To. Dear Prof. Keenan
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The Semantics of Locative Prepositional Phrases in English

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy
in Linguistics

by

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The dissertation of Seungho Nam is approved.

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To my parents, Jihyun and Jaeoh,

my wife, Yonhee,

son, Moongun,

and daughter, Yejin

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ABSTRACT OF THE DISSERTATION

The Semantics of Locative Prepositional Phrases in English

by

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The dissertation provides a semantic analysis of locative prepositional phrases in English. The goal of the dissertation is two-fold: (i) To identify the denotational constraints on the possible interpretations of locative PPs; and (ii) to build up the general logic for the semantics of spatial expressions which can account for various semantic facts involved in the spatial expressions. In addition to the lexical semantics of locative prepositions, our analysis identifies the primitive notions for the logic of space and the ways that natural language structures space, and further we account for the semantic relations among spatial expressions (e.g., entailment, ambiguity).

The dissertation introduces the space as a new ontological domain and illustrates that the structural properties/relations among the spatial entities (regions, paths, and orientations) are much more intricate than those of the temporal ones. This dissertation adopts the framework of model-theoretic semantics, and our interest in the denotational

semantics of locative PPs naturally calls for the precise formal methods developed in Generalized Quantifier Theory and (boolean) algebraic semantics.

Chapter 2 investigates the kind of semantic objects English locative PPs denote. We note that there are two semantic analyses of the locative PPs and give a unified semantics of the two: (i) Locative PPs as *predicate modifiers*, and (ii) locative prepositions as *predicate extensors*. We show that locative PPs denote in a special subset of the functions from n-ary relations into n-ary relations, which we identify as *intersective functions*. The intersectivity constraint derives from the intuition that locative PPs are extensional and so *argument-oriented*. Chapter 3 builds up the general logic for the semantics of locative expressions, based on the mereology of the space (Σ) and the primitive concept *region*. The space Σ is defined as the set of regions with three primitive relations among them, the *part-to-whole* relation ($\subseteq$), the *betweenness* relation, and the *relative distance* relation. In terms of these primitives, we define *paths* and *orientations*, and postulate *Path structure* and *Orientation structure*: the former for *movement-directional* interpretations, and the latter for *stative-locational* interpretations. Chapter 4 illustrates the linguistic applications of the formal apparatus developed in chapter 3, and discusses two concepts, *symmetry* and *locative perspective*, involved in the semantics of locative PPs. In addition to the lexical semantics of locative prepositions — classified into four natural subclasses: *topological invariants*, *symmetric*, *orientational*, and *directional* locatives — we identify two special types of paths determined by locatives: *symmetric* paths and *homogeneous* paths. Finally we provide the semantics of perspectival interpretation of locative PPs in terms of *binary preposition* and *deictic orientation.*

Chapter 1

Introduction: Space in Language

1.1 Objects and Goals of the Study

The dissertation provides a semantic analysis of locative prepositional phrases (PPs) in English as they occur in the following sentences.

(1) a. *John saw Mary* <u>*in the garden*</u>

b. *The boys swam* <u>*across the river*</u>

c. *The ball is* <u>*in front of the tree*</u>

d. *John rushed* <u>*into the office*</u>

The locative PPs of interest here are extensional ones which refer to the location of one or more arguments in a sentence.[1] The goal of the dissertation is two-fold: (i) To identify the denotational constraints on the possible interpretations of locative PPs; and (ii) to build up the general logic for the semantics of spatial expressions which can

[1]The PP in (1a) above refers to the location of the object argument 'Mary', so (1a) entails 'Mary was in the garden'. The extensionality is a distinctive feature of locative modifiers, and it is characterized in terms of argument orientation in section 2.2.2. Other modifiers such as manner adverbials, however, are hard to be interpreted as extensional, and they do not denote a property or relation of argument but denote a property of an action or a state: For example, in *John treated Mary kindly*, the adverb *kindly* modifies the verb so denotes a manner of an action, but its extensional meaning is not clear at all.

account for various semantic facts involved in the spatial expressions. In addition to the lexical semantics of locative prepositions, the semantic analysis of the spatial expressions requires us to identify the primitive notions for the logic of space and the ways that natural language structures space, and further requires us to account for the semantic relations among spatial expressions (e.g., entailment, ambiguity).

Our semantics will as well provide a natural classification of locative prepositions characterized in terms of the notions defined in the logic of space. In section 4.1, we illustrate four types of locative prepositional phrases: (i) *topological invariants*, (ii) *symmetric* locatives, (iii) *orientational* locatives, and (iv) *directional* locatives.

The locative semantics designed here is not concerned with the physical structure of space itself, but only concerned with the ways that natural language talks about the properties and relations over regions in the space. Thus, we only introduce formal structural devices that are necessary for the semantics of spatial expressions, and we use primitives that are straightforwardly involved in the semantics of spatial expressions. The *inclusion* (or *containment*) relation between spatial entities (regions and paths), for example, can be identified in the following entailments induced by the spatial expressions, *from Los Angeles*, *to New York*, and *from California*. In 3.3.3, we lay out the theorems to account for the entailments.

(2) a. *John flew from Los Angeles to New York* entails

b. $\models$ *John flew from California to New York*

(given Los Angeles is in California) and

c. $\models$ *John flew to New York*

Furthermore, the logic for the locative semantics developed here provides a natural account of the different behaviors of different prepositions (cf. (3) and (4)), and various types of ambiguity induced by locative PPs (cf. (5)-(7)).

(3) Symmetric entailment

a. *The boy walked <u>across</u> the street, and came back immediately*

a'. $\models$ *The boy walked <u>across</u> the street twice*

b. *The boy walked <u>into</u> the room, and came back immediately*

b'. $\not\models$ *The boy walked <u>into</u> the room twice*

(4) Homogeneity of paths

a. *John drove <u>to</u> the city in an hour*

b. **John drove <u>toward</u> the city in an hour*

(5) Quantifier scope ambiguity [2.3.2]

John saw <u>a policeman</u> on <u>every street corner</u>

(6) Event-counting/Path-counting ambiguity [4.2.2]

John jogs around the park <u>twice</u> everyday

(7) Path/Orientation ambiguity [4.3.5]

John jogged <u>across</u> the street (<u>from</u> here)

The entailment patterns illustrated in (3) are accounted for by characterizing symmetric locatives in terms of *path symmetry* in 4.2. The aspectual difference illustrated in (4a) and (4b) is accounted for in terms of *path homogeneity* in 4.1.5.3. The ambiguities illustrated in (5-7) are discussed in detail in sections 2.3.2, 4.2.2, and 4.3.5, respectively.

1.2 Theoretical Frameworks

In the formal tradition of natural language semantics, ontological primitives assumed in the discourse universe have been extended from individual objects to indices (possible worlds), mass (plural or group) entities, events, and so on. Recent works on the semantics of adverbial modifiers require a temporal domain in the universe: Kamp (1979), and van Benthem (1983) among others. Van Benthem (1983) suggests a structural similarity between the temporal domain and the spatial domain. This thesis illustrates, however, that the structural properties/relations among the spatial entities are much more intricate than those of the temporal ones. For example, Landman (1991) defines the temporal domain (called "period structure") as a set of intervals with primitive relations of *precedence* and *inclusion*, but we postulate the spatial domain as a set of regions with three primitive relations, *inclusion*, *betweenness*, and *relative nearness* relations. The latter two relations are ternary ones which are not reducible to binary relations. Furthermore, paths and orientations are defined as new spatial objects in terms of those primitives.

This dissertation adopts the framework of model-theoretic semantics which has been developed by Montague (1970, 1973) and Keenan and Faltz (1985) among others. Recent development in Generalized Quantifier Theory has inspired formal semantic analyses of natural language determiners, and the formal methods it employs have been applied to the semantics of other linguistic categories. Our interest in the denotational semantics of locative PPs naturally calls for such precise formal methods in determining constraints on the possible interpretations. We make crucial use of boolean structures to characterize the logical (semantic) structures of predicates and their modifiers.

1.3 Overview of the Dissertation

Chapter 2 investigates the kind of semantic objects English locative PPs denote. We will see that there are basically two ways the locative PPs can be interpreted: (i) we interpret locative PPs as *predicate modifiers*, and (ii) locative prepositions as *predicate extensors*. Predicate modifiers are functions mapping n-ary relations into n-ary relations, whereas predicate extensors are those mapping n-ary relations into $(n+1)$-ary relations. The two semantic analyses will be unified in 2.4. In section 2.2, we note that locative PPs denote in a special subset of the functions from n-ary relations into n-ary relations, which we identify as *intersective functions*. The intersectivity constraint derives from the intuition that locative PPs are extensional and refer to the location or trajectory of arguments of the predicates they modify. The extensionality of locative PPs will be identified in their argument orientation patterns when they combine with predicates.

Chapter 3 builds up the general logic for the semantics of locative expressions in English. Our semantics for locative expressions is based on the mereology of the space (Σ) and the primitive concept *region*. Thus, the space Σ is defined as the set of regions with three primitive relations among them, the *part-to-whole* relation ($\subseteq$), the *betweenness* relation, and the *relative distance* relation. In terms of these primitives, we define *paths* and *orientations*, and postulate *Path structure* and *Orientation structure*. These two kinds of spatial objects play an important role in the semantics of locatives: One for *movement-directional* interpretations, and the other for *stative-locational* interpretations.

Chapter 4 illustrates the linguistic applications of the formal apparatus developed in chapter 3 to interpret spatial expressions, and discusses two concepts, *symmetry* and *locative perspective*, involved in the semantics of locative PPs in English. In addition to the lexical semantics of locative prepositions — classified into four subgroups: *topological invariants*, *symmetric* locatives, *orientational* locatives, and *directional* locatives — we identify two special types of paths determined by locatives: *symmetric* paths and *homogeneous* paths. Finally we provide the semantics of perspectival interpretation of locative PPs in terms of binary preposition and deictic orientation. Throughout the whole chapter, we widely use the spatial primitives and relations introduced in Chaper 3.

Chapter 2

Primary Data: Semantic Types of Locative PPs

This chapter investigates the kind of semantic objects English locative PPs denote. When a certain category of linguistic expressions denote a set of semantic objects, we call the set *a semantic type* of the category. We will see there are basically two ways the locative PPs can be interpreted: First, we interpret locative PPs as *predicate modifiers* (cf. sections 2.1-2.2), and second, locative prepositions as *predicate extensors* (cf. section 2.3). Predicate modifiers are functions mapping n-ary relations to n-ary relations, whereas predicate extensors are those mapping n-ary relations to $(n+1)$-ary relations. The two semantic analyses will be unified in 2.4, where we give a symmetric semantics for the two semantic types of prepositions.

In section 2.2, we note that locative PPs do not denote a random set of functions from n-ary relations into n-ary relations, but they denote in a special subset of the functions, which we identify as *intersective functions*. The intersectivity constraint comes from the intuition that locative PPs are extensional and refer to the location or trajectory of arguments of the predicates they modify. In addition to unary predicate modifiers, we identify *binary predicate modifiers* which extends the expressive power of locative PPs.

2.1. Locative PPs as Predicate Modifiers

2.1.1. Predicate Modifiers

Following the tradition of Montague (1973) and Keenan and Faltz (1985), we treat locative PPs as predicate modifiers, i.e., they combine with a one-place predicate (intransitive verb) to make another one-place predicate. For example, (1) below has a locative PP *into the library* which modifies the one-place predicate *walked.*

(1) *The boys walked into the library*

Here we adopt the apparatus of Flexible Categorial Grammar (Moortgat 1988, Steedman 1989) and Type-Polymorphism (Keenan & Faltz 1985), and we start with primitive categories including n-place predicates. We assume n-place predicates denote sets of n-tuples over the universe entities, i.e., n-ary relations. We use the syntax and semantics of *Function Application* of categorial grammar defined as follows:[1]

(2) *Function Application* (A):

a. Semantics: $A(f)(x) = f(x)$

b. Syntax: $Y/X + X = Y$

$X + Y\backslash X = Y$

[1]We will use more features of Flexible Categorial Grammar in interpreting scope ambiguity in Appendix to Chapter 2, where we make use of Function Composition [B] and Type lifting [T and VL].

As shown in the syntax of Function Application, we use two slashes ('/' and '\') to refer to relative positions between a function and an argument: Thus, a function of type Y/X ("Y over X") looks for an argument of type X to its right, and a function of type Y\X ("Y under X") looks for an argument of type X to its left.

Labelling one-place predicates P1, we assign the predicate modifier *into the library* the syntactic category of P1\P1. The same PP, however, can modify two-place predicates, three-place predicates and so on. Thus, the sentence (3) contains a two-place predicate *saw* and the locative PP *in the garden* which we treat as combining with *saw* to yeild a derived P2 *saw in the garden.*

(3) *John saw Mary in the garden*

Fully generalizing the modifier categories, then, we treat locative PPs polymorphically as taking *n*-place predicates to give *n*-place predicates for $n \geq 1$. We label the category Pn\Pn. The semantic type for Pn\Pn would be the functions from *n*-ary relations to *n*-ary relations. We might sketch the interpretation of (3) as follows:

(4) *in the garden* Pn\Pn: **in-the-garden**
saw P2: **saw**
saw in the garden
P2: **in-the-garden(saw)**
saw Mary in the garden
P1: **(in-the-garden(saw))(mary)**
John saw Mary in the garden
P0: **(in-the-garden(saw))(mary)(john)**

Since a locative PP denotes a predicate modifier, a preposition is interpreted as a function from NP denotations to predicate modifier denotations. Thus the category of prepositions is (Pn\Pn)/NP.

2.1.2. Semantic Structures of Predicates and Modifiers – Boolean Semantics

Before we discuss denotational constraints on locative PPs, let us briefly consider an extensional logic we use for the semantics of locatives. We follow the formal extensional logic developed by Montague (1970, 1973) and Keenan and Faltz (1985). As in Keenan and Faltz (1985), we crucially use boolean algebras to represent the semantic structures of linguistic categories in natural language. In the rest of the thesis, we fix the universe $\mathbb{E}$ and hold it constant.

2.1.2.1. Predicate Algebras

Following Keenan and Faltz (1985), we characterize the semantic structures of predicates and modifiers in terms of *boolean algebra.* This thesis will use the following definition of boolean algebra.[2]

[2]We have a familiar alternative definition to (5): The following defines a boolean algebra as a six-tuple.
Definition:

β is a boolean algebra iff β is a six-tuple $\langle \mathbf{B}, 0_\beta, 1_\beta, \wedge_\beta, \vee_\beta, '_\beta \rangle$ where **B** is a non-empty set called the *domain* of the algebra β, 0_β and 1_β are elements of **B**, called the *zero* and *unit* elements respectively, $\wedge_\beta$ and $\vee_\beta$ are binary functions on **B** (i.e., functions from $\mathbf{B}\times\mathbf{B}$ into **B**) called *meet* and *join* respectively, and $'_\beta$ is a unary function on **B** called *complement*, which satisfy the following conditions (We omit the subscript β in the statement of the conditions): For all x, y, z$\in$**B**,

(a) $0 \neq 1$

(5) Definition:

β is a boolean algebra iff β is a pair <**B**, $\leq$> where **B** is a non-empty set called the *domain* of the algebra β, $\leq$ is the binary relation between elements in **B**, which satisfy the following conditions,

(a) $\leq$ is a partial order: reflexive, antisymmetric, and transitive,[3]

(b) β is a lattice, i.e., for all x, y$\in$**B**, {x, y} has a *greatest lower bound*, $\wedge$\{x, y\} (or x$\wedge$y "x *meet* y"), and a *least upper bound*, $\vee$\{x, y\} (or x$\vee$y "x *join* y"), which are defined in (6) and (7),

and provably the greatest lower bound and the least upper bound are unique to {x, y},

(c) meets and joins are distributive, i.e., for all x, y, z$\in$**B**, $(x\wedge(y\vee z)) = (x\wedge y) \vee (x\wedge z)$ and $(x\vee(y\wedge z)) = (x\vee y) \wedge (x\vee z)$,

(d) there are 0_β and $1_\beta \in$ **B**, called the *least* (or *zero*) and the *greatest* (or*unit*) elements, respectively, defined by:

For all x$\in$**B**, $0_\beta \leq x$ and $x \leq 1_\beta$, and

(e) for all x$\in$**B**, there is y$\in$**B** such that $(x\wedge y) = 0$ and $(x\vee y) = 1$.

(6) Definition:

For **B** an arbitrary boolean algebra and D any subset of **B**,

(a) a *lower bound* (lb) for D in **B** is an element x$\in$**B** such that

for all d$\in$D, x$\leq$d;

(b)	$x\wedge y = y\wedge x$ $x\vee y = y\vee x$	(Commutativity Laws)
(c)	$(x\wedge(y\vee z)) = (x\wedge y)\vee(x\wedge z)$ $(x\vee(y\wedge z)) = (x\vee y)\wedge(x\vee z)$	(Distributivity Laws)
(d)	$(x\wedge x') = 0$ $(x\vee x') = 1$	(Complement Laws)
(e)	$(x\vee 0) = x$ $(x\wedge 1) = x$	(Laws of zero and unit)

[3]A partial order $\leq$ in a boolean algebra **B**, by definition, satisfies the following: (i) reflexive, i.e., for all x$\in$**B**, x$\leq$x; (ii) transitive, i.e., for all x, y, z$\in$**B**, if x$\leq$y and y$\leq$z, then x$\leq$z; and (iii) antisymmetric, i.e., for all x, y$\in$**B**, if x$\leq$y and y$\leq$x, then x=y.

(b) an *upper bound* (ub) for D in **B** is an element $x \in$ **B** such that for all $d \in D$, $d \leq x$.

(7) Definition:

For **B** an arbitrary boolean algebra and D any subset of **B**,

(a) an element $x \in$ **B** is a *greatest lower bound* (glb) for D iff

(i) x is a lb for D and

(ii) for all lower bounds y for D in **B**, $y \leq x$;

(b) an element $x \in$ **B** is a *least upper bound* (lub) for D iff

(i) x is an upper bound for D and

(ii) for all upper bounds y for D in **B**, $x \leq y$; and

(c) if D has a glb it is denoted $\wedge D$; if D has a lub it is denoted $\vee D$.

For example, *formulas* in standard first order logic denote a truth value of {0 (=False), 1 (=True)}, and the truth value set, simply named **2**, has been characterized as a boolean algebra <**2**, ≤> where the order ≤ is defined as follows: $0 \leq 0$, $0 \leq 1$, $1 \leq 1$; and the order is a partial order, i.e., ≤ is reflexive, transitive, and antisymmetric. This boolean algebra then interprets conjunction, disjunction, and negation of formulas as the meet, join, and complement functions, respectively. The above definitions use different names for a boolean algebra (β) and its domain (**B**), but the thesis hereafter will use the name of the domain (**B**) for the name of algebra if no confusion arises.

Now we claim that the semantic type (the denotation set) of *n*-place predicates in English forms a boolean algebra. In other words, for any set of *n*-tuples of individuals, there is a *n*-place predicate in English denoting the relation. Keenan and Faltz (1985) take *n*-place predicates as denoting homomorphic functions mapping NP-denotations into the (n-1) place predicate denotations. For example, a transitive verb is interpreted as a function taking NP denotations (sets of sets of properties as in Montague (1973)) into one-place predicate denotations (properties).[4]

We rather simplify the semantic types of predicates, but assign a polymorphic type for NPs. That is, we just take n-place predicates as denoting sets of n-tuples of individuals (i.e., n-ary relations over a universe Ξ), and NPs as denoting a function from (n+1)-ary relations to n-ary relations, which are pointwise over relations.

Now it is straightforwad to see that the set of n-ary relations form a boolean algebra ($\mathbf{R}^n$, $\leq$) where the partial order $\leq$ is the subset relation ($\subseteq$) in a power set algebra and the least element is the empty set ($\emptyset$) and the greatest element is the entire set of n-tuples over the universe. For the case of unary relations (i.e., $\mathbf{P}$ (or $\mathbf{R}^1$), the set of properties), ($\mathbf{P}$, $\leq$) is a boolean algebra with the least element $0_{\mathbf{P}} = \emptyset$, and the

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[4]Keenan and Faltz (1985) claim that the semantic type (the set of possible denotations) of n-place predicates, i.e., n-ary relations, forms a boolean algebra which satisfies the conditions stated as follows:
Definition (Keenan and Faltz 1985:101)

> For all $n \geq 0$, T_{P_n}, the semantic type for n-place predicates, is defined inductively as follows:
> (a) $T_{P_0} = \mathbf{2}$.
> (b) $T_{P_{n+1}}$ is the set of complete homomorphisms from the set of NP denotations into T_{P_n}, regarded as a complete and atomic boolean algebra where the operations are defined pointwise on the individuals.

Putting aside the formal definitions of *homomorphisms*, and *complete/atomic/pointwise* boolean algebras, we just note that the conditions in the above definition reflect the intuition illustrated in the following (Keenan & Faltz 1985:87). That is, (ia) entails (ib), and (ib) and (ic) are logically equivalent; and each pair of sentences in (ii-iii), are logically equivalent, but (iva) and (ivb) are not.

(i)	a.	*John spoke*
	b.	$\models$ *Either John or Mary spoke*
	c.	= *Either John spoke or Mary spoke*
(ii)	a.	*Either every student or every teacher spoke*
	b.	= *Either every student spoke or every teacher spoke*
(iii)	a.	*John was either singing or dancing*
	b.	= *Either John was singing or John was dancing*
(iv)	a.	*Every student sing or dance*
	b.	$\neq$ *Every student sing or every student dance*

greatest element $1_P = \exists$, the entire set of individuals. So for English one-place predicates, the greatest element of the semantic algebra would be a property denoted by *exist (in the domain of discourse)*, and the least element would be its complement denoted by *not exist (in the domain of discourse)*

Due to the general structure of boolean algebra, as Keenan and Faltz (1985) note, now for any boolean category there will be an entailment relation among its expressions. For example, *John walks slowly* entails *John walks*, since the denotations of *walks slowly* and *walks* are ordered in terms of the partial order in the algebra of properties (one-place predicate denotations). Furthermore, since the boolean structure directly interprets conjunction, disjunction, and negations of expressions in that category, the following entailment patterns follow immediately:

(8) a. *John walks and talks* entails
$\models$ *John walkes* and
$\models$ *John talks*

b. *John walks* entails
$\models$ *John walks or talks*

c. *John neither walks nor talks* entails
$\models$ *John does not walk* and
$\models$ *John does not talks*

2.1.2.2. Modifier Algebras

Locative PPs are interpreted as *extensional* in the sense that for all one-place predicates S and T, and **f** a locative PP function, if S'=T', i.e., they denote the same set of individuals, then **f**(S') = **f**(T'). For example, if the individuals who walk are the same as those who sing, then the walkers in the park should be the same as those who sing in the park. Keenan and Faltz (1985) claim that, in general, extensional modifiers donote *restricting* functions, defined by (9). The order, $\leq$, in a boolean algebra is partial as defined in 2.1.2.1, and it corresponds to the subset relation ($\subseteq$) in a power set algebra.

(9) Definition:

Let **B** be a boolean algebra, and let $f \in [\mathbf{B} \rightarrow \mathbf{B}]$, the set of functions from **B** into **B**. Then f is *restricting* iff for each $x \in \mathbf{B}$, $f(x) \leq x$.

For instance, the PP *in the park* in (10) modifies the one-place predicate *was running*, and the PP restricts the denotation of the predicate, so (10) entails *John was running*. In other words, the set of runners in the park is a subset of the set of runners.

(10) *John was running in the park.*

Such restricting functions are identified in other constructions with extensional modifiers. When an attributive adjective modifies a common noun, it denotes a restricting function (Keenan & Faltz 1985). The adjective *tall* in (11) below modifies *student* and denotes a restricting function, so (11) entails *John is a student.*

(11) *John is a tall student.*

Predicate modifiers are functions from n-ary relations into n-ary relations, and the set of restricting functions of predicate modifiers forms a boolean algebra. Keenan and Faltz (1985) gives the following theorem identifying the boolean algebra of restricting functions.

(12) Theorem (Keenan and Faltz 1985:129):

Let $R_{[\mathbf{B}\to\mathbf{B}]} = \{f\in[\mathbf{B}\to\mathbf{B}]$: f is restricting$\}$, where $\mathbf{B}$ is an arbitrary boolean algebra. Then $R_{[\mathbf{B}\to\mathbf{B}]}$ is a boolean algebra under the operations $\wedge$, $\vee$, and ' defined as follows: For f, $g\in R_{[\mathbf{B}\to\mathbf{B}]}$ arbitrary,

(i) $f\wedge g$ is defined by setting $(f\wedge g)(b) = f(b) \wedge g(b)$ for each $b\in B$.

(ii) $f\wedge g$ is defined by setting $(f\vee g)(b) = f(b) \vee g(b)$ for each $b\in B$.

(iii) f' is defined by setting $f'(b) = b \wedge (f(b))'$ for each $b\in B$.

But locative PPs in English do not denote the entire domain of restricting functions. We will present a significant constraint on their denotations in the next section.

We will also investigate the logical relationship among subtypes of Locative PP denotations, so in the following sections 2.2-2.3, we will look at the denotational constraints of locative PPs and the differences among different types of locative PPs. We will consider three types of locative PPs: (i) asymmetric stative (or orientational) locatives, (ii) asymmetric directional locatives, and (iii) symmetric locatives. In the last chapter 4, we get into the details of the semantics of individual locative PPs.

2.2. The Intersectivity Constraint on the Locative PP Denotations

In this section, we study denotational constraints on locative prepositional phrases (PPs) in English. The crucial claim we make is that locative PPs show a unique way of modifying predicates: i.e., *argument-orientation*. The patterns of argument orientation reveal a substantial constraint on possible interpretations of locative PPs in English. For example, one of the patterns identifies itself in a sentence such as (13) where the PP *in the garden* refers to the location of the object argument 'Mary' and so the PP is said to be interpreted as *object-oriented.*

(13) *John saw Mary in the garden*

In section 2.2.1, we review some claims of previous work on locative PP denotations: Keenan and Faltz (1985) and Crow (1989), among others. Keenan and Faltz (1985), restricting data to *stative* locatives, claim that stative locatives denote intersective functions from *n*-ary relations to *n*-ary relations, but they do not generalize the claim for non-stative (directional or symmetric) locatives. Crow (1989), agreeing with Keenan and Faltz's claim, tries to characterize non-stative locatives as non-intersective. However, extending the claim of Keenan and Faltz (1985), we will show that non-stative locatives also denote intersective functions.

In the subsequent section 2.2.2, we illustrate four patterns of *argument orientation* of locative PPs; and in 2.2.3, many different classes of predicates are examined in terms of argument orientation. The argument orientation patterns illustrated in the sections provide a basis for identifying the denotational constraints in the subsequent section 2.2.4, where we find a non-trivial logical property which the unary and binary PPs have in common: Namely, the n-place PPs are isomorphic to the set of intersective functions from n-place predicates to n-place predicates, all $n \in \{1,2\}$. This work then supports the view that two place predicates (transitive verb phrases) should be categorially distinct from one place ones (verb phrases). Thus, each has its own modifiers, and at least some two place ones are not reducible to boolean compounds or "lifts" of one-place ones. That is, there are functions f such that $(f(R))(x)(y) \neq f(R(x))(y)$ for binary relations R and individuals x and y.

2.2.1. Stative (Orientational) Locatives — Keenan & Faltz (1985), Crow(1989)

We treated, in 2.1, locative PPs as denoting predicate modifiers, i.e., functions from n-ary relations to n-ary relations. In general, extensional modifiers denote restricting functions (Keenan & Faltz 1985). Now we note that locative PPs denote in a proper subset of the restricting functions, namely the *intersective* functions defined as follows:

(14) Definition:[5]

> Let **B** be a boolean algebra, and let $f \in [\mathbf{B} \rightarrow \mathbf{B}]$ be arbitrary. Then f is *intersective* iff there is some $y \in \mathbf{B}$, such that for all $x \in \mathbf{B}$, $f(x) = x \wedge f(y)$.

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[5]Keenan and Faltz (1985:123) define *intersective* functions as follows:
Definition: Let **B** be a boolean algebra, and let $f \in [\mathbf{B} \rightarrow \mathbf{B}]$ be arbitrary.
Then f is *intersective* iff for each $x \in B$, $f(x) = x \wedge f(1_B)$, where $1_\mathbf{B}$ refers to the greatest (unit) element in **B**.
Thus, each intersective function determines its value when applied to the unit in **B**. The definition given in (14) looks more general than the above one, but proveably they define exactly the same set of functions.

