

LOGICAL DEPENDENCY IN QUANTIFICATION

**-- A Study Conducted within the Framework of
Labelled Deductive Systems, with Special
Reference to English and Mandarin Chinese**

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" Logicians should note that a deductive system is concerned not just with unlabelled entailments or sequents $A \rightarrow B$ (as in Gentzen's proof theory), but with deductions or proofs of such entailments. In writing $\underline{f}: A \rightarrow B$ we think of \underline{f} as the 'reason' why A entails B ."

(Lambek & Scott 1986)

" Once we have introduced the notion of a 'considered' choice to eliminate quantifiers, we may wonder whether we cannot describe a quantifier exhaustively in terms of assignment statements with the appropriate argument. That is, can a quantifier be proof-theoretically described purely in terms of the assignments that are used to eliminate and introduce it ?"

(Meyer Viol 1995)

"...while aiming at finding out how Chinese logic operates, we shall probably end up with finding out how logic operates in Chinese. "

(Yuen Ren Chao 1976)

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Abstract

This thesis is a study on quantification in the formal logical system of Labelled Deductive Systems as applied to Natural Language Understanding (LDS_{NL} for short). Chapter 1 starts with a discussion on the treatment of quantification in the GB framework, followed by an examination on branching quantification. Then, in Chapter 2, details of LDS_{NL} are introduced in a way that its logical motivations are explained in the context of natural language understanding. Chapter 3 first discusses Game-theoretic Semantics and its treatment of quantifiers. This is followed by discussions of some other procedural treatments of quantification alternative to the first-order treatments. After that, detailed treatments of quantification in English by LDS_{NL} as proposed by Gabbay & Kempson (1992b) are presented in Chapter 4. Instead of viewing quantifiers as operators, I have followed the works of Gabbay & Kempson in treating them as words projecting meta-variables over the labels, whose values are to be instantiated in the dynamic process of utterance interpretation, which is conceived as a procedural, proof-deductive process. Instantiation of variables will bring about the construction of dependency relation, the varieties of which lead to ambiguity of scope. Chapter 5 first presents the crucial data in Chinese and a short survey of the past literature. It then gives an analysis of Chinese quantification in LDS_{NL} as well as a comparative study of the phenomenon between Chinese and English. Different properties of quantification between English and Chinese are attributed to a delaying mechanism which is at work in English but not in Chinese. A deeper linguistic

motivation is given in the form of the Kempson & Jiang Hypothesis. Additional supporting evidence for the hypothesis is also provided from the study of double-object constructions and dative/locative constructions. A comparative discussion between LDS_{NL} and treatments in Categorical Grammars and Discourse Representation Theory is given in Chapter 6. The thesis also attempts to relate the notions, mechanisms and findings in LDS to other linguistic frameworks, notably the Government-Binding Theory, Montague Semantics, Categorical Grammars, Discourse Representation Theory, Game-Theoretical Semantics and Branching Quantifier Theory.

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Quantifiers and Quantification Theory

0. Preamble

The study of quantification in natural language is closely related to its counterpart in logic. Logicians have been making insightful analyses of quantification in formal languages, which linguists have found to be a constant source of inspiration. Yet quantification in natural language is also highly distinct because natural language contains properties that are much harder to characterize in logical terms, notably ambiguity and indirectness. A proper treatment of quantification in natural language will tell us a lot about its syntactic and semantic structures and its logical properties that may in turn contribute to the building of a logical system that is specifically concerned with human reasoning in language.

This thesis is devoted to the study of dependency relations between quantified expressions in multiply quantified sentences. I will not examine cases involving the interaction between quantifiers and other phenomena such as anaphora, ellipsis, and control, which will be topics for further investigation once we work out the basic dependency cases.

This first chapter is a critical survey of two approaches to quantification that have exerted great influence on the study of the subject: quantifier-raising(QR) at Logical Form(LF), which is still the best-known treatment of quantification in GB syntax, and the branching quantifier analysis(BQ), which extends our understanding of quantification (both in logic and in natural language) beyond the scope of first-order predicate logic. The criteria of evaluation are proper representation, proper interpretation, and better explanation. The inadequacies of the QR approach are found to be inherent in the logical system it relies on: first-order predicate calculus(FOPC). The BQ theory addresses issues that FOPC cannot cope with. But examinations on the BQ analysis also call for a more principled account of quantification in syntax and semantics, for we need a unified theory to account for the facts that the BQ theory does not cover but the FOPC can handle well. Judging by our three evaluating criteria, the theory we want to construct should also give adequate explanations besides providing proper representations and interpretations.

