The man believes he is happy. I saw the elephant We understand I want a pizza
FORMAL	Acausal argument with no temporal existence	Typically abstractions like propositions, event/action types, etc.	He believes that the money's gone I want to go He seems crazy It weighs five pounds

Core Argument Roles			
Role	***Definition***	***Intuitive tests***	***examples***
BENEFICIARY	The entity that benefits from an action, but that it not essential to be meaning of the event	Many entities filling other argument roles may benefit from the event (e.g., I gave him $50), but these are not beneficiaries because they are central to the event - you can't have a giving without an recipient (AFFECTED-RESULT). BENEFICIARY is only used to add optional additional information to an event.	I opened the door for him I opened him the door

Relational Causal Relations			
Role	***Definition***	***Intuitive tests***	***examples***
RESULT	This relates an event to its culminating state	The proposition that is a RESULT role must start to be true exactly at the end of the event. In fact, many events are defined in terms of the RESULT becoming true.	I **climbed** onto the box He **swept** the crumbs from the table He **cried** himself asleep **Put** it in the corner
SOURCE	Relates an event to an initiating state	The SOURCE proposition must be true before the event and end before the end of the event, and is almost always signaled using the word *from*	He **left** from the station
TRANSIENT-RESULT	Relates an event a causal state during the event	The TRANSIENT-RESULT must be true during the event and caused by the event, but does not hold at the end of the event	He **walked** by the factory
METHOD	This indicates a causal relationship between two events, the main event occurs because the argument occurs	A METHOD argument must be another event, or sequence of events, which p lay a causal role to the main event. This might be an abstract event, e.g., *using a wrench*. Note that stative uses of verbs, by their very definition, cannot take a METHOD modifier,	He **opened** the door with a hammer The oven **heats** by emitting microwave radiation A bomb exploded **destroying** the building
REASON	A relationship between an event and a state/event that describes causal information about why the event occurred.	There are many ways in which one may describe the causal reason for an event, including the motivation of the agent (e.g., describing a goal or purpose) as well as physical causality (e.g., a because clause)	He unlocked the door to let him in I work for money The tank exploded because it got too hot

Relational Causal Relations			
Role	***Definition***	***Intuitive tests***	***examples***
MANNER	This argument modifies or augments event with a quality or style.	MANNER is distinguished from METHOD in that is does not indicate a causal relationship. Rather is modifies the quality or style of the way an event is performed. The MANNER cannot be another event.	He walked slowly She laughed in short bursts Arrange the forms by size

Relations of Locating			
Role	***Definition***	***Intuitive tests***	***examples***
LOCATION	This relates an event to the location where it occurred	The location relation may be in spatial or abstract spaces and hold *just before* and throughout the duration of the event.	He **sang** in the corner
TIME	This argument temporally locates the event	Note that some schemes divide out roles into final_time, initial_time, etc. Such information, however, it captured by the predicate in the argument (i.e,., the preposition/adverbial).	He arrived at 3 o'clock The party lasted from 6PM*TIME* to midnight*TIME* He laughed while the game continued
EXTENT	The argument captures the extent of the event along some dimension	While the most common extents are spatial or temporal, and scale with units can be expressed (e.g., temperature, money).	We ran three miles He studied for a long time The temperature rose many degrees I spent twenty dollars It weighs five pounds
ORIENTATION	For events or objects that involve some form of orientation, this identifies constraints on the orientation	The same propositions that can be used in locations and result expressions are used, but in this case the object being located is an abstract point identifing the orientation. This is typically used for statives, as events of change can usually be interpreted in terms of the RESULT relation	The house **faces** towards the river He **pointed** north The **road** to Chicago
FREQUENCY	This argument indicates multiple occurrences or frequency of occurrence	These FREQUENCY construction covers both sentences that deal with multiple occurrences, as well as sentences that describe the likelihood of events	We ran the race three times He rarely comes to meetings They win once in a blue moon

Other roles

There are a number of other role names used for non-verbal predicates and some special constructions such as time. There are summarized briefly here.

	Role Name	*Definition*	*Example*
GENERAL MODIFICATION RELATIONS			
	MOD	links to a predicate term that modifies the current term	The red **block**, **running** quickly
	ASSOC-WITH	links to another term that modifies the current term in some unspecified way	The house **boat**
	ASSOC-POSS	Links to a term that is in some abstract possession relationship	My **car**, the cat's **food**
	IDENTIFIED-AS	Links an NP to another description of the same object (e.g., appositives)	**John**, the President, arrived
ADJECTIVE/ADVERB ROLES			
	FIGURE	the argument that is being characterized with respect to other objects (the GROUND), a scale, or an relative sub scale (the STANDARD),	**The man** is heavy.
	GROUND	An explicit reference group of objects with which the FIGURE is being compared	The heavier of **the two blocks**
	SCALE	The scale on which a predication is based (typically implicit in the predicate)	The heaviest block of **the blocks**
	STANDARD	a relative subscale defined by a predicate, ranging from fairly simple (e.g., tall for a dog, the standard is the height subscale associated with dogs) to complex (e.g., short to reach the shelf defined a standard that is a subscale of heights where someone could reach the shelf.	He is tall **for a dog**
	EXTENT	The amount by which the figure differs from the ground in a comparison operation	She is **a foot** taller than me
	DEGREE	A qualitative measure of value on a scale	She is **very** tall
TIME/DATE			
	YEAR	The year - of type ONT::NUMBER	2010, Two thousand ten
	MONTH	The month, ONT::MONTH-NAME	July