By definition, f is intersective just in case $f(x) = x \wedge f(y)$ for some y. In other words, an intersective function (f) determines a unique value (f(y)) in terms of a certain element (y) in its domain: For example, the attributive adjective *male* denotes an intersective function from properties to properties since it determines a property 'male individual'.[6] Thus, *male students* are students and male individuals, i.e., **male** (**student**) = **student** $\wedge$ **male** (**individual**). The property denoted by (*being an*) *individual*' might well be identified as the greatest element ($1_{\mathbf{P}}$) in the property algebra (**P**), so every object in Ξ has the property. Keenan and Faltz (1985) defines *intersective* functions in terms of the greatest element ($1_{\mathbf{B}}$) in the boolean algebra **B** as in the footnote 6.

The set of properties **P** forms a boolean algebra $\langle \mathbf{P}, \leq \rangle$ where the partial order $\leq$ is defined as the set-theoretic inclusion relation, and greatest lower bounds ($\wedge$), least upper bounds ($\vee$), and complements (') provide denotations for conjunctions, disjunctions, and negations of properties. Thus we can interpret *and, (either)–or, not*, and *neither–nor–* as boolean operations or their compounds. The unit (greatest) element of the algebra ($1_{\mathbf{P}}$) is the property that every individual has, and the zero element ($0_{\mathbf{P}}$) is the property that no individual has. Keenan and Faltz (1985) refer to the unit element as '**exist**', since 'x exists' is true for all individuals x. In the context of PPs, it is more natural to write simply '**be**' for the unit element. The following sentence (15a) entails (15b), and vice versa. Thus we see that *in the park* determines a unique property 'being in the park', and the PP denotes an intersective function from properties to properties as shown in (15c).

[6] An attributive adjective like *male* denotes a function from properties to properties, when it modifies common nouns. Here, following Keenan and Faltz (1985), we interpret common nouns as denoting a property, i.e., a set of individuals.

(15) a. *John is jogging in the park*

b. *John is jogging and John is in the park*

c. **in-the-park(jogging) = jogging** $\wedge$ **in-the-park(be)**

Keenan and Faltz (1985) show that the stative locative PPs (ones headed by *in*, *on*, *at*, *under*, *above*, *in front of*, *behind*, etc.) are isomorphic to the set of intersective functions from properties to properties. Generalizing this claim for PPs modifying n-ary relations, they note that the stative locatives denote *argument oriented* functions. The following definition is from Keenan and Faltz (1985), writing $\mathbf{R}^n$ for the set of n-ary relations over the universe, i.e., the set of possible denotations of n-place predicate.

(16) Definition [Keenan & Faltz 1985]:

The function $g \in [\mathbf{R}^n \rightarrow \mathbf{R}^n]$, is *argument-oriented of degree n* iff, for each n-ary relation $f \in \mathbf{R}^n$ and for each set of n individuals $I_1, ..., I_n$, the following equation holds:

$(g(f))(I_n)...(I_1) = f(I_n)...(I_1) \wedge g(1_{\mathbf{P}})(I_n)$

(17) Definition [Keenan & Faltz 1985]:

The function $g \in [\mathbf{R}^n \rightarrow \mathbf{R}^n]$, is *argument-oriented* iff it is argument-oriented of degree n for every $n \geq 1$.

Thus the stative locative PPs are claimed to denote argument oriented functions mapping n-ary relations into n-ary relations, which claims by definition that a locative PP determines a property restricting the (immediate) n-th argument of n-ary relations. For example, the following sentences of (18) contain an argument-oriented PP, and the

PP determines the property of 'being in the garden'. Thus the property restricts the subject argument in (18a), and the object argument in (18b).

(18) a. *John is singing in the garden*

b. *John saw Mary in the garden*

Thus (18b) is interpreted roughly as: **in-the-garden**(**see**)(**mary**)(**john**) = **see**(**mary**)(**john**) $\wedge$ **in-the-garden**(**be**)(**mary**), i.e., (18b) is logically equivalent to 'John saw Mary and Mary was in the garden'.

Now let us briefly review Crow's (1989) discussion on intersective and non-intersective locatives. Crow(1989:163) gives an informal definition of intersective locatives as follows:

> "A simple locative is intersective if it defines a property which holds of individuals (objects, events, states) which (simultaneously) satisfy both a predicate and locative modifier. For example, *is sleeping in a tree* is satisfied by those individuals who are both *sleeping* and *in a tree*."

Crow claims, as Keenan and Faltz (1985) do, that *stative* (or *static*) locatives are intersective, and that "*path* locatives do not appear to be uniformly intersective; there are cases which can be construed as intersective and others which are definitely not."(Crow 1986:165) Then considering the sentence (19), she wonders what it means for an object to be (simutaneously) *running* and *to Rumphius.*

(19) *Ailey is running to Rumphius*

(20) a. *Ailey is skipping toward Rumphius*

b. *Ailey is walking through the yard*

The other examples (20a) and (20b), which are also from Crow (1989), at first glance seem to be suggesting that *non-stative* (i.e., *directional* or *symmetric*) locatives are not intersective. In the subsequent sections, however, we will see that non-stative locatives also denote intersective functions with a generalized domain.

2.2.2. Argument Orientations of Locative PPs

This section illustrates one of the important semantic properties of locative PPs: The locative PPs are interpreted as *argument oriented* functions — they refer to the location or trajectory of arguments. This property is crucial to identify *intersectivity* constraint on the denotations of locative PPs. We also extend the data to include non-stative locative PPs (symmetric or directional PPs), which are not considered in Keenan & Faltz (1985).

The non-stative locative PPs, like stative ones, refer to the location or trajectory of arguments, so they can locate the subject argument of intransitive verbs or the object argument of transitive verbs. Further, they can locate the subject argument of transitive verbs. For example, the locative PPs in (21a,b) below refer to not only the location of 'Mary' but also the location of 'John', the subject, so they locate both the subject and the object arguments.

(21) a. *John escorted Mary into the theater*
b. *John saw Mary through the window*

In (21a), *into the theater* refers to the trajectory of both 'John' and 'Mary', and *through the window* in (21b) indicates spatial relation between 'John' and 'Mary', that is, 'John and Mary are on the opposite sides of the window'. Such PPs are said to be oriented to multiple arguments.

Now we illustrate argument orientation patterns in detail, since the patterns reveal a substantial constraint on the interpretation of locative PPs. Then we will consider the issue of denotational constraints on locative PPs. In the literature on event semantics, locative phrases are treated as locating events or states. So in the sentence *John saw Mary in the garden*, the locative PP *in the garden* is locating the 'seeing-event'. Then what does it mean to say a 'seeing-event is located in the garden'? There has been agreement that locating an event or a state is locating participants of the event or state. To clarify this, Sondheimer (1978) exploits meaning-postulates, and Parsons (1990) gives a general principle of locating participants.[7]

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[7]Sondheimer's (1978) position is on the track of lexicalism, but Parsons (1990), claiming every verb takes a Theme-argument, proposes the following:

> "Using 'onto' and 'on' as a paradigm, my proposal is this: Any event that is onto something results in a state of being on that thing. The Themes of the event and the state are the same. ... This postulate, which is independent of any choice of verb, yields all of the following inferences when applied to the logical forms of the sentences:
>
> Mary will throw the ball onto the roof →
> The ball will be on the roof
> Mary will push the cow into the barn →
> The cow will be in the barn
>
> ......"(Parson 1990:79)

But we will see shortly that Parson's prediction is far from being true, i.e., locative PPs are not uniquely oriented to Theme arguments, no matter how it is defined in terms of "event types". For example, one locative PP can be oriented to multiple arguments, and also there are cases where we have ambiguity of argument orientation, e.g., *The policeman shot the suspect from the rooftop.*

Here we are not concerned with a syntactic or semantic account of which orientation pattern is involved in which construction, but we determine a typology of argument locating patterns of locative PPs. Following Keenan and Faltz (1985), we put them under the name of "argument orientation". Restricting ourselves to the sentences built from transitive verbs, we illustrate four types of argument orientation.

2.2.2.1. Object Orientation

The first pattern is *object-orientation* where locative PPs refer to the location or trajectory of an object argument. Thus formally,

(22) Definition:

For all functions $f \in [\mathbf{R}^2 \rightarrow \mathbf{R}^2]$, f is *object-oriented* (OO) iff
for all binary relations $S,T \in \mathbf{R}^2$, if $S_2 = T_2$ then $(f(S))_2 = (f(T))_2$,
where for all $R \in \mathbf{R}^2$, $R_2 =_{df.} \{\beta | \exists\alpha. <\alpha,\beta> \in R\}$.

In other words, object-oriented functions treat sets of second coordinates of binary relations uniformly. For instance, if at a particular point in time, 'those who are being sent by someone' and 'those who are being returned by someone' are identical, 'those who are being sent by someone to the library' and 'those who are being returned by someone to the library' are identical. The locative PPs in (23) are object oriented, and (23a,b) entail (24).

(23) a. *John threw the ball into the box*
b. *John kicked the ball into the box*

(24) $\models$ *The ball went into the box*

2.2.2.2. Subject Orientation

The second pattern is *subject-orientation* where locative PPs refer to the location of a subject argument. A general definition of subject-oriented predicate modifiers is given in (25). Here we write $\mathbf{R}^2$ for the set of binary relations over a given universe.

(25) Definition:

For all functions $f \in [\mathbf{R}^2 \rightarrow \mathbf{R}^2]$, f is *subject-oriented* (SO) iff for all binary relations $S,T \in \mathbf{R}^2$, if $S_1 = T_1$ then $(f(S))_1 = (f(T))_1$, where for all $R \in \mathbf{R}^2$, $R_1 =_{df.} \{\alpha | \exists\beta. <\alpha,\beta> \in R\}$, i.e., R_1 = the domain of R.

In other words, subject-oriented functions treat sets of first coordinates of binary relations uniformly. For instance, if at a particular point in time 'those who are criticizing someone' and 'those who are discussing someone' are identical, 'those who are criticizing someone at the meeting' and 'those who are discussing someone at the meeting' are identical. The locative PPs in (23a,b) are interpreted by subject-oriented functions. Thus, (26a,b) entail (27a) but not (27b).

(26) a. *John criticized the teacher at the meeting*

b. *John mentioned the teacher at the meeting*

(27) a. $\models$ *John was at the meeting*

b. $\not\models$ *The teacher was at the meeting*

2.2.2.3. Subject and Object Orientation

The third pattern is *subject and object-orientation* where locative PPs refer to the location or trajectory of a subject and an object argument independently. The definition goes:

(28) Definition:

For all functions $f \in [\mathbf{R}^2 \rightarrow \mathbf{R}^2]$, f is *subject and object-oriented* (S+O) iff f is both subject-oriented and object-oriented.

The PPs in (29) and (31) subject and object oriented, so (29) entails both (30a) and (30b), and (31) entails both (32a) and (32b).

(29) *John met Mary in the office*

(30) a. $\models$ *John was in the office* and

b. $\models$ *Mary was in the office*

(31) *John escorted Mary into the museum*

(32) a. $\models$ *John went into the museum* and

b. $\models$ *Mary went into the museum*

(30) and (32) use a single spatial property to locate arguments, so 'being in the office' is used in (30), and 'going into the museum' in (32). But, the sentences in (33) illustrate that a locative PP can refer to the locations of subject and object arguments with a pair of different spatial properties which are complements of each other, i.e.,

'being in the control tower' and 'not being in the control tower'. Thus both (33a) and (33b) entail (34).

(33) a. *John spied on Mary from the control tower*

b. *John saw Mary from the control tower*

(34) $\models$ *John was in the control tower and Mary was not in the control tower*

2.2.2.4. Subject-Object Orientation

The last pattern is *subject-object orientation* where locative PPs refer to a spatial dependency between the subject and the object arguments. For example, (35) entails (36), which imposes a unique spatial relation between the two arguments. The definition is given as (37) below:

(35) *John saw Mary through the window*

(36) $\models$ *John and Mary were on the opposite sides of the window*

(37) Definition:

For all functions $f \in [\mathbf{R}^2 \rightarrow \mathbf{R}^2]$, f is *subject-object-oriented* (S×O) iff for all $S \in \mathbf{R}^2$, if $<x,y> \in f(S)$ then $<x,y> \in R_f$, where R_f is a relation determined by f.

Thus, *through the window* in (35) determines a spatial relation R(x,y) = 'x and y are on the opposite sides of the window' which holds between the subject and the object argument.

This pattern is different from *subject and object orientation*(S+O) in that not all the functions in (S×O) cannot be reduced to a boolean compound of a subject-oriented function and an object-oriented function, while the latter functions in (S+O) can. We say that such PPs denote *binary predicate modifiers*. Symmetric locatives (PPs headed by *across*, *through*, *over*, *past*, and *around*) induce this pattern (S×O), and refer to a spatial dependency between subject and object arguments.

We note, without proof, relations among the argument oriented functions: First, if a function is subject and object oriented(S+O), then it is subject oriented(SO) and object oriented(OO). Second, if a function is SO or OO, then it is subject-object oriented(S×O), so SO⊆S×O and OO⊆S×O.

Argument oriented functions take a binary relation R as a pair of sets, i.e., $<R_1,R_2>$, where R_1 and R_2 refer to the set of first coordinates and that of the second coordinates, respectively, and restrict one or both of the sets. In other words, a locative PP modifying a binary relation R uniquely determines a function which restricts R_1 or/and R_2. We will show that such functions are restricting, increasing, and additive, and thus intersective. Further we will prove that the set of possible denotations of unary locative PPs (and binary ones) is isomorphic to the set of properties (and binary relations).

For instance, *into the room* induces the property P = 'move from outside to inside of the room' to restrict R_1 or/and R_2. Thus *x pushed y into the room* is true iff 'x pushed y' and 'y moved from outside to inside the room', i.e., **into the room** (**push**)(y)(x) = **push** (y)(x) ∧ P(y).

It is interesting to note that it is not natural to coordinate two locative PPs which are oriented to different arguments in a sentence, thus:

(38) *John saw a policeman either on the street corner or in front of Bill's house*

(39) a. **John saw Mary either in the garden or from the rooftop*

b. *John saw Mary in the garden from the rooftop*

c. *?John saw Mary from the rooftop in the garden*

(38) is good with a coordination of two object-oriented locative PPs, whereas (39a) is bad with a coordination of an object-oriented PP *in the garden* and a subject-oriented PP *from the rooftop*. (39b) has two PPs which are oriented to different arguments. We can give a correct semantics to (39b) by interpreting the PPs as modifying different predicates: The object-oriented PP *in the garden* modifies the two place predicate *saw* but the subject-oriented PP *from the rooftop* modifies the whole VP *saw Mary in the garden*, i.e., **from the rooftop** ((**in the garden** (**saw**)) (**mary**)) (**john**). We do not really require the adjacency of a function and its argument in surface structure, but the ordering of locative PPs in (39c) suggests that object-oriented PPs tend to be closer to the object NP than subject-oriented PPs do.

2.2.3. Types of Locative PPs and Predicates

This section illustrates various classes of transitive verbs with which locative PPs induce argument orientations. Here we consider four types of locative PPs:

(40) a. Stative Locatives: PPs with *in, on, under, above, in front of, behind*

b. Directional Locatives: PPs with *into, out of, onto, off, up, down*

c. Symmetric Locatives: PPs with *across, through, over, past, around*

d. Source Locatives: PPs with *from*

The four types show different syntactic and semantic characteristics. In the following, we give examples of combination of two place predicates and locative PPs. To the right of each example, we noted the argument orientation pattern of the locative PP in the example. For simplicity, the following abbreviation is used: O(object-orientation), S(subject-orientation), S+O(subject and object orientation), S×O(subject-object orientation).

(41) Motion-Causative verbs:

draw, drag, pull, push, throw, hit, knock, run, walk, jump

Verbs of Sending/Carrying:

mail, convey, deliver, pass, return, carry, take, bring

a. *John drew the box in/into the room* [O]

b. *Kim pushed Mary off the bed* [O]

c. *Sue threw the ball across the field* [O]

d. *Sue passed the book across the table* [O]

e. *Tom took the kids from their school* [O]

(42) Verbs of Placement: *place, arrange, install, position, set, situate, put*

Verbs of Hunting: *dig, hunt, mine, shop, watch*

a. *John installed the machine in the office* [O]

b. *Kim dug a fork into/out of the pie* [O]

c. *Sarah watched the man across the street* [O]

d. **Sarah put the book from the bag*

As (42d) shows, verbs of 'placement' or 'hunting' do not go with a source locative like *from the bag*. (42c) is ambiguous that the reference point for the PP can be interpreted deictically (e.g., 'from here') or as given by the location of Sarah (i.e., 'from Sarah'). Both of the readings induce object-orientation of *across the street.*

(43) Verbs of Combining/Attaching: *mix, whip, tape*
Verbs of Housing: *house, contain, fit, hold, seat, sleep, store, serve*

	a.	*John mixed water and flour on the plate*	[O]
	b.	*They sleep four people in each room*	[O]
	c.	*The captain housed the soldiers in the big hotels*	[O]

(44) Verbs of Perception:
find, see, touch, feel, hear, sense, observe, examine, discover, watch
Verbs of Communication: *call, wire, cable*
Verbs of Contact: *touch, pat*

	a.	*John found Mary in the garden*	[O]
	b.	**John found Mary into the garden*	
	c.	*John touched Mary across the table*	[S×O]
	d.	*John watched Mary from the rooftop*	[S+O]

The verbs of perception exibit three different types of argument orientation: (44a) is an example of object orientation; (44c) subject-object orientation so the PP *across the table* refers to a spatial dependency between John and Mary, i.e., 'John and Mary are on the opposite sides of the table'. (44d) is another example of mutiple orientation but a different one from (44c): (44d) entails 'John was on/at the rooftop' and 'Mary was not on/at the rooftop', so the PP *from the rooftop* involves the locations of John and Mary but independently. This type of argument orientation (S+O) is illustrated by other transitive verbs below.

(45) Verbs of Co-movement: *escort, accompany, chase, follow, tail, lead, guide*

a. *John escorted Mary in/into the museum* [S+O]

b. *The dog chased the cat across the garden* [S+O]

c. *The teacher led the kids from the playground* [S+O]

(46) Verbs of Social Interaction: *meet, date, hug, marry, fight, visit, quarrel*

a. *John met Mary at the meeting* [S+O]

b. **John visited Mary into her office*

The lexical meaning of each verb in (45-46) naturally implies the subject and the object arguments are located in the same place and locative PPs refer to it. Finally, we illustrate verbs which only induce subject orientation of locative PPs.

(47) Verbs of Judgement: *criticize, compliment, honor, thank, insult, ridicule*
Psych-verbs: *adore, idolize, miss, worship, despise*
Intensional verbs: *search for, look for, seek, mention*

a. *John criticized Mary at the meeting* [S]

b. *John was looking for a knife in the kitchen* [S]

c. *John mentioned Mary at the meeting* [S]

(Table-1) below summarizes the facts we have seen in this section. The stars (*) in the table indicate the relevant combinations are not acceptable. We note the following facts from the table:

(i) If a non-stative locative combines with a transitive verb, it is always oriented to the object argument. That is, it can be either O, S+O, or S×O;

(ii) if a transitive verb can combine with a non-stative locative, then stative locatives are object-oriented with that verb, i.e., either O or S+O;

(iii) only symmetric locatives can be S×O, i.e., other locatives are all reducible in terms of unary locative functions; and

(iv) there is only one case where PPs exclusively involve subject-orientation [S]: verbs of 'judgement', psych-verbs, and intensional verbs. This suggests that object orientation is more basic than subject orientation.

Table-1: Argument Orientation Patterns of Locative PPs with Transitive Verbs

	Stative Loc.	Directional Loc.	Symmetric Loc.	Source Loc.
Motion-Causatives, Verbs of 'Sending/Carrying'	**O**	**O**	**O**	**O**
Verbs of Placement, Verbs of 'Hunting'	**O**	**O**	**O**	*
Verbs of 'Combining/Attaching', Verbs of 'Housing'	**O**	**O**	*	*
Verbs of 'Perception', Verbs of 'Communication', Verbs of 'Contact'	**O**	*	**S×O**	**S+O**
Verbs of 'Co-movement'	**S+O**	**S+O**	**S+O**	**S+O**
Verbs of 'Social Interaction'	**S+O**	*	*	*
Verbs of 'Judgement', Psych-verbs, Intensional verbs	**S**	*	*	*

[B. Levin (1993) for most of the verb classes]

2.2.4. The Intersectivity Hierarchy for Locative PPs

This section establishes a general claim that n-place locative PPs denote intersective functions from n-ary relations to n-ary relations, all $n \in \{1,2\}$. (See 2.2.1 for the definition of *intersective functions*.) That is, unary locative PPs denote intersective functions from properties to properties, and binary ones denote intersective functions from binary relations to binary relations.

In order to figure out this *intersectivity hierarchy*, we characterize three denotational contraints on the interpretation of locative PPs in English. We claim: English locative PPs are interpreted as denoting (i) *restricting* functions, (ii) *monotone increasing* functions, and (iii) *additive* functions. Due to the constraint of (iv) *argument-orientation* discussed in the preceding sections, these bring us a highly restrictive class of functions the locative PPs can denote, namely *intersective* functions.

In the following, we illustrate that locative PPs should satisfy the constraints. The four constraints (i-iv) are nearly independent from each other, so none of the constraints implies any one of the others except that (iii) *additivity* implies (ii) *monotone increasing*.

First, locative PPs denote *restricting* functions (the definition repeated in (48)). Thus (49a) entails (49b), i.e., **in-the-garden** (**sing**) is a subset of the property **sing**.

(48) Definition:

Let **B** be a boolean algebra, and let $f \in [\mathbf{B} \rightarrow \mathbf{B}]$ be arbitrary.
Then f is *restricting* iff for each $x \in \mathbf{B}$, $f(x) \leq x$.

(49) a. *John is singing in the garden*
b. $\models$ *John is singing*

Second, locative PPs denote *monotone increasing* functions defined as in (50). (a)-sentences in (51-53) entail (b)-sentences, respectively. These illustrate locative PPs denote monotone increasing functions mapping unary/binary relations to unary/binary relations.

(50) Definition:

Let **B** be a boolean algebra, and let $f \in [\mathbf{B} \to \mathbf{B}]$ be arbitrary. Then f is *monotone increasing* iff for all $x, y \in \mathbf{B}$, if $x \leq y$, then $f(x) \leq f(y)$.

(51) a. *John roughly pushed Mary into the bus*

b. *John pushed Mary into the bus*

(52) a. *John drove from LA to San Jose*

b. *John went from LA to San Jose*

(53) a. *John saw and touched Mary through the window*

b. *John saw Mary through the window and John touched Mary through the window*

In (51a), *into the bus* is interpreted as a monotone increasing function since the two place predicate *roughly pushed* denotes a subset of the set denoted by *pushed* in (51b) and *roughly pushed into the bus* denotes a subset of the set denoted by *pushed into the bus*: That is, **roughly(push)** $\subseteq$ **push**, so **into the bus (roughly(push))** $\subseteq$ **into the bus (push)**. As for (52), since **drive** $\subseteq$ **go**, so **from LA to San Diego (drive)** $\subseteq$ **from LA to San Diego (go)**. In (53), since **see and touch** $\subseteq$ **see** and **see and touch** $\subseteq$ **touch**, so **through the window (see and touch)** $\subseteq$ **through the window (see)** and **through the window (see and touch)** $\subseteq$ **through the window (touch)**.

Now we show locative PPs denote *additive* functions defined by (54). The locative PPs in (55a) and (56a) are interpreted as an additive function, thus the (a)-sentences of (55-56) entail the (b)-sentences, respectively, and vice versa.

(54) Definition:

Let **B** be a boolean algebra, and let $f \in [\mathbf{B} \rightarrow \mathbf{B}]$ be arbitrary. Then f is *additive* iff for all $x,y \in \mathbf{B}$, $f(x \vee y) = f(x) \vee f(y)$.

(55) a. *John walked or jogged in the park*

b. $\leftrightarrow$ *John walked in the park or John jogged in the park*

(56) a. *John kicked or threw the ball over the fence*

b. $\leftrightarrow$ *John kicked the ball over the fence or John threw the ball over the fence*

The locative PP *over the fence* in (56a) modifies the complex two place predicate *kicked or threw*, and the sentence entails (56b), and vice versa: That is, **over the fence** (**kick** $\vee$ **throw**) = **over the fence** (**kick**) $\vee$ **over the fence** (**throw**).

The fourth constraint is *argument orientation* of locative PPs. The following just refers to the definitions of *subject orientation* and *object orientation* given in the previous section. We claim that locative PPs denote argument-oriented functions.

(57) Definition:

For all functions $f \in [\mathbf{R} \rightarrow \mathbf{R}]$ where $\mathbf{R} = \mathbf{P} \cup \mathbf{R}^2$, the set of unary or binary relations (over $\mathbb{E}$ assumed given), f is *argument-oriented* iff f is subject-oriented or object-oriented.

The domain of argument-oriented functions includes unary relations (properties) as well as binary relation. When they modify a binary relation R, they take R as a pair of sets, i.e., $<R_1,R_2>$, and each function affects R_1 or/and R_2 depending on whether it is subject-oriented or/and object-oriented. Thus, an object-oriented function and a subject-oriented function determine a certain (intersecting) property to restrict the set R_1 and R_2, respectively, for R a relation it modifies. Let us define the set of such functions as follows (again, $\mathbf{R} = \mathbf{P} \cup \mathbf{R}^2$):

(58) Definitions:

$\mathbf{SO} =_{df.} \{f \in [\mathbf{R} \rightarrow \mathbf{R}] \mid$ f is restricting, increasing, additive, and subject-oriented$\}$

$\mathbf{OO} =_{df.} \{f \in [\mathbf{R} \rightarrow \mathbf{R}] \mid$ f is restricting, increasing, additive, and object-oriented$\}$

Now we can show that the two sets of functions are isomorphic to the set of intersective functions mapping properties (**P**) to properties (**P**) (Theorem-1).

(59) Theorem-1:

Both **SO** and **OO** are isomorphic to $INT_{[\mathbf{P} \rightarrow \mathbf{P}]}$, the set of intersective functions in $[\mathbf{P} \rightarrow \mathbf{P}]$. (Proof included in Appendix to Chapter 2)

By the following general theorem in (60), the set of intersective functions from properties into properties, $INT_{[\mathbf{P} \rightarrow \mathbf{P}]}$, has the cardinality of 2^n, and we get (61) Theorem-2.[8] Theorem (60) states that **B** is isomorphic to the set of intersective functions from **B** into **B**, thus they have the same cardinality.[9]

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[8]Let $\mathbb{E}$ be the universe of individuals and $|\mathbb{E}| = n$, then the set of denotations of one place predicates, **P**, has the cardinality 2^n, and the total number of functions from **P** into **P**, i.e., $|[\mathbf{P} \rightarrow \mathbf{P}]| = (2^n)2^n = 2n{\bullet}2^n$.

[9]However, there are locative phrases denoting non-intersective functions. For example, the sentence *John jogged in no park* does not entail 'John jogged', suggesting the PP denotes a non-intersective function. Since the sentence means 'John did not jogged in a park', we interpret *in no park* as denoting a boolean complement of *in a park*, and so we might include the complements of intersective functions in the denotation set of locative phrases, which can be stated as follows:

(60) Theorem (Keenan and Faltz 1985:147):

Let **B** be a boolean algebra, and let the function u: $[\mathbf{B}\rightarrow[\mathbf{B}\rightarrow\mathbf{B}]]$ be defined as follows: given $b \in \mathbf{B}$, u(b) is that function from **B** into **B** such that for each $c \in \mathbf{B}$, $(\mathrm{u}(b))(c) = c \wedge b$. Then u is an isomorphism of **B** onto $INT_{[\mathbf{B}\rightarrow\mathbf{B}]}$, the set of intersective functions from **B** into **B**.

(61) Theorem-2:

Both **SO** and **OO** are isomorphic to the set of properties **P**.

(59) and (61) state a main result on the denotational constraints for unary locative PPs. This result also holds true for binary locative PPs: Each binary locative PP (symmetric locatives) uniquely determines a spatial relation between two arguments. And, as we showed for unary locatives, such locatives denote restricting, increasing, and additive functions, thus the set of their denotations is isomorphic to the set of intersective functions from $\mathbf{R}^2$ into $\mathbf{R}^2$, and so isomorphic to the set of binary relations ($\mathbf{R}^2$). Formally, with the definition in (62), we get (63) and (64):

The algebra of predicate modifier functions is *the algebra generated by intersective functions closed under pointwise meets, joins, and complements.*

This algebra generated by intersective funtions shows a new structure which is a minimal extension of the intersective algebra in the sense that only the complements of the intersective functions are added to it to form a pointwise boolean algebra. We note: Let $|\mathbb{E}| = n$, then the denotations of one place predicate $|\mathbf{P}| = 2^n$ and so the set of intersective functions, $INT_{[\mathbf{P}\rightarrow\mathbf{P}]}$, has the cardinality of 2^n and $|[\mathbf{P}\rightarrow\mathbf{P}]| = (2^n)^{2^n}$. Now, (a) if we close $INT_{[\mathbf{P}\rightarrow\mathbf{P}]}$ under complements the resulting set will be of cardinality of $2 \cdot 2^n$, and (b) if we close this under meets and joins the cardinality of the set would still be $2 \cdot 2^n$. This closure forms a pointwise boolean algebra (like an argument-algebra).