As the discussion unfolds, I gradually introduce the technical notions related to the analysis of quantification in logic and in natural language, the understanding of which will turn out to be of great value to the studies in the following chapters.

1. QR at LF

In natural language, when two or more quantified phrases(shortened as QP's, which include adverbs of quantification, more often as QNP's, when only quantified noun phrases are under investigation) appear in the same sentence, ambiguity of scope

gives rise to different interpretations. According to the analytic mechanisms of first-order predicate calculus(henceforth FOPC), each of the quantified phrases are segmented into three parts: the quantifier as operator, the variable, and the common noun(CN). The CN is given the role of a predicate over one or more occurrence(s) of the variable bound by the operator, followed by other elements in the logical formula representing the meaning of the sentence concerned. In first-order formulae containing quantified structures, different orderings of operators represent distinct scope readings, unless all the quantifiers are of the same type,¹ as shown in the following two pairs of representations of English sentences:

(1) Every student admires some professor.

a. $\forall x(Sx \rightarrow \exists y(Py \wedge A(x, y)))$

b. $\exists y(Py \wedge \forall x(Sx \rightarrow A(x, y)))$

[Key: Sx : x is a student; Px : x is a professor; Axy : x admires y . Domain: people.]

(2) Some student admires every professor.

a. $\exists x(Sx \wedge \forall y(Py \rightarrow A(x, y)))$

b. $\forall y(Py \rightarrow \exists x(Sx \wedge A(x, y)))$

[Key and Domain same as (1)]

Incorporating the FOPC convention into the linguistic framework of Generative

¹ In the latter case, difference in scope domain does not give rise to difference in interpretation, because of the following permutation rules:

(i) $(\forall x)(\forall y)\phi(x,y) \Leftrightarrow (\forall y)(\forall x)\phi(x,y)$

(ii) $(\exists x)(\exists y)\phi(x,y) \Leftrightarrow (\exists y)(\exists x)\phi(x,y)$

cf. Lemmon(1965), Partee et al.(1990).

Grammar, May (1977) represented the distinct scope readings of quantifiers in an ambiguous sentence at the level of Logical Form(LF), where quantified NP's are adjoined to S/IP through quantifier-raising(QR)², which is a form of Move- α . Difference in the order of application of QR yields different scope effects. For example, (1) would be analysed as (3), which is glossed in the form of restricted quantification, the latter being considered a more accurate translation of natural language quantification.³

- (3) a. $[_{CP} \dots [_{IP} \text{ every student}_x [_{IP} \text{ some professor}_y [_{IP} e_x \text{ admires } e_y]]]]]$
 For all x , x a student, there is some y , y a professor, such that x admires y .
- b. $[_{CP} \dots [_{IP} \text{ some professor}_y [_{IP} \text{ every student}_x [_{IP} e_x \text{ admires } e_y]]]]]$
 There is some y , y a professor, such that for all x , x a student, x admires y .

With such a treatment of quantification in natural language, May (1977) predicted that given an n number of quantifiers, $n!$ ways of possible scope

² For ease of citation, I have refrained from completely updating the older notations in the past GB literature.

³ The major reasons against un-restricted quantification in natural language are presented in McCawley (1993): (I) unequal representations of formulae prefixed by universal quantifiers and those by existential quantifiers, the former being a material implication and the latter, a conjunction; (II) quantifiers like *most* have to be treated as restricted quantifiers to yield the right truth conditions; and (III) quantifiers carrying an existential commitment should be treated as restricted quantifiers so as to identify the predicate involved in the pragmatic presupposition of existence. Discussions can also be found in Lewis (1972), Dummett (1973), Barwise & Cooper (1981), Hodges (1983), and Lappin (1991).

interpretation could be obtained on purely logical grounds. However, due to considerations of ECP and branching quantifiers (the latter to be discussed shortly), May (1985) proposed a much revised version which he termed the Scope Principle:

The Scope Principle

'...call a class of occurrences of operators Ψ a Σ -sequence iff for any O_i , $O_j \in \Psi$, O_i governs O_j , where "operator" means "phrases in A-bar positions at LF", and let us propose that members of Σ -sequences are free to take on any type of relative scope relation.'⁴

Under this principle, two quantifiers at the level of LF forming a Σ -sequence (as illustrated by (3b)) can be allowed to have three interpretive relations: one quantifier being dependent on the other and vice versa, these two being the $n!$ readings captured in the treatment of May (1977), plus the branching quantifier reading by which the quantifiers are interpreted independently of each other. The number of possible scope readings is thereby extended to $n!+1$. Besides, this approach also avoids the ECP violation entailed in May (1977), as shown in the representation (3a), where e_x cannot be properly governed by *every student_x*. As the reading of (3a) is now captured by (3b), which is an interpretation over a Σ -sequence, the former is no longer needed as a distinct representation.