	Role Name	Definition	Example
	DAY	The day of the month, ONT::NUMBER	July **4th**
	DOW	The day of the week, ONT::DAY-NAME	Monday, Tuesday
	AM-PM	AM or PM indication, ONT::TIME-OBJECT	AM, A.M., morning, evening
	HOUR	The hour of the day, ONT:::NUMBER	1,..., 12, one, ...,twelve
	MINUTE	The minute of the time, ONT::NUMBER	5:**30**, 6:**45**
	CENTURY	The century, ONT::NUMBER	The third century
	ERA	The era, ONT::ERA	3rd Century **BC**
	PHASE	Vague ranges of a date, ONT::STAGE-VAL	**Mid**-July
SPEECH ACTS			
	CONTENT	The propositional content of the speech act	
	FOCUS	The focused element in a WH-question	We saw **whom** **What** did you see He saw a dog in **what house**
	MOD	A discourse modifier connecting this sentence to the prior context	**So** he laughed.
SEQUENCES			
	SEQUENCE	The first elements of a sequence	
	SEQUENCE1	the second element of a sequence	
	SEQUENCE2	the third element of a sequence	
	etc	And so on...	
QUANTITIES			
	:QUANTITY	the amount of stuff in a mass term, either in quantitive terms (e.g., three pounds) or qualitative (e.g., much)	Ten pounds of potatoes
	UNIT	The unit of measurement being used in a quantity expression (and relative to a scale)	Ten pounds of potatoes
	AMOUNT	The number of units in a quantity expression	Ten pounds of potatoes
QUANTIFIER/SPECIFIER SPECIFIC ROLES			

	Role Name	Definition	Example
	PROFORM	The actual lexicon pronoun in the sentence	
	QUAN	He actual lexical quantifier in the sentence	
	REFSET	A link to a term defining reference set for quantifiers (*most of the trucks* is relative to a specific set of trucks)	Most of the trucks
	NAME-OF	The actual lexical name used	
TENSE, ASPECT AND MODALITY ROLESS			
	NEGATION	+/- indicating negation	
	TENSE	PAST, PRES, FUT	
	PROGR	+/- progressive aspect	
	PERF	+/- perfect aspect	
	PASSIVE	+/- passive use	
	MODALITY	Various modalities (see Figure 6)	He could have run

Appendix B: Some Senses of Key Verbs

Main verb be

The main verb be has three main forms. The first use, ONT::HAVE-PROPERTY, associates an object with a property which is realized by an adjective, PP, or other predicative form. To save space, we will suppress the LF for the various pronominal forms.

It was red

(F h1 (:* ONT::HAVE-PROPERTY W::BE) :NEUTRAL it1 :FORMAL p1)
(F p1 (:* ONT::RED W::RED) :FIGURE it1)

It is in the truck

(F h1 (:* HAVE-PROPERTY W::BE) :NEUTRAL it1 :FORMAL p1)
(F p1 (:* ONT::IN-LOC W::IN) :FIGURE it1 :GROUND a1)
(THE a1 (:* ONT::LAND-VEHICLE W::TRUCK))

He was late

(F h2 (*: ONT::HAVE-PROPERTY W::BE) :NEUTRAL he1 :FORMAL p2)
(F p2 (:* ONT::SCHEDULED-TIME-MODIFIER W::LATE) :FIGURE he1)

The second sense of be indicates a relationship between objects, which often is equality, but also might involve some contextually-defined relations. For instance, the utterance *Three miles is four hours* states that the relation "time to travel" relates three miles to four hours. The predicate ONT::BE is used for this, and determining the exact relation is left for contextual processing.

It is the best truck.

(F be1 (*: ONT::BE BE) :NEUTRAL it1 :NEUTRAL1 b1)
(THE b1 (:* ONT::LAND-VEHICLE TRUCK) :MOD bd1)
(F bd1 (:* ONT::MAX-VAL W::GOOD) :FIGURE b1 :SCALE ONT::ACCEPTABILITY-VAL)

Three miles is four hours

(F v0 (:* ONT::BE BE) :NEUTRAL v3 :NEUTRAL1 v1)
(A v1 (:* ONT::QUANTITY DURATION-SCALE) :UNIT(:* ONT::DISTANCE-UNIT ONT::HOUR)) :AMOUNT v2)
(A v2 ONT::NUMBER :VALUE 4)
(A v3 (:* ONT::QUANTITY LENGTH-SCALE) :UNIT(:* ONT::LENGTH-UNIT ONT::MILE)) :AMOUNT v4)
(A v4 ONT::NUMBER :VALUE 4)

The third sense is existence, and is typically seen in utterances like "there is the truck".

There is a person there

(F v0 ONT::EXISTS :NEUTRAL v1 :TENSE PRES))
(A v1 (:* ONT::PERSON PERSON) :MOD v2)
(F v2 (:* ONT::THERE THERE) :FIGURE v1 :GROUND v3)
(IMPRO v3 ONT::LOCATION :PROFORM W::THERE)

Main verb have

The verb have is another verb that takes on many different meanings depending on its arguments. We do not attempt to capture these variations in entailments in the sense of the verb, but rather view the entailments arising in later processing, and based on the verb-argument combinations. Thus the senses for have reflect the structural restrictions seen in language. The sense ONT::HAVE takes an NEUTRAL and NEUTRAL1 role and asserts some relationship between the two (e.g., in a prototypical case, possession). A second sense, ONT::UNDERGO, has an AFFECTED role and a FORMAL that is an event/situation, and roughly asserts that the AFFECTED undergoes the event described (e.g., he has a headache). Finally, the sense ONT::MAKE-IT-SO involves a causal agent force an object to undergo some event, as in *He had me open the can*. The senses are shown in Table 11, along with the fine-grained WordNet senses. Only one wordnet sense (the third one), requires splitting examples between our senses, since an idea is an abstract object in our ontology, whereas feelings, emergencies and headaches are situations.

Table 11: The senses of "have" and their WordNet mappings

Sense	Comment	Roles	Examples	WordNet Sense #
HAVE	NEUTRAL in relation to NEUTRAL1	:NEUTRAL :NEUTRAL1	She has $1000 in the bank. She has two daughters	1
			This restaurant has the best chef in France.	2
			I have three houses in Florida.	4
			He has a postdoc/lover.	7
			I don't have any money left. They have two years before they retire.	9
			She has arthritis	12
			I had an idea	3
			I had a letter from them	15
			I had her (archaic)	19
HAVE-EXPERIENCE	NEUTRAL undergoes a situation described by NEUTRAL1	:NEUTRAL :NEUTRAL1	I have a feeling. We have an emergency, I have a headache.	3
			He had a reception/party.	8
			We have a fine mess. What do we have here?	10
			The stocks had a fast runup.	11
			I won't have this dog in the house	14
			She had an accident.	16
			The team had 4 goals.	17
			My wife had twins yesterday.	18
MAKE-IT-SO	AGENT causes AFFECTED to be related is a situation described by FORMAL	:AGENT :AFFECTED :FORMAL	He had me in for a big surprise. Have him open the door	5
			They had me buy a VCR.	13
CONSUME	An agent consumes some substance	:AGENT :AFFECTED	We had fish for dinner	6
NECESSITY	A person is required to do something	:NEUTRAL :FORMAL	I had to go, The files had to be destroyed.	

Here are a few examples uses some of the senses.

I have a car

(F V444588 (:* ONT::HAVE W::HAVE) :NEUTRAL v44 :NEUTRAL1 v45
:TENSE PRES))
(PRO v44 (:* ONT::PERSON W:I) :PROFORM W::I)
(A v45 (:* ONT::VEHICLE W::CAR))

We have an emergency

(F h1 (:* ONT::HAVE-EXPERIENCE HAVE) :NEUTRAL we1 :NEUTRAL1 ha1)
(PRO i1 (SET-OF (:* ONT::PERSON W:WE)) :PROFORM W::we)
(A ha1 (:* ONT::EVENT W::EMERGENCY))

I had Fred go

(F v0 (:* ONT::MAKE-IT-SO W::HAVE) :AGENT v1 :AFFECTED v2 :FORMAL v3 :TENSE PAST))
(PRO v1 ONT::PERSON :PROFORM I)
(F v3 (:* ONT::MOVE GO) :AGENT v2)
(THE v2 ONT::PERSON :NAME-OF FRED)

I had some water (in the consumption reading)

(F v0 (:* ONT::CONSUME HAVE) :AGENT v1 :AFFECTED v2 :TENSE PAST))
(PRO v1 ONT::PERSON :PROFORM I)
(A v2 (:* ONT::FOOD WATER))

Recent Changes

Date	Section	Change
May, 2016	**Section 5**	Completely rewritten section on scalar constructions
April, 2016	**Appendix A**	Adding new role ORIENTATION, that links an event or object to a spatial predicate that locates some point on the line of orientation
	Section 4, Table 7	Added a new table that helps distinguishes the different roles related to quantity
July 2016	**Section 5**	Updated section on scales eliminating the OF and VAL roles. Added more examples of complex constructions like ENOUGH. Eliminating mention of ONT::ENOUGH, which doesn't exist. We already have ONT::ADEQUATE which does the job.
	Intro	New introductory material
	Appendix A	reorganized the presentation of roles, separating out the causal relations. Adding a new role roughly corresponding to TRAJECTORY — a result that is causes by the event but does not hold at the end. Currently called TRANSIENT-RESULT, but open to other names