(62) $\mathbf{S}\times\mathbf{O} =_{df.} \{f \in [\mathbf{R}^2 \rightarrow \mathbf{R}^2] \mid$ f is restricting, increasing, additive, and subject-object oriented$\}$

(63) Theorem-3:

$\mathbf{S}\times\mathbf{O}$ is isomorphic to $INT[\mathbf{R}^2 \rightarrow \mathbf{R}^2]$, the set of intersective functions in $[\mathbf{R}^2 \rightarrow \mathbf{R}^2]$. (Proof follows the pattern of Theorem-1)

(64) Theorem-4: $\mathbf{S}\times\mathbf{O}$ is isomorphic to the set of binary relations $\mathbf{R}^2$.

For example, the locative PP in *John spied on Mary across the street* determines a spatial relation R(x,y) = 'x and y are on the opposite sides of the street', thus **across the street** (**see**)(y)(x) = **see** (x,y) $\wedge$ R(x,y). Finally, let us consider a sentence with a three place predicate and a binary locative PP:

(65) *John showed the picture to Mary through the window*

(65) contains a three place predicate *show* and a symmetric locative *through the window*. The PP is oriented to the second and third arguments, and the sentence entails 'the picture and Mary were on the opposite sides of the window'. Thus, the binary PP determines a spatial relation between the two arguments 'the picture' and 'Mary'. Notice that the PP does not randomly pick up arguments to be oriented to but a specific pair of arguments, i.e., the second and the third arguments.

APPENDIX to 2.2.4

—— Proof of Theorem-1

(59) Theorem-1:

Both **SO** and **OO** are isomorphic to $INT_{[\mathbf{P}\to\mathbf{P}]}$, the set of intersective functions in $[\mathbf{P}\to\mathbf{P}]$.

Proof: We show $INT_{[\mathbf{P}\to\mathbf{P}]}$ is isomorphic to **SO**, then it follows analogously that $INT_{[\mathbf{P}\to\mathbf{P}]}$ is isomorphic to **OO**. Let the function h: $INT_{[\mathbf{P}\to\mathbf{P}]}\to\mathbf{SO}$ be defined as follows: Given $f\in INT_{[\mathbf{P}\to\mathbf{P}]}$, and $\mathbf{R} = \mathbf{P}\cup\mathbf{R}^2$,

$$h(f)(R) = \begin{cases} f(R), \text{ if } R\in\mathbf{P} \\ R \wedge \{(R_1 \wedge f(\mathbf{1_P})) \times \mathbb{E}\}, \text{ if } R\in\mathbf{R}^2 \end{cases}$$

Then from the definition, it immediately follows that h(f) is subject-oriented, restricting, and additive, i.e., $h(f) \in \mathbf{SO}$.

(i) Now suppose f, $g\in INT_{[\mathbf{P}\to\mathbf{P}]}$ and $f \neq g$. Then by definition, $h(f) \neq h(g)$, since if $f \neq g$, there are some $\alpha\in\mathbf{P}$ such that $f(\alpha) \neq g(\alpha)$. This proves h is one-to-one.

(ii) Suppose now that m is an arbitrary function in **SO**, then due to the above definition of h, there is some function $m_h\in INT_{[\mathbf{P}\to\mathbf{P}]}$ such that $h(m_h) = m$. This proves h is onto.

We have shown that h: $INT_{[\mathbf{P}\to\mathbf{P}]}\to\mathbf{SO}$ is one-to-one and onto. Now we complete the proof by showing h is homomorphism. Keenan and Faltz (1985) identifies the set of restricting functions ($RES_{[\mathbf{B}\to\mathbf{B}]}$) as a boolean algebra, and the set of intersective functions ($INT_{[\mathbf{B}\to\mathbf{B}]}$) as a subalgebra of $RES_{[\mathbf{P}\to\mathbf{P}]}$:

Theorem (Keenan and Faltz 1985:142):
Let $RES_{[\mathbf{B}\to\mathbf{B}]} = \{f\in[\mathbf{B}\to\mathbf{B}] : f \text{ is restricting}\}$, where B is an arbitrary boolean algebra. Then $RES_{[\mathbf{B}\to\mathbf{B}]}$ is a boolean algebra under the operations $\wedge$, $\vee$, and ' defined as follows: For f, $g\in RES_{[\mathbf{B}\to\mathbf{B}]}$ arbitrary,

(i) $f\wedge g$ is defined by setting $(f\wedge g)(b) = f(b)\wedge g(b)$ for each $b\in B$.

(ii) $f\wedge g$ is defined by setting $(f\vee g)(b) = f(b)\vee g(b)$ for each $b\in B$.

(iii) f' is defined by setting $f'(b) = b\wedge(f(b))'$ for each $b\in B$.

Theorem (K&F 1985:145):
Let $INT_{[\mathbf{B}\to\mathbf{B}]} = \{f\in RES_{[\mathbf{B}\to\mathbf{B}]} : f \text{ is intersective}\}$, where B is an arbitrary boolean algebra. Then $INT_{[\mathbf{B}\to\mathbf{B}]}$ is a subalgebra of $RES_{[\mathbf{B}\to\mathbf{B}]}$. Moreover, if B is complete, then $I_{B/B}$ is complete, and if B is atomic $I_{B/B}$ is atomic.

From these theorems, we show that h preserves meets and complements: Let f and g be arbitrary intersective functions from **P** into **P**. For all $R\in\mathbf{P}$, by definition and the theorems above, $h(f\wedge g)(R) = (f\wedge g)(R) = f(R)\wedge g(R) = h(f)(R)\wedge h(g)(R)$.
For all $R\in\mathbf{R}^2$, $h(f\wedge g)(R)$

$$= R\wedge\{(R_1\wedge(f\wedge g)(\mathbf{1_P}))\times\mathbb{E}\}$$
$$= R\wedge\{(R_1\wedge(f(\mathbf{1_P})\wedge g(\mathbf{1_P}))\times\mathbb{E}\}$$
$$= R\wedge\{((R_1\wedge f(\mathbf{1_P}))\wedge(R_1\wedge g(\mathbf{1_P})))\times\mathbb{E}\}$$
$$= (R\wedge\{(R_1\wedge f(\mathbf{1_P}))\times\mathbb{E}\})\wedge(R\wedge\{(R_1\wedge g(\mathbf{1_P}))\times\mathbb{E}\})$$
$$= h(f)(R)\wedge h(g)(R)$$

Therefore h preserves meets.

Finally, let f be an arbitrary intersective function from **P** into **P**. For all $R\in\mathbf{P}$, by definition and the theorems above, $h(f')(R) = f'(R) = (h(f))'(R)$.
And for all $R\in\mathbf{R}^2$, $h(f')(R) = R\wedge\{(R_1\wedge f'(\mathbf{1_P}))\times\mathbb{E}\} = R\wedge\{(R_1\wedge(h(f))'(\mathbf{1_P}))\times\mathbb{E}\}$ $= (h(f))'(R)$. Therefore h preserves complements. Thus h is a homomorphism, and

from (i) and (ii), h is one-to-one and onto. Therefore h is an isomorphism of $INT_{[\mathbf{P}\to\mathbf{P}]}$ onto **SO**. This completes the proof. ###

2.3. Locative Prepositions as Predicate Extensors

We have so far treated locative PPs as denoting intersective predicate modifiers, i.e., intersective functions from n-ary relations to n-ary relations. Thus, the locative prepositions are interpreted as functions from NP denotations into predicate modifier denotations. We now consider another way of interpreting locative prepositions which was proposed and compared with the previous treatment in Keenan & Faltz (1985). This alternative takes prepositions as combining with a predicate to raise its arity by one. We call this approach *predicate extensor* analysis of prepositions, since prepositions allow predicates to take one more extra argument. Then, the semantic denotations of prepositions are functions from n-ary relations to $(n+1)$-ary relations, for $n \geq 1$. The following tree shows an example of the analysis.[10] This analysis provides a coherent way of interpreting prepositions, which is implicit in syntactic treatments of certain kinds of reanalysis.

(66)

They	*marched*	*along*	*this road*
NP	P1	Pn+1\Pn	NP
	P2		
	P1		
P0			

The preposition *along* is assigned a polymorphic category (Pn+1\Pn), which reflects the idea that prepositions raise the arity of the predicates they combine with. Recall that

[10]Here again we use the following notations for predicate categories: P0(sentences), P1(one place predicates), P2(two place predicates), and Pn(n-place predicates) for $n \geq 0$.

prepositions are assigned the category of (Pn\Pn)/NP, in the preceding section. In 2.4, we will compare this approach and the predicate modifier approach, and see they provide a symmetrical semantics. In other words, prepositions of the category (Pn\Pn)/NP can be defined in terms of corresponding predicate extensor of the category (Pn+1\Pn), and vice versa. This section illustrate some syntactic and semantic behaviours of locative prepositions supporting the predicate extensor analysis.

2.3.1. Syntax of Predicate Extensors

First there is syntactic evidence showing that prepositions without a complement NP can form a constituent with a predicate.

2.3.1.1. Prepositional Passive

Intransitive verbs are not subject to passivization in English, but if they are followed by a PP, the preposition in the PP can support them to be passivized. Couper-Kuhlen (1979) gives an extensive corpus of such constructions under the name of *prepositional passive*. The following are some examples from Couper-Kuhlen (1979).

(67)
- a. *The bed was bounced <u>on</u> till it broke*
- b. *Her skirt was always being clung <u>to</u> by one child or another*
- c. *This road has been marched <u>along</u> thousands of times*
- d. *I was advanced <u>towards</u> by a strange-looking man*
- e. *His arms had been bitten <u>through</u> by a crocodile*
- f. *Mr. Green's house was called <u>at</u> by the money raisers*

g. *The tree had been crashed into by a bus*
h. *It is countries with booming economics which are usually emigrated to*
i. *The bridge is too high to be dived from*
j. *The wall next to the trampoline must be low enough to be bounced over*
k. *Trees must be climbed down/up carefully*
l. *The road could only be driven across at great risk*
m. *The bed had not been slept in*

Each example contains a locative preposition which combines with a one place predicate and the combination goes through passivization. This pervasive use of prepositional passive constructions motivates the predicate extensor approach, which reanalyzes the collocation of intransitive verb and a preposition as a transitive verb phrase. Thus, in the following analysis of an active sentence, the phrase *crushed into* gets the category P2, two-place predicate (transitive verb phrase), and so to be passivizable.

(68)

A bus	*crashed*	*into*	*the tree*
NP	P1	Pn+1\Pn	NP
	P2		
	P1		
P0			

The corresponding passive sentence is analyzed as follows:

(69)

The tree	PASS(*was+en*)	*crashed into*	*by a bus*
NP	Pn/Pn+1	P2	Pn\Pn
	P1		
	P1		
P0			

Following Keenan's (1980, 1985) theory of passive, the passive morpheme, PASS = (*was+en*), is assigned a polymorphic category Pn/Pn+1, and reduces the arity of the predicate it combines with by one. Thus, in the above analysis (69), the passive morpheme combines with a P2 *crashed into* to yield a P1.

2.3.1.2. Preposition Incorporation/Extrusion

English has lexical verbs which inherently contain a spatial meaning. Thus, some transitive verbs can be paraphrased as a complex of an intransitive verb and a locative preposition. For example, the verb *enter* has the same meaning as *go/come into*, *reach* as *arrive at*, *exit* as *go/come out of*, *leave* as *go/come from*, *cross* as *go/come across* and so on. Baker (1988, 1992) studies extensively this phenomenon in Bantu languages, where the prepositional meanings are incorporated in verbal predicates with an affix called an *applicative*. Let us consider the following examples in Chichewa from Baker (1988).

(70)	a.	Mbidzi zi-na-**perek**-a	msampha	**kwa**	nkhandwe
		zebra SP-PAST-**hand**-ASP	trap	**to**	fox
		'The zebras handed the trap to the fox.'			
	b.	Mbidzi zi-na-**perek-er**-a	nkhandwe	msampha	
		zebra SP-PAST-**hand**-APPL-ASP	fox	trap	
		'The zebras handed the fox the trap.'			

(70a) contains a standard preposition *kwa*, while (70b) lacks a preposition but has an applicative or "applied suffix" *-ir*. As for the sentences in (70), Baker (1988) claims that they share the same D-structure where both the object NP and the PP with *kwa/-ir* occur, and (70b) is derived from the D-structure by "preposition incorporation", which moves the preposition into the verbal element leaving a trace. But notice that the preposition and the applicative suffix share no formal similarity. The following illustrate another pattern of incorporation in Kinyarwanda. The data are from Kimenyi (1980) cited in Baker (1988).

(71) a. *Umwaana y-a-**taa**-ye igitabo **mu** maazi*
child SP-PAST-**throw**-ASP book **in** water
'The child has thrown the book into the water.'

b. *Umwaana y-a-**taa**-ye-**mo** amaazi igitabo*
child SP-PAST-**throw**-ASP-**in** water book
'The child has thrown the book into the water.'

(72) a. *Abaana b-**ïica**-ye **ku** meeza*
children SP-**sit**-ASP **on** table
'The children are sitting on the table.'

b. *Abaana b-**ïica**-ye-**ho** meeza*
children SP-**sit**-ASP-**on** table
'The children are sitting on the table.'

Kinyarwanda shows clear morphological correlation between prepostions and applicative suffixes: i.e., *mu* and *mo* in (71), and *ku* and *ho* in (72). Here we are not concerned with how to derive syntactically one of the two constructions from the other. We might assume that the prepositional constructions in (71a) and (72a) are derived from applicative constructions in (71b) and (72b), which we call *preposition extrusion*.[11] In any event, such syntactic correspondence reveals that the locative prepositions can link to a predicate (an intransitive or transitive verb) to form a syntactic constituent. And semantically, such applicative suffixes can be characterized as predicate extensors raising the number of argument positions of predicates by one.

Let us now consider a language which has diverse locative verbal affixes but no corresponding overt prepositions for spatial meanings. Totonac as described by Reid et al (1968) has a productive system of locative verbal affixes which usually precede verbal head, but the language does not have overt locative prepositions except a limited class of prepositions — *na/nac* ('at, on, in') and borrowed ones from Spanish like *de* ('from') and *con* ('with').[12] The following are from Reid *et al* (1968:35-37):

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[11]There are languages like Totonac which have productive verbal prefixes indicating spatial relations. The following sentences are from Reid *et al* (1968:35-37) and each sentence contains a verbal prefix.

(i) *Tâ'-**pû**-tzâ'la-lh* ***i'xcahuayuj***
with.him-**on/in**-he.flees-PAST **his horse**
'He fled on his horse.'

(ii) *Tâ'-**tê**-putza-lh* ***huanmâ' câ'lacchicni'***
with.him-**through**-he.seeks.it-PAST **that town**
'He sought it through that town.'

Totonac, however, lacks overt prepositional constructions which might correspond to the sentences.

[12]The locative preposition *na/nac* ('at, on, in') seems to occur with a restricted class of verbs, whereas the verbal prefix *pû-* illustrated in (73a) does not have such restriction. The corpus of data in Reid *et al* (1968) illustrate PPs with *na/nac* which occur with verbs meaning the following: 'arrive'(p.22, 56, 82, etc.), 'stay'(p.55), 'put'(p.60, 65, 134, 144), 'peek'(p.61), 'visit'(p.68), 'throw'(p.88), 'walk'(p.127, 128, 166), 'lie down'(p.128), 'insert'(p.129), 'tie'(p.129), 'find'(p.131), and 'hide' (p.134)). Sometimes the preposition is used in the meaning of 'to, into' with verbs like 'go'(p.63, 158, 169)'bring'(p.59), 'climb'(p.61), 'enter'(p.78, 162), and 'return'(p. 168).

(73) a. *Tâ'-**pû**-tzâ'la-lh* ***i'xcahuayuj***
with.him-**on/in**-he.flees-PAST **his horse**
'He fled with him on his horse.'

b. *Tâ-**tê**-putza-lh* ***huanmâ' câ'lacchicni'***
with.him-**through**-he.seeks.it-PAST **that town**
'He sought it through that town.'

(73a) contains a verbal prefix *pû-* ('on, in'), and (73b) contains *tê-* ('through, passing by'). Reid *et al* (1968) calls such verbal prefixes *referential prefixes*, which can be analysed as predicate extensors.[13] Thus, the locative prefix *pû-* in (73a) takes a one-place predicate *tzâ'la* ('he flees') to yield a two-place predicate, and *tê-* in (73b) takes the two-place predicate *putza* ('he seeks') to yield a three-place predicate. Reid *et al* (1968) give more locative prefixes: *laclh-* ('in the midst of, on, on top of'), *lak-* ('to, toward'), and *mak-* ('from'). More than one locative prefix can occur in a single verbal complex as in the following (Reid *et al* 1968:36):

(74) a. *Tâ'-**pû-lak**-min*
with.him-**in**.it-**to**.him-he.comes
'He comes in it to him with him.'

[13]Such referntial prefixes add an argument other than subject, object, and indirect object arguments of the predicates they combine with. They can refer to a contextual referent without an overt noun phrase within the sentence, thus such NP is optional. (Reid *et al* 1968:24) In (74a), the extra argument positions created by the verbal extensors are not filled with overt NPs, but the instrumental NP argument *tumîn* in (74b) is overtly expressed.

b. *lî-tê-**mak**-tamâhua-lh* ***tumîn***
with.it-**passing.by**.it-**from**.him-he.buys.it-PAST money
'He bought it from him passing by it with money.'

Two locative prefixes in (74a) raise the number of the argument positions of *min* ('he comes') so to yield a three-place predicate. (74b) shows an instrumental verbal prefix *lî-* ('with it') which is another verbal extensor creating one more argument position for *tumin* ('money').

2.3.2. Semantics of Predicate Extensors

2.3.2.1. Argument Orientation of Locative PPs

We discussed argument orientations of locative PPs in detail in 2.2.2. Locative PPs refer to a location or trajectory of specific argument(s) of the predicate they combine with. For example, in (75) and (76), (a)-sentences entail (b)-sentences respectively, but not necessarily (c).

(75) a. *John found Bill in the park*
b. *Bill was in the park*
c. *John was in the park*

(76) a. *John saw Bill from the rooftop*
b. *John was on the rooftop'*
c. *Bill was on the rooftop*

The locative PP in (75a) is oriented to the object argument of *found*, and the PP in (76a) is oriented to the subject argument of *saw*. What is more intriguing is the ambiguity between different orientations. For example, (77) entails either 'John was on the bus'(Subject Orientation) or 'Mary was on the bus'(Object Orientation).

(77) *John pulled Mary from the bus*

We treat the argument orientation phenomena as lexical in nature, since the same locative PP can be oriented to different arguments by combining with different predicates. Thus, the PP *in the park* is interpreted as oriented to the object in (78a), to the subject in (78b), and to the subject and the object in (78c).

(78) a. *John found Mary in the park*
b. *John praised Mary in the park*
c. *John met Mary in the park*

Further the orientation effect is determined only by the predicate and the preposition in locative PPs, and NPs in the PPs do not participate in determining argument-orientation patterns at all. This suggests that, in order to get a correct interpretation observing Compositionality, we should allow a preposition of a locative PP to combine with a predicate first without its object NP.

2.3.2.2. Scope Ambiguity

The following sentences illustrate scope ambiguity between two quantifiers, one of which is inside a locative PP. Thus (79a) has two readings: (i) there was some policeman such that he/she was standing on every street corner, and (ii) for each street corner, there was some policeman standinding on it. (79b) is ambiguous in the same way.

(79) a. *A policeman was standing on every street corner*

b. *John saw a policeman on every street corner*

c. **a policeman (on every street corner (see))(john)**

The locative PPs, however, do not vary their argument orientation pattern depending on the scope interpretation. That is, in both of the readings of (79b), the PP *on every street corner* is oriented to the object. Now we note that the *predicate modifier* analysis has a problem in accounting for the ambiguity of the sentences:

Keenan and Faltz (1985) extended the domain of predicate modifiers to the set of generalized *n*-ary relations. As we saw in the preceding section (and discussed in detail in 2.2), locative PPs determine their patterns of argument orientation due to the preposition and the type of the predicate they combine with. Thus it is determined by lexical forces. If we want to adhere to Compositionality of semantic interpretation and want to interpret the PP *on every street corner* as object-oriented, we would not interpret the object-oriented PP as modifying the whole VP *saw a policeman* but as modifying the transitive verb *saw*, as in (79c). However, this will always give us an interpretation where the universal NP *every street corner* has a narrow scope under the object NP, *a policeman*, thus fails to account for the ambiguity of (79b).

If we adopt *predicate extensor* analysis, however, we can account for the scope ambiguity in the same way we do for the scope interpretation of simple transitive (or ditransitve) sentences. The *predicate extensor* analysis takes a preposition as denoting a function from n-ary relations to $(n+1)$-ary relations, and according to the class of the n-place predicates, a predicate extensor determines which argument(s) of the predicates it is oriented to. So for f a preposition, and $1 \leq k \leq n$, we define $\mathbf{f}_k$, a function of predicate extensor oriented to the k-th argument of n-ary relations as follows.

(80) Definition: *k-th argument oriented predicate extensor*

For R a n-ary relation, f a preposition (denoting a function from NP denotations into predicate modifiers), and for $1 \leq k \leq n$,
$\mathbf{f}_k$, the *k-th argument oriented predicate extensor* of f, is defined by:
$\mathbf{f}_k(\mathbf{R})$ is a $(n+1)$-ary relation such that for all n-tuples $<\alpha_1,..., \alpha_n> \in E^n$, $<\alpha_1,...,\alpha_n, \beta> \in \mathbf{f}_k(\mathbf{R})$ iff $<\alpha_1,..., \alpha_n> \in \mathbf{R}$ and $\mathbf{f}(\beta)(\mathbf{be})(\alpha_k)$

For example, $\mathbf{on}_2$ is a predicate extensor taking a n-ary relation to give a $(n+1)$-ary relation, so let **see** be a binary relation such that **see** = $\{<x,y>| \text{ x sees y}\}$, then $\mathbf{on}_2(\mathbf{see})$ is a ternary relation such that $\mathbf{on}_2(\mathbf{see}) = \{<x,y,z>| <x,y> \in \mathbf{see}$ & y is on z$\}$. The above interpretation of *on* as an *object oriented predicate extensor* generalizes the observation that PPs with *on* are oriented to the object argument of a predicate like *see*, *find*, *place*, etc. (see Table 1 in section 2.2.3).

The PP in *John praised Mary at the meeting* is subject-oriented, thus the preposition *at* is interpreted as a subject-oriented predicate extensor when it combines with *praise*. Thus we define the predicate extensor $\mathbf{at}_1$ as follows: $<\alpha_1,...,\alpha_n, \beta> \in \mathbf{at}_1(R)$ iff $<\alpha_1,..., \alpha_n> \in R$ and $\mathbf{at}(\beta)(\mathbf{be})(\alpha_1)$.

The appendix to chapter 2 (pp. 56-64) provides a general account of quantifier scope ambiguity elaborated by Nam (1991) in the framework of Categorial Grammar. And it is illustrated that the predicate extensor analysis gives a way of accounting for the scope ambiguity in (79a) and (79b) with a correct interpretation of argument orientation.

2.4. Unifying the two views of (2.1) and (2.3)

This section shows how to unify the two views discussed in 2.1—predicate modifier analysis, and 2.3—predicate extensor analysis. First we note that there is "Curry correspondence" between the two views: (i) Predicate modifier analysis takes prepositions as functions taking NP denotations to give functions from n-ary relations to n-ary relations; and (ii) predicate extensor analysis treats prepositions as functions taking n-ary relations to give $(n+1)$-ary relations. Roughly, the following:

(81) Semantic type for prepositions as forming predicate modifiers with an NP:

$$[\mathbb{E} \rightarrow [\wp(\mathbb{E}^n) \rightarrow \wp(\mathbb{E}^n)]$$

(82) Semantic type for prepositions as predicate extensors:

$$[\wp(\mathbb{E}^n) \rightarrow \wp(\mathbb{E}^{n+1})] = [\wp(\mathbb{E}^n) \rightarrow [\mathbb{E} \rightarrow \wp(\mathbb{E}^n)]]$$

where the set of $(n+1)$-ary relations, $\wp(\mathbb{E}^{n+1})$, is the set of complete homomorphisms from the set of NP denotations into the set of n-ary relations, where the operations are defined pointwise on the individuals.

The two treatments are semantically equivalent to each other. That is, we get an equivalent interpretation from the following different analyses of the sentence *John jumped on the bed*: that is, (**on**(**the bed**))(**jump**)(**john**) = (**on**(**jump**))(**the bed**)(**john**). Now we define new functions with an extended domain including those of the two preposition functions. The new functions f is defined by:

(83) The domain of f is $\mathbb{E} \cup \wp(\mathbb{E}^n)$ and the co-domain of f is $[\wp(\mathbb{E}^n) \rightarrow \wp(\mathbb{E}^n)] \cup \wp(\mathbb{E}^{n+1})$ such that for all $a \in \mathbb{E}$, for all $n \geq 1$, and for all $R \in \wp(\mathbb{E}^n)$, $(f(a))(R) = (f(R))(a)$.

The semantics with the above functions then unifies the properties accounted for by predicate modifier analysis and predicate extensor analysis by assigning prepositions a richer semantics than normally expected. The semantics is symmetric in the sense that the meanings of prepositions of the type (81) can be defined in terms of the meanings of corresponding predicate extensors, and vice versa. Different languages use the two semantic types differently depending on the syntactic or morphological structures they employ. Thus, for example, English uses prepositions more often as denoting a function in (81) than as denoting a predicate extensor, but some languages like Totonac would use the functions in predicate extensors more often. But Kinyarwanda would be in the middle of the two extremes.

APPENDIX TO CHAPTER 2:

— A Generalized Account of Scope Ambiguity

A generalized quantifier in a locative PP can interact scopally with other qunatifiers in the same sentence. The locative PP in (1) below contains a scopeless NP *the corner*, so we do not get scope ambiguity, but the PP in (2) contains a universal quantifier which brings out scope ambiguity in the sentence: (i) *a policeman* takes wide scope over *every street corner*, (ii) *every street corner* takes wide scope over *a policeman*. The last line of the interpretation in (1) states: (1) is true iff there is some policeman d such that the policeman is standing and is on the corner. (The notation I_d denotes a Montagovian individual (i.e., a set of properties) generated by the atomic property that only the object d has. Such individuals are characterized as ultrafilters in the property algebra **P**.) Here NPs are given the polymorphic category of Pn/Pn+1, which takes (*n*+1)-ary predicates to yield *n*-ary predicates.