⁴ The notions of *government* and *c-commanding* are defined as follows:

- (i) α governs β =_{df} α c-commands β and β c-commands α , and there are no maximal projection boundaries between α and β .
- (ii) α c-commands β =_{df} every maximal projection dominating α dominates β , and α does not dominate β .

It is worth noting that QR still plays a role in this revised treatment. The Scope Principle can only operate on structures like (3b), which has already undergone QR for both of the quantifiers.⁵

The Scope Principle also marked a conceptual departure from the previous treatments of quantification in GB syntax: syntax is no longer held responsible for distinct representations of multiply quantified sentences. LF only provides an initial representation, an input to semantic interpretations. The LF representations are weak enough to be compatible with the varied semantic interpretations as mediated by the Scope Principle.⁶ While QR in May (1977) also reveals the relationship between different interpretations via different landing sites and order of application, this effect can no longer be obtained from May (1985).

⁵ In fact, (3b) is not exactly the LF structure given by May (1985). The precise representation should be (i):

(i) $[_{CP} \dots [_{IP} [_{NP_x} [_{NP_y} \text{some professor}_y] [_{NP_x} \text{every student}_x]] [_{IP} e_x \text{admires } e_y]]]$

(i) differs from both (3a) and (3b) in the manner of QR adjunction. In (3a,b), reflecting the treatment of May (1977), QR can adjoin both QNP's to IP/S. But in (i), reflecting the treatment of May (1985), QR first adjoins NP_x to IP and then adjoins NP_y to NP_x . According to Lappin (1991), this is due to the fact that May adopted a constraint on LF which specifies that only one operator can be adjoined to any given level of X' projection and that he also allowed adjunction to VP and NP. This constraint makes no difference to our discussion here, as the raised QNP's in (3a,b) and in (i) are all in A' positions.

⁶ This position seems to share some assumptions with Kempson & Cormack (1981), though the solutions are markedly different. Both K&C's logical representation and the LF representation of May are single representations aiming to entail all the possible ambiguous readings. The distinction among the readings is to be drawn later: in K&C's practice, through pragmatic and logical operations; in May's approach, by the Scope Principle.

Two questions immediately suggest themselves: (I) Does this approach provide an adequate treatment of the complexities of quantification in natural language? (II) Is it possible to construct a more articulate^d treatment of quantification which, on the one hand, disambiguates the structures with distinct representations and, on the other hand, reveals the correlations between the different representations in a principled way? Answers to these two questions constitute the bulk of the rest of this thesis. These two questions are raised here with the knowledge that many other insightful studies have been conducted on quantification in natural language, notably in Montague Semantics (Montague: 1974; Barwise & Cooper: 1981, Cooper: 1983), Categorical Grammar(s) (Emms: 1992b; Carpenter: n.d. (a,b); Morrill: 1994, 1995; Park: n.d.; Pereira: 1990), Discourse Representation Theory (Kamp & Reyle: 1993), File Exchange Theory (Heim: 1982), Lexical Functional Grammar (Dalrymple et al.: 1994), Situation Theory (Gawron & Peters: 1990), and some other individual approaches (e.g. Poesio: 1994, 1995). Although findings of some of these studies will be discussed, it is not possible for me to do full justice to all of them. Instead, I will adhere to a proof-theoretic approach, the Labelled Deductive System, and will try to provide answers to the above-raised questions within this framework. At this initial stage of discussion, I also leave open the issue of whether the second question ought to be tackled in syntax or in semantics, or in both areas -- the empirical studies that follow this chapter will provide partial answers. A third point to note is that May's approach to quantification, invoking QR at LF and the Scope Principle, is not the only theory of quantification in GB. There are other proposals that either handle the issue at S-structures, thereby not supporting the postulation of LF and QR (e.g. Riemsdijk & Williams: 1986; Williams: 1986, 1988, 1994; and Pesetsky (1982), with his Path

Containment Theory), or handle the issue at S-structures while taking QR at LF to be responsible for the proper representation of elliptic constructions and discontinuous units, thus advocating for a non-quantificational LF (e.g. Reinhart: 1991), or accept QR at LF but formulate other conditions or principles of representation/interpretation (e.g. Aoun & Li: 1993, with their Minimal Binding Requirement; and Diesing: 1992, with her mapping algorithm). Lappin (1991) also argued that it was not necessary to assume a distinct level of LF, and logical form, taken as the input to rules of model-theoretic semantic interpretation (in accordance with the method of NP storage proposed in Cooper (1983)), can be identified directly with S-structure. He also argued that the QR approach cannot handle some interpretation of QNP in an opaque context, which requires the QNP be interpreted in its argument position.

