Chapter 4
Logical Connections of Statements at the Ontological Level

Cungen Cao
Chinese Academy of Sciences, China

Yuefei Sui
Chinese Academy of Sciences, China

Yu Sun
Chinese Academy of Sciences, China

ABSTRACT

In the classical formal logics, the negation can only be applied to formulas, not to terms and predicates. In (frame-based) knowledge representation, an ontology contains descriptions of individuals, concepts and slots, that is statements about individuals, concepts and slots. The negation can be applied to slots, concepts and statements, so that the logical implication should be considered for all possible combinations of individuals, concepts, slots and statements. In this regard, the logical implication at the ontological level is different from that at the logical level. This paper attempts to give such logical implications between individuals, concepts, slots, statements and their negations.

INTRODUCTION

In the first-order logic, there are three logical connectives $\vee$, $\wedge$ and negation $\neg$, where $\neg$ can only be applied on formulas to form new formulas, and for any formula $\neg\varphi$ and any model M, $\neg\varphi$ is true in M if and only if φ is not true in M.

In natural languages, the connectives and negations have many forms. For example, the exclusive disjunction (exclusive or) and inclusive disjunction (inclusive or). For the negation, the forms are varying. The negation can be applied to a statement (He is not happy), a concept (not a happy man), an individual (Not he is happy) and a value of an attribute (unhappy).

To formalize the different forms of the negation in natural languages, we consider the nega-

tion at the ontological level, where the levels are a classification of the various primitives used by knowledge representation systems, firstly defined by Brachman (1979), based on which Guarino (1994) added the ontological level to the levels:

- The logical level;
- The epistemological level;
- The ontological level;
- The conceptual level, and
- The linguistic level.

We believe that every level has its own negation.

The negation at the logical level is the logical negation $\neg$ on formulas. In the first order logic, the negation $\neg$ is applied only to formulas, i.e., if φ is a formula then so is $\neg\phi$; and φ is false if and only if $\neg\varphi$ is true. Hence, φ and $\neg\varphi$ are contradictory.

The negation at the epistemological level is the negation on formulas and on modalities. For example, let B be the epistemological modal *believe*, and φ be a first-order formula. Then, we have the following formulas:

$$B\varphi, (\neg B)\varphi, B(\neg\varphi), \neg(B\varphi);$$

where the negation in $(\neg B)\varphi$ is at the epistemological level; the negations in $B(\neg\varphi)$ and $\neg(B\varphi)$ are at the logical level. For example, the following sentences

Lois believes that Clark Kent is strong.
Lois does not believe that Clark Kent is strong.
Lois believes that Clark Kent is not strong.
It is not true that Lois believes that Clark Kent is strong.

are represented as

$$B\varphi, (\neg B)\varphi, B(\neg\varphi), \neg(B\varphi).$$

It is clear that $(\neg B)\varphi$ is different from $B(\neg\varphi)$ and $\neg(B\varphi)$. In a consistent mind, $B\varphi$ and $B(\neg\varphi)$ are contrary, i.e., $B\varphi$ and $B(\neg\varphi)$ cannot be both true, though they may be both false. For example, either it is not true that *Lois believes that Clark Kent is strong,* or it is not true that *Lois believes that Clark Kent is not strong.* In a consistent mind, $B\varphi$ and $(\neg B)\varphi$ are contradictory; in an inconsistent mind, $B\varphi$ and $(\neg B)\varphi$ are not. $B\varphi$ and $\neg(B\varphi)$ are contradictory.

At the ontological level, the negation can be applied not only to statements, but also to concepts and slots, even to the components in concepts and slots, such as the negation on values.

- The negation can be applied to slots. Let a be an attribute. If the domain of a comprises a Boolean algebra then the negation on values is the complement in the Boolean algebra. For example, let a be an attribute to say whether a person is happy, and then D_a, the domain of a, has three values: *happy, not happy and not unhappy, unhappy*, where the complement of *happy* is *unhappy*; the complement of *unhappy* is *happy*, and the complement of *not happy and not unhappy* is itself. *unhappy* is applied on a concept C (for example, C is concept *man*) and a new concept $unhappy \sqcap C$ (unhappy man), where $happy \sqcap C$ and $unhappy \sqcap C$ are contrary, i.e., there is no individual which is an instance of both $happy \sqcap C$ and $unhappy \sqcap C$, and there may be an individual which is an instance of both the complements of $happy \sqcap C$ and $unhappy \sqcap C$.
- The negation can be used relative to some concept. For example, the logical negation $\neg^C$ relative to C is applied on concept $happy \sqcap C$ (happy man) and a concept $(\neg happy) \sqcap C$ (a not-happy man) is formed, where $happy \sqcap C$ and $(\neg happy) \sqcap C$ are contradictory with respect to C,

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