(1) *A policeman is standing on the corner*

a policeman	*is standing*	*on*	*the corner*
Pn/Pn+1	P1: **stand**	(Pm\Pm)/(Pn-1\Pn): **on**	Pn-1\Pn: **the corner**

———————————————— [A]

Pm\Pm: **on(the corner)**

———————————————— [A]

P1: **on(the corner)(stand)**

$= \{x \mid$ **stand**(x) & **on(the corner)(be)**$(x)\}$

———————————————— [A]

P0: **a policeman (on(the corner)(stand))**

$= \vee_{d \in \text{Policeman}}\, I_d\, (\{x \mid$ **stand**(x) & **on(the corner)(be)**$(x)\})$

(2) *A policeman is standing on every street corner*

(2a-b) below show how to derive the reading in which the universal quantifier *every street corner* takes narrow scope under the subject quantifier *a policeman.* In the derivation of (2b), the one place predicate (P1) *was standing* and the preposition *on* are composed to be of a functional type P1/(Pn-1\Pn). But this gives the same interpretation as (2a) where we use only Function Application [A]. In (2b), we use Type lifting [T] and Function Composition [B] defined as follows:

Function Composition [B]:

a. Semantics: $((B(f))(g))(x) = (f \bullet g)(x) = f(g(x))$

b. Syntax: $Z/Y + Y/X = Z/X$

$Y\backslash X + Z\backslash Y = Z\backslash X$

Type Lifting [T]:

a. Semantics: $(T(x))(f) = x^*(f) = f(x)$

b. Syntax: $X \rightarrow Y/(Y\backslash X)$

$X \rightarrow Y\backslash(Y/X)$

(2a) Universal-narrow scope: (by Function Application only)

a policeman	*is standing*	*on*	*every street corner*
Pn/Pn+1	P1: **stand**	(Pm\Pm)/(Pn-1\Pn):**on**	Pn-1\Pn: **every street corner**

==============================[A]

Pm\Pm: **on(every street corner)**

——————————————————————[A]

P1 : **on(every street corner)(stand)**

$= \mathbf{on}(\wedge_{c \in \text{Streetcorner}} I_c)(\mathbf{stand})$

$= \wedge_{c \in \text{Streetcorner}} \mathbf{on}(I_c)(\mathbf{stand})$

$= \wedge_{c \in \text{Streetcorner}} \{x \mid \mathbf{stand}(x) \ \& \ \mathbf{on}(I_c)(\mathbf{be})(x)\}$

——————————————————————[A]

P0: **a policeman (on(every street corner)(stand))**

$= \vee_{d \in \text{Policeman}} I_d \, (\wedge_{c \in \text{Streetcorner}} \{x \mid \mathbf{stand}(x) \ \& \ \mathbf{on}(I_c)(\mathbf{be})(x)\})$

(2b) Universal-narrow scope: (by Function Composition[B] of *was standing* and *on*)

a policeman	*is standing*	*on*	*every street corner*
Pn/Pn+1	P1: **stand**	(Pm\Pm)/(Pn-1\Pn):**on**	Pn-1\Pn: **every street corner**

$$\frac{\text{P1: } \mathbf{stand}}{\text{X/(X\backslash P1): } \mathbf{stand^*}}\,[T]$$

==================[B]

P1/(Pn-1\Pn): (**stand***)•(**on**)

————————————————————[A]

P1: ((**stand***)•(**on**))(**every street corner**)

= (**stand***)(**on**(**every street corner**))

= **on**(**every street corner**)(**stand**)

= $\mathbf{on}(\wedge_{c\in \text{Streetcorner}}\, I_c)(\mathbf{stand})$

= $\wedge_{c\in \text{Streetcorner}}\, \mathbf{on}(I_c)(\mathbf{stand})$

= $\wedge_{c\in \text{Streetcorner}}\, \{x \mid \mathbf{stand}(x)\ \&\ \mathbf{on}(I_c)(\mathbf{be})(x)\}$

————————————————————[A]

P0: **a policeman** (**on**(**every street corner**)(**stand**))

= $\vee_{d\in \text{Policeman}}\, I_d\, (\wedge_{c\in \text{Streetcorner}}\, \{x \mid \mathbf{stand}(x)\ \&\ \mathbf{on}(I_c)(\mathbf{be})(x)\})$

Now how can we derive the other reading in which the universal quantifier takes wide scope over the subject? Since we now take a predicate and a preposition as a compound predicate, the scope ambiguity in (2) is similar to that in simple transitive sentences. Scope ambiguity often suggests that the scope-dependency relation is not derivable only from the surface syntactic (c-command) relation. Thus an NP can have wide scope over another NP which syntactically c-commands it in surface structure. In order to account for such *inverse scope relations*, a theory of grammar should either derive disambiguated logical representations via rules like *Movement* or derive multiple semantic interpretations from an ambiguous surface structure. Here we provide a solution of the latter strategy within a theory of flexible categorial grammar.

Nam (1991) accounts for scope ambiguity in terms of Value Lifting, which is a generalized way of assigning relative scope relations to quantifiers. The syntax and semantics of Value Lifting is defined as follows:

(3) Value Lifting (VL):

For all functional types X/Y such that Y is a subtype of X,
VL_Z, or *value-lifting with respect to type* Z, is defined by:
$VL_Z(X/Y) = (Z/(Z/X))/Y$

Semantics of VL:

For any $P \in T_Y$ (the semantic type of Y), and $Q \in T_{Z/X}$,
if $\lambda P.\ \alpha'(P)$ is a translation of α with type (X/Y), then
$\lambda P \lambda T.\ \alpha'(T(P))$ is a translation of α^* with the type $VL_Z(X/Y)$

The *subtype* relation used in the above is defined as follows: For all types X and Y, Y is a subtype of X iff the set of possible denotations of Y (i.e., T_Y) is a subset of that of X (i.e., T_X). Notice that the VL changes the ultimate value type, and assignes one more argument of type (Z/X) to the original function. Furthermore the semantics requires this new argument be interpreted as having narrower scope than the original function α. For instance, when the NP type Pn/Pn+1 is value-lifted to (Z/(Z/Pn))/Pn+1, the new argument of the type (Z/Pn) is interpreted as being under the scope of the original NP function. Before we account for the ambiguity in (2), let us look at how Value Lifting works in general ambiguous contexts like *everyone loves someone*. (4a) and (4b) derive its subject wide scope reading and its object wide scope reading respectively.

(4) *Everyone loves someone*

a. Subject wide scope reading:

$$
\begin{array}{lll}
\underline{\textit{everyone}} & \underline{\textit{loves}} & \underline{\textit{someone}} \\[6pt]
Pn/Pn{+}1\text{: } \mathbf{everyone} & P2\text{: } \mathbf{love} & Pn{-}1\backslash Pn\text{: } \mathbf{someone} \\
\cline{2-3}
 & \multicolumn{2}{l}{P1\text{: } \mathbf{someone}\ (\mathbf{love}) \quad [A]} \\
\hline
\multicolumn{3}{l}{P0\text{: } \mathbf{everyone}(\mathbf{someone}\ (\mathbf{love})) \quad [A]} \\
\multicolumn{3}{l}{\quad = \bigwedge_{a\in E} \bigvee_{b\in E} I_a(I_b(\mathbf{love}))}
\end{array}
$$

b. Object wide scope reading:

$$
\begin{array}{lll}
\underline{\textit{everyone}} & \underline{\textit{loves}} & \underline{\textit{someone}} \\[6pt]
Pn/Pn{+}1\text{: } \mathbf{everyone} & P2\text{: } \mathbf{love} & Pn{-}1\backslash Pn\text{: } \mathbf{someone} \\
\cline{3-3}
 & & (X\backslash(X/Pn{-}1))\backslash Pn\text{: } \mathbf{someone}^* \quad [VL] \\
\cline{2-3}
 & \multicolumn{2}{l}{X\backslash(X/P1)\text{: } \mathbf{someone}^*(\mathbf{love}) \quad [A]} \\
\hline
\multicolumn{3}{l}{P0\text{: } \mathbf{someone}^*(\mathbf{love})(\mathbf{everyone}) = \mathbf{someone}\ (\mathbf{everyone}(\mathbf{love})) \quad [A]} \\
\multicolumn{3}{l}{\quad = \bigvee_{b\in E} \bigwedge_{a\in E} I_b(I_a(\mathbf{love}))}
\end{array}
$$

Let us now interpret the ambiguous sentence (2): the preposition *on* is taken as a predicate extensor, and it combines with the predicate *is standing* to make a two place predicate.

(5) Universal-narrow scope reading: (*on* as a predicate extensor)

a policeman	*is standing*	*on*	*every street corner*
Pn/Pn+1	P1: **stand**	Pn+1\Pn: $\mathbf{on}_1$	Pn-1\Pn: **every street corner**

—[A]

P2: $\mathbf{on}_1(\mathbf{stand})$

—[A]

P1: **every street corner** $(\mathbf{on}_1(\mathbf{stand}))$

$= (\bigwedge_{c\in \text{Streetcorner}} I_c)(\mathbf{on}_1(\mathbf{stand}))$

$= \bigwedge_{c\in \text{Streetcorner}} \{x \mid I_c(\{y \mid (\mathbf{on}_1(\mathbf{stand}))(<x,y>)=1\})\}$

$= \bigwedge_{c\in \text{Streetcorner}} \{x \mid I_c(\{y \mid \mathbf{stand}(x)=1\ \&\ \mathbf{on}(y)(\mathbf{be})(x)=1\})\}$

—[A]

P0: **a policeman** (**every street corner** $(\mathbf{on}_1(\mathbf{stand}))$)

$= \bigvee_{d\in \text{Policeman}} I_d\,(\bigwedge_{c\in \text{Streetcorner}} \{x \mid I_c(\{y \mid \mathbf{stand}(x)=1\ \&\ \mathbf{on}(y)(\mathbf{be})(x)=1\})\})$

$= \bigvee_{d\in \text{Policeman}} \bigwedge_{c\in \text{Streetcorner}} I_d\,(\{x \mid I_c(\{y \mid \mathbf{stand}(x)=1\ \&\ \mathbf{on}(y)(\mathbf{be})(x)=1\})\})$

The last line of (5) states that there is some policeman d such that for all street corner c, d is standing and d is on c. Thus, (5) interprets the universal quantifier *every street corner* as taking narrow scope under the subject *a policeman.*

(6) Universal-wide scope reading: (*on* as a predicate extensor)

a policeman	*is standing*	*on*	*every street corner*
Pn/Pn+1	P1: **stand**	Pn+1\Pn: $\mathbf{on}_1$	Pn-1\Pn: **every street corner**

—[A] —[VL]

P2: $\mathbf{on}_1(\mathbf{stand})$ (X\(X/Pn-1))\Pn: **every street corner***

—[A]

X\(X/P1): **every street corner***$(\mathbf{on}_1(\mathbf{stand}))$

—[A]

P0: **every street corner***$(\mathbf{on}_1(\mathbf{stand}))$**(a policeman)**

= every street corner(a policeman$(\mathbf{on}_1(\mathbf{stand}))$**)**

$= \bigwedge_{c\in \text{Streetcorner}} \bigvee_{d\in \text{Policeman}} I_d(\{x \mid I_c(\{y \mid (\mathbf{on}_1(\mathbf{stand}))(x,y)=1\})=1\})$

$= \bigwedge_{c\in \text{Streetcorner}} \bigvee_{d\in \text{Policeman}} I_d(\{x \mid I_c(\{y \mid \mathbf{stand}(x)=1\ \&\ \mathbf{on}(y)(\mathbf{be})(x)=1\})=1\})$

Informally speaking, the last line of (6) states that for all street corner c there is some policeman d such that d is standing and d is on c, so to give a wide scope to the universal quantifier.

Finally, let us see how to interpret the ambiguous sentence (7) below, where the PP *on every street corner* is object-oriented in both readings. Again we interpret the preposition *on* as an object-oriented predicate extensor, i.e., $\mathbf{on}_2$. (8) sketches the interpretation of (7) with universal quantifier narrow scope reading, and (9) with universal quantifier wide scope reading.

(7) *John saw a policeman on every street corner*

(8) Universal narrow scope reading of (7): (PP— object oriented)

John	*saw*	*a policeman*	*on*	*every street corner*
Pn/Pn+1	P2	Pn\Pn+1	Pn+1\Pn	Pn\Pn+1

saw on = P3: $\mathbf{on}_2(\mathbf{see})$

saw on every street corner = P2:

$$(\mathbf{every\ street\ corner})(\mathbf{on}_2(\mathbf{see}))$$
$$= \bigwedge_{c\in \text{Streetcorner}} \{<x,y> \mid I_c(\{z \mid \mathbf{on}_2(\mathbf{see})(<x,y,z>)=1\})=1\}$$
$$= \bigwedge_{c\in \text{Streetcorner}} \{<x,y> \mid I_c(\{z \mid \mathbf{see}(<x,y>)=1 \ \&\ \mathbf{on}(z)(\mathbf{IS})(y)=1\})=1\}$$

saw a policeman on every street corner = P1:

$$(\mathbf{some\ policeman})((\mathbf{every\ street\ corner})(\mathbf{on}_2(\mathbf{see})))$$
$$= \bigvee_{d\in \text{Policeman}} \{x \mid I_d (\{y \mid \bigwedge_{c\in \text{Streetcorner}} \{<x,y> \mid I_c(\{z \mid \mathbf{see}(<x,y>)=1 \ \&\ \mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\}$$

$= \vee_{d\in \text{Policeman}} \wedge_{c\in \text{Streetcorner}} \{x \mid I_d(\{y \mid \{<x,y> \mid I_c(\{z \mid \mathbf{see}(<x,y>)=1$
$\& \ \mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\}$

John saw a policeman on every street corner = P0:

$= I_{john}(\vee_{d\in \text{Policeman}} \wedge_{c\in \text{Streetcorner}} \{x \mid I_d(\{y \mid \{<x,y> \mid I_c(\{z \mid$
$\mathbf{see}(<x,y>)=1 \ \& \ \mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\})$

$= \vee_{d\in \text{Policeman}} \wedge_{c\in \text{Streetcorner}} I_{john}(\{x \mid I_d(\{y \mid \{<x,y> \mid I_c(\{z \mid$
$\mathbf{see}(<x,y>)=1 \ \& \ \mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\})$

The last line states that 'there is some policeman d such that for each street corner c John (I_{john}) saw d and d was on the street corner.

(9) Universal wide scope reading of (7):

John	*saw*	*a policeman*	*on*	*every street corner*
Pn/Pn+1	P2	Pn\Pn+1	Pn+1\Pn	Pn\Pn+1
				[VL]
				(X\(X/Pn-1))\Pn: **every street corner***

saw on = P3: $\mathbf{on_2}(\mathbf{see})$

saw on every street corner = X\(X/P2):

$(\textbf{every street corner*})(\mathbf{on_2}(\mathbf{see}))$

saw a policeman on every street corner = P1:

$(\textbf{every street corner*})(\mathbf{on_2}(\mathbf{see}))(\textbf{some policeman})$

$= (\textbf{every street corner})(\textbf{some policeman})(\mathbf{on_2}(\mathbf{see}))$

$= \wedge_{c\in \text{Streetcorner}} \{x \mid I_c(\{z \mid \vee_{d\in \text{Policeman}} I_d(\{y \mid (\mathbf{on_2}(\mathbf{see}))(<x,y,z>)=1\})$
$=1\})=1\}$

$= \wedge_{c\in \text{Streetcorner}} \{x \mid I_c(\{z \mid \vee_{d\in \text{Policeman}} I_d(\{y \mid \mathbf{see}(<x,y>)=1 \ \&$
$\mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\}$

$= \wedge_{c\in \text{Streetcorner}} \vee_{d\in \text{Policeman}} \{x \mid I_c(\{z \mid I_d(\{y \mid \mathbf{see}(<x,y>)=1 \ \&$
$\mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\}$

John saw a policeman on every street corner = P0:

$$= I_{john}(\wedge_{c\in \text{Streetcorner}} \vee_{d\in \text{Policeman}} \{x \mid I_c(\{z \mid I_d(\{y \mid \mathbf{see}(<x,y>)=1\ \&\ \mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\})$$

$$= \wedge_{c\in \text{Streetcorner}} \vee_{d\in \text{Policeman}}\ I_{john}(\{x \mid I_c(\{z \mid I_d(\{y \mid \mathbf{see}(<x,y>)=1\ \&\ \mathbf{on}(z)(\mathbf{be})(y)=1\})=1\})=1\})$$

The last line states that 'for each street corner c there was a policeman d such that John saw d and d was on c'

Chapter 3

The Natural Logic of Space: Technical Concepts

Meanings of the spatial expressions in English can be categorized into two groups: (i) *movement-directional*, and (ii) *stative-locational*. Movement-directional meaning shows up in the events where some object changes location, and a spatial expression is said to be movement-directional if it imposes a meaning of location-change on the meaning of a sentence. Stative-locational meanings are identified when an event takes place at some place, and a spatial expression locates the event (or its participants) at that place. The real world itself does not distinguish the two categories, but they come into the semantics of locatives in terms of *path* and *orientation*.

This chapter builds up the general logic for the semantics of locative expressions in English. Our logical semantics for locative expressions builds on the mereology of the space (Σ) and its primitive concept *region*. In other words, the space Σ is the set of regions, and the primitive *part-to-whole relation* ($\sqsubseteq$) is given between regions in the space. We also introduce two primitive ternary relations among regions, which impose geometric structures on the space: They are *betweenness* relation and *relative nearness* relation. In terms of these primitives, we define *paths* and *orientations*, and postulate their structures with relations and conditions.

3.1 Space with Mereological Primitives

Our logic of space is based on the primitive notion of *region* which enables us to treat locative PPs as denoting predicate modifiers represented in terms of properties and relations over regions. Locative PPs now supply such relevant properties and relations for its compositional interpretation. In terms of these ontological primitives we define other important notions like *path* and *orientation* with the help of the mathematical notions (e.g., 'sequence', 'ordered set').

We start with a mereological space Σ with the primitive *part-to-whole* relation $\subseteq$. The elements in Σ are called *regions*, so Σ is the set of regions.[1]

(1) The Local Space $<\Sigma, \subseteq, \emptyset>$:[2]

a. Σ is a set of regions,

b. $\subseteq$ is a partial order between regions, intended as the relation of spatial inclusion: (i) Reflexive, (ii) transitive, and (iii) antisymmetric, and

c. $\emptyset \in \Sigma$ and if $A \in \Sigma$, $\emptyset \subseteq A$.

We define relational notions in terms of the part to whole relation as follows:

(2) Definitions:

a. A region A is called a *proper part* of a region B, $A \subset B$, if $A \subseteq B$ and $A \neq B$.

---

[1]The idea of mereological structure of space is developed in Tarski (1929) from the tradition of Lesniewski.

[2]The local space Σ is defined as a complete atomic lattice in (1) and (2). Hinrichs (1985) defines Σ as a complete join semilattice.

b. A region A is said to be *disjoint* from a region B if there is no region C $\neq\emptyset$ such that both $C\subseteq A$ and $C\subseteq B$.

c. A region A is called the *sum* of all elements of a set R of regions ($\cup R$) if every element of R is a part of A and if no part of A is disjoint from all elements of R.

d. A region A is called an *intersection* of all elements of a set R of regions ($\cap R$) if A is non-empty part of each element of R and if there is no region B such that B is a part of each element of R and A is a proper part of B.

e. Regions A and B *intersect* each other, INTR(A,B), if there is an intersection of {A,B}.

f. A non-empty region $A\neq\emptyset$ is called an *atomic region* if there is no region $B\neq\emptyset$ such that $B\subset A$.

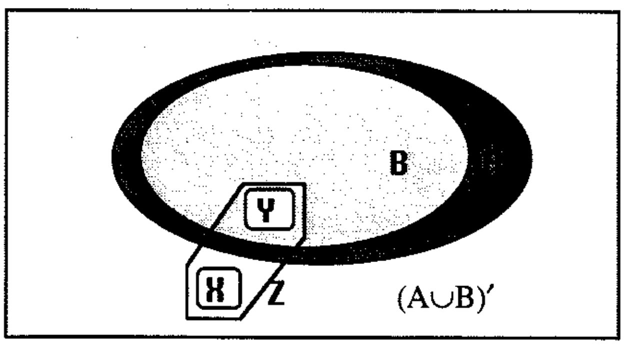
Due to the definitions, we can see that the *proper part* relation is transitive, and the sum and the intersection of a set R are uniquely determined by the set. Our formalism of spatial mereology is largely based on Tarski's (1927) geometry of solids, where he takes the *relation of part to whole* as the only primitive relation. Tarski (1927), adopting the notion of *sphere* from Huntington (1913), defines *point* and *equidistance of two points from a third*, by means of which all the concepts of Euclidean geometry can be defined. However, we define *atomic regions* in terms of the part-to-whole relation, and atomic regions correspond to *points* in Eucledean geometry. Now we define the notion *boundary* as follows:

(3) **Definition:**

A is a *boundary* for B if A and B are disjoint regions and for all regions $X \not\subset (A\cup B)$ and for all $Y\subseteq B$, if $(X\cup Y)\subseteq Z$ then Z intersects A.

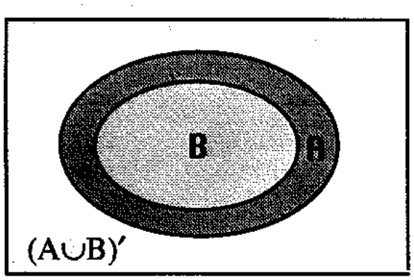
The following figure illustrates the *boundary* relation between A and B, i.e., the region A is a boundary of B.

(Figure 3-1)

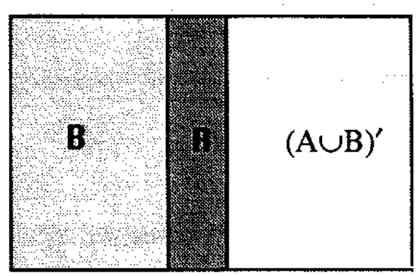


The notion *boundary* defined as the above is symmetric in the sense that if A is a boundary for B then A is also a boundary for the complement of (A∪B), i.e., (A∪B)'. Thus a boundary itself does not tell us whether the two regions are in a symmetric or an asymmetric relation. In both of the following figures, A is a boundary of B and (A∪B)'.

(Figure 3-2)



(Figure 3-3)



We will note in 4.2, however, that there are two types of division of space which are reflected in spatial expressions in English, i.e., symmetric vs. asymmetric division.

Regions are of a new kind of entity in our semantics, so the space Σ provides a new ontological domain for our semantics of spatial language. Since every concrete object in the universe occupies a unique region, we introduce a function to map objects in the universe $\mathbb{E}$ to the regions in the space Σ. The function ® takes a pair of an object and a time interval to give a region, where we introduce the set of *intervals* $\mathbb{T}$ as new in ontology and time *point* defined in terms of interval.[3] We do not go into details of the interval structure, since we mostly hold the time coordinate constant to interpret sentences containing a locative PP. As the region occupied by a given object may vary over time, we relativize locations to "times" as follows:

(4) Definition:

®$\in [(\mathbb{E}\times\mathbb{T})\rightarrow\Sigma]$ assigns a unique region to each individual object in $\mathbb{E}$ at an interval $T\in\mathbb{T}$.

Thus, ®(**john**, T) denotes the region that John occupies at the interval T. If the function maps an object to a constant region in Σ regardless of time (interval) shift, i.e., the object is immobile, we will omit the interval argument T in the rest of this thesis.

[3] For the relations between *interval structure* and *point structure*, see Kamp (1979) and van Benthem (1983). We take the interval structure $(\mathbb{T}, \subseteq, <)$ where $\subseteq$ and $<$ are the relations of inclusion (reflexive, transitive, and anti-symmetric) and precedence (transitive and irreflexive), respectively. Later in this thesis, we take an interval as a linearly ordered set of points. van Benthem (1983) states that for any atomic interval (period) structure, there exists a corresponding point structure where the domain is the set of atomic intervals.

Recall that (2e) defined INTR as a binary relation between regions, but we want now to extend the domain of the relation as follows:

(5) Definition:

For X a region and ρ a set of regions, INTR(X, ρ), X *intersects* ρ, iff there is a region $A \in \rho$ such that $A \subseteq X$.

Thus we extend the relation to hold between a region and a set of regions. We will use the extended relation in 3.4 to locate objects in orientations.

3.2 Primitive Relations in the Space

This section introduces two primitive ternary relations among regions, which impose geometric structures on the space Σ. They are *betweenness* relation and *relative nearness* relation, and they are widely used in the semantics of locatives in English. Tarski's (1959) axiom system for Elementary Geometry contains two ternary primitive relations, *betweenness* relation and *equidistance* relation (AB=CD). Our formalism with the relative nearness is richer than Tarski's, since the relative nearness relation can easily define the equidistance relation.[4] Robinson (1959) shows that it is impossible for one or more binary relations to serve as the primitive notions in Euclidean geometry. Thus the ternary nature of spatial relations reveal that the space is more complex than

[4]Robinson (1959) notes Pieri's (1908) finding that, in Euclidean geometry, it is possible to define the quarternary equidistance relation AB=CD ("A is as distant from B as C is from D") in terms of the ternary relation AB=BC ("A is as distant from B as C is"), that of a point being equally distant from two other points. From this, we can see easily that the relative nearness relation can define Tarski's equidistance relation.

the temporal domain which is usually characterized by the binary relations, *precedence* and *overlap* relation (e.g., Kamp 1979; van Benthem 1983).

3.2.1 Betweenness

There are some spatial expressions in English which inherently refer to three spatial regions. For example, to interpret the sentence (6) below, we evaluate the spatial relation among three regions, (i) the region where John started walking from, (ii) the region of the road, (iii) the region where John wound up being. That is, the road is between the source and the goal of John's path. To capture such spatial relations, we introduce the ternary relation BETWEEN:[5]

(6) *John walked across the road*

---

[5]Huntington (1913) gives the following theorems among others which suggest that the notions of *inclusion* and *betweenness* is basic for spatial relations in two- and three- dimensional space.

Theorem-11: If four points are in a plane ABC, then either:
(i) one of them belongs to the triangle formed by the other three; or
(ii) the segment joining two of them intersects the segment formed by the remaining two. (Necessary & Sufficient condition for 4 points to be *Coplanar*)

Theorem-44: If five points are in a space ABCD, either
(i) one of them belongs to the tetrahedron formed by the other four; or
(ii) the segment joining two of them intersects the triangle formed by the remaining three. (Necessary & Sufficient condition for 5 points to be *Cospacial*)

Huntington (1913) proposes a set of axioms for ordinary Euclidean geometry where he uses (i) the *solid body* instead of the *point* as an undefined concept ('the class of ordinary spheres), and (ii) the simple undefined relation of *inclusion*. Then he defines systematically the *straight line*, the *plane*, and the *three-dimensional space*. Tarski's (1929) axiomatic system of three dimensional elementary geometry is also based on the primitive notions of ternary *betweenness* and quarternary *equidistance*.

(7) For X, Y, Z$\in\Sigma$ pairwise disjoint regions, BETWEEN(X, Y, Z) is a primitive ternary relation intended to mean "Y lies between X and Z", which is

(i) transitive:[6] if BETWEEN(X, Y, U) and BETWEEN(Y, Z, U) then BETWEEN(X, Z, U), and

(ii) symmetric on 1st and 3rd arguments: if BETWEEN(X, Y, Z) then BETWEEN(Z, Y, X).

We can see from the definition that the betweenness relation basically represents the ordering relation among three points in the space, so we define *line* in terms of BETWEEN and *atomic region*.

(8) Definitions:

a. Let A and B be any distinct atomic regions in Σ.
Define Λ_{AB}, the *line determined by* A *and* B, as follows:
Λ_{AB} =df. {X$\in\Sigma$| X is an atomic region and either X=A or X=B or BETWEEN(X, A, B), or BETWEEN(A, X, B), or BETWEEN(A, B, X)}.

b. If two lines Λ and Λ' have no atomic region in common, i.e., $\Lambda\cap\Lambda' = \emptyset$, then they are said to be *parallel* to each other.

In 3.4, we will use the notions defined above to introduce the notion of *orientation* in the semantics of locative prepositions. The betweenness relation is used to interpret a wide range of spatial relations expressed by locative PPs in English. Some of the expressions are illustrated in the following:

[6]The transitivity axiom of betweenness is of slightly different form from Tarski's (1959), but they are equivalent to each other. Tarski's (1959) axiom is given by: If BETWEEN(X, Y, Z) & BETWEEN(Y, U, Z) then BETWEEN(X, Y, U).

(9) Perspectival Prepositions

in front of — *behind/in back of*

to/on the left of — *to/on the right of*

across, through, over, past, around, on the other side of

3.2.2 Relative Distance

A path of movement consists of its *source*, *route*, and *goal*, and we can describe the movement in terms of relative distance among the regions. If John ran from the post office to the house, then, during the period of his running, the distance between John and the post office increased and the distance between John and the house decreased. Increasing or decreasing of distance with respect to a specific point can be represented by a ternary relation. More revealing is the sentence, *John walked toward the house*, which crucially refers to the distance between the house and John's position during the walking period, i.e., the sentence claims that the distance between John and the house decreased in the period. We introduce the ternary relation NEARER to represent this notion of 'distance change' in terms of *relative nearness*:

(10) For X, Y, Z $\in \Sigma$, NEARER (X, Y, Z) is a primitive ternary relation intended to mean "X is nearer to Y than Z is", which is

(i) irreflexive: For all X, Y $\in \Sigma$, $\neg$NEARER (X, Y, X) and $\neg$NEARER (Y, X, X),

(ii) transitive: For all regions X, Y, Z, and U,
if NEARER (X, Y, Z) and NEARER (Z, Y, U) then NEARER (X, Y, U), and

(iii) asymmetric on 1st-3rd arguments: For all regions X, Y, Z,
if NEARER (X, Y, Z) then $\neg$NEARER (Z, Y, X).

English uses *nearer-than-* to denote the relation defined above, and the converse of the relation is denoted by *farther-from-*. Thus 'x is farther from y than z is' is true iff NEARER(®(z),®(y),®(x)). We can also define *equidistance* relation E-DIST (X, Y, Z) which means 'Y is equally distant from X and Z as follows: E-DIST (X, Y, Z) iff ¬ NEARER (X, Y, Z) and ¬NEARER (Z, Y, X).

The relative nearness relation is a primitive ternary relation which tells about difference or change of distance. By contrast, a metric distance function from pairs of point into real numbers (with distance units like *meter, foot,* and *mile*) is secondary to the relative nearness relation, and culturally determined. We interpret the preposition *towards* and movement verbs like *approach* in terms of NEARER. Now equipped with the two ternary relations BETWEEN and NEARER, we have the structure of the space Σ as a quintuple $<\Sigma, \subseteq, \emptyset$, BETWEEN, NEARER$>$.