A more recent treatment of quantification in Chomsky's Minimalist framework (Chomsky 1993) is Kitahara (1994), who argued that within the theory of feature-checking, movements are triggered by the need to check Case features. The resulting structure can be used to derive ambiguity of multiple quantification within a chain-based theory of scope interpretation, using a revised version of the Scope Principle originally proposed by Aoun & Li (1989, 1993). Kitahara therefore concluded that the LF-rule of QR plays absolutely no role, at least for argument-quantifiers bearing the structural Case-features.

There are other motivations for the postulation of the existence of LF and the necessity of QR, which are summarized in Lappin (1991).

Before we make any more comments on May's approach, some general observations have to be made. Any assertions with regard to the number of possible scope readings of ambiguous quantified structures have to be modified in several ways when we look at the logic of natural language more closely. First, the quantifiers have to interact with each other, which does not always take place. Second, the number of scope ambiguities as predicted by the representation in formal logic may not be fully manifested in a natural language due to its structural and logical idiosyncrasies. Third, individual quantifiers in a language exhibit varied logical characteristics which make the result of their interaction less predictable. These three points call for analyses of quantification in natural language as being not identical to that in predicate logic, and they also provide the criteria for evaluating any particular theories formulated with that purpose.⁷ I will therefore put the Scope Principle cum QR at LF to the test, but not before taking a look at the branching quantifier(BQ) analysis.

2. The Branching Quantifier Analysis

2.1. Linear and Branching Quantification

The syntax of FOPC is strictly linear. In cases of multiple quantification, a quantifier either takes the wide scope or must necessarily be in the scope of another quantifier, which is to its left. A quantifier, therefore, may end up being in the

⁷ The fact that hearers tend to get only one of the several possible readings in an ambiguous sentence(which they take as the most relevant with regard to the context of the utterance) belongs to a different topic and is only briefly discussed in Chapter 5 with reference to data elicitation in Chinese.

different but overlapping scopes of all the linearly preceding quantifiers. In the same vein, the semantic interpretation of each quantified structure is to be construed as being dependent on each and every preceding quantified structures, whenever such a dependency can be logically constructed.⁸ This convention has been initially taken for granted in the interpretation of quantified structures in natural language.⁹ It works pretty well in most cases, in which interaction of quantifiers takes place. (4) will make this point clear:

- (4) Every member of the appointments committee interviewed two candidates with a good academic record.

In a strictly linear interpretation of (4), *two candidates* is interpreted with reference to *every member of the appointments committee*, such that each member interviewed two different candidates.¹⁰ *a good academic record* is in turn dependent

⁸ I will discuss this last modification in Section 4.

⁹ Dummett (1973: Chapter 2) ascribed to the genius of Frege the practice of making quantifier prefixes in modern symbolic logic linearly ordered. Sher (1991: Chapter 5) provided a concise summary of Dummett's points, with the aid of a graphically illustrative multiple-tree representation. Gil (1982) speculated that "the pervasive linearity of formal logical notations is a result of their being modelled after and designed to reflect activities - e.g. thought processes, speech production and perception - which are inescapably embedded in the uni-dimensional temporal continuum." Gil's remark may be an apt one for the LDS_{NL} enterprise studied in the later chapters in this thesis, but not for FOPC. The latter is not expressive enough to model human thought processes.

¹⁰ 'different' here is intended to be an informal paraphrasing. Strictly speaking, if the word 'different' explicitly appears in the sentence, then the meaning is no longer a simple case of $\forall\exists$, as the dependency now expressed should be *one-to-one*, which should be treated as a case of binary generalized quantifier (a type of polyadic quantifiers). Cf. van Benthem (1989). The studies in this thesis will not go beyond the treatments of unary quantifiers.

on both of the preceding quantified structures, with the resulting reading that each member interviewed two different candidates who each had a good academic record. However, this interpretation is implicit in an FOPC representation. FOPC cannot present an explicit formula to display the choice of dependency of succeeding quantifiers on the preceding ones. Only by using Skolem functions in second-order logic can we represent the dependency relations explicitly.

Sher (1991: fn.8) defines a *Skolem function* as "a function that [assigns a second-order functional representation to] an existential quantifier in a [first-order] quantifier prefix of the form $(\forall x_1) \dots (\forall x_n)(\exists y)$ " (where $n \geq 1$). Thus a statement of the form "Every x stands to some y in the relation R " is logically equivalent to "There is a function f such that every x stands to $f(x)$ in the relation R ." Roughly speaking, if we use a single term c to replace the function form $f(x)$, we get a *Skolem constant*,¹¹ which comes into being as the result of *Skolemization*. The basis of *Skolemization* is the *Skolem normal form theorem*. Again quoting Sher's definition, the theorem says "that every first-order formula is logically equivalent to a second-order prenex formula of the form

$$(\exists f_1) \dots (\exists f_m)(\forall x_1) \dots (\forall x_n) \Phi,$$

where x_1, \dots, x_n are individual variables, f_1, \dots, f_m are functional variables ($m, n \geq 0$),

¹¹ Although the notion of *Skolem constant* c was not used in Sher (1991), it was used in many other works of logic such as Davis (1994), de Queiroz (1994), de Queiroz & Gabbay (1995), Gabbay (1994a), Gabbay et al. (1994), Gabbay & Kempson (1992b), and Kempson (1994a). Cf. Chapter 3, Section 4 for more discussions on Skolem constant and Skolem function, especially on their differences.

and Φ is a quantifier-free formula. This second-order formula is a *Skolem normal form*, and the functions satisfying a Skolem normal form are *Skolem functions*." The mechanism of Skolemization can be illustrated with the following transformational procedures:¹²

- (5) a. $(\exists y)(\forall x)(\exists z)(\forall u)(\forall v)(\exists w)F(y, z, w) \equiv$
 b. $(\exists y)(\exists f)(\forall x)(\forall u)(\forall v)(\exists w)F(y, f(x), w) \equiv$
 c. $(\exists y)(\exists f)(\exists g)(\forall x)(\forall u)(\forall v)F(y, f(x), g(x, u, v))$

(5a) is a multiply-quantified formula in FOPC. In a strictly linear interpretation z is to be understood as being dependent on x ; and w , on x , u , and v . In (5b), the function f indicates the choice of a dependable element for the complete valuation of z in (5a), the latter therefore being substituted by the Skolem function in the second-order logic formula (5b), which involves explicit quantification over functions, i.e. second-order quantification over first-order predicate functions. A further step of Skolemization yields (5c), in which the function g instantiates the value of w in (5b). Both f and g are partial instantiations because z and w may have their own inherent values. Only the values of z and w are not self-sufficient. The dependency relations implicit in (5a) thus receive a complete representation in (5c).¹³ Hence, (5b) and (5c) can serve as translations or explications of (5a). This illustrates the observation of

¹² Taken from Partee et al.(1990). The predicate F in (5) is assumed not to contain any quantifiers. x , u , and v can also be arguments in F , but that does not affect our discussion here.

¹³ y in (5a), being the first in the formula, does not depend on any universal quantifiers. x , u , and v , being bound by universal quantifiers, do not depend on any other quantifiers for interpretation -- a point I will elaborate in Section 4.

Barwise (1979) that syntactically, an FOPC formula with multiple quantification appears to quantify over individuals, but semantically it actually contains hidden existential quantifiers over the set of all functions from D into D (D = the domain of discourse).

Coming back to (4), we can represent its dependency relations by (6):

$$(6) \quad (\exists f)(\exists g)(\forall x, \text{ member of the committee } x)(f(x), \text{ candidate } f(x), |f(x)| = 2) \\ (g(x, f(x)), \text{ record } g(x, f(x))) \text{ Interviewed}[x, f(x) \text{ with } g(x, f(x))]$$

However, this does not exhaust the manner of dependency either in logic language or in natural language. Drawing on the studies on Finite Partially-ordered(FPO) quantifiers (also called Henkin quantifiers) in logic,¹⁴ Hintikka argued in a series of papers¹⁵ that such a type of quantification in logic is manifested in natural language as well and that FOPC cannot represent such structures adequately.

Hintikka pointed out that it was not inconceivable that the interpretation of (5) may not go in a strictly linear fashion. To be more precise, w in (5) does not have to depend on each and every universal quantifier that precedes it. w can choose to be dependent on u and v , but not on x . This will yield (7):

$$(7) \quad (\exists y)(\exists f)(\exists g)(\forall x)(\forall u)(\forall v)F(y, f(x), g(u, v))$$

¹⁴ Cf. Enderton (1970), Henkin (1950,1961), and Walkoe (1970).

¹⁵ Hintikka (1974;1976a,b;1979a).

This is a situation which cannot be expressed even implicitly by linearly ordered quantifiers in FOPC. It involves finite partially-ordered(FPO) quantifiers or Henken quantifiers. If we want to supply a representation that does not involve Skolemization at the outset, or if we want to provide a representation that includes uninterpreted existential quantifiers and will serve as the basis for the correct application of Skolemization, or if we simply want to find a representation alternative(but equivalent) to the representation involving Skolemized interpretations, we can let quantifiers branch. The branching quantifier(BQ) analysis assumes the following general forms:

$$(8) \quad \begin{array}{l} (\exists x) \\ \quad \quad \quad \left. \vphantom{\begin{array}{l} (\exists x) \\ (\forall y) \end{array}} \right\} F(x, y) \\ (\forall y) \end{array}$$

$$(9) \quad \begin{array}{l} (\forall x)(\exists y) \\ \quad \quad \quad \left. \vphantom{\begin{array}{l} (\forall x)(\exists y) \\ (\forall z)(\exists w) \end{array}} \right\} F(x, y, z, w) \\ (\forall z)(\exists w) \end{array}$$

$$(10) \quad (\exists x) \left\{ \begin{array}{l} (\forall y)(\exists u) \\ \quad \quad \quad \left. \vphantom{\begin{array}{l} (\forall y)(\exists u) \\ (\forall z)(\exists w) \end{array}} \right\} F(x, y, u, w) \\ (\forall z)(\exists w) \end{array} \right.$$

$$\begin{aligned}
 (11) \quad & (\forall x_1)(\forall y_1)(\exists z_1) \\
 & (\forall x_2)(\forall y_2)(\exists z_2) \\
 & \quad \quad \quad \left. \vphantom{(\forall x_2)(\forall y_2)(\exists z_2)} \right\} F(x_1, x_2, \dots, x_k, y_1, y_2, \dots, y_k, z_1, z_2, \dots, z_k) \\
 & \quad \quad \quad \dots \\
 & (\forall x_k)(\forall y_k)(\exists z_k)
 \end{aligned}$$

(7) can now be represented in a BQ analysis as (12):

$$(12) \quad (\exists y) \left\{ \begin{array}{l} (\forall x)(\exists z) \\ (\forall u)(\forall v)(\exists w) \end{array} \right\} F(y, z, w)$$

Here what matters is the horizontal order of quantifiers, not the vertical order. In the words of Enderton (1970), "the idea is that each existentially quantified variable is to depend on just those universally quantified variables which precede it in the partial ordering." The equivalent formula in Skolem functions is given by Enderton as (13):

$$\begin{aligned}
 (13) \quad & \exists F_1 \dots \exists F_n \forall x_1 \dots \forall x_n \varphi(x_1, \dots, x_m, F_1(\vec{x}_1), \dots, F_n(\vec{x}_n)) \\
 & \text{where } \vec{x}_i \text{ is a sublist of } x_1, \dots, x_n.
 \end{aligned}$$

2.2. BQ in Natural Language

Besides the purely logical considerations, Hintikka gave examples in natural language that required a BQ analysis. Together with a few examples given in van Benthem (1983), these examples fall into several categories:

Conjoined NP's

- (14) Some relative of each villager and some relative of each townsman hate each other.

Branching of Complex Subject & Object NP's

- (15) Some element of each a contains some element of each b (assuming that a and b are sets of sets).
- (16) Some book by every author is referred to in some essay by every critic.
- (17) Some novel by every novelist is mentioned in some survey by every critic.
- (18) Some family member of some customer of each branch office of every bank likes some product of some subdivision of each subsidiary of every conglomerate.
- (19) Some product of some subdivision of every company of every conglomerate is advertised in some page of some number of every magazine of every newspaper chain.
- (20) Some reviewer of every magazine of each newspaper chain admires some book by every author of each publisher, although this book is disliked by some proof-reader of each printer in every city.

Comparative Constructions

- (21) Every writer likes a book of his almost as much as every critic dislikes some book he has reviewed.

Relative Clauses with Multiple Antecedents

- (22) Every villager envies a relative and every townsman admires a friend who hate each other.
- (23) Each player of every baseball team has a fan, each actress in every musical has an admirer, and each aide of every senator has a friend, who are cousins.
- (24) Every actor of each theatre envies a film star, every review of each critic mentions a novelist, and every book by each chess writer describes a grand master, of whom the star admires the grand master and hates the novelist while the novelist looks down on the grand master.

BQ Involving Non-standard Quantifiers and Numerals

- (25) Most students admire most professors.
- (26) Three directors have made five movies.
- (27) Nobody loves nobody.¹⁶

¹⁶ Cf. van Benthem (1989) for an analysis which analyses the quantifiers involved in this sentence in terms of polyadic quantification of the form (i):

(i) No $xy . \phi(x, y)$

All the examples listed above admit an interpretation that requires the BQ analysis. Indeed, some allow nothing other than such an interpretation. Their difference from the linear readings can be exemplified by the contrasts, say, between the logical representations (14') and (21'), being the interpretive forms of (14) and (21), on the one hand, and (28') and (29') on the other, the latter two being the interpretive forms of (28) and (29), which admit only linear interpretations:

(14) Some relative of each villager and some relative of each townsman hate each other.

(14') $(\exists f)(\exists g)(\forall x)(\forall y)[(x \text{ is a villager} \wedge y \text{ is a townsman}) \rightarrow (f(x) \text{ is a relative of } x \wedge g(y) \text{ is a relative of } y \wedge f(x) \text{ and } g(y) \text{ hate each other})]$

(28) The eldest relative of each villager and that relative of each townsman who is closest in age to the villager hate each other.

(28') $(\exists f)(\exists g)(\forall x)(\forall y)[x \text{ is a villager} \rightarrow (f(x) \text{ is the eldest relative of } x \wedge (y \text{ is a townsman} \rightarrow (g(x, y) \text{ is a relative of } y \text{ and is closest in age to } x \wedge f(x) \text{ and } g(x, y) \text{ hate each other}))))]$

(21) Every writer likes a book of his almost as much as every critic dislikes some book he has reviewed.

no here is a polyadic quantifier binding two variables at once.

(21') $(\exists f)(\exists g)(\forall x)(\forall z)[(x \text{ is a writer} \wedge z \text{ is a critic}) \rightarrow (f(x) \text{ is a book} \wedge x \text{ has authored } f(x) \wedge g(z) \text{ is a book} \wedge z \text{ has reviewed } g(z) \wedge x \text{ likes } f(x) \text{ almost as much as } z \text{ dislikes } g(z))]$

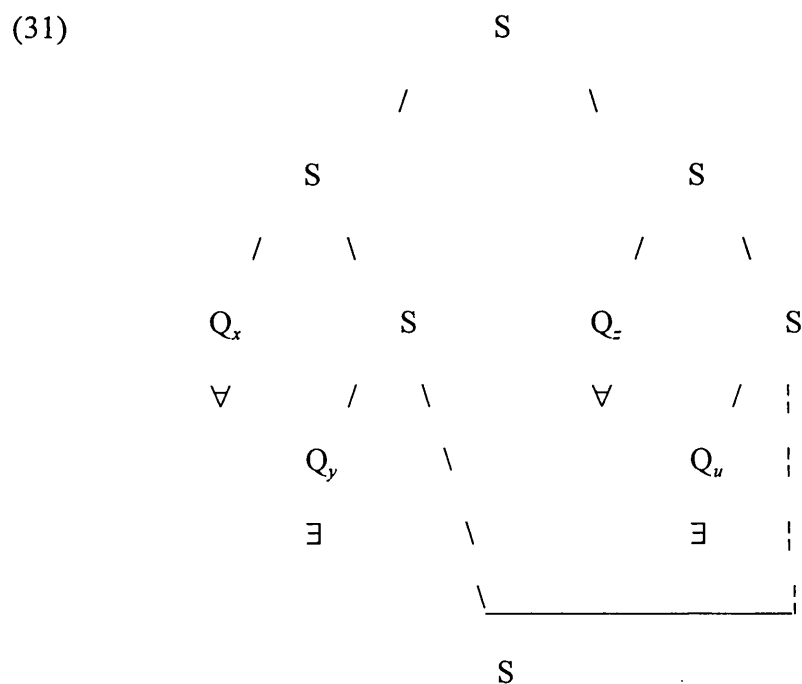
(29) Every writer likes his latest book almost as much as every critic dislikes the first book by that writer he had to review.

(29') $(\exists f)(\exists g)(\forall x)(\forall z)[x \text{ is a writer} \rightarrow (f(x) \text{ is a book} \wedge x \text{ has authored } f(x) \wedge (x \text{ is a critic} \rightarrow (g(x, z) \text{ is a book} \wedge z \text{ has reviewed } g(x, z) \wedge x \text{ likes } f(x) \text{ almost as much as } z \text{ dislikes } g(x, z))))]$

With regard to the quantifier type of the BQ examples, (14) to (24) involve only the standard quantifiers used in FOPC, viz. the universal and the existential quantifiers. These examples all contain at least four quantifiers, justifying Hintikka's point that at least four standard quantifiers are needed to construct a BQ example that has no equivalent in FOPC. All of them can be represented by the BQ constructions (9) to (11). (25) to (27) involve non-standard quantifiers or numeric expressions. Two such quantifiers suffice to construct a BQ structure. As this thesis will not discuss the proper representation of non-standard quantifiers (except for the numerals), I will simply give a general BQ form to these examples as (30):

$$(30) \quad \begin{array}{c} \alpha \\ \left. \vphantom{\begin{array}{c} \alpha \\ \beta \end{array}} \right\} R(\alpha, \beta) \\ \beta \end{array}$$

Drawing evidence from natural language, McCawley (1993) rejected the term branching quantifiers as misleading and suggested that an alternative term *convergent quantifiers* be used instead. The reasons being: (I) *branching* in the present context refers to $\overset{\Delta}{\wedge}$ relation that starts from the matrix S, branching out or upward. But as a conventional linguistic term, *branching* always has a downward orientation, splitting into smaller units. (II) The branching formulae are not just disparate pieces of material that converge into a matrix S but are themselves parts of a larger structure to start with. McCawley illustrated the relationship in natural language by (31):



In the light of (31), McCawley argued that logicians should have represented BQ diagrams like (32), rather than (9):

$$(32) \quad \left\langle \begin{array}{c} (\forall x)(\exists y) \\ (\forall z)(\exists u) \end{array} \right\rangle F(x, y, z, u)$$

Many more examples of BQ were supplied by Gabbay & Moravcsik (1974), Barwise (1979), and Sher (1991). Some examples given in Barwise (1979) do not involve any first-order quantifiers. Gil (1982) and Liu (1990) noted that Jackendoff (1972) gave examples of branching quantification in natural language (involving numerals), pre-dating Hintikka (1974). Gabbay & Moravcsik (1974) gave examples which add dimensions to our understanding of the BQ phenomenon in natural language. Four points from G&M relating to the complexity of branching configurations are worth our attention:

First, among cases where distinct branches are held together by a predicate, there are cases in which the branches are preceded by a common node, thus forming a diamond-like structure, as shown in (33) and its BQ representation (33'):

- (33) Men who make a deal with a certain chisler and women who keep company with him deserve the same fate.

$$(33') \quad \text{There is a chisler s.t.} \left\langle \begin{array}{c} \text{men who ...} \\ \text{women who ...} \end{array} \right\rangle \text{deserve the same fate}$$

[s.t. = such that]

(33') is equivalent to the abstract form (10), of which Hintikka did not seem to supply an example, in ~~view of~~ the works I have consulted (cf. Bibliography). From (33'), we can learn that logicians reserve (32) for a more specific structure of BQ: what G&M (1974) called the "diamond-like" structure. Therefore, to adopt (32) as the general form of BQ, according to McCawley's suggestion, may give rise to notational confusions. It is also clear that (33') is an interpreted structure which may not conform to the original syntactic structure. Thus McCawley's argument for a proper representation of BQ with a purely S-structure based syntactic motivation does not seem to be in line with what logicians originally had in mind.

Second, the main predicate can apply to more than one class denoted within any one of the branches. In (34), all four NP's are tied to the main predicate; and further complexity involving more QNP's are possible:

- (34) Some lie of every politician and some weakness of every voter make the voters hate the politicians.

Third, any number of branches can be obtained with proper conjunctions, and predicates like the one in (35) can apply to any number of branches:

- (35) Every farmer has some sons and every banker has some daughters who belong to the same club.

Fourth, branches with arbitrary length can be formed. In English this is guaranteed by the syntactic device of the word *of* allowing an arbitrary number of iterations in the form: "QNP of QNP of ...".

2.3. Formal Properties of BQ

Hintikka's interpretation of BQ cases in natural language was questioned by Fauconnier (1975) and Stenius (1976).¹⁷ While earlier debates did not seem to lead to consensus, in later works like Barwise (1979) and Sher (1991) the formal properties of BQ were systematically laid out and earlier misunderstandings corrected. Barwise (1979) pointed out that we can make good sense of branching quantification of (36) only when both Q_1 and Q_2 are monotone increasing or when they are both monotone decreasing.¹⁸ He noted that "there is no sensible way to interpret [(36)] when one is increasing and the other is decreasing." