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Realization of Logical Categories in Linguistic Structures: A Formal-Semantic Approach

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ABSTRACT

The article examines the realization of logical categories in linguistic structures from the perspective of formal semantics and the interaction between language and logic. Particular attention is paid to the linguistic representation of such fundamental logical categories as negation, affirmation, quantification, conjunction, disjunction, implication, modality, and predication. The study considers the mechanisms through which logical relations are encoded at lexical, morphological, and syntactic levels and analyzes the correspondence between formal logical structures and natural language expressions. A formal-semantic approach is employed to identify the similarities and differences between logical operations and their linguistic manifestations. The analysis demonstrates that logical categories are not reproduced mechanically in language but are realized through structurally and semantically diverse linguistic means. The findings also reveal that the interpretation of logical meaning depends on grammatical structure, semantic context, and the functional relations between linguistic units. The study contributes to a more systematic understanding of the relationship between logical and linguistic structures and provides a theoretical basis for further research in theoretical linguistics, formal semantics, and computational linguistic modeling.

Keywords: Logical categories, linguistic structure, formal semantics, language and logic, negation, quantification, conjunction, disjunction, implication, modality, predication, semantic structure.

INTRODUCTION

The relationship between language and logic constitutes one of the fundamental issues at the intersection of linguistics, philosophy of language, and formal semantics. Language is not merely a system for naming objects and describing events; it also provides structural mechanisms for expressing relations such as affirmation and negation, conjunction and disjunction, implication, quantification, modality, and predication. These relations have traditionally been associated with logical reasoning, yet their linguistic realization is considerably more complex than their representation in formal logical systems. The development of formal semantics has made it possible to investigate this relationship systematically by examining how linguistic expressions are mapped onto formally defined semantic structures.

A major theoretical foundation for this approach was established by Richard Montague, whose model-theoretic treatment of natural language demonstrated that linguistic meaning could be analyzed through formal mechanisms traditionally associated with mathematical logic [1]. This perspective contributed significantly to the development of compositional semantics, according to which the meaning of a complex linguistic expression is determined by the meanings of its constituent elements and the structural principles governing their combination. Subsequent developments in formal semantics have further elaborated this principle by establishing systematic correspondences between syntactic configurations and semantic interpretation [2]. In this framework, linguistic structures are regarded not as isolated grammatical forms but as configurations whose semantic properties can be represented through functions, predicates, arguments, operators, variables, quantifiers, and truth conditions.

The formal-semantic tradition has therefore provided a methodological basis for examining the linguistic manifestation of logical categories. Chierchia and McConnell-Ginet emphasize that the analysis of linguistic meaning requires the use of formal tools capable of representing propositional relations, truth conditions, quantification, binding, intensionality, and the interaction between meaning and context [3]. From this perspective, categories such as negation, conjunction, disjunction, implication, quantification, modality, and predication occupy a particularly important position because they establish relations between propositions, entities, properties, and possible states of affairs. At the same time, the linguistic forms through which these categories are expressed do not always correspond directly to the operators recognized in classical logic.

This lack of complete correspondence represents one of the central problems in the study of language–logic interaction. Logical systems normally define operators according to strictly specified formal conditions, whereas natural language meaning is influenced not only by truth-conditional relations but also by syntactic structure, semantic scope, contextual interpretation, pragmatic inference, and discourse conditions. Recent research on linguistic connectives, for instance, demonstrates that conjunction and disjunction possess a logical truth-conditional component, while their actual interpretation may additionally involve implicatures, presuppositions, and reasoning processes [4]. Consequently, the semantic value of a linguistic connective cannot always be reduced to the truth table of its corresponding logical operator. This observation highlights the necessity of distinguishing between a logical category as an abstract relation and the linguistic mechanisms through which that relation is realized.

The same problem is evident in the lexicalization of logical operators. Incurvati and Sbardolini show that natural languages lexicalize only a restricted subset of logically possible connectives and quantifiers and argue that the distribution of such operators is related to their semantic and dynamic properties [5]. This finding is particularly significant for linguistic theory because it indicates that the logical possibilities available within a formal system are broader than the set of structures conventionally encoded by natural language. Language therefore does not reproduce the inventory of formal logic mechanically. Instead, logical relations are selectively represented and distributed across different linguistic structures.

Quantification provides another clear illustration of this interaction. Within formal semantics, quantificational expressions are analyzed through relations between sets, variables, scope, and compositional interpretation. Contemporary studies continue to examine the semantic status of natural-language quantification and the ways in which quantificational expressions interact with linguistic structure [6]. Similar questions arise in the analysis of negation, modality, implication, and predication. The interpretation of these categories depends not only on the presence of a particular lexical item or grammatical marker but also on its structural position, semantic scope, interaction with other operators, and relation to the proposition as a whole. Thus, the study of logical categories requires an approach capable of connecting abstract logical relations with their concrete linguistic realization.

Logical meaning may be manifested at more than one level of linguistic structure. At the lexical level, particular words and lexical-semantic groups may encode opposition, possibility, necessity, inclusion, exclusion, quantity, or relational meaning. At the morphological level, grammatical markers may modify polarity, modality, quantity, or the semantic status of a proposition. At the syntactic level, relationships between clauses and sentence constituents can express conjunction, disjunction, condition, implication, negation, predication, and other forms of logical organization. These manifestations suggest that logical structure should not be treated as an autonomous layer completely separated from linguistic organization. Rather, it emerges through the interaction of semantic content with the structural resources of language.

Recent developments in formal semantics also demonstrate that the theoretical apparatus employed for describing natural-language meaning continues to evolve. Contemporary type-theoretical approaches, for example, extend traditional semantic models and offer increasingly sophisticated mechanisms for representing propositions, quantification, anaphora, modification, and other complex semantic phenomena [7]. Such developments confirm that the relationship between linguistic form and logical-semantic representation remains an active theoretical problem.

They also indicate that a comprehensive analysis of logical categories requires attention not only to individual operators but also to the general principles governing their realization within linguistic structures.

Although negation, quantification, logical connectives, modality, predication, and related phenomena have received extensive individual treatment in linguistic and philosophical research, these categories are often examined within separate theoretical domains. This creates a need for an integrative perspective that considers them as components of a broader system of relations between logical organization and linguistic structure. Such an approach makes it possible to identify both common mechanisms and category-specific features in the transformation of abstract logical relations into linguistically interpretable structures. In particular, it is important to determine where direct correspondence between logical and linguistic structures is possible, where such correspondence is partial, and where linguistic interpretation requires additional semantic or contextual mechanisms.

Accordingly, the present study aims to investigate the realization of fundamental logical categories in linguistic structures through a formal-semantic approach. The analysis focuses on the mechanisms through which negation, affirmation, conjunction, disjunction, implication, quantification, modality, and predication acquire linguistic representation and participate in the formation of semantic structure. Special attention is given to the relationship between logical operators and linguistic means, the role of compositionality, semantic scope, and structural organization, as well as the factors responsible for divergences between formal logical models and natural-language interpretation.

The contribution of the study lies in treating logical categories not simply as elements borrowed from formal logic for linguistic description, but as semantic relations whose linguistic realization is conditioned by the internal organization of language. By integrating logical representation with the analysis of linguistic structure, the study seeks to develop a systematic framework for describing how abstract logical relations become encoded, combined, and interpreted in natural language. Such a framework can contribute to theoretical linguistics and formal semantics while also providing a conceptual basis for the formal representation and computational modeling of linguistic meaning.

LITERATURE REVIEW

The formal-semantic investigation of logical categories has developed through several interconnected research traditions, each focusing on particular aspects of the relationship between logical representation and linguistic structure. While early formal-semantic theories established the general possibility of representing natural-language meaning through logical models, subsequent studies have demonstrated that individual logical categories exhibit considerably different patterns of linguistic realization. Quantification, negation, predication, conjunction, disjunction, implication, and modality therefore cannot be treated merely as direct linguistic equivalents of operators defined in classical logic. Their interpretation depends on the interaction between semantic composition, syntactic organization, scope relations, contextual information, and pragmatic inference.

One of the most influential developments in this area is the theory of generalized quantifiers proposed by Barwise and Cooper [8]. Their approach significantly expanded the traditional logical treatment of quantification by showing that natural-language quantificational expressions cannot be adequately described through the existential and universal quantifiers of first-order logic alone. Determiners and quantified noun phrases were analyzed as higher-order relations between sets, allowing expressions corresponding to notions such as “all,” “some,” “most,” “few,” and “no” to be incorporated into a unified semantic framework. The significance of this theory extends beyond the analysis of quantity itself. It demonstrates a fundamental principle concerning the relationship between logic and language: formal logical structures must often be extended or reformulated in order to capture the actual semantic organization of natural-language expressions. Thus, quantification provides clear evidence that linguistic categories interact with logical categories without necessarily being structurally identical to them.

The problem becomes even more apparent in the study of negation. De Swart & Sag [9] investigated the interaction between negation, negative indefinites, and negative concord and demonstrated that apparently similar negative structures can receive either a single-negation or a double-negation interpretation. Their analysis is particularly relevant to the present research because it shows that the semantic contribution of a negative element cannot always be determined independently of the structural configuration in which it occurs. The scope of the operator, interaction among negative expressions, and grammatical mechanisms responsible for concord all participate in the construction of the final logical-semantic representation. Consequently, linguistic negation cannot simply be equated with the unary logical operator $\neg$. Instead, the correspondence between logical and linguistic negation must be established at the level of the entire semantic structure.

Predication represents another fundamental area in which linguistic organization and logical structure intersect. Williams [10] approached predication as a structural relation connecting a subject with a predicate and argued for a distinct level of representation in which subject–predicate relations are formally encoded. The importance of this conception lies in its treatment of predication not merely as a surface syntactic relationship but as an organizing principle that connects grammatical structure with semantic interpretation. From a logical perspective, predication establishes a relation between an argument and a property or between several arguments and a relational predicate. From a linguistic perspective, however, this relation may be realized through structurally diverse constructions. The analysis of predication therefore requires attention to both logical argument structure and the grammatical mechanisms by which predicates and their arguments are organized.

More recent formal-semantic research has further demonstrated the complexity of the interaction between logical operators and linguistic representations. Bernard and

Champollion [11], for example, develop a compositional account of negative events and address the difficulty of integrating linguistic negation into event semantics. Their analysis shows that classical complement negation creates problems when verbal meanings are represented as sets of events rather than simple truth values. The authors consequently formulate a specific negation operation compatible with event-semantic representations and examine its interaction with conjunction, disjunction, and quantification. This research is particularly important because it demonstrates that the semantic type of a linguistic expression influences the formal realization of a logical operator. In other words, the same abstract logical category may require different representational mechanisms depending on the semantic domain in which it operates.

Modality provides an equally significant case of divergence between elementary modal logic and natural-language semantics. Roberts [12] examines epistemic modality within a framework in which modal expressions are interpreted relative to contextually determined bodies of information. The study develops the idea that epistemic modals are dependent on a modal base supplied by discourse context and that their interpretation therefore cannot be reduced to an invariant possibility or necessity operator. This observation supports the broader distinction between logical modality and linguistic modality. Although formal modal logic traditionally represents necessity and possibility through operators such as $\Box$ and $\Diamond$, linguistic modal expressions receive their actual interpretation through the interaction of modal force, contextual premises, speaker knowledge, and discourse conditions. Modality therefore illustrates particularly clearly how an abstract logical relation becomes linguistically differentiated through semantic and pragmatic parameters.

The relationship between disjunction and modality has generated an especially productive line of formal-semantic research. Goldstein [13] analyzes the phenomenon of free-choice interpretation, in which a disjunctive expression under a possibility modal can produce an inference that each alternative is individually permitted or possible. Such interpretations are problematic for classical logic because standard modal logic and

Boolean disjunction do not directly generate the observed inference. Goldstein proposes an analysis based on homogeneity and demonstrates that free-choice interpretations interact systematically with negation and logical principles such as Disjunction Introduction and the Law of Excluded Middle. These findings provide further evidence that natural-language disjunction possesses interpretive properties that go beyond the simple Boolean operator ∨.

The divergence between logical disjunction and linguistic interpretation is investigated in greater detail by Aloni [14]. Her analysis of free-choice phenomena explicitly addresses the relationship between logic and conversation and argues that certain apparently non-logical linguistic inferences arise from the interaction between semantic representation and pragmatic enrichment. Importantly, the study demonstrates that these effects are sensitive to polarity: interpretations available in positive contexts may disappear or change under negation. From the perspective of logical categories, this indicates that the meaning of a connective cannot be described solely through a static truth-functional definition. The linguistic realization of logical operators must also account for the informational state of interlocutors and the inferential mechanisms associated with actual language use.

Marty & Romoli [15] provide further evidence for the complexity of disjunction by examining free-choice readings and scalar implicatures at both assertion and presupposition levels. Their research shows that disjunctive expressions can generate exclusivity, ignorance, and free-choice inferences whose interpretation depends on structural embedding and the interaction between semantic composition and pragmatic strengthening. The study is significant for the theory of logical categories because it challenges a strict separation between encoded logical meaning and derived linguistic meaning. It suggests that the interpretation of linguistic structures containing logical operators emerges through multiple interacting levels rather than through a one-to-one correspondence between linguistic signs and logical symbols.

These studies collectively demonstrate that logical categories operate differently when embedded in natural linguistic systems. Quantification involves scope and relations between sets; negation interacts with polarity and structural dependency; predication depends on argument organization; modality requires contextual restriction; and disjunction generates interpretations shaped by alternatives, inference, and semantic environment. Consequently, linguistic realizations of logical categories cannot be adequately explained through truth tables or elementary symbolic correspondences alone. Formal semantic analysis must determine how logical meaning is compositionally constructed within the architecture of linguistic structure.

An additional dimension of the problem has emerged from research connecting formal semantics with computational approaches to language. Carstensen [16], examining quantification from the perspective of natural language generation, argues that quantificational meaning involves complex interactions among collectivity, distributivity, cumulativity, plurality, and scope. By approaching quantification not only as a problem of interpretation but also as a problem of generating appropriate linguistic expressions from structured representations, the study demonstrates the relevance of formal semantic categories to computational linguistic modeling. This perspective is important because computational systems require logical-semantic distinctions to be represented explicitly enough to permit systematic processing, generation, and inference.

The connection between linguistic structures and formal inference has become particularly important in contemporary computational linguistics. Gubelmann et al. [17], through a systematic examination of natural language inference resources, demonstrate that inference in language encompasses a wide range of phenomena that cannot be reduced to a single generic relation between sentences. Logical, lexical, syntactic, semantic, and pragmatic mechanisms all contribute to whether one linguistic statement entails, contradicts, or remains neutral with respect to another. From the perspective of formal semantics, this confirms the continuing relevance of accurately representing negation, quantification, modality, predication, and related logical relations. Computational inference therefore provides an applied environment in which the adequacy of linguistic models of logical structure can be evaluated.

The reviewed literature reveals two major tendencies. The first tendency is the increasing sophistication of formal models developed for individual logical-semantic phenomena. Quantification, negation, modality, disjunction, and predication have each produced specialized theories capable of explaining fine-grained interpretive patterns. The second tendency is the growing recognition that linguistic interpretations cannot always be derived directly from the corresponding operators of classical logic. Semantic type, grammatical structure, scope, context, presupposition, alternatives, and pragmatic inference frequently modify or enrich the logical relations expressed by linguistic forms.

Nevertheless, an important research gap remains. A substantial proportion of previous studies concentrate on a single logical category or on a restricted interaction between two phenomena, such as negation and quantification, modality and disjunction, or disjunction and scalar inference. This specialization has produced detailed analyses of particular constructions but has also resulted in a comparatively fragmented understanding of the broader system through which logical categories are realized in linguistic structures. There remains a need for an integrative framework capable of comparing several fundamental logical categories according to common criteria and of distinguishing their abstract logical properties from the lexical, morphological, syntactic, and semantic mechanisms involved in their linguistic realization.

The present study addresses this gap by examining negation, affirmation, conjunction, disjunction, implication, quantification, modality, and predication within a unified formal-semantic perspective. Rather than assuming a direct equivalence between logical operators and linguistic forms, the study investigates the conditions under which such correspondence is complete, partial, structurally transformed, or dependent on additional interpretive mechanisms. In doing so, it seeks to systematize the relationship between logical and linguistic structures and to establish a theoretical basis that may subsequently support formal representation and computational modeling of logical-semantic relations in natural language.

RESEARCH METHODOLOGY

The study employs a qualitative formal-semantic research design aimed at identifying and systematizing the mechanisms through which logical categories are realized in linguistic structures. The methodological framework combines formal-semantic analysis, structural-semantic analysis, logical modeling, and comparative interpretation. This combination makes it possible to examine logical categories not only as abstract operators of formal systems but also as semantic relations manifested through lexical, morphological, syntactic, and compositional structures in natural language.

The study is theoretically grounded in the principle of compositionality developed within formal semantics, according to which the interpretation of a complex expression depends on the meanings of its constituents and the structural relations between them. At the same time, the methodology takes into account the fact that linguistic expressions do not always correspond directly to operators of classical logic. Consequently, the analysis distinguishes between the abstract logical representation of a category and the linguistic mechanisms responsible for its realization.

The object of the study is the relationship between logical and linguistic structures in the semantic organization of natural language. The principal units of analysis are linguistic constructions that express the following logical-semantic categories: affirmation, negation, conjunction, disjunction, implication, quantification, modality, and predication.

These categories were selected because they represent fundamental operations involved in the organization of propositional meaning and because they can be formally represented while simultaneously exhibiting structurally diverse linguistic realizations. Their inclusion also makes it possible to investigate different types of relationships between formal logical structures and natural-language meaning.

The analysis is not restricted to a particular language. Instead, it focuses on structurally representative linguistic constructions discussed in formal-semantic and theoretical-linguistic research. This approach allows the study to identify general mechanisms of logical-semantic realization rather than language-specific grammatical patterns.

The analytical material was selected according to three principal criteria. First, the construction had to contain an identifiable logical-semantic relation. Second, its interpretation had to permit formal representation through a logical operator, predicate, quantifier, modal operator, or relation between propositions. Third, the construction had to demonstrate either correspondence or divergence between its linguistic form and formal logical interpretation.

Particular attention was given to minimal and structurally transparent constructions because such examples make it possible to isolate the semantic contribution of individual operators. Where necessary, contrasting constructions were compared in order to determine how changes in syntactic position, scope, polarity, or semantic environment influence logical interpretation.

RESULTS AND DISCUSSION

The analysis demonstrates that logical categories do not display an identical pattern of correspondence with linguistic structures. Although affirmation, negation, conjunction, disjunction, implication, quantification, modality, and predication can all be represented through formal logical notation, their realization in natural language varies according to structural level, semantic scope, compositional organization, and contextual dependence. The results therefore support the view that the relationship between logical and linguistic structures should be understood as a graded rather than strictly isomorphic correspondence. The comparative analysis of the eight categories is summarized in Table 1.

Table 1. *Logical-linguistic correspondence matrix*

Logical category	**Formal repress-entation**	**Primary semantic function**	**Typical linguistic realization**	**Dominant linguistic level**	**Scope/ context sensitivity**	**Main divergence from formal logic**	**Corres pondence type**
Affirmation	P	Establishing the validity or positive polarity of a proposition	affirmative clause structure, positive polarity markers, lexical confirmation	syntactic-semantic	Low to moderate	affirmation is often formally unmarked, while its communicative force may depend on discourse context	Direct / partial
	$\neg P$	Reversing or denying propo sitional validity	negative particles, affixes, negative pronouns, negative constructions	Morph ological, lexical, syntactic	High	negative concord, scope ambiguity, and pragmatic interpretation may produce structures not reducible to a single operator ¬	Structurally transformed
Conjunction	$P \wedge Q$	Combining propositions or semantic units	coordinating connectives, juxtaposition, coordinated structures	lexical-syntactic	Moderate	linguistic conjunction may additionally express temporal sequence, causality, emphasis, or discourse continuity	Partial
Disjunction	$P \vee Q$	Presenting alternatives	disjunctive connectives, alternative constructions	lexical-syntactic	High	inclusive/ exclusive readings, free-choice effects, and pragmatic enrichment exceed Boolean disjunction	Context-dependent
Implication	$P \rightarrow Q$	Establishing conditional or inferential dependence	conditional clauses, inferential constructions, cause–consequence relations	syntactic-semantic	High	natural-language conditionals do not always behave as material implication and may depend on modality, causality, or speaker assumptions	Partial / context-dependent

Quantification	$\forall x\, P(x)$, $\exists x\, P(x)$	Specifying the domain and quantity of entities satisfying a predicate	determiners, quantificational expressions, indefinite expressions, distributive constructions	lexical-syntactic-compositional	Very high	scope ambiguity, generalized quantification, plurality, distributivity, and contextual domain restriction exceed first-order quantification	Structurally transformed
Modality	$\Box P$, $\Diamond P$	Expressing necessity, possibility, obligation, probability, or epistemic status	modal auxiliaries, modal predicates, adverbs, grammatical mood	lexical, morphological, syntactic	Very high	modal interpretation depends on modal base, force, speaker knowledge, norm, discourse context, and possible-world restrictions	Context-dependent
Predication	$P(x)$, $R(x,y)$	Assigning a property or relation to an argument	predicate–argument constructions, copular structures, verbal and nominal predicates	syntactic-semantic	Moderate	linguistic predication involves argument structure, information structure, tense, aspect, and grammatical realization beyond elementary predicate logic	Direct / structurally transformed

GENERAL DISTRIBUTION OF CORRESPONDENCE TYPES

The results reveal that none of the eight categories can be described through a completely uniform one-to-one relationship between a logical operator and a linguistic form. Even categories that initially appear relatively transparent, such as affirmation and conjunction, display additional structural or pragmatic properties when realized in natural language. This finding confirms the methodological assumption that logical representation functions as an analytical abstraction rather than as a complete substitute for linguistic meaning.

Among the categories investigated, **affirmation** shows the highest degree of direct correspondence with formal representation. An affirmative proposition can generally be represented as P, without introducing an additional logical operator. However, linguistic affirmation is frequently formally unmarked. Its interpretation may also acquire emphatic, corrective, contrastive, or confirmatory force in discourse. Thus, while its core propositional structure corresponds relatively directly to formal logic, its communicative realization may be semantically richer.

The analysis of **negation** reveals a substantially more complex pattern. In elementary logic, negation is represented through a unary operator applied to a proposition:

$$\neg P.$$

In linguistic structures, however, negation may be encoded morphologically, lexically, syntactically, or through the interaction of several negative elements. Negative concord provides a particularly clear example of this divergence. Multiple formally negative expressions do not necessarily produce multiple semantic negations [9]. As a result, a surface structure containing several negative elements may correspond to only one semantic negation. This demonstrates that the number of overt linguistic markers cannot be mechanically equated with the number of logical operators.

Negation also interacts significantly with scope. Compare:

$$\neg\forall x\, P(x) \text{ and } \forall x\, \neg P(x).$$

The first representation means that the property does not apply universally, whereas the second indicates that the property fails to apply to every individual in the domain. The linguistic distinction between these two structures may depend on word order, grammatical configuration, prosody, or contextual interpretation. Negation must therefore be treated as a structurally transformed logical category rather than as a simple lexical equivalent of $\neg$.

The category of **conjunction** demonstrates a relatively close but incomplete correspondence with Boolean conjunction. In its basic interpretation,

$$P \wedge Q$$

requires both conjuncts to be true. Natural-language conjunction frequently preserves this semantic core. Nevertheless, linguistic coordination may introduce additional relations that are absent from the truth-functional definition. A sequence equivalent to P and Q may imply that P occurred before Q, that P caused Q, or that Q represents a consequence or elaboration of P. These interpretations demonstrate that conjunction may simultaneously perform logical and discourse-organizational functions.

This finding supports the classification of conjunction as a case of **partial correspondence**. Its logical nucleus is generally preserved, but linguistic interpretation may enrich the relation between conjuncts. The distinction is theoretically important because it shows that formally identical structures can receive semantically different readings depending on lexical content and discourse organization.

Disjunction exhibits an even greater degree of divergence from classical logic. Standard Boolean disjunction is represented as:

$$P \wedge Q$$

In formal logic, this structure is normally inclusive unless additional restrictions are introduced. Natural-language disjunction, however, may be interpreted either inclusively or exclusively. It can also trigger ignorance inferences, exclusivity effects, and free-choice interpretations. Under modal embedding, a construction corresponding to $\Diamond\ (P \vee Q)$ may be interpreted as licensing both alternatives individually, generating a reading close to: $\Diamond\ (P \wedge \Diamond\ Q)$.

Such interpretations cannot be derived from ordinary Boolean disjunction alone. Previous research on free choice confirms that alternatives, polarity, modality, and pragmatic inference all contribute to the semantic interpretation of disjunctive constructions [13-15]. The present analysis therefore classifies disjunction as predominantly **context-dependent correspondence**.

The category of **implication** similarly demonstrates that formal and linguistic structures only partially overlap. Material implication is conventionally represented as:

$$P \rightarrow Q.$$

In natural language, however, conditional constructions typically encode more than the truth-functional relationship captured by material implication. They may express causal dependency, epistemic reasoning, hypothetical consequence, counterfactuality, predictive relations, or normative conditions. The interpretation of a conditional therefore depends on the semantic relationship established between antecedent and consequent.

This distinction becomes particularly significant in cases where a material implication would be formally true merely because the antecedent is false, whereas an equivalent natural-language conditional may still sound semantically inappropriate. Linguistic implication thus requires additional conditions involving relevance, dependency, modality, or possible situations. Consequently, implication occupies an intermediate position between **partial and context-dependent correspondence**.

The findings concerning **quantification** reveal one of the most substantial differences between elementary logic and linguistic semantics. Formal logic commonly represents universal and existential quantification as: $\forall x\, P(x)$and $\exists x\, P(x)$.

Natural language, however, possesses a considerably richer quantificational inventory. Expressions corresponding to “all,” “some,” “most,” “few,” “many,” “several,” “no,” and related meanings cannot all be adequately represented through the two classical quantifiers alone. The theory of generalized quantifiers provides a broader formal framework in which determiners are interpreted as relations between sets [8].

The analysis further confirms that quantification is highly sensitive to semantic scope. For example, when two quantified expressions occur within the same linguistic structure, different scope assignments may produce different interpretations:

$\forall x \exists y\, R(x, y)$ and $\exists y \forall x\, R(x, y)$.

The first formula permits a potentially different y for each x, whereas the second requires one particular y to stand in relation R to every x. Since surface linguistic form does not always uniquely determine these scope relations, quantification constitutes a clear example of **structurally transformed correspondence**.

Quantificational interpretation may additionally depend on contextual restriction of the domain. An expression formally interpreted as *all* rarely refers to every entity in the universe; instead, it refers to all relevant entities within a contextually defined domain. This further demonstrates that formal representation must interact with contextual information to model linguistic quantification adequately.

Among the analyzed categories, **modality** displays the highest degree of contextual dependence. Formal modal logic distinguishes primarily between necessity and possibility:

$\Box P$ and $\Diamond P$

Natural-language modality, by contrast, differentiates epistemic, deontic, dynamic, evidential, dispositional, and other interpretations. The same modal form may express different kinds of possibility or necessity according to context. An expression of necessity, for instance, may indicate logical necessity, legal obligation, social expectation, evidential conclusion, or speaker certainty.

The analysis therefore confirms that a modal operator cannot be interpreted independently of its **modal base** and **modal force**. Context determines which possible worlds, bodies of knowledge, norms, or circumstances are relevant to the interpretation [12]. Consequently, linguistic modality represents not simply an elaboration of modal logic but a multidimensional semantic category whose interpretation emerges from the interaction of lexical meaning, grammatical structure, speaker perspective, and discourse context.

Predication, finally, represents one of the most fundamental points of contact between linguistic and logical structures. The elementary logical representation

$$P\,(x)$$

assigns a property P to an argument x, whereas

$$R\,(x, y)$$

represents a relation between two arguments. Such structures correspond broadly to linguistic predicate–argument configurations.

The analysis shows, however, that linguistic predication involves a richer set of structural relations. Predicates differ in argument number, semantic role assignment, event structure, tense, aspect, voice, and information structure. Moreover, predicational relations may be expressed by verbal, adjectival, nominal, or copular constructions. Thus, although predication exhibits a relatively direct conceptual correspondence with predicate logic, its grammatical realization is often structurally transformed [10].

CROSS-CATEGORICAL COMPARISON

Comparison across the eight categories reveals three important patterns.

First, the degree of logical–linguistic correspondence decreases as contextual and scope-dependent factors increase. Affirmation and basic predication demonstrate comparatively stable relations between logical form and linguistic structure. By contrast, modality, disjunction, implication, and quantification require substantially more contextual or structural information.

Second, scope represents a central mechanism connecting linguistic structure with logical interpretation. This is particularly evident in negation, quantification, and modality. A change in the hierarchical relation between operators can alter the interpretation even when the same lexical material is retained. Thus, scope should be regarded as one of the principal mediating categories between syntax and logical-semantic representation.

Third, logical categories are distributed across several linguistic levels rather than being confined to isolated lexical markers. Negation may be morphological or syntactic; modality may be lexical, morphological, or constructional; implication may emerge through a conditional syntactic relation without an overt logical connective; predication depends on grammatical configuration rather than a single lexical unit. This confirms that logical meaning is frequently a compositional property of linguistic structure.

Affirmation is located closest to the direct end of the continuum. Basic conjunction and predication occupy an intermediate position because their logical cores are relatively stable while their linguistic realizations introduce additional structural information. Negation and quantification are characterized primarily by structural transformation and scope dependence. Disjunction, implication, and especially modality occupy the context-dependent end of the continuum because their interpretation frequently requires information unavailable in formal truth-functional representation alone.

DISCUSSION

The findings have several implications for the theoretical interpretation of the relationship between language and logic. Most importantly, they challenge a strict one-to-one model in which each logical operator is assumed to correspond to a particular linguistic marker. Instead, the analysis supports a many-to-many correspondence model. A single logical category may be realized through different lexical, morphological, and syntactic mechanisms, while a single linguistic construction may simultaneously encode several logical-semantic relations.

For example, a conditional structure may combine implication, modality, temporal reference, and causality. A quantified negative construction may involve quantification, negation, scope relations, and contextual domain restriction simultaneously. A disjunctive modal expression may integrate disjunction, modality, alternatives, and pragmatic inference. Logical categories should therefore be analyzed not as isolated units but as interacting components of semantic structure.

The results are consistent with the foundational principle of formal semantics that linguistic meanings can be systematically represented through formal tools [1-3]. At the same time, they support subsequent research demonstrating that natural-language semantics frequently requires representations richer than those provided by classical propositional or predicate logic [8; 9; 11; 12; 13; 14; 15].

An important theoretical distinction consequently emerges between logical invariant and linguistic realization. The logical invariant refers to the abstract semantic relation preserved across different linguistic manifestations. For example, the logical invariant of negation concerns the reversal of propositional polarity, while the invariant of quantification concerns restrictions imposed on the relation between a domain and a predicate. Linguistic realization, by contrast, refers to the specific lexical, morphological, syntactic, semantic, and contextual mechanisms through which the invariant becomes interpretable.

From the perspective of theoretical linguistics, the proposed framework provides a systematic way of relating formal logic to semantic and grammatical structures. From the perspective of computational linguistics, it offers a basis for developing structured representations of logical-semantic phenomena. Automatic semantic analysis, natural language inference, semantic parsing, and machine reasoning all require computational systems to distinguish between surface linguistic markers and underlying semantic relations [16; 17]. The classification developed in this study can therefore contribute to the annotation and computational representation of logical categories in natural-language data.

Overall, the results demonstrate that the relationship between logical and linguistic structures is systematic but non-isomorphic. Logical categories provide abstract organizing principles for semantic relations, whereas natural language realizes these principles through structurally diverse and context-sensitive mechanisms. The degree of correspondence varies according to the category involved, its structural position, scope relations, and dependence on contextual interpretation. The proposed Logical–Linguistic Correspondence Matrix therefore provides an integrated framework for describing both the common foundations and the category-specific differences involved in the linguistic realization of logical structures.

CONCLUSION

The study has demonstrated that the relationship between logical categories and linguistic structures is systematic, but it cannot be reduced to a direct one-to-one correspondence between formal operators and linguistic forms. Although affirmation, negation, conjunction, disjunction, implication, quantification, modality, and predication can all be represented through formal logical notation, their realization in natural language depends on a broader set of structural, semantic, contextual, and pragmatic factors.

The comparative analysis revealed that the eight categories differ considerably in the degree of correspondence between logical representation and linguistic realization. Affirmation and basic predication exhibit the closest relationship to their formal counterparts, whereas conjunction generally preserves its logical core while allowing additional discourse and semantic interpretations. Negation and quantification show a stronger dependence on structural configuration and scope, while disjunction, implication, and modality demonstrate a particularly high level of contextual and interpretive variability.

One of the central findings of the study is that logical categories should be regarded as semantic invariants rather than as direct equivalents of specific lexical or grammatical markers. A single logical relation may be expressed through several linguistic mechanisms, including lexical, morphological, syntactic, and compositional resources. Conversely, a single linguistic construction may simultaneously encode more than one logical-semantic relation. This many-to-many correspondence constitutes an essential feature of the interaction between logical and linguistic organization.

The analysis also confirmed the methodological importance of semantic scope. In negation, quantification, and modality in particular, the relative position and interaction of operators determine substantial differences in interpretation. Consequently, scope functions as one of the principal mechanisms linking syntactic organization with logical-semantic structure. This finding reinforces the need to analyze logical categories not in isolation, but within the broader compositional environment in which they occur.

From a theoretical perspective, the findings contribute to a more integrated understanding of the relationship between logic and language by combining formal-semantic representation with structural and contextual analysis. The results show that formal logic provides an important analytical foundation, but natural-language meaning frequently extends beyond the boundaries of elementary truth-functional representation. Linguistic interpretation therefore requires consideration of compositionality, grammatical organization, scope, context, and pragmatic inference.

The findings also have potential implications for computational linguistics. A systematic distinction between logical categories, their semantic functions, and their linguistic realizations can support the development of semantic annotation schemes, natural language inference systems, semantic parsers, and computational models of meaning. In particular, the proposed correspondence framework may serve as a conceptual basis for representing logical-semantic relations in machine-readable linguistic data.

In conclusion, logical and linguistic structures should be viewed as closely interconnected but non-isomorphic systems. Logical categories provide abstract principles for organizing semantic relations, while language transforms these principles into structurally diverse and context-sensitive forms. The investigation of this interaction therefore requires an integrated formal-semantic approach capable of accounting for both logical invariance and linguistic variability. Future research may extend the proposed model through corpus-based, experimental, contrastive, and computational studies in order to test its applicability across different linguistic systems and broader datasets.

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