3.3 Paths

Path is one of the basic concepts discussed in the literature on spatial language and it is claimed to be crucial for the perception/cognition of movement or journey, and it is one of the main cognitively motivated devices for representing changes of location (see Miller and Johnson-Laird (1976), Cresswell (1978) and Jackendoff (1983, 1990) among others). In order to describe a movement we express its manner and its path (or location change).[7] English motion verbs express different manners of movement, and

[7]English of course has lexical verbs that only encode the meaning of movement (location change) without encoding its manner. For example, *go, come, leave, arrive, cross, pass, enter, depart,* etc.

locative prepositional phrases refer to the paths of movement. The following is a small sample of such expressions:

(11) a. *John walked from the library to his office*
b. *The boys jogged around the park*
c. *They drove into Los Angeles*
d. *Mary ran five miles away from the village*

This section defines path structure and exhibits conditions and relations in the structure. From the mereology of space introduced in the last section, the notion *region* is crucial for defining *path* and *orientation*. Thus, *paths* are defined as sequences of regions, which is a purely spatial and non-temporal definition.[8] One of the immediate applications of the notion *path* is illustrated by the ternary relation TRAV which is intended to mean "traverse": Thus, TRAV(x,π,T) means the object x traverses the path π during the time interval T. In 3.3.3 we lay out some theorems which provide accounts for the entailment patterns like the following: *John came from Los Angeles*

---

[8]There have been other views to paths in the literature: Cresswell (1978a,b) gives a temporal definition of path, but he employs paths to locate non-moving objects as well as moving ones (see section 4.1.3). Hinrichs (1985) defines a path as a three-place relation among "locations", which refer to the origin, the goal, and the path itself. Locations in his semantics refer to *spatio-temporal chunks*. Crow (1989) suggests a possibility of defining paths as non-temporal, purely spatial entities, so a path is defined as a *n*-ary merge of a series of regions. In Jackendoff (1991), paths are simply introduced as a basic ontological category, i.e., semantic primitive.

We pursue here a non-temporal view to path, since locative PPs referring to paths can be used in non-temporal contexts as the following examples illustrate:
(i) *John made a phone call to New York*
(ii) *Freeway 10 runs from Los Angeles to Miami*
(iii) *John saw Mary through the window*
(iv) *They shouted at each other across the street*

and Los Angeles is in California entails *John came from California*, but the latter does not entail the former.

3.3.1 Path Structure and Conditions

The mereological space is a set of regions which are organized by the part-whole relation ($\subseteq$), the betweenness relation (BETWEEN), and the relative nearness relation (NEARER). Now we build more structure in the space with paths: The regions in a space are connected in terms of paths, so the space now bears a set of *paths*. The paths in a space might be taken as real or hypothetical. The notion of path we are interested here is not of course a physical one but an abstract one. The same physical path then can be represented in different abstract paths: If John flew from Los Angeles to Houston and then to New York, John's path can be represented as **<los angeles–new york>** or as **<los angeles–houston–new york>**, and English expresses the path with different prepositional phrases, i.e., *from Los Angeles to New York* or *from Los Angeles to New York via Houston*. The abstract notion of path now lacks the continuity of physical movement (or geometric lines). This is what renders our semantics of space sufficiently elegant as to interpret spatial expressions.

A path (or journey/trajectory) represents a route of movement of an object, so we think of a path as denoted by a set of place names. But importantly there is an internal structure in a path, that is, a path has a starting point (a *source*) and an ending point (a *goal*), and a path can be cyclic, i.e., a path can go through the same region more than once. So a path cannot be represented by a mere 'set' of regions, and we make use of the notion 'sequence' to give a proper treatment of paths. We note two crucial advantages of this approach: (i) our notion of path is not temporal, so paths are introduced in our semantics as purely spatial entities; (ii) it is flexible enough to accomodate cyclic paths that allow some regions can occur more than once in a single path.

We define *Path Structure* as a set of paths which are partially ordered by the containment (subpath) relation. Paths are defined as sequences of regions, which are time-free, i.e., paths themselves are not superimposed with temporal meaning. A sequence is a function with a domain of natural numbers from zero through some k, represented as $[0, k]$ in (12b), thus a path is a function from $[0, k]$ into Σ. This thesis uses the following notation for a sequence of a path: $<\pi(0),\pi(1),...,\pi(k)>$ represents the path π such that its domain is $[0, k]$ and for each $0 \leq i \leq k$, $\pi(i) \in \Sigma$.

(12) *Path Structure*: $<\Pi(\Sigma), \subseteq, +>$

a. $\Pi(\Sigma)$ is the set of paths in the space Σ.

b. A path π is a sequence of regions, i.e., $\pi \in [[0, k] \rightarrow \Sigma]$ for some $k \in \mathbb{N}$, where $[0, k] = \{n \in \mathbb{N} \mid 0 \leq n \leq k\}$), and satisfies the following:
For all paths $\pi \in \Pi(\Sigma)$, and for all $i \in$ Domain(π),
$\pi(i-1) \not\subset \pi(i)$ and $\pi(i) \not\subset \pi(i+1)$

c. $\subseteq$ is the containment relation between paths.
Let π and π' be paths, then π' *is contained in* (or *a subpath of*) π, $\pi' \subseteq \pi$, if
(i) Domain(π') $\subseteq$ Domain(π) and Range(π') $\subseteq$ Range(π), and
(ii) there is some $i \in$ Domain(π) such that
$\pi'(0) = \pi(i)$ and for all $j \in$ Domain(π'), $\pi'(j) = \pi(i+j)$.

d. + is a concatenation function in $[\Pi(\Sigma) \times \Pi(\Sigma) \rightarrow \Pi(\Sigma)]$:
Let π and π' be arbitrary paths with Domain(π) = $[0, n]$ and Domain(π') = $[0, m]$.
The *concatenation* of π and π', $\pi + \pi'$, is defined by:

$$\pi+\pi'(k) = \begin{cases} \pi(k) & \text{if } 0 \leq k < n \\ \pi(k) = \pi'(0) & \text{if } k = n \\ \pi'(k-n) & \text{if } n < k \leq n+m \end{cases}$$

(12b) imposes a general condition on the path structure which is motivated by the linguistic intuition on the following sentences:

(13) a. *John drove from Los Angeles to San Diego*
b. **John drove from Los Angeles to California*
c. **John drove from California to San Diego*

The locative PP in (13a) refers to a path like **<los angeles, san diego>**, but the PPs in (13b) and (13c) make the sentences meaningless since they fail to refer to a legitimate path. Thus, we want to rule out paths such that some region in the path-sequence is included in the next region of the path, or vice versa. Thus there is no path in $\prod(\Sigma)$ like the following: **<california, the united states>** or **<california, los angeles>**, etc.

By (12c), every continuous part of the sequence of a path is a subpath: For example, suppose X, Y, Z, and W are regions in Σ, and π = <X,Y,Z,W>, i.e., $\pi(0)$ = X, $\pi(1)$ = Y, etc., then π has 10 subpaths as the following: <X>, <Y>, <Z>, <W>, <X,Y>, <Y,Z>, <Z,W>, <X,Y,Z>, <Y,Z,W>, <X,Y,Z,W>. But neither <X,Z> nor <X,W> is a subpath of π.

We note here some theorems coming from the definition of the *subpath* relation: First, the relation is (i) reflexive, for all paths π, $\pi \sqsubseteq \pi$; (ii) transitive, if $\pi \sqsubseteq \pi'$ & $\pi' \sqsubseteq \pi''$ then $\pi \sqsubseteq \pi''$; and (iii) antisymmetric: $\pi \sqsubseteq \pi'$ & $\pi' \sqsubseteq \pi \Rightarrow \pi = \pi'$.

The *concatenation* function defined in (12d) takes two paths π and π' to give another path $(\pi+\pi')$ whose initial part is π and the subsequent part is π'. Notice that the concatenation is not a total function, that is, for some paths π and π', $(\pi+\pi')$ is not defined. This is due to the condition given in the defintion, i.e., the last region of the first path and the first region of the second path have to coincide, i.e., $\pi(k) = \pi'(0)$. In other words, concatenation of π and π' exists iff the goal of π and the source of π' are the same (*goal* and *source* are defined below).

(14) Definitions:

Let π be a path with Domain(π)=[0, k], then
the *goal* of π, π_g, is $\pi(k)$ and the *source* of π, π_s, is $\pi(0)$.

Unlike set-theoretic sum, the concatenation is not commutative: $\pi+\pi' \neq \pi'+\pi$. But it is associative: $(\pi+\pi')+\pi'' = \pi+(\pi'+\pi'')$.

Now we note a very special relation between paths: the *converse* relation. For all paths π, we have a path which reverses the ordering of π. We define:

(15) Definition:

Let π be a path with Domain(π) = [0, k], then
π^{-1}, the *converse* of π, is defined by:
Domain(π^{-1}) = [0, k], and
for all $i \in$ Domain(π^{-1}), $\pi^{-1}(i) = \pi(k-i)$.

By the definition, $\pi^{-1}(0) = \pi(k)$, $\pi^{-1}(k) = \pi(0)$, i.e., the source of π^{-1} is the goal of π and the goal of π^{-1} is the source of π. We crucially rely on the notion of *path-converse* for the semantics of symmetric locatives and some special adverbs/verbs like *back* and *return*. For example, the path π = <**new york, chicago, los angeles**> and π' = <**los angeles, chicago, new york**> are in converse relation to each other. The relation as defined is symmetric.

3.3.2 Paths in the relation TRAV ("traverse").

The intuitive notion of *path* involves a movement of an object. The previous section defines paths simply in spatial terms, so no temporal meaning is incorporated in paths. But every movement has to be performed in a specific time interval. Now to represent this notion of *movement through a path*, we introduce a predicate TRAV which is a ternary relation in $\mathbb{E}\times\Pi(\Sigma)\times\mathbb{T}$, where $\mathbb{E}$ is the universe of individuals, $\Pi(\Sigma)$ the set of paths in the local space Σ, and $\mathbb{T}$ the set of time intervals.

Informally, TRAV(x, π, T) means 'x traverses the path π during the interval T'. Here π is a sequence of regions with its domain in natural numbers, $\mathbb{N}$, and T a linearly ordered set of time points. In order to define this predicate formally, we use the function $® \in [(\mathbb{E}\times\mathbb{T})\rightarrow\Sigma]$ which assigns a unique region to each individual object at an interval (defined in 3.1). Thus, for some object x, and a time interval T, ®(x)(T) denotes the region which x occupies during the interval T. Now formally,

(17) Definition:

TRAV(x, π, T) is True iff there is an "order-preserving" map μ from Range(π) to T such that for all $i \in$ Domain(π), INTR(®(x)($\mu(\pi(i))$), $\pi(i)$).

We take an interval T as a linearly ordered set of time points, but the domain of μ is not an ordered set but a sequence (functions from $K \subseteq \mathbb{N}$ into Σ). Thus we use the term "order-preserving" in a special sense defined as follows:

(18) Definition:

For a path π and an interval T, a function μ from Range(π) = $\{\pi(i) \mid i \in \text{Domain}(\pi)\}$ to T is *order-preserving* iff for all $i, j \in$ Domain(π), if $i \leq j$, then $\mu(\pi(i)) \leq_T \mu(\pi(j))$ and $\mu(\pi_s) = \mathbf{0}_T$ and $\mu(\pi_g) = \mathbf{1}_T$.

An interval T is ordered by the precedence relation ($\leq_T$), and the least element of T, $\mathbf{0}_T$, refers to the initial point of the interval T, and the greatest element $\mathbf{1}_T$ refers to the terminal point of T. The TRAV relation will be used to interpret sentences referring to a path and a movement. For example, *John ran into the house* will be interpreted to be true iff 'John ran' and 'John traversed the path π, i.e., TRAV(**john**,π,T), such that the source of the path is outside the house and the goal is inside the house'.

3.3.3 Theorems on Path Structure and Relations

Given the *Path Structure* and the relation TRAV defined in the previous sections, we can account for some general entailment patterns determined by spatial expressions. First consider (19) and (20):

(19) a. *John came from Los Angeles and Los Angeles is in California* entails

b. $\models$ *John came from California*

(20) a. *John drove from Las Vegas to Los Angeles* entails

b. $\models$ *John drove from Las Vegas to California* and

c. $\models$ *John drove from Nevada to California*

This entailment pattern reveals one of the basic strategies for spatial inference based on the "inclusion" relation. Our semantics of path and movement accounts for this with no stipulation. The locative PP in (19a) determines a path referring to its source region, **los angeles**, so we have:

(21) *John came from Los Angeles*
is true iff
for an interval T<**now**, TRAV(**john**, π, T) where π_s = ®(**los angeles**).

If TRAV(**john**, π, T) is true then INTR(®(**john**)($\mathbf{0}_T$), ®(**los angeles**)). Since ®(**los angeles**) $\subseteq$ ®(**california**), INTR(®(**john**)($\mathbf{0}_T$), ®(**california**)). Therefore, if (19a) is true, then (19b) is true. This accounts for the entailment in (20) in the same way. The following theorem (22) gives an account of the entailment pattern. We refer to a subpath of a path with a subscript notation defined in (23).

(22) Theorem-1:
For all paths π and π', and intervals T,
TRAV(x, π, T) implies TRAV(x, π', T), if π and π' satisfy the following:
(i) π is a path such that Domain(π) = [0, k] and
(ii) for some $0 \leq i \leq j \leq k$, and a region R$\in\Sigma$,
$\cup$Range($\pi_{[i,j]}$) $\subseteq$ R, and
π' is defined as follows:
Domain(π') = [0, k–(j–i)], and

$$\pi'(n) = \begin{cases} \pi(n) & \text{if } 0 \le n < i \\ \mathrm{R} & \text{if } n = i \\ \pi(n-(j-i)+1) & \text{if } i < n \le k \end{cases}$$

(23) Notation:

For π a path with the domain of $[0,k]$, and for some $0 \le i \le j \le k$,
$\pi_{[i,j]}$ is a subpath of π defined by:
$\mathrm{Domain}(\pi_{[i,j]}) = \{0,\ldots,(j\text{-}i)\}$, and
$\pi_{[i,j]}(n) = \pi(n+i)$ for all $n \in \mathrm{Domain}(\pi_{[i,j]})$

The theorem tells us, for example, if x traversed the path π= <**seattle**, **san francisco**, **los angeles**, **houston**> during a time interval T, then it should be true that x traversed the path π'= <**seattle**, **california**, **houston**>. This follows from the fact that ®(**san francisco**) $\subseteq$ ®(**california**) and ®(**los angeles**) $\subseteq$ ®(**california**). The following figure illustrates how we get the effect of Theorem-1, where the regions B and C in the path π are included in the region R in the path π'.

```
       π(0)                π(k)
   π:  A-----------B-C-----------D
       |            V            |
  π':  A------------R------------D
       π'(0)               π'(k')
```

Let us now consider (24) and (25) below where the entailment patterns involve the notion of "subpath": (24a) entails (24b,c), and (25a) entails (25b,c).

(24) a. *John flew from Los Angeles to San Diego, and then to Las Vegas*
b. $\models$ *John flew from Los Angeles to Las Vegas* and
c. $\models$ *John flew from San Diego to Las Vegas*

(25) a. *John drove through the forest from here to the village* entails

b. $\models$ *John drove from here to the village*

c. $\models$ *John drove from here (through the forest)*

d. $\models$ *John drove (through the forest) to the village* and

c. $\models$ *John drove through the forest*

The intuition is, if an object traversed a path π, then it must have traversed the subpaths of π. Theorem -2 and -3 in (26-27) account for the entailment patterns.

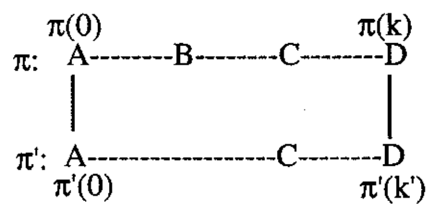
(26) Theorem-2:

For all paths π with Domain(π) = $[0, k]$ and π' with Domain(π') = $[0,k']$, and intervals T, TRAV(x, π, T) implies TRAV(x, π', T), if π and π' satisfy the following:

(i) Domain(π') $\subseteq$ Domain(π), i.e., $k' \leq k$,

(ii) $\pi'(0) = \pi(0)$ and $\pi'(k') = \pi(k)$, and

(iii) for all $0 \leq i' \leq j' \leq k'$, there are i and j such that $0 \leq i \leq j \leq k$ and $\pi'(i') = \pi(i)$ and $\pi'(j') = \pi(j)$.



Theorem-2 states that, during an interval T, if an object traversed a path π, then it also traversed a path π' which shares the same source and goal with π and has some (or all) of the regions in Range(π) in the same order. Thus, for example, suppose π = <**los**

angeles, **san diego**, **las vegas**> and $\pi' =$ <**los angeles**, **las vegas**>, then TRAV(x, π, T) implies TRAV(x, π', T). Thus we have the entailment illustrated in (24).

(27) Theorem-3:

Let π and π' be paths such that π' is a subpath of π.
If TRAV(x,π,T), then TRAV(x,π',T') for some T' a subinterval of T.

```
               π(i)      π(j)
π:    A--------B---------C--------D
               |         |
               |         |
π':            B---------C
              π'(0)     π'(k')
```

This theorem guarantees that if an object traversed a path π then it traversed its subpaths of π. Notice that this theorem refers to a time interval and its subinterval, whereas Theorem-2 refers to the same interval for π and π'.

3.4 Orientations (front, back, ..., upside down, ...)

Natural language expressions refer to spatial orientations to locate some object in the space, so for example, the PP in (28) below refers to *front-orientation* of the car to locate the subject argument 'John'.

(28) *John is sitting in front of the car*

Thus the sentence is true only if John's region is on the front orientation of the car. This section defines *Orientation Structure* as a set of orientations in the space, and introduces three types of spatial orientation: *Extrinsic Orientations*, *Intrinsic Orientations*, and *Conventional Orientations*.

3.4.1 Orientation Structure

When we say *John is in front of the car*, we use the notion *orientation* as a region or some set of regions, i.e., John's region intersects the front orientation of the car. Let us then clarify what we mean by *front orientation*. A car has an inherent front, which can be determined either by its formal features or by its moving direction. However its front part is determined, this provides a way to characterize its front orientation. Roughly, a front orientation of a car can be characterized as a half axis moving out from the car in the direction to its front part. This provides an intuitive way of defining spatial orientations: That is, we take orientations as spatial objects like rays which have a designated point (= Origin) and a direction. Rays, in their geometric sense, are collections of *points*, but we define orientations in terms of *atomic region* instead of *point*. Here the definition of *atomic region* is repeated from 3.2.

(29) Definition:

For all non-empty regions $R \in \Sigma$, R is *atomic* iff there is no non-empty region $R' \in \Sigma$ such that $R' \subset R$.

Orientation Structure is defined as the set of orientations (equivalent to *rays*) with the *containment* relation ($\subseteq$) between them.

(30) *Orientation Structure* $<\mathbf{R}(\Sigma), \subseteq_{\mathbf{R}}>$:

a. $\mathbf{R}(\Sigma)$ is the set of *orientations* in a local space Σ

b. For each orientation $\rho \in \mathbf{R}(\Sigma)$, ρ is a linearly ordered set $(\rho, <)$ of atomic regions in Σ such that

(i) there is a unique least element (Origin(ρ)),

(ii) there is an atomic region $X \in \rho$ such that for all atomic regions $Y \in \Sigma$,

$Y \in \rho$ iff either BETWEEN (Origin(ρ), Y, X) or

BETWEEN (Origin(ρ), X, Y), and

(iii) for all atomic regions X, $Y \in \rho$, $X < Y$ iff

NEARER (X, Origin(ρ), Y)

c. $\subseteq_{\mathbf{R}}$ is the binary *containment* relation between orientations:

For all orientations $\rho, \rho' \in \mathbf{R}(\Sigma)$, $\rho \subseteq_{\mathbf{R}} \rho'$ iff $\rho \subseteq \rho'$ and for all X, $Y \in \rho$, $X <_{\rho} Y$ iff $X <_{\rho'} Y$.

A linearly ordered set is defined in terms of a linear order, here represented by <. The linear order is intended to be the relative distance relation from the origin of the orientation, as defined in (30b-iii). A linear order is total, irreflexive, asymmetric, and transitive. Thus, for each orientation (r, <),

(i) $\forall X, Y \in \rho$, either $X < Y$ or $Y < X$,

(ii) $\forall X \in \rho$, $\neg(X < X)$,

(iii) $\forall X, Y \in \rho$, if $X < Y$, then $\neg(Y < X)$, and

(iv) $\forall X, Y, Z \in \rho$, if $X < Y$ and $Y < Z$, then $X < Z$.

The betweenness condition given in (30b-ii) guarantees that for any orientation r, there is a line Λ such that all the atomic regions in r belong to Λ. (See 3.2.1 for the definition of *line*.) In other words, orientations are defined to be rays in geometric space. We define some relations holding between orientations as follows:

(31) Definitions:

a. Let ρ and ρ' be orientations, then ρ *faces* ρ' iff Origin(ρ) intersects ρ', Origin(ρ') intersects ρ, and Origin(ρ) $\neq$ Origin(ρ').

b. Let ρ and ρ' be orientations, then ρ *is the complement of* ρ', ρ = Compl(ρ') iff $\rho \cup \rho'$ is a line and $\rho \cap \rho'$ = Origin(ρ) = Origin(ρ')

c. Let ρ and ρ' be orientations, then ρ *is parallel to* ρ' iff the two lines Λ and Λ' containing ρ and ρ', respectively, are parallel to each other. (See 3.2.1 for the definition of *parallel lines*.)

d. Let ρ and ρ' be orientations, then ρ and ρ' *have the same direction* iff they are parallel to each other, and for all X$\in \rho$ and X $\neq$ Origin(ρ), and for all Y$\in \rho'$ and Y $\neq$ Origin(ρ'), the line-segment [X, Y] does not intersect the line-segment [Origin(ρ), Origin(ρ')].[9]

Orientations will be used to interpret stative (orientational) locatives and perspectival locatives which are referring to the location of a static object.

[9]A *line-segment* is determined by two atomic regions (points). We give the following intuitive definition: Definition — For all atomic regions A and B, $\Lambda_{[A, B]}$, the *line-segment determined by* A *and* B, is defined by: $\Lambda_{[A, B]} =_{df.} \{X \in \Sigma \mid X$ is an atomic region and either X=A or X=B or BETWEEN(A, X, B)$\}$.

3.4.2 Spatial Orientations

We distinguish three types of spatial orientations which structure the space globally or locally. First, *extrinsic orientations* are ones which structure the global space and which are assumed independently of the inherent properties of objects in the space. The second type, *intrinsic orientations*, are determined by the inherent properties of the objects. The third type is the ones which are determined by an overt or covert (observer's) perspective point. The last two types of orientation participate in structuring local spaces.

3.4.2.1 Extrinsic orientations for the global structure of Space

The space is structured in terms of extrinsic orientations. Natural language expressions use two kinds of extrinsic orientation: (i) The Gravity Dimension (*up/down*), (ii) Compass orientations (*East/West/North/South*). The Gravity dimension is a ubiquitous orientation on the earth and human bodies always have to recognize the orientation to survive. There are many English words referring to the gravity dimension: Prepositions like *up*, *down*, *on top of*; and verbs like *ascend*, *descend*, *rise*, *fall*; etc.

A new special spatial object is introduced in the space Σ to define the gravity dimension: that is, the center of gravity, **G**. For each object x, we assign a gravity dimension, Ω_G, which is defined as an orientation which has its origin at the center of x and intersects **G**, the center of gravity:

(32) Definition:

For all individuals $x \in \mathbb{E}$, and all intervals $T \in \mathbb{T}$,

$\Omega_{\mathbf{G}}(x,T)$, the *gravity dimension* for x at T, is an orientation ρ such that

$\mathrm{Origin}(\rho) = ®(\mathbf{P}_{\mathrm{center}}(x,T))$ and $\mathrm{INTR}(\mathbf{G}, \rho)$.

The compass orientations are assigned to the surface of the earth by convention, and the following expressions refer to them to be interpreted: *to the east/west of*, *eastward*, *southbound*, etc.

3.4.2.2 Intrinsic orientations for Local structures of Space

Object internal properties also participate in structuring a local space. For example we use intrinsic orientations of the human body (front/back, head/foot, left/right) to evaluate spatial relations between objects. Thus (33) below can only be interpreted by referring to Mary's front side or back side.

(33) *John is in front of/behind Mary*

Objects have their intrinsic orientations, e.g., front-back, top-bottom, left-right, and in-out orientations. We claim here that such objects get the intrinsic orientations due to their different parts. In other words, if an object has inherent front and back parts, it can be assigned front-back orientations determined by them. For example, a car has an inherent front part, no matter how it is determined (whether it is determined by the normal direction of movement or by a formal characteristics of its front part), so we can assign front or back orientation to it. In other words, we think of *intrinsic orientation* as a derived concept from *parts* of objects.

If an object has top-bottom and front-back orientations then they determine its left-right orientations. However, the three orientations are independent of each other in the sense that no one of them entails the existence of any one of the other . Thus, not all objects with top-bottom orientations have front-back or left-right orientations (e.g., vases, unlabeled bottles), and objects with front-back orientations do not have to have top-bottom orientations (e.g., rockets, bullets). Some objects have no inherent orientations: e.g., a blank sheet with no marking on it and a tennis ball.

The following illustrate different primitive functions in $[\mathbb{E}\rightarrow \mathrm{Part}_{\mathbb{E}}]$ partitioning an object into different parts. For instance, $\mathbf{P}_{\mathrm{front}}$(the car) refers to the front part of the car, and so on. These functions are partial since objects may lack some (or all) of the intrinsic orientations.

(34) $\mathbf{P}_{\mathrm{front}}(x)$, $\mathbf{P}_{\mathrm{back}}(x)$, $\mathbf{P}_{\mathrm{top}}(x)$, $\mathbf{P}_{\mathrm{bottom}}(x)$, $\mathbf{P}_{\mathrm{left}}(x)$, $\mathbf{P}_{\mathrm{right}}(x)$, $\mathbf{P}_{\mathrm{inside}}(x)$, $\mathbf{P}_{\mathrm{outside}}(x)$, $\mathbf{P}_{\mathrm{center}}(x)$

Now we define orientations as determining a ray with an origin and a direction in terms of parts of objects (equivalently, a linearly ordered set of minimal regions with a least element), and such orientations are given as a function from pairs of an object and a time interval to rays, i.e., $[\mathbb{E}\times\mathbb{T}]\rightarrow\mathbb{R}(\Sigma)$, where $\mathbb{E}$ is the universe of individuals, $\mathbb{T}$ a set of intervals, and $\mathbb{R}(\Sigma)$ the set of orientations in Σ.

(35) $\Omega_{\mathrm{front}}(x,t)$ is an orientation ρ such that $\mathrm{Origin}(\rho) = ®(\mathbf{P}_{\mathrm{center}}(x),t)$ and ρ intersects $®(\mathbf{P}_{\mathrm{front}}(x),t)$, i.e., $\rho\cap®(\mathbf{P}_{\mathrm{front}}(x),t) \neq \emptyset$.

(36) $\Omega_{back}(x,t)$, $\Omega_{up}(x,t)$, $\Omega_{down}(x,t)$, $\Omega_{left}(x,t)$, $\Omega_{right}(x,t)$

Each function assigns an orientation to an object at an instance, and the orientation has its origin at the center of the object and intersects its relevant part. *In front of the car*, for example, involves the front orientation of 'the car', $\Omega_{front}(\textbf{the car},t)$, which is a linearly ordered set of minimal regions with its origin at the center of 'the car' and directed to its front side. The following illustrate some objects with their intrinsic orientations:

(37)	*man, car*:	Top/Bottom, Front/Back, Right/Left, In/Out
	telephone:	Top/Bottom, Front/Back, In/Out
	vase, boulder:	Top/Bottom, In/Out
	tree:	Top/Bottom
	rocket:	Front/Back
	box, ball:	In/Out

3.4.2.3 Deictic Orientations

The partitioning functions introduced in the preceding section are not total functions, and there are objects lacking some or all of the intrinsic orientations. For instance, tennis balls are not in the domain of any partitioning functions except $\mathbf{P}_{inside}(x)$, $\mathbf{P}_{outside}(x)$, and $\mathbf{P}_{center}(x)$, and trees are not in the domain of $\mathbf{P}_{left}$, $\mathbf{P}_{right}$, $\mathbf{P}_{front}$ or $\mathbf{P}_{back}$.

Now what happens if the nouns denoting these objects are taken as a reference object in stative orientational locatives (e.g., PPs with *in front of, behind, to the left/right of...*). Consider the following:

(38) a. *John is sitting in front of the tree.*
b. *John ran behind the tree.*
c. *The old cottage is across the river.*

Trees do not have *front-* or *back-* orientation, so the sentences need a deictic locative perspective (point of view) to be interpreted. This deictic perspective can be either 'from here' (from where the speaker is), or 'from you' (from the hearer), or 'from someone/something else' depending on the context. Not all locative PPs induce a deictic orientation, but symmetric locatives (PPs with *across*, *through*, *over*, *past*, *around*) and stative orientational locatives (PPs with *in front of*, *behind*, *to the left/right of*, *up*, *down*) do. In 4.3, we will see how to interpret sentences with these perspectival locative PPs.

We represent the deictic orientations with Ω-notation as we did for inherent ones, but different subscripts are used to distinguish deictic orientations from intrinsic ones. The origin of a deictic orientation is determined by the utterance context, so in the definition (39) the second argument y refers to the locative perspective point of the context.

(39) Definition:

For all objects x, $y \in \mathbb{E}$, and all intervals $T \in \mathbb{T}$, $\Omega_{from}(x,y,T)$ is a *deictic orientation* ρ such that Origin(ρ) $\subseteq$ ®(y) and ρ intersects ®(x,T).

For example, if *John is sitting in front of the tree* is interpreted with a deictic locative perspective point 'from here', then 'here' provides the origin of an orientation determined by the PP *in front of the tree.*

English uses a PP with *from* to explicitly indicate a locative perspective. In a sentence like (40), the PP *from here* provides a perspective point to locate the region of the old cottage, in cooperation with the other PP, *across the river*. In other words, neither of the two PPs determines the location of the old cottage independently of the other. Thus we treat the two prepositions as denoting a binary preposition which takes two NPs to locate an object. We can assign a rough semantic representation to the sentence as (41):

(40) *The old cottage is across the river from here*

(41) **(across•from (here)(the river))(is)(the old cottage)**

Chapter 4

Linguistic Applications

This chapter illustrates the linguistic applications of formal apparatus we have developed so far to interpret spatial expressions in English and discusses two issues related to the semantics of locative PPs in English, *symmetry* and *locative perspective*. Thus we show that the natural logic we have developed in the preceding chapters is satisfactory enough to give intuitive interpretations for English locatives and to provide natural accounts of the issues we bring out in this chapter (section 4.2 & 4.3). We widely use the spatial primitives and relations that we introduced in Chaper 3.

Data of concern in this chapter are locative prepositional phrases occurring with an intransitive or a transitive verb, and their subject is a noun phrase. Thus locative PPs dealt with here refer to the location of the subject or the object argument of the predicates.

4.1. Interpretation of Locative PPs

First, section 4.1.1. deals with a group of basic prepositions, *at*, *in*, and *on*, which are called *topological invariants*. In section 4.1.2, we introduce two general semantic rules for interpreting sentences with a motion verb or a stative verb. In the subsequent sections 4.1.3-4.1.5, three major classes of prepositions are discussed in detail under the rubrics of *symmetric*, *orientational*, and *directional* locatives.

4.1.1. Topological Invariants

As will be clear in the latter sections, locative prepositions in English make use of fundamental concepts and properties of geometry.[1] In particular, so called *topological properties* are widely involved in the semantics of spatial expressions. This section focuses on three locative prepositions which are characterized as denoting a *topological invariant*, and we take these prepositions as denoting primitive relations between regions corresponding to the topological invariants. By *topological invariants*, we mean those relations (and properties) which are unchanged by *topological transformations*. Formally,

(1) Definition:

A *topological transformation* of one geometrical figure A into another figure A' is given by any correspondence

$$p \leftrightarrow p'$$

between the points p of A and the points p' of A' which has the following two properties:

---

[1]Elementary geometry deals with the magnitude (length, angle, and area) that are unchanged by the *rigid motions*, while projective geometry deals with the concepts (point, line, incidence, and cross-ratio) which are unchanged by the still large group of *projective transformations*. But both the regid motions and the projective transformations are very special cases of what are called *topological transformations* (or *homeomorphisms*): Topological properties of figures are of the greatest interest and importance in many mathematical investigations. They are in a sense the deepest and most fundamental of all geometrical properties, since they persist under the most drastic changes of shape.

> (i) *The correspondence is biunique.* This means that to each point p of A corresponds just one point p' of A', and conversely.
> (ii) *The correspondence is continuous in both directions.* This means that if we take any two points p, q of A and move p so that the distance between it and q approaches zero, then the distance between the corresponding points p', q' of A' will also approach zero, and conversely.

Any property of a geometrical figure A that holds as well for every figure into which A may be transformed by a topological transformation is called a *topological invariant* of A, and topology is the branch of geometry which deals with the topological invariants of figures.

The most intuitive examples of topological transformations are the *elastic deformations.* Imagine a figure such as a sphere or a triangle to be made of or drawn upon a thin sheet of rubber, which is then stretched and twisted in any manner without tearing it and without bringing distinct points into actual coincidence. (Bringing distinct points into coincidence would violate condition (i). Tearing the sheet of rubber would violate condition (ii), since two points of the original figure which tend toward coincidence from opposite sides of a line along which the sheet is torn would not tend towards coincidence in the torn figure.) The final position of the figure will then be a topological image of the orginal.

Among the topological invariants, here we consider three for the interpretations of the following prepositions: *at*, *in*, and *on*, which realize the topological invariants, *intersecting*, *inclusion*, and *tangential*, respectively.[2] These topological invariants are

[2]Herskovits (1986:127) groups the three prepositions under the name of "topological prepositions", and she claims that "three ideal meanings ... are cognitively

also used in interpreting other locative prepositions which are more complex than the three discussed here, e.g., the preposition *through* refers to *inclusion* relation as well as *betweenness* relation.

4.1.1.1. AT: [INTERSECTION]

The topological invariant of interest here is a binary *intersecting* relation between regions. Two regions X and Y intersect each other, if there is a non-empty region shared by them. This relation can not be changed by elastic deformations. If John is *at* the school, the region which John occupies would overlap with the region of the school, thus John's region intersects the region of the school. We gave the formal definition of the relation in 3.1, repeated below:

(2) Definition:

For all regions X, $Y \in \Sigma$, INTR(X,Y) iff there is some $Z \in \Sigma$ such that $Z = X \cap Y \neq \emptyset$.

The lexical semantics of *at* is given in (3), and we interpret the sentences in (4) with *at* in terms of the intersection relation:

---

basic, essentially topological, relations (the ideal meanings of *at* and *in*, respectively coincidence and surrounding, are topological relations, preserved under elastic deformations, but the ideal meaning of *on* involoves the physical relation of support in addition to the topological relation of contiguity in the three-dimensional case)".

(3) For α an individual denoting NP, and P a n-place predicate, interpret the n-place predicate $P+at+\alpha$, where $at+\alpha$ is k-th argument oriented ($1 \le k \le n$), as follows:[3]

$$(\mathbf{at}(\alpha)(\mathbf{P})) = \{<x_1,...,x_n> \mid \mathbf{P}(<x_1,...,x_n>) \text{ and } \mathrm{INTR}(®(x_k), ®(\alpha))\}$$

(4) a. *John is at the post office*
is True iff **be**(**john**) and INTR(®(**john**), ®(**the post office**))[4]

b. *John saw Mary at the market*
is True iff **see**(<**john**, **mary**>) and INTR(®(**mary**), ®(**the market**))

c. *John praised Mary at the meeting*
is True iff **praise**(<**john**, **mary**>) and INTR(®(**john**), ®(**the meeting**))

The PP in (4b) is interpreted as an object-oriented function, and the PP in (4c) as a subject-oriented one. But notice that there is vagueness in determining *at*-regions of reference objects. We can use (4a) when John is not exactly inside the post office but in front of it waiting on line, thus outside the post office. Then the region of the post office does not have its absolute boundary for interpreting the relation denoted by *at*. The interpretation for (4b) again does not refer to the absolute region of the market, but a relativized one which varies according to the context. Such vagueness is evident in (4c) where the reference object is an event denoted by *the meeting*. It is never clear how to determine the region of an event like a meeting, a class, or a conference.

Talmy (1983) and Herskovits (1986) note that the distance between two objects X and Y cannot be absolutely determined 'for X to be at Y', but there are contextual

[3]The definition of k-*th argument orientation* is given in 2.3.2.2.

[4]The function $® \in [(\mathbb{E} \times \mathbb{T}) \rightarrow \Sigma]$ assigns a unique region to each individual object x at a time interval T, i.e., ®(**john**)(**now**) refers to the region that John occupies now. For simplicity, the temporal argument is held constant and omitted in (4).

constraints deciding the distance.[5] We leave it open how to characterize the contextual factors for the relativized regions of reference objects, but we claim that the spatial relation denoted by *at* crucially refers to the intersection relation between the region of the located object and that of refence object. Instead here we take the relation denoted by *at* as a primitive binary relation, AT(X, Y), which locates an object with respect to the relativized region of reference object.

4.1.1.2. IN: [INCLUSION]

The inclusion relation has been introduced as the primitive relation in defining mereological space Σ in section 3.1. We can notice that this relation is a topological invariant. The inclusion relation is an asymmetric one holding between two regions one of which is contained in the interior determined by the other region. We will use the symbol '$\subset$' for the relation (the *proper part* relation defined in 3.1). The prepositional phrases with *in* are interpreted in terms of the relation as follows:

(5) For α an individual denoting NP, and *P* a *n*-place predicate, interpret the *n*-place predicate, $P+in+\alpha$, where $in+\alpha$ is *k*-th argument oriented ($1 \leq k \leq n$), as follows:

$$(\mathbf{in}(\alpha)(\mathbf{P})) = \{<x_1,\ldots,x_n> \mid \mathbf{P}(<x_1,\ldots,x_n>) \text{ and } ®(x_k) \subset ®(\alpha), \text{ i.e., } \mathrm{IN}(®(x_k), ®(\alpha))\}$$

[5]Herskovits (1986:131) claims that the distance depends on the kind of objects that X and Y denote. However, we claim that the geometrical or orientational properties (magnitude, direction) of a located object do not participate in determining spatial relations between regions of a located object and a reference object.

(6) a. *John is in the garden*
is True iff **be(john)** and ®(**john**) $\subset$ ®(**the garden**)

b. *The garden is in the church*
is True iff **be(the garden)** and ®(**the garden**) $\subset$ ®(**the church**)

c. *John is in the church*
is True iff **be(john)** and ®(**john**) $\subset$ ®(**the church**)

The preposition *in* of the above sentences is interpreted as denoting *proper part* relation ($\subset$). (6a) and (6b) together entail (6c), which is readily accounted for by the transitivity of the inclusion relation. The inclusion relation is involved in interpreting the following prepositions:

(7) *in, within, inside, outside*
into, out of, through

4.1.1.3. ON [TANGENTIAL]

The topological invariant characterized by *on* is *tangentiality* (or *contiguity*), which is again unchanged by continuous elastic deformation. Tangentiality is not of course sufficient to describe the various uses of *on*, thus Herskovits (1986) defines the meaning of *on* as a composite of a geometrical contiguity relation and a physical support relation.[6] But we take tangentiality as the very core meaning of *on*, and introduce ON(X, Y) as a primitive spatial relation between regions.

[6]Herskovits (1986:140) gives the "ideal meaning" of *on* as follows: "*on*: for a geometrical construct X to be contiguous with a line or surface Y; if Y is the surface of an object O_Y, and X is the space occupied by another object O_X, for O_Y to support O_X."

(8) For α an individual denoting NP, and P a n-place predicate, interpret the n-place predicate, $P+on+\alpha$, where $on+\alpha$ is k-th argument oriented $(1 \leq k \leq n)$, as follows:

$$(\mathbf{on}(\alpha)(\mathbf{P})) = \{<x_1,...,x_n> \mid \mathbf{P}(<x_1,...,x_n>) \text{ and } \text{TANGENTIAL}(®(x_k), ®(\alpha)), \text{ i.e., } \text{ON}(®(x_k), ®(\alpha))\}$$

The intuitive meaning of tangentiality is relational: That is, the relation holds between two disjoint regions which are close to each other that no other object intervenes between them.

(9) Definition:

For all regions X, $Y \in \Sigma$, TANGENTIAL(X, Y) iff
$X \cap Y = \emptyset$ and there is no object z such that BETWEEN(X, ®(z), Y).

Moreover, Herskovits (1986) illustrates some examples where we can hardly find *tangential* relation. She admits that in the following examples the range of possible relations between a located object and a reference object excludes contiguity or support, so claims that the use of *on* can simply indicate superposition without contact.

(10) a. *the dark clouds on the island*
b. *His eye fixed, through the telescopic sight, upon the crosshair on the soldier's chest* [Herskovits (1986:146)]

But as she illustrates, physical support relation is not necessary for the relation denoted by *on*: For example, *A dog on a leash, Do not put your dirty fingers on my clean suit!*, and *On the left wall, there is a chest of drawers.*

However, these examples seem to reveal the meaning of tangentiality as we defined under (9), i.e., there is no intervening object between two regions. Thus, we do assert, uttering (10a), that there is no intervening object between the island and the dark clouds; and as for (10b), no intervening object between the crosshair and the soldier's chest. The following show more or less transparent uses of *on*:

(11) a. *The book is on the table*
is True iff **be(the book)** and TANGENTIAL(®(**the book**), ®(**the table**))
b. *John is driving on Freeway-10*
is True iff **drive(john)** and TANGENTIAL(®(**john**), ®(**freeway-10**))
c. *John saw Mary on the street*
is True iff **see(<john, mary>)** and TANGENTIAL(®(**mary**), ®(**the street**))

4.1.2. General Interpretative Rules for Locatives

Based on the formal structures of paths and orientations defined in 3.3-3.4, we now interpret symmetric/asymmetric locatives with a couple of rules general enough to fit the different locative PPs. Following the general dichotomy of movement vs. stative readings of locatives, we interpret locatives as denoting paths or orientations. The paths are associated with the movement readings induced by a motion verb, and the orientations are associated with the stative readings induced by a stative verb. The first rule in (12) is for interpreting sentences with a motion verb and a locative PP, which naturally induces a path which an object traverses. (The ternary relation TRAV is introduced in 3.3.2.)

(12) Semantic Rule–1:

For m a n-place motion predicate, and f an extensional locative modifier, interpret the n-place predicate, $m+f$, where f is k-th argument oriented ($1 \leq k \leq n$), as follows:

$$\mathbf{f}(\mathbf{m}) = \{<x_1,...,x_n>|\ \mathbf{m}(<x_1,...,x_n>) \text{ and } \mathrm{TRAV}(x_k, \pi_f, T)\}$$

where π_f is a path determined by f.

For example, if a PP is interpreted as an object (second argument) oriented function, then the PP denotes a path that the object argument (x_2) traverses. Different locatives determine different paths. For example, *into the room* refers to a path whose source is a region outside the room, and whose goal is a region inside the room, and *over the fence* refers to a path whose source and goal are on the opposite sides of the fence, etc. Thus, *John jumped over the fence* is true iff John jumped during a past interval T and John traversed the path from one side of the fence to the other during T. In 4.1.3-4.1.5, we will see how locative PPs in English determine a path.

The second rule in (13) is for interpreting sentences with a stative verb and a locative PP, so their interpretations do not involve a change of location.

(13) Semantic Rule–2:

For s a n-place (stative) predicate, and f an extensional locative modifier, interpret the n-place predicate, $s+f$, where f is k-th argument oriented ($1 \leq k \leq n$), as follows:

$$\mathbf{f}(\mathbf{s}) = \{<x_1,...,x_n>|\ \mathbf{s}(<x_1,...,x_n>) \text{ and } \mathrm{INTR}(®(x_k), \rho_f)\}$$

where ρ_f is an orientation determined by f.

INTR is a binary relation between regions: For all X, $Y \in \Sigma$, INTR(X, Y) iff $X \cap Y \neq \emptyset$. In 3.1, we extended the relation to hold between a (atomic) region and a set (or a sequence) of regions, and so we have cases where a point intersects a path or a region intersects an orientation. The latter case is the one the second rule-2 refers to, thus INTR(®(x), ρ_f) means the region of x intersects the orientation ρ_f. In section 3.4.2, intrinsic/extrinsic orientations (e.g., $\Omega_{front}(x,t)$, $\Omega_{up}(x,t)$, $\Omega_G(x,t)$, etc.) are defined and assigned to objects. In the following sections we define deictic orientations and see how to interpret sentences with a symmetric locative or an orientational locative.

4.1.3. Symmetric Locatives

Symmetric locatives include locative PPs with *across*, *through*, *over*, *around*, and *past*. The semantics of the symmetric locatives involve *betweenness* relation BETWEEN(X, Y, Z) introduced in section 3.2.1. In this section we give lexical meanings of symmetric prepositions which interpret symmetric locative PPs. Before considering individual prepositions, let us note a common characteristics of symmetric locatives: In section 2.2.5, we have shown that only symmetric locatives are oriented to both subject and object, denoting a binary spatial relation between the arguments. Section 4.2 will propose a semantic condition which symmetric locatives satisfy but not others, and we show that only symmetric locatives involve quantification over subpaths of a bigger one.

4.1.3.1. Path/Orientation Ambiguity and Binary Prepositions

Symmetric locative PPs trigger ambiguity in a sentence with a motion verb, so the sentence (15) below is ambiguous:

(15) *John was jogging across the street from here*

One reading is (i) a movement directional reading in which John crossed the street and *here* denotes his starting place; and the other reading is (ii) a stative perspectival reading in which John was on the opposite side of the street from here jogging. In other words, the symmetric PP *across the street* refers to a *path* for the movement directional reading and an *orientation* for the stative perspectival reading.[7] Analogous examples are the following with a symmetric locative.

(16) a. *The horse jumped over the fence*
b. *The river runs through the woods*
c. *The band was marching around the corner*

The first reading of (15) can be roughly represented as (17) where the *from*-phrase denotes a source point of movement and the two PP-functions apply to the

[7]This ambiguity is preserved under the following operations:
(i) Negation: *John did not jog across the street*
(ii) Quantification: *everybody was jogging across the street*
(iii) VP ellipsis: *John jogged across the street, and so did Mary*
(ii) and (iii) are ambiguous with a directional and a perspectival reading, but do not allow a reading where the two readings are mixed. That is, (iii) is not true, if John crossed the street jogging and Mary was on the other side of the street jogging.

predicate **was jogging** one after the other. The second reading, however, can be represented as (18) with a binary preposition **across•from** which is not paraphrasable in terms of unary prepositions. We will give the general semantics for binary prepositions later in 4.3. Binary prepositions take two NP arguments to give a predicate modifier, where one of the arguments refers to a reference object and the other a perspective point.

(17) **(<u>from</u> here (<u>across</u> the-street (was jogging)))(john)**

(18) **[<u>across•from</u> (the-street)(here)](was jogging)(john)**

Now let us illustrate interpretations of symmetric locatives with a lexical semantics of relevant prepositions. (19a) is an instantiation of Semantic Rule –1 (cf. (12)), and defines the meaning of *across* as a unary preposition and *across* α determines a path π such that BETWEEN(π_s,®(α),π_g) and for some object x and a time point t, ON(®(x,t),®(α,t)).

(19) a. *across* α

For m a n-place motion predicate, for α an individual denoting noun phrase, interpret the n-place predicate m+*across*+α, where *across* α is k-th argument oriented ($1 \leq k \leq n$), as follows:

(**across**(α))(**m**) = {<x_1,...,x_n>| **m**(<x_1,...,x_n>) and TRAV(x_k, π, T) where BETWEEN(π_s, ®(α), π_g) and for some t$\in$T, ON(®(x_k,t), ®(α,t))}

b. *across-from*:

For s a n-place predicate, for α, β individual denoting noun phrases, interpret the n-place predicate s+*across*+α+*from*+β, where *across*+α+*from*+β is k-th argument oriented ($1 \leq k \leq n$), as follows:

$(\mathbf{across{\bullet}from}(\alpha)(\beta))(\mathbf{s}) = \{<x_1,...,x_n>|\ \mathbf{s}(<x_1,...,x_n>)$ and

INTR(®(x_k),ρ) for some orientation ρ, where for T an interval, $\rho = \Omega_{\text{from}}(\alpha, \beta, T)$, BETWEEN(®($\beta$), ®($\alpha$), ®($x_k$)), and there is some atomic region $A \in \rho$, ON(A, ®(α))}

(19b) is an instantiation of Semantic Rule–2 (cf.(13) in 4.1.2) and defines the meaning of *across-from* as a binary preposition involving a locative perspective point. Notice that the complex PP *across* α *from* β determines an orientation ρ moving out from β and intersecting α, and for some atomic region $A \in \rho$, ON(A,®(α)).

Now we can derive the two readings of (15) from (17) and (18) applying (19a) and (19b) above. Let us first give the directional reading of (17) where *across the street* determines a path and *from here* specifies the source of the path.

(17') a. (**across the-street** (**was jogging**))(**john**)

is true iff

for some interval T<**now**, **jog**(**john**)(T) and TRAV(**john**, π, T) where

BETWEEN(π_s, ®(**the-street**), π_g) and

for some $t \in T$, ON(®(**john**,t), ®(**the-street**, t))

b. (**from here** (**across the-street** (**was jogging**)))(**john**)

is true iff

for some interval T<**now**, **jog**(**john**)(T) and TRAV(**john**, π, T) where

BETWEEN (**here**, ®(**the street**), π_g) and

for some $t \in T$, ON(®(**john**, t), ®(**the street**, t))

(17'a) is an interpretation of (17) without *from here*, where *across the street* determines a path π that John traversed and the street is between the source and the goal of the path. (17'b) shows that the PP *from here* specifies the source of the path (π_s) as **here**.

Notice that the interpretation given in (17') guarantees the following entailment due to the condition, ON(®(x,t),®(α)), imposed on the semantics of *across* in (19a).

(20)	a.	*John jogged <u>across</u> the street*	entails
	b.	$\models$ *John was <u>on</u> the street*	

Such entailment pattern is crucial for distinguishing different symmetric locative PPs, so we account for the following entailment:

(21)	a.	*John drove <u>through</u> the tunnel*	entails
	b.	$\models$ *John was <u>in</u> the tunnel*	
(22)	a.	*The helicopter flew <u>over</u> the field*	entails
	b.	$\models$ *The helicopter was <u>above</u> the field*	
(23)	a.	*The bus ran <u>past</u> the school*	entails
	b.	$\models$ *The bus was <u>at</u> the school*	

Now let us see how our semantics of the binary preposition *across-from* gives a perspectival reading to (15) *John was jogging across the street from here*. Applying (19b) to (18), we get the following interpretation:

(18') (**across•from** (**the-street**)(**here**))(**was jogging**)(**john**)

is true iff

for some interval T<**now**, **jog**(**john**)(T) and INTR(®(**john**),ρ) where $\rho = \Omega_{\text{from}}$(®(**the street**), ®(**here**), T),

BETWEEN (®(**here**), ®(**the street**), ®(**john**)), and there is some atomic region A$\in\rho$, ON(A, ®(**the street**))

Notice that the perspectival reading involves a stative meaning of the locative PP, which determines an *orientation* to locate an object. Thus, (18') says nothing about the movement of John but the entire region where john jogged.

The ambiguity between a *movement* reading and a *stative* reading has been well noted by Bennett (1975) and Cresswell (1978). Bennett (1975) calls the first reading *directional*, and the second *locative*. The semantics of spatial language developed by Cresswell (1978) employs *paths* but not *orientations*, thus the stative perspectival reading of (15) is interpreted in terms of path and an abstract function determining the goal region (the end) of a path. Thus, his example (24) below gets two interpretations as in (25a) and (25b) which Cresswell calls "λ-deep structures":[8]

(24) *Arabella walks across a meadow from Bill* [Cresswell 1978:8]

(25) a. $\langle\langle\lambda, x, \langle\mathbf{Arabella}, \underline{\langle\langle\mathbf{walks}, \langle\mathbf{across}, x\rangle\rangle, \langle\mathbf{from}, \mathbf{Bill}\rangle}\rangle\rangle\rangle, \langle\mathbf{a\ meadow}\rangle\rangle$

b. $\langle\langle\lambda, y_1, \langle\langle\lambda, x_1, \langle\mathbf{Arabella}, \langle\mathbf{walks}, \langle\mathbf{at^*}, x_1\rangle\rangle\rangle\rangle,$ $(G, \langle\lambda, x_{<0,1>}, \langle\underline{\langle x_{<0,1>}, \langle\mathbf{across}, y_1\rangle\rangle, \langle\mathbf{from}, \mathbf{Bill}\rangle}\rangle\rangle\rangle\rangle\rangle,$ $\langle\mathbf{a\ meadow}\rangle\rangle$

[8]The semantics set in Cresswell (1978) is based on the framework of Cresswell (1973), where he develops a λ-categorial language together with a compositional semantics.

(25a) represents the movement reading where Arabella's walk occupies a path across the meadow and the walk begins where Bill is. We can notice from the underlined part of (25a) that the two PPs *across a meadow* and *from Bill* are treated as unary predicate modifiers, i.e., *across a meadow* modifies *walks*, and *from Bill* modifies *walks across a meadow*

The stative perspectival ("point of view") reading of (24) is given under (25b) – there is a *hypothetical journey* from Bill's region which goes across a meadow and which ends where Arabella is walking, i.e., Arabella walks at the end of a journey across a meadow from Bill. The interpretation of (25b) crucially uses three kinds of abstract entities: (i) the abstract preposition '**at***' which does not occur in surface structure, (ii) the function G which is intended to pick out the 'end' of a journey referred to by *across the meadow from Bill*, and (iii) an abstract object which takes a hypothetical journey. Notice also that the two PPs interpreted in (25b) determines a region (i.e., the end of the hypothetical journey), but they are treated as separate unary PPs. Thus, <**across**,y_1> applies first, then <**from,Bill**> applies to determine the 'end' region. As we have seen, however, neither of the two PPs can determine the region independently of each other.

Our semantics equipped with orientations as well as paths can give an elegant account of the ambiguity. First, to give a stative perspectival interpretation of (24), we interpret the PPs in terms of binary preposition as denoting an orientation, which is independently motivated in order to interpret a wide range of orientational PPs, e.g., *in front of, behind, to the left of, to the right of*, etc. Thus, we can avoid the heavy load on the hypothetical and abstract entities Cresswell adopts. This is also consistent with our general strategy that orientations and paths are distinctively used to locate stationary objects and moving objects, respectively. We postulated two interpretative rules in 4.1.2, Semantic Rule–1 and Semantic Rule–2, which correspond to the path/orientation distinction.[9]

As will be discussed in detail in 4.3, *from*-phrases in stative perspectival readings have distinctive charateristics from those in directional readings. Thus we introduce a new category to inrterpret such prepositions, i.e., binary prepositions. Cresswell's (1978) account, however, does not capture the difference between the two uses of *from*-phrases, since he ambiguously uses *paths* to locate either a moving object or a stationary object.

4.1.3.2. *Across*, *through*, *over*, *past*, and *around*

Symmetric prepositions differ from each other in selecting reference objects, thus for example, *across* prefers an object that has a main axis (the longest axis or an equivalent, e.g., a longer side of a blackboard or a flow direction of a river, etc.), *through* takes a reference object that has nontrivial interior volume, and *over* takes an object that has a height. The following illustrate the point:

(26) a. *John lives across/?*over/*through the river*

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[9]The directional vs. stative ambiguity arises in other constructions with stative (orientational) prepositions: e.g., *in front of, behind, under*. The following are ambiguous:

(i) *John walked in front of/behind the building*

(ii) *John swam under the bridge*

Thus, (ii) has two readings: (1) 'John swam from somewhere else to the region under the bridge'; and (2) 'John swam within the region under the bridge'.

b. *John lives through/?over/?across the forest*

c. *John lives over/?across/??through the hill*

Now let us consider lexical meanings of symmetric prepositions. The meaning of *across* is already given in (19) in the preceding section, and other symmetric prepositions are interpreted as follows (each preposition is followed by an example sentence accompanied by an informal interpretation):

(27) *through*:

For m a n-place motion predicate, for α an individual denoting noun phrase, interpret the n-place predicate m+*through*+α, where *through* α is k-th argument oriented ($1 \leq k \leq n$), as follows:

$(\mathbf{through}(\alpha))(\mathbf{m}) = \{<x_1,...,x_n>|\ \mathbf{m}(<x_1,...,x_n>)$ and $\mathrm{TRAV}(x_k, \pi, T)$ where $\mathrm{BETWEEN}(\pi_s, ®(\alpha), \pi_g)$ and for some $t \in T$, $\mathrm{IN}(®(x_k,t), ®(\alpha,t))\}$

(28) *John drove through the tunnel*

is true iff

for an interval T<**now**, John drove during T and there is a path π such that John traversed π during T and the tunnel is between the source and the goal of the path, and at some time point in T John was inside the tunnel.

(29) *over*:

For m a n-place motion predicate, for α an individual denoting noun phrase, interpret the n-place predicate m+*over*+α, where *over* α is k-th argument oriented ($1 \leq k \leq n$), as follows:

$(\mathbf{over}(\alpha))(\mathbf{m}) = \{<x_1,...,x_n>|\ \mathbf{m}(<x_1,...,x_n>)$ and $\mathrm{TRAV}(x_k, \pi, T)$

where $\text{BETWEEN}(\pi_s,®(\alpha),\pi_g)$ and for some $t \in T$, $\text{ABOVE}(®(x_k,t),®(\alpha,t))\}$[10]

(30) *The helicopter flew <u>over</u> the field*

is true iff

for an interval T<**now**, the helicopter flew during T and there is a path π such that the helicopter traversed π during T and the field is in between the source and the goal of π, and at some time point t in T the helicopter was above the field.

(31) *around*:

For *m* a *n*-place motion predicate, for α an individual denoting noun phrase, interpret the *n*-place predicate *m+around+α*, where *around α* is *k*-th argument oriented ($1 \le k \le n$), as follows:

$(\mathbf{around}(\alpha))(\mathbf{m}) = \{<x_1,...,x_n> \mid \mathbf{m}(<x_1,...,x_n>)$ and $\text{TRAV}(x_k, \pi, T)$ where $\text{BETWEEN}(\pi_s,®(\alpha),\pi_g)$ and for all $t \in T$, $\text{AT}(®(x_k,t),®(\alpha,t))\}$

(32) *The boy ran around the corner*

is true iff

for an interval T<**now**, the boy ran during T and there is a path π such that the boy traversed π during T and the corner is in between the source and the goal of π, and during the entire interval T the boy was at/near the corner.

(33) *past*:

For *m* a *n*-place motion predicate, for α an individual denoting noun phrase, interpret the *n*-place predicate *m+past+α*, where *past α* is *k*-th argument oriented ($1 \le k \le n$), as follows:

$(\mathbf{past}(\alpha))(\mathbf{m}) = \{<x_1,...,x_n> \mid \mathbf{m}(<x_1,...,x_n>)$ and $\text{TRAV}(x_k, \pi, T)$ where $\text{BETWEEN}(\pi_s,®(\alpha),\pi_g)$ and for all $t \in T$, $\text{AT}(®(x_k,t),®(\alpha,t))\}$

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[10] The meaning of ABOVE will be discussed in 4.1.4.3.

(34) *The bus ran past the school*

is true iff

for an interval T<**now**, the bus ran during T and there is a path π such that the bus traversed π during T and the school is in between the source and the goal of π, and for a time point t in T the bus was at/near the school.

Notice that the only difference among the symmetric prepositions is the condition they impose on the intermediate location of the moving object. This accounts for the entailment patterns illustrated in (21-23) of 4.1.3.1, and we have the following correspondences:

(35)	*across*	$\Rightarrow$	*on*
	through	$\Rightarrow$	*in*
	over	$\Rightarrow$	*above*
	past/around	$\Rightarrow$	*at*

4.1.4. Orientational Locatives

This section deals with locative PPs involving a spatial orientation (*front/back, right/left, up/down*). Such locative PPs are called *orientational*, and the prepositions in orientational locatives *orientational prepositions*. To this class belong the following prepositions:

(36) a. *in front of, behind*
  b. *to the left of, to the right of*
  c. *above, below*

In 3.4, we set up *Orientation Structure*, where an orientation is defined as a linearly ordered set of atomic regions (equivalently as a *ray*), and in 4.1.2, two semantic interpretative rules, Semantic Rule–1 & –2, were proposed to interpret sentences with a motion/stative verb and a locative PP. They are repeated below for convenience.

(37) Semantic Rule–1:

For *m* a *n*-place motion predicate, and *f* an extensional locative modifier, interpret the *n*-place predicate, *m+f*, where *f* is *k*-th argument oriented ($1 \leq k \leq n$), as follows:

$$\mathbf{f(m)} = \{<x_1,...,x_n> \mid \mathbf{m}(<x_1,...,x_n>) \text{ and } \mathrm{TRAV}(x_k, \pi_f, T)\}$$

where π_f is a path determined by f.

(38) Semantic Rule–2:

For *s* a *n*-place stative predicate, and *f* an extensional locative modifier, interpret the *n*-place predicate, *s+f*, where *f* is *k*-th argument oriented ($1 \leq k \leq n$), as follows:

$$\mathbf{f(s)} = \{<x_1,...,x_n> \mid \mathbf{s}(<x_1,...,x_n>) \text{ and } \mathrm{INTR}(®(x_k), \rho_f)\}$$

where ρ_f is an orientation determined by f.

As shown in the rules, moving objects are located in terms of *path* and TRAV relation, whereas stative objects are located in terms of *orientation* and INTR relation. The INTR (intersecting) relation was defined in 3.1 as a binary relation holding between two regions, but we extend the relation to hold between a region and an orientation. Thus we have:

(39) Definition:

For ρ an orientation, and A a region, A intersects ρ, INTR(A, ρ), iff there is some region $X \in \rho$ such that $X \subseteq A$.

The following sections illustrate the lexical semantics of orientational prepositions. Each preposition determines a unique type of path or orientation to locate an argument. The first class contains those involving *front-back* orientations, the second *left-right* orientations, and the third the *gravity* dimension. For the first two classes of orientational locatives, we will see that they can be interpreted either as a unary preposition or as a binary one, depending on the reference object. That is, if a reference object combined with an orientational preposition has a relevant intrinsic orientation, the preposition gets unary interpretation, but if not, they are interpreted as a binary preposition looking for another argument (referring to a perspective point) to determine a relevant orientation. This section, however, handles only the unary interpretations, and section 4.3 will discuss in detail the binary interpretations.

4.1.4.1. *in front of* and *behind*

They involve front-back orientations of reference objects which can be either intrinsic or extrinsic. According to the Semantic Rules –1 and –2, we give the following semantics for *in front of*:

(40) *in front of* α

a. determines a path π such that for an orientation $\rho = \Omega_{\text{front}}(\alpha, T)$, $\text{INTR}(\pi_g, \rho)$ for some interval T.[11]

b. determines an orientation $\rho = \Omega_{\text{front}}(\alpha, T)$ for some interval T.

The locative PPs in (41a) and (41b) refer to the intrinsic front orientations of the stage and the car to locate a subject argument, thus applying Semantic Rule –1 and –2 with the above semantics of *in front of*, we get the following interpretations:

(41) a. *Kim walked in front of the stage*
is true iff
there is an interval T<**now** and a path π such that **walk(kim)**(T), TRAV(**kim**, π, T), and for an orientation $\rho = \Omega_{\text{front}}$ (**the stage**, T), $\text{INTR}(\pi_g, \rho)$.

b. *Kate is sitting in front of the car*
is true iff
for an interval **now**$\subseteq$T and an orientation ρ, **sit** (**kate**)(T), INTR(®(**kate**, T),ρ), and $\rho = \Omega_{\text{front}}$ (**the car**, T).

Notice that (41a) contains a motion verb *walk*, so the PP first refers to a path and then the goal of the path is specified by the intrinsic front orientation of the reference object. Thus the sentence means Kim's walk ended on the front orientation of the stage. (41b)

[11]As shown in (40a), *in front of* and other orientational prepositions determine a path whose goal region is conditioned so to intersect a relevant orientation, e.g., (40a) gives the condition $\text{INTR}(\pi_g, \rho)$ which specifies the goal region (π_g) with respect to the front orientation (Ω_{front}) of the reference object. This reveals that orientational locatives refer to a path with its goal specified when they modify a motion verb, but there is no orientational locatives that refer to a path with a source specified.

has a stative verb *is sitting*, so the truth conditions does not refer to a path but an orientation.

The semantics of *behind* is exactly the same as that of *in front of* except it involves the *back* orientation of a reference object. Thus,

(42) *behind* α

a. determines a path $\bar{\pi}$ such that for an orientation $\rho = \Omega_{\text{back}}(\alpha, T)$, $INTR(\pi_g, \rho)$ for some interval T.

b. determines an orientation $\rho = \Omega_{\text{back}}(\alpha, T)$ for some interval T.

(43) a. *Mike ran behind the stage*
is true iff
there is an interval T<**now** and a path π such that **run(mike)**(T), TRAV(**mike**, π, T), and for an orientation $\rho = \Omega_{\text{back}}$ (**the stage**, T), $INTR(\pi_g, \rho)$.

b. *Adam was hiding behind the curtain*
is true iff
for an interval T<**now** and an orientation ρ, **hide (adam)**(T), INTR(®(**adam**, T),ρ), and $\rho = \Omega_{\text{back}}$ (**the curtain**, T).

English has other locative PPs than *in front of* and *behind* that refer to front or back parts of a reference object: E.g., *at/in the back of, at/in the front of*, which contain a definite article *the*. We do not take these as simple prepositions but as a complex of a preposition *at* or *in* and an NP. Thus, we get a compositional interpretation from the meaning of *at* or *in* and the denotation of the NP. The following sentences suggest that the meanings of *at the front of* and *at the back of* are not referring to a front or back orientation of the classroom.

(44) a. *The boys are sitting* [$_{PP}$ *at* [$_{NP}$ *the front of the classroom*]]

b. *The girls are sitting* [$_{PP}$ *at* [$_{NP}$ *the back of the classroom*]]

The NPs, *the front/back of the classroom* refer to the front/back part of the classroom, and the whole PPs locate the subject arguments *the boys/the girls* in the region inside the classroom. Thus, the sentences get different interpretations from those for the following, where the subject arguments are located outside the classroom:

(45) a. *The boys are sitting* [$_{PP}$ *in front of* [$_{NP}$ *the classroom*]]

b. *The girls are sitting* [$_{PP}$ *behind* [$_{NP}$ *the classroom*]]

4.1.4.2. *to the left of* and *to the right of*

English has a set of prepositions which are used to locate objects in terms of *left-right orientations*, and the orientations are defined by inherent parts of an object. This section only discusses the intrinsic left-right orientations which are employed by unary interpretations of *to the left of* and *to the right of*.[12] We can give interpretations for *to the right of* analogously.

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[12]English has the following prepositional phrases which refer to the inherent right/left parts of reference objects: *on/in the left (side) of the auditorium*, *on/in the right (side) of the auditorium*. As we noted in the previous section, these PPs, like *at/in the front/back of ...*, do not refer to an orientation but an inherent part of the reference object, the auditorium. Thus,

(i) *Put your name on the left side of the page*

(ii) *The baby was seated in the right side of the car*

(46) *to the left of* α

a. determines a path π such that for an orientation $\rho = \Omega_{left}(\alpha, T)$, $INTR(\pi_g, \rho)$ for some interval T.

b. determines an orientation $\rho = \Omega_{left}(\alpha, T)$ for some interval T.

(47) a. *Sarah crept to the left of Mary*
is true iff
there is an interval T<**now** and a path π such that **creep**(**sarah**)(T), TRAV(**sarah**, π, T), and for an orientation $\rho = \Omega_{back}$ (**mary**, T), $INTR(\pi_g, \rho)$.

b. *John was seated to the left of the teacher*
is true iff
for an interval T<**now** and an orientation ρ, **seated** (**john**)(T), INTR(®(**john**, T),ρ), and $\rho = \Omega_{left}$ (**the teacher**, T).

4.1.4.3. *above* and *below*

They involve the gravity dimension, Ω_G, defined in 3.3.2.1 (repeated below). So they refer to a spatial relation between two regions in terms of relative highness. As illustrated in (49), *above* and *below* do not seem to go well with a motion verb, which suggests that they do not refer to paths but to orientations which locate stative objects.

(48) Definition:
For all individual $x \in \mathbb{E}$, and all interval $T \in \mathbb{T}$,
Ω_G (x,T), the *gravity dimension* for x at T, is an orientation ρ such that Origin(ρ) = ®($\mathbf{P}_{center}$ (x), T) and INTR(**G**, ρ).

(49) a. *??The boy crept below the table*

b. *?The helicopter flew above the mountain*

Therefore we only provide an orientational interpretation to the prepositions, and locative PP with *below* or *above* will be interpreted by Semantic Rule –2 in terms of the gravity dimension. First we have lexical meanings of the prepositions:

(50) *below* α

determines an orientation Ω_G (α, T), the gravity dimension for α at an interval T.

(51) *above* α

determines an orientation ρ such that ρ is the complement of Ω_G (α, T), for T an interval, i.e., Compl(Ω_G (α, T)).

Thus *below* α determines an orientation that is exactly the same as the gravity dimension for α. And as stated in (51), the orientation determined by *above* α has its origin at the center of α, and the direction is opposite to the gravity dimension for α, Ω_G (α, T). The following sentences are interpreted by the Semantic Rule –2:

(52) a. *The children were sitting below the tree*

is true iff

for an interval T<**now**, and an orientation ρ,

INTR(®(**the children**, T),ρ), and ρ = Ω_G (**the tree**, T).

b. *John's picture is above the fireplace*

is true iff

for an interval T, **now**$\subseteq$T, and an orientation ρ,

INTR(®(**john's picture**, T),ρ), and ρ = Compl(Ω_G (**the fireplace**, T)).

4.1.5. Directional Locatives

Prepositional phrases with *to*, *from*, *into*, *out of*, and *towards* are called *directional locatives*, which are used to indicate directions of movement by referring to the source or goal of a path. Thus, *to*, *into*, and *towards* refer to the goal of a path, and *from* and *out of* the source of a path. *To* and *from* are semantically more basic than *into* and *out of* in the sense that the latter not only specify the goal or the source of a path but indicate the goal or the source are in the interior region of a reference object. The following entailment patterns illustrate the difference.[13]

(53)	a.	*Cindi walked to/from the market*	does not entail
	b.	$\not\models$ *Cindi was in the market*	
	c.	*Cindi walked into/out of the market*	entails
	d.	$\models$ *Cindi was in the market*	

The contrast supports the intuition that, unlike *out of*, *from* takes a reference object as a point abstracted from a volume or an area. The following contrast between *from* and *out of* also suggests that *out of* takes a reference object as a container with a non-trivial interior region.

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[13]We do not consider the stative interpretation of *from* and *out of* as illustrated in the following:

(i) *Our house is three miles away from/out of the village*
(ii) *I live sixty miles from/out of Los Angeles*

But let us note that they are still different from each other in such stative uses:

(iii) *The mountains are far from/?*out of here*
(iv) *His house is across the park from/*out of us*
(v) *The distance from/*out of Los Angeles to San Diego is 150 miles*

(54) a. *The prisoner escaped from his guards!*

a'. **The prisoner escaped out of his guards!*

b. *His friend saved him from a lion*

b'. **His friend saved him out of a lion*

c. *He guards his master from enemies*

c'. **He guards his master out of enemies*

d. *I put the book out of the box*

d'. **I put the book from the box*

Now we give lexical semantics of the directional prepositions: First for *to* and *from*, and second for *into* and *out of*. Then we compare *towards* with *to* in 4.1.5.3, where we account for their aspectual difference in terms of *path homogeneity* involved in the meaning of *towards*.

4.1.5.1. *to* and *from*

In normal contexts, these prepositions do not go with a stative verb, so we do not use Semantic Rule –2 to interpret them. Accordingly, their semantics will only refer to a path with respect to a reference object.

(55) a. *to* α: determines a path π such that π_g = ®(α) and $\pi_g \cap \pi_s = \emptyset$

b. *from* α: determines a path π such that π_s = ®(α) and $\pi_g \cap \pi_s = \emptyset$

(56) *John ran to the post office*

is true iff

there is an interval T<**now**, and a path π such that **ran** (**john**, T) and TRAV(**john**, π, T) where π_g = ®(**the post office**) and $\pi_g \cap \pi_s = \emptyset$

Notice that (55a) guarantees the following entailment induced by *to* and *from*, since in (56) TRAV(**john**, π, T) and INTR(π_g, ®(**the post office**)) imply AT(®(**john**, T_l), ®(**the post office**)) where T_l denotes the terminal time point of T. And ditto for (58).

(57) a. *John ran to the post office* entails

b. $\models$ *John was at the post office*

(58) a. *John ran from the post office* entails

b. $\models$ *John was at the post office*

4.1.5.2. *into* and *out of*

The semantics of *into* and *out of* gives a more restricted condition on the goal or the source of the path they determine. Like *to* and *from*, they do not modify a stative verb, so they are interpreted by Semantic Rule –1 only.

(59) a. *into* α: determines a path π such that $\pi_g \subset$ ®(α)

b. *out of* α: determines a path π such that $\pi_s \subset$ ®(α)

(60) *Mary walked out of the office*

if true iff

there is an interval T<**now**, and a path π such that

walk(mary, T) and TRAV(**john**, π, T) where $\pi_s \subset$ ®(**the office**)

(59) correctly predicts that (60) entails 'Mary was inside the office' and 'Mary was outside the office' at the initial point and the final point of a past interval T.

4.1.5.3. *Towards* and Homogeneity of Paths

To and *towards* both refer to the direction of a movement, but the reference object of *towards* does not refer to the goal of the movement, whereas that of *to* determines the goal. Thus, (61a) but not (61b) entails (61c).

(61) a. *John ran to the post office*
b. *John ran towards the post office*
c. *John was at the post office*

Since *towards* refers to the direction of a movement, we interpret the preposition in terms of path and the *relative nearness relation*, NEARER defined in 3.2.2, as follows:

(62) *towards* α:
determines a path π such that for all $i \leq j \in \text{Domain}(\pi)$,
NEARER $(\pi(j), ®(\alpha), \pi(i))$.

(62) states that the path determined by *towards* α continuously approaches the region of α. Then Semantic Rule–1 interprets (61b) as follows:

(63) *John ran towards the post office*
is true iff
there is an interval T<**now**, and a path π such that
ran(john, T) and TRAV(**john**, π, T) where for all $i \leq j \in \text{Domain}(\pi)$,
NEARER $(\pi(j), ®(\textbf{the post office}), \pi(i))$.

Due to (62), the interpretation does not imply 'John ended up being at the post office', and it implies that for any path π determined by *towards the post office*, the relative nearness relation holds among two regions in π and the reference object. This last point lets *towards* determine *homogeneous* paths:

(64) Definition:

For f a locative PP, f determines a *homogeneous* path π iff
if π' is a subpath of π, then π' is also determined by f.

Hinrichs (1985, 1986) observes the aspectual difference between *to* and *towards* in the following examples:

(65) a. *Fangs slithered to the rock* [Hinrichs 1986:349]
b. *Fangs slithered toward the rock*
c. *John walked to the library in an hour* [Hinrichs 1986:349]
d. **John walked toward the library in an hour*
e. *It took Fangs ten minutes to slither to the rock* [Hinrichs 1985:204]
f. **It took Fangs ten minutes to slither toward the rock*

In Hinrichs (1985), (65a) and (65b) are classified into Vendler's verb classes of *accomplishment* and *activity*, respectively, and so the results of (65c-f).[14] Adopting Vendler's (1967) temporal criteria (*continuity* vs. *puntuality* and *homogeneity* vs. *heterogeneity*) for his four verb classes, Hinrichs characterizes the difference in (65) in

[14]Vendler (1967) gives four different verb classes which he calles *statives*, *activities*, *accomplishment*, and *achievement*. Among these, only *statives* and *activities* are temporally homogeneous, and only *activities* and *accomplishments* are continuous. Vendler points out that only achievements and accomplishments, i.e., temporally heterogeneous events can occur with temporal modifiers like *in an hour*.

terms of *temporal heterogeneity/homogeneity*: Hinrichs (1985) gives a lexical account of the aspectual difference with the notion of spatio-temporal location and Carlson's (1977) dichotomy of stage level and individual level predicates. Hinrichs paraphrases Vendler's (1967:101) ideas as follows:

> "Since doing something *for* x amount of time means doing something during most if not all subintervals of the interval x, sentences such as (65b), which refers to atelic events or activities, can be characterized as being *temporally homogeneous....*
>
> To do something *in* x amount of time, on the other hand, means to do something at some unique interval within x. Since telic events or accomplishments can be modified by temporal *in*, they, in contrast to activities or atelic events, can be described as being temporally heterogeneous,..." (Hinrichs 1986:349)

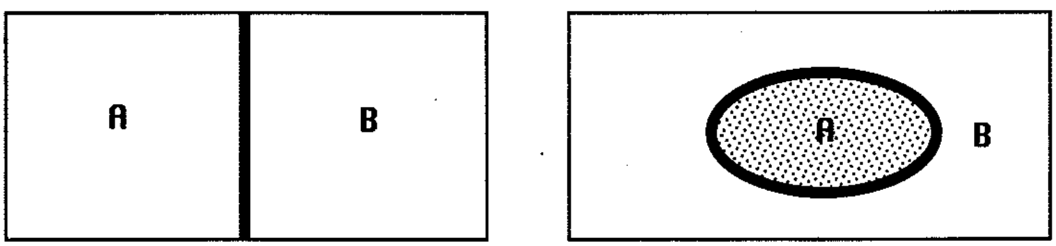
Here we associate the aspectual difference, Vendler (1967) dubbed *temporal heterogeneity* vs. *homogeneity*, with the difference among paths the locatives determine. The parallel definition given in (64) reveals an intuitive correspondence between the tempotal homogeneity of events and the spatial homogeneity of paths. We can show that due to the homogeneity of the path determined by *towards the post office*, the interpretation in (63) above implies the temporal homogeneity of the event: That is, if the sentence is true for some past interval T<**now**, then for most if not all subintervals T' of T, the sentence is true. But we can notice quickly that PPs with *to* do not determine homogeneous paths, and so the interpretation of (56) *John ran to the post office* in 4.1.5.1 does not imply temporal homogeneity of the event.

4.2. Symmetry of Paths

4.2.1. Symmetric Division of Space

We can divide a space or a region into two in many different ways, but there are two types of division of space: (i) *symmetric division* which does not impose any asymmetric spatial relation between the two subspaces; and (ii) *asymmetric division* which imposes some asymmetric spatial relation between them. This section discusses how spatial expressions reflect the different types of division, and accounts for the contrast of symmetric vs. asymmetric locatives in terms of *symmetry of paths*. Consider Figure 4-1 below:

Figure 4-1



(i) Symmetric Division (ii) Asymmetric Division

Suppose each rectangle indicates a local space and there is no assumed orientation or direction. In (i) symmetric division, the two regions divided by the boundary are not in an asymmetric relation with respect to the boundary such as interior/exterior asymmetry. Thus, if some objects x and y are located in the regions A and B respectively, there is no asymmetric relation between them which can be stated in terms of the boundary. But we would say *x and y are on the opposite sides of the boundary* or *x is across the boundary from y, and vice versa*. When x moved from A to B, we say *x moved across the boundary*.[15]

If we look at the asymmetric division illustrated by (ii) of Figure 4-1, we can immediately notice that the two regions A and B are in an asymmetric relation with respect to the boundary: That is, A is its interior region, and B its exterior region. Thus if some objects x and y are located at the regions A and B, we would say *x is inside the boundary* and *y is outside the boundary*. If some object x moved from A to B, we would say *x moved out of A* and if x moved from B to A, we say *x moved into A*.

Let us then make it a little more lucid what *symmetry* means in the semantics of spatial expressions. We note two kinds of facts that involve the notion of symmetry: (i) undirectionality of movement, and (ii) symmetric patterns of entailment. First, when we say (66), we do not actually refer to the direction of John's walking, but just state that John crossed the street.

(66) *John walked across the street*

That is, the truth conditions of the sentence do not depend on which side of the street John started from and which side he wound up being on. We can readily explain this fact in terms of symmetric division of space: When we say (66), we have a local space

---

[15]The boundary can be a (minimal) region in a path/orientation: That is, if we have a path π depicted as follows, then the region Y is a boundary dividing the whole path π into two symmetric subpaths.

X----------------Y----------------Z
(π_s) (π_g)

in mind which is divided by the street as illustrated by Figure 4-1 (i), thus the two subspaces are symmetric to each other. We can identify such symmetry in the following sentences, too.

(67) a. *The soldiers marched <u>through</u> the forest*
b. *The boy jumped <u>over</u> the fence*
c. *The bus ran <u>past</u> the bus stop*
d. *John walked <u>around</u> the street corner*

The prepositions used in (67a-d) were named symmetric prepositions in 4.1.3, and we interpreted sentences containing a symmetric locative in terms of *betweenness* relation. The symmetry is represented in terms of the relation BETWEEN which is self-symmetric in the sense that: BETWEEN(X,Y,Z) iff BETWEEN(Z,Y,X).

Now let us consider symmetric patterns of entailment. First of all, symmetric prepositions involve a symmetric spatial relation. For example, both (68a) and (68b) refer to the binary relation 'being across the street from', and they entail each other. This is not an accidence but a coherent pattern for symmetric prepositions, so neither (69a) nor (69b) entails the other.

(68) a. *The house <u>is across the street from</u> the bus stop*
b. $\leftrightarrow$ *The bus stop <u>is across the street from</u> the house*

(69) a. *Bill <u>is to the left of the tree from</u> John*
b. *John <u>is to the left of the tree from</u> Bill*

This symmetry for the symmetric prepositions is also identified in the following entailment pattern which does not hold for other prepositions (orientational or directional prepositions): (70a) entails (70b), but (71a) does not entail (71b).

(70) a. *The boy walked <u>across</u> the street, and came back immediately*
  b. *The boy walked <u>across</u> the street twice*

(71) a. *The boy walked <u>into</u> the room, and came back immediately*
  b. *The boy walked <u>into</u> the room twice*

(70) contain a symmetric preposition *across*, but (71) contain an asymmetric directional preposition *into*. The contrast comes from the different types of dividing space: i.e., symmetric vs. asymmetric illustrated above.

4.2.2. Symmetric Locatives

In 4.1.2, two general interpretative rules (Semantic Rule–1 and Semantic Rule–2) are given for different types of locatives combining with movement verbs and stative verbs. Now we give an account of the symmetry illustrated in this section by identifying some unique characteristics of the semantics of symmetric locatives. We characterize symmetric locatives as ones satisfying the following stronger form (73) of Semantic Rule–1 (repeated below):

(72) Semantic Rule–1:

For m a n-place motion predicate, and f an extensional locative modifier, interpret the n-place predicate, $m+f$, where f is k-th argument oriented ($1 \leq k \leq n$), as follows:

$$\mathbf{f}(\mathbf{m}) = \{<x_1,...,x_n>|\ \mathbf{m}(<x_1,...,x_n>) \text{ and } \mathrm{TRAV}(x_k, \pi_f, T)\}$$

where π_f is a path determined by f.

(73) Definition: *Symmetric Locatives*

For *m* a one-place motion predicate, and *f* an extensional locative modifier, *f* is *symmetric* iff

$$\mathbf{f}(\mathbf{m})(x) \text{ iff } \mathbf{m}(x) \text{ and } \mathrm{TRAV}(x, \pi_f, T) \text{ or } \mathrm{TRAV}(x, \pi_f^{-1}, T)$$

where π_f^{-1} is the converse of π_f, a path determined by f.

As we saw in 4.1.3, symmetric locatives determine a path, and, due to (73), the truth conditions of a sentence containing a symmetric locative can be satisfied either by the path π_f determined by the locative *f* or by its converse π_f^{-1}. For example, let us see if the PP in (74) below is symmetric. By Semantic Rule-1 in (72), (74) is interpreted as follows:

(74) *John ran across the street*

is true iff

for some interval T<**now**, **run** (**john**)(T) and TRAV(**john**, π, T)

for a path π where BETWEEN (π_s, ®(**the street**), π_g) and for some $t \in T$, ON(®(**john**, t), ®(**the street**, t)).

Thus, (74) is true iff John traversed a path π during a past interval T and the street is between the source and the goal of the path, and John was on the street at some time point in T. Now the path π determined by *across the street* can be characterized as symmetric since both π and π^{-1} satisfy the betweenness condition given in (74): That is, for a path π, if BETWEEN (π_s, ®(**the street**), π_g), then due to the symmetry of BETWEEN defined in 3.2.1, BETWEEN (π_g, ®(**the street**), π_s). Now by definition, π_g =

$\pi^{-1}{}_s$ and $\pi_s = \pi^{-1}{}_g$, and so BETWEEN($\pi^{-1}{}_s$, ®(**the street**), $\pi^{-1}{}_g$). Thus, if John traversed either π or its converse π^{-1}, then the sentence (74) should be true. But we can see that asymmetric locatives do not satisfy the condition (73).

Now to account for the symmetric entailment pattern illustrated in (70), let us give a semantics of *back* and *twice* as follows. We used a subscript to indicate a binding relation between $back_f$ and its antecedent locative PP *f*.

(75) *back* as a path-anaphoric adverbial:

Assuming a binding relation between an antecedent locative *f* and $back_f$, for *m* a one place motion verb, interpret the VP $m{+}back_f$ as follows:

back$_f$ (**m**)(x) iff **m**(x) and TRAV(x,$\pi_f{}^{-1}$,T)

where $\pi_f{}^{-1}$ is the converse of π_f determined by f.

(76) *twice* as quantifying over paths:

For *m* a one place motion verb, and *f* a locative modifier, interpret the VP *m+f+twice* as follows:

twice (**f**)(**m**)(x) iff **m**(x) and TRAV(x,π,T)

where π contains exactly two "disjoint" subpaths π_f determined by f.

Speaking informally, two subpaths of a path π are *disjoint* to each other if they do not ovrelap in the original path π. For example, let π = <A, B, C, D, E>, then <A, B> and <B, C, D> are disjoint subpaths of π. Now, (75) and (76) account for the entailment in the following: (70a) entails (70b).

(70) a. *The boy walked across the street, and came back immediately*

b. $\models$ *The boy walked across the street twice*

Let us think more about the example (70b). This sentence with a frequency adverb *twice* is ambiguous: (i) First (70b) has an *event-counting* reading where the frequency adverb counts separate events, i.e., there are two separate events each of which is John's walking across the street; and (ii) second, (70b) has a *path-counting* reading where the event is considered as a single one but *twice* counts subpaths of a bigger path. This second reading is actually what (76) gives us. The following examples reveal the ambiguity more clearly.

(77) *John jogs around the park twice everyday*

The event-count reading of (77) does not depend on the subpaths of John's jogging, but simply asserts that John's jogging happens twice every day. The path-counting reading, however, counts subpaths of the path John traverses jogging, so it asserts that the path contains exactly two subpaths which are determined by the locative *around the park.* Notice that the two types of frequency modification can occur in the same clause as shown below.

(78) a. *John swam across the pool ten times twice a day*
b. ≠ *John swam across the pool twice ten times a day*

Now can every locative induce such ambiguity? No. (79) below suggest that directional locatives like *into/out of the office, to/from the hospital,* do not have a path-counting reading but an event-counting reading only.

(79) a. *John sneaked into/out of the office twice*

b. *Mary drove from the hospital twice*

(80) a. *Kim walked in front of the stage twice*

b. *Mike ran behind the tree twice*

The orientational locatives in (80) above do not give a path-counting reading, either. Thus we can see that the symmetric locatives distinguish themselves as inducing the event/subpath ambiguity.

We have not considered the following compound locatives in (81) which sound more or less directional, but we can easily see that they are not directional but symmetric in the sense that it does not matter which direction comes first then the other comes. So the cat could have started chasing the mouse either from inside or outside of the room for (82a) to be true, and analogously for (82b).

(81) *in and out (of), back and forth, up and down, side to side, to and fro*

(82) a. *The cat chased the mouse in and out of the room several times*

b. *The ball bounced up and down a few times*

Now let us consider a symmetric locative modifying a stative verb. In the preceding section 4.2.1, we observed that the symmetric prepositions refer to a symmetric relation. Now we show how our semantics correctly interprets the prepositions to be symmetric. First recall that, in 4.1, we had the following interpretative rule for locative PPs combining with a stative verb.

(83) Semantic Rule–2:

For s a n-place stative predicate, and f an extensional locative modifier, interpret the n-place predicate, $s+f$, where f is k-th argument oriented ($1 \leq k \leq n$), as follows:

$$\mathbf{f}(\mathbf{s}) = \{<x_1,...,x_n>|\ s(<x_1,...,x_n>) \text{ and } \mathrm{INTR}(®(x_k), \rho_f)\}$$

where ρ_f is an orientation determined by f.

(84) Deictic Orientations:

For all objects x, y$\in \mathbb{E}$, and all intervals T$\in \mathbb{T}$, Ω_{from}(x, y, T):

a ray ρ such that Origin(ρ) $\subseteq$ ®(y) and ρ intersects ®(x, T).

Due to Semantic Rule–2 and the semantics of the binary preposition *across-from* given in 4.1.3.1, we give the following interpretation for (85).

(85) *John's house is across Main street from the post office*

is true iff

there is an orientation ρ such that INTR(®(**john's house**),ρ),

$\rho = \Omega_{from}$(**Main Street, the post office, now**), and

BETWEEN (®(**the post office**), ®(**main street**), ®(**john's house**)).

(86) *The post office is across Main Street from John's house*

We provide an account of the entailment between (85) and (86) noted in 4.2.1. To show this we assume (85) is True, thus:

There is an orientation ρ such that

INTR(®(**john's house**),ρ), $\rho = \Omega_{from}$(**main street, the post office, now**),

and BETWEEN (®(**the post office**), ®(**main street**), ®(**john's house**)).

Then by the symmetry of BETWEEN, we have

BETWEEN (®(**john's house**), ®(**main street**), ®(**the post office**)), and

INTR(®(**the post office**),ρ).

Then there is an orientation

$\rho = \Omega_{\text{from}}$(**main Street, john's house, now**).

Therefore, (86) is True.

The other direction of the proof is analogous to this. More examples are given below to show that symmetric prepositions refer to a symmetric spatial relation.

(87)	a.	*The haunted castle was through the forest from the village*
	b.	*The village was through the forest from the haunted castle*
(88)	a.	*The school is past City Hall from your house*
	b.	*Your house is past City Hall from the school*
(89)	a.	*The market is around the corner from the gas station*
	b.	*The gas station is around the corner from the market*

4.3. Locative Perspectives

This section is devoted to a semantic analysis of deixis involoved in locative prepositional phrases (PPs), a topic which has been much studied in the literature (Clark 1973; Cresswell 1978; Hill 1982; Klein 1983; Cuyckens 1984; Herskovits 1986; Crow 1989).

In the first section 4.3.1, we illustrate a variety of deictic interpretations of PPs which require a deictic *locative perspective* (or point of view). The following section

4.3.2 notes that *symmetric locatives* are distinguished from others in that their interpretation is dependent on the deictic perspective and so inherently binary. In section 4.3.3, based on the formal structures of paths and orientations established in chapter 3, we give a semantics of the locative perspective in English.

4.3.1. Deictic Locative Perspectives in PPs

A locative PP syntactically consists of a preposition and a noun phrase, where the preposition induces a spatial relation between two objects and the noun phrase refers to a reference object involved in the relation. In a sentence like *John is in the garden*, the PP *in the garden* locates the subject argument *John* in terms of the relation induced by *in* and the reference object denoted by *the garden*. In the literature (Talmy 1983 among others), the reference object is often called a *ground* (or *landmark*) and the located object is called a *figure* (or *trajector*). In this paper, we will use the terminology, *reference object* for *figure* to avoid the restricted sense of the latter term in the literature.

Among English locative PPs, some require a locative perspective (or point of view) to get a proper interpretation, and here we refer to such PPs as *perspectival locative PPs*. A locative perspective determines a spatial setting for the relation between a located object and a reference object. English makes use of a PP headed by *from* to supply a locative perspective, but it can be identified deictically by the utterance context. To interpret such perspectival PPs, a locative perspective assigns spatial orientations (front/back, right/left, etc.) to a reference object at an instance (an interval). For example, the sentence (90)

(90) *John's house is across Main street from the theater*

contains a prepositional phrase *from the theater* indicating a locative perspective, so the PP refers to 'the theater' as a source point of the perspective, and the perspective assigns an orientation crossing 'Main Street' to locate 'John's house'. Thus, roughly, the sentence is true iff John's house is located on (or intersects) the orientation which moves out from the theater and crosses Main Street (more or less perpendicular to Main Street).

Now we illustrate various locative PPs which involve a locative perspective, and the example sentences considered here lack an overt phrase for the perspective so to get a deictic locative perspective from the utterance context. We are concerned with two major classes of the locative PPs discussed in 4.1: (i) Symmetric locatives, and (ii) orientational locatives.

In (91), the PPs headed by *across, through, over,* and *past* are symmetric locatives. In each sentence, a deictic locative perspective determines an orientation to locate the subject argument.

(91) Symmetric Locatives

a. *The post office is across the street*

b. *The village is through the forest*

c. *The boys were playing over the hill*

d. *The library is just past the post office*

Let us suppose the sentences are provided with a deictic perpective point referring to the utterance place, i.e., *from here*. Then (91c), for example, locates 'the boys' on the orientation moving from 'here' crossing the fence.

In (92), each sentence contains an asymmetric locative, a PP headed by *in front of, behind, to the left/right of, up,* or *down*, and the PP involves an orientation with an origin determined by a deictic perspective, e.g., *from here*.

(92) Asymmetric Locatives

a. *John was sitting in front of the tree*
b. *John walked in front of the tree*
c. *Mary was hiding behind the rock*
d. *Mary ran behind the rock*
e. *John's desk is to the right/left of Mary's*
f. *John moved his desk to the right/left of Mary's*
g. *John's house is up the road*
h. *The village is down the river*

Thus (92a) locates 'John' on the front-orientation of the tree, which is determined by the perspective point 'here', so the sentence is true only if John's region intersects the orientation which moves out from 'the tree' and intersects the region denoted by 'here'.

4.3.2. Perspectival Locative PPs: Some Descriptive Generalizations

4.3.2.1 Stative vs. Movement Predicates

(93) Generalization–1:

Symmetric and asymmetric locatives differ with respect to their semantic interpretation with verbs of motion

Symmetric locatives we consider here are PPs headed by *across, through, over, past,* and *around.* (94) contains a symmetric path locative and we can give an interpretation to the sentence only with a locative perspective out of context, e.g., 'from here'. But we do not need a locative perspective to interpret (95), since the truth conditions of (95) do not depend on the direction of the boy's walking, i.e., which side of the street the boy started from need not be specified, but he only has to cross the street for (95) to be true. So a deictic perspective is not necessary to interpret (95).

(94) *An old cottage is <u>across the river</u>*

(95) *The boy walked <u>across the street</u>*

Among the perspectival locative PPs, belong *orientational locatives* (PPs with *in front of, behind, to the right/left of*) which require a locative perspective to get a proper interpretation. Thus, both (96a) and (96b) need a locative perspective.

(96) a. *John is sitting in front of the tree*

b. *John walked in front of the tree*

c. *Mary was hiding behind the rock*

d. *Mary ran behind the rock*

(96a) is true iff John is sitting and he is on the front-orientation of the tree determined by the utterance context. In 3.4.1, we defined orientations as a linearly ordered set of atomic regions (or equivalently as a ray), and in 3.4.2.3, a deictic orientation is defined as determined by a contextual perspective point. (96b) is true iff John walked and John ended up being on the front-orientation of the tree; again the front-orientation is determined by context. Unlike symmetric locatives, orientational locatives among the asymmetric ones involve a locative perspective in construction both with stative verbs (*is sitting* in (96a)) and with movement verbs (*walked* in (96b)).

4.3.2.2 Intrinsic Orientations

(97) Generalization–2:

a. Only orientational locatives predicate of the intrinsic orientation of the reference object, if it has one.

b. In-out orientations are never assigned deictically.

Second, the symmetric locatives do not involve intrinsic orientations of a reference object, but orientational locatives do as shown in (98). That is, if a reference object has an intrinsic orientation, orientational locatives make use of it, but if not, the utterance context has to determine a relevant orientation. Thus we use intrinsic front/back or right/left orientations of 'the car' and 'the desk' to interpret (98a,b). As for (99a) and (99b) with a symmetric locative, however, we do not need to refer to the intrinsic orientations of the reference objects, 'the field' or 'the building'.

(98) a. *The boy is playing in front of/behind the car.*

b. *The bookshelves were on the right of the desk.*

(99) a. *The boy ran across the field*

b. *The boy ran past the building*

Prepositions like *up, down, on the top of* make use of other intrinsic orientations, i.e., top/bottom orientations, so the sentences in (100) can be interpreted only when the reference object has intrinsic top/bottom orientations. Another preposition *on top of* behaves differently from *on the top of*, in that the former does not require a reference object to have an intrinsic top/botom orientation.

(100) a. *John's house is up/down the hill*

b. *The book is on the top of the table*

We leave out one of the important intrinsic orientations: in/out orientations. Many English words including prepositions, verbs, and adverbs involve this orientation, e.g., *into, out of, inside, outside, enter, exit, outward, inward*, etc. We note here that the in/out orientations are never assigned deictically, but reference objects must have their intrinsic orientation, i.e., their intrinsic inside/outside parts.

4.3.2.3. Binary Prepositional Phrases

(101) Generalization–3:

Only symmetric locatives denote an *unreducible binary* relation, i.e., a relation which is not paraphrasable as a boolean compound of unary spatial relations.

As stated in generalization–3, only symmetric locatives denote an unreducible binary relation, that is, a relation which is not paraphrasable as a boolean compound of unary spatial relations such as *is in front of the car* and *is on the table*, etc. Equivalently, we claim they denote intersective functions from binary relations to binary relations.[16] In (102a), the PP *across the street* does not refer to a location of a single argument but a spatial relation between the two arguments 'John' and 'Mary'. Thus the sentence entails 'John and Mary were on the opposite sides of the street'. (102b) also determines another spatial relation: 'being on the opposite sides of the window' between the subject and the object arguments. Such spatial dependency between two objects cannot be represented only in terms of unary spatial relations.

(102) a. *John saw Mary across the street*
b. *John spied on Mary through the window*

(103) a. *John saw Mary in front of the house*
b. *John spied on Mary from the rooftop*

But (103a) with an orientational locative and (103b) with a directional locative do not determine a spatial relation between arguments, instead they refer to a location of a single argument. Thus (103a) entails 'Mary was in front of the house', and (103b) 'John was on the rooftop'.

[16]Recall that we claimed in 2.2 the intersectivity constraint was not only for stative locatives but for path type locatives (symmetric/directional locatives). We noted also that only symmetric locatives can denote a spatial relation between the subject and the object arguments.

4.3.3. Interpretation of Deictic Locative Perspectives

In this section, we provide a formal semantics of locative perspectives involved in locative PPs. We analyse "locative perspective" as a means of locating an object along an *orientation* moving out from its origin which can be either a reference object or a (deictic) perspective point. Thus (104a) locates an old cottage along the orientation moving out from the village and crossing the river (more or less perpendicularly).

(104) a. *An old cottage is across the river (from the village)*
b. *John was sitting in front of the rock (from here)*

(104b) has an orientational locative *in front of the rock*, but the reference object 'the rock' does not have an intrinsic front/back orientation. Thus we need a deictic perspective to interpret (104b): so assuming the deictic perspective is given by *from here*, we interpret the sentence as 'John was sitting and John was on the front-orientation of the rock which is moving out from the rock and intersecting the region denoted by 'here'. Thus, the direction (the direction being understood as that from the origin to the second point) is determined by a perspective point supplied by an overt *from*-phrase or deictically.

Deictic perspectives come into play when a source point for a locative perspective is not overtly expressed. We have looked at two classes of locatives involving locative perspectives: (i) Symmetric locatives, and (ii) Orientational locatives. We also noted that two classes of verbs (movement verbs and stative verbs) are different in triggering locative perspectives (cf. 4.3.2). Based on the formal structure of paths and orientations defined in chapter 3, we interpret extensional locatives with the two interpretative rules (Semantic Rule–1 and –2, introduced in 4.1.2)

First, consider perspectival locative PPs modifying a stative predicate. In 3.4.2.3, we defined a deictic orientation, $\Omega_{\text{from}}(x,y,T)$, which we will use to interpret sentences like (106). The definition of *deictic orientation* is repeated below:

(105) Definition:

For all objects x, $y \in \mathbb{E}$, and all intervals $T \in \mathbb{T}$, $\Omega_{\text{from}}(x,y,T)$ is a *deictic orientation* ρ such that $\text{Origin}(\rho) \subseteq ®(y)$ and ρ intersects $®(x,T)$.

By Semantic Rule-2, we interpret (106) as follows, assuming the context provides a deictic perspective point with 'here'.

(106) a. *An old cottage is <u>across</u> the river*

is True iff for some interval **now**$\subseteq$T, **be** (**an old cottage**)(T) and for ρ an orientation, INTR(®(**an old cottage**),ρ), $\rho = \Omega_{\text{from}}$(**the river, here, now**), and BETWEEN (®(**here**), ®(**the river**), ®(**an old cottage**))

b. *John was sitting <u>in front of</u> the rock*

is True iff for some interval T<**now**, **sit** (**john**)(T) and for ρ an orientation, INTR(®(**john**),ρ), $\rho = \Omega_{\text{from}}$(**the rock, here,** T), and BETWEEN(®(**here**), ®(**john**), ®(**the rock**))

c. *John was sitting behind the rock*

is True iff for some interval T<**now**, **sit** (**john**)(T) and for ρ an orientation, INTR(®(**john**),ρ), $\rho = \Omega_{\text{from}}$(**the rock**, **here**, T), and BETWEEN(®(**here**), ®(**the rock**), ®(**john**))

(106b,c) above require a deictic perspective to assign a front (or back) orientation to 'the rock'. The PPs in (106) determine a deictic orientation satisfying a certain betweenness condition in it. We can see here that the deictic orientation, Ω_{from}, is designed for a wide range of perspectival prepositions: *symmetric perspectival* ones and *front/behind*,

Now let us consider a sentence containing a perspectival locative PP and a motion verb. Such sentences involve a movement, so the PP will determine a path. But since the PP is perspectival, a deictic perspective point would be required to determine the path. For example, consider (107) with a motion verb *ran* and a perspectival locative PP *behind the tree*. Notice that the sentence is interpreted in terms of both *path* and *orientation*.

(107) *John ran behind the tree*

is True iff for some interval T<**now**, there is a path π such that **run** (**john**)(T), TRAV(**john**, π, T) and for ρ an orientation, INTR(®(**john**),ρ), $\rho = \Omega_{\text{from}}$(**the tree**, **here**, T), and BETWEEN (®(**here**), ®(**the tree**), π_g)

It is assumed that the deictic perspective point of the sentence is 'here'. The orientation ρ has its origin at the 'here-region' and the tree intersects it. Further, it determines the goal region of the path π, i.e., the region that John wound up being at.

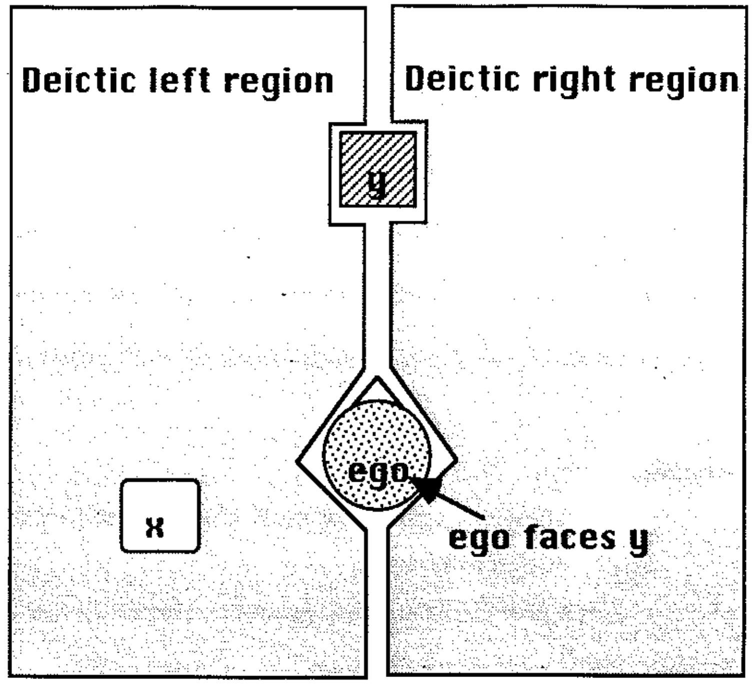
Now we introduce two more deictic orientations involved in orientational prepositions like *to the left of* and *to the right of*. Miller and Johnson-Laird (1976: 399) claim that the deictic left/right orientations can be defined in terms of the relative distances of the located object and the hands of the observer (the perspective point), if it is assumed that the observer stands in a normal orientation with a reference object in front of him. Thus, they define the deictic right orientation of a reference object y in order to locate an object x, symbolized $\text{RIGHT}_d(x,y)$, as follows:

(108) $\text{RIGHT}_d(x,y)$:

A referent x is "to the right of" the relatum y deictically if
$\text{FRONT}_d(y,ego)$ and:
(i) GREATER(DISTANCE(x, ego's left hand), DISTANCE(x, ego's right hand))

This definition requires that the perspective point (or the observer), indicated by 'ego' in (108), should stand in front of the reference object (y). But the deictic orientation can be assigned even in case the perspective point turns back to the reference object. Further, the definition does not shift the perspective from the observer to the reference object, thus the reference object does not play a role in determining deictic left/right region. The following figure shows the deictic left/right regions defined by Miller and Johnson-Laird (1976).

Figure 4-3



Since x is nearer to ego's (the perspective point) left hand than to ego's right hand, the definition will render the object x in the figure to be to the left of y, which is counter intuitive. We instead claim that the deictic left/right orientations should be assigned to the reference object by the perspective holder's intrinsic orientations. In other words, we shift the orientations of the perspective point to the reference object. Thus, the deictic left/right orientations are defined as follows:

(109) Definition:

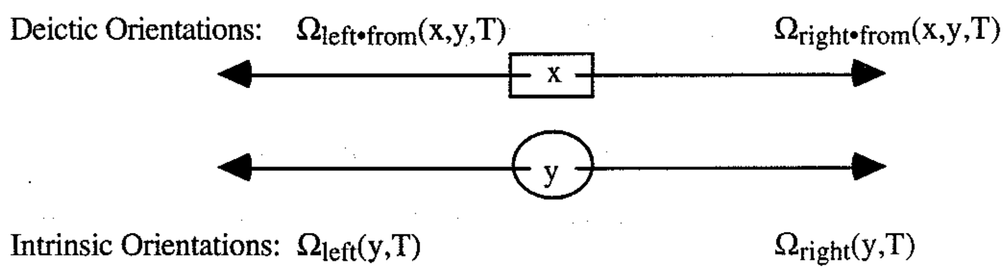
For x and y objects in $\mathbb{E}$, and T an interval,
a *deictic left orientation* of x with the deictic perspective point y, $\Omega_{left \cdot from}(x,y,T)$, is an orientation ρ such that Origin(ρ) $\subseteq$ ®(x) and ρ has the same direction as y's intrinsic left-orientation at T (i.e., $\Omega_{left}(y,T)$).

(110) Definition:

For x and y objects in Ξ, and T an interval,
a *deictic right orientation* of x with the deictic perspective point y, $\Omega_{right \bullet from}(x,y,T)$, is an orientation ρ such that Origin(ρ) $\subseteq$ ®(x) and ρ has the same direction as y's intrinsic right-orientation at T (i.e., $\Omega_{right}(y,T)$).

The binary relation "has the same direction as" is defined in 3.4.1. Figure 4-4 shows how deictic orientations are assigned to the reference object x with the perspective point y, when x lacks intrinsic left/right orientations.

Figure 4-4



In the above figure, the front/back orientations of y do not play a role in assigning deictic orientations, that is, the definitions of (109) and (110) apply either when y faces x or when y turns back to x. Our definitions predict that deictic left/right orientations can be assigned only when the locative perspective has its own intrinsic left/right orientations.

With these deictic orientations and Semantic Rule-2, we interpret the following. It is assumed that the perspective point is '**you**'.

(111) a. *John is to the left of the rock (from you)*
is True iff **be(john)** and for ρ an orientation, INTR(®(**john**),ρ),
and $\rho = \Omega_{\text{left}\bullet\text{from}}$(**the rock, you, now**).

b. *John is to the right of the rock (from you)*
is True iff **be(john)** and for ρ an orientation, INTR(®(**john**),ρ),
and $\rho = \Omega_{\text{right}\bullet\text{from}}$(**the rock, you, now**).

So the sentences are interpreted in terms of the left/right orientations of '**you**' (the addressee). The deictic left-right orientations can also be determined by the perspective of a participant of an event. Thus a person facing a blank sheet of paper will assign left-right orientations to it according to his/her intrinsic orientations. If a person is driving on a freeway saying "*The village is to the right of the freeway*", the direction of movement will determine deictic front-back orientations of the freeway and her intrinsic left-right orientations will determine its left-right orientations.

4.3.4. Non-perspectival Locatives

Our analysis predicts that just the prepositions whose semantic interpretation involves locating an object along an orientation exhibit a perspectival interpretation. This enables us to naturally interpret "projective" prepositional phrases (e.g., PPs with *in front of/behind*), which are noticed by Herskovits (1986), and symmetric locatives.

Thus we predict that no perspectival reading is induced when the reference object has an intrinsic orientation (e.g., cars have an inherent *front-back* orientation), since the object itself provides the origin and the direction of the orientation. But when applied to unoriented objects, as in (112), we need another point to determine the direction. Our semantic analysis also predicts the absence of a perspectival interpretation for directional locatives with *inside*, *outside*, *into*, *out of*, *to*, *from*, as in (113).

(112) *The ball is <u>in front of</u> the tree*

(113) a. *The boy is sitting <u>inside</u> the room*

b. **The boy is sitting <u>inside</u> the room <u>from</u> here*

The PP *inside the room* does not induce an orientation to interpret the sentence, but the PP just determines a region 'inside the room'.

4.3.5. Binary Prepositions

Finally we note that our analysis introduces the new category of *binary preposition*. The symmetric locatives with *across, through, over,* and *past* do not take reference objects as inherently oriented and so they require two arguments to locate an object – the reference object and a "perspective point" are needed to determine an orientation. Thus formally we extend here the analysis in Montague (1973) and Keenan & Faltz (1985) by a new class of binary prepositions: *across-from*, *through-from*, *over-from*, etc.

(114) a. Unary prepositions: $(P_n\backslash P_n)/NP$
b. Binary prepositions: $((P_n\backslash P_n)/NP)/NP$

Unary prepositions take one NP to be a predicate modifier ($P_n\backslash P_n$), but binary prepositions take two NPs to be a predicate modifier. This enables us as well to account for the deictic interpretation of locative PPs without an overt perspective point expressed.

We note syntactic evidence supporting our analysis of binary prepositions. (115) is ambiguous, having (i) a directional reading in which John crossed the street and 'from here' denotes his starting place, and (ii) a stative perspectival reading in which John was on the opposite side of the street from here jogging. However, the second reading does not allow us to dislocate the perspectival *from*-phrase or to separate the two PPs, thus the perspectival reading of (115) disappears in (116). But the perspectival reading is preserved in (117) where the two PPs are dislocated as a whole.

(115) *John jogged <u>across</u> the street <u>from</u> here*
(116) a. *John jogged <u>from</u> here <u>across</u> the street*
b. *<u>From</u> here, John jogged <u>across</u> the street*
c. *John jogged <u>across</u> the street very fast <u>from</u> here*
(117) *<u>Across</u> the street <u>from</u> here, John jogged*

The first reading can be roughly represented as (118) where the *from*-phrase denotes a source point of movement and the two PP functions apply to the predicate 'jogged' one after the other. The second reading, however, can be represented as (119) with a binary preposition **across•from** which is not reducible to a boolean compound of unary prepositions.

(118) (**<u>from</u> here (<u>across</u> the-street (jogged)))(john)**

(119) **[(<u>across•from</u> (the-street)(here)](jogged)(john)**

Binary prepositions are interpreted as functions taking a pair of NP denotations to give a predicate modifier. The following illustrates how to interpret *across-from* in terms of orientation and perspective point. In (120), α and β denote the first and the second arguments of the binary preposition, respectively.

(120) Binary Preposition: *across-from*

For s a n-place predicate, for α, β individual denoting noun phrases, interpret the n-place predicate s+*across*+α+*from*+β, where *across*+α+*from*+β is k-th argument oriented ($1 \leq k \leq n$), as follows:

(**across•from**(α)(β))(s) = {<x$_1$,...,x$_n$>| s(<x$_1$,...,x$_n$>) and INTR(®(x$_k$), ρ) for some orientation ρ, where for T an interval, $\rho = \Omega_{\text{from}}(\alpha, \beta, T)$, BETWEEN (®($\beta$), ®($\alpha$), ®(x$_k$)), and there is some atomic region A$\in \rho$, ON(A,®(α))}

Then the rule interprets (115) as follows:

(121) *John jogged **across** the street **from** here*

is true iff

for some interval T<**now**, **jog(john)**(T) and INTR(®(**john**), ρ) where $\rho = \Omega_{\text{from}}$(®(**the street**), ®(**here**), T),

BETWEEN (®(**here**), ®(**the street**), ®(**john**)), and there is some atomic region A$\in \rho$, ON(A,®(**the street**))

Analogous to (121) is the semantics of other binary prepositions. Thus for example, *through-from* is given the following interpretation:

(122) Binary Preposition: *through-from*

For s a n-place predicate, for α,β individual denoting noun phrases, interpret the n-place predicate s+*across*+α+*from*+β, where *across*+α+*from*+β is k-th argument oriented ($1 \leq k \leq n$), as follows:

(**through•from**$(\alpha)(\beta))(s) = \{<x_1,...,x_n>|\ s(<x_1,...,x_n>)$ and INTR(®(x_k), ρ) for some orientation ρ, where for T an interval, $\rho = \Omega_{\text{from}}(\alpha, \beta, T)$, BETWEEN(®($\beta$), ®($\alpha$), ®($x_k$)), and there is some atomic region $A \in \rho$, IN(A,®(α))\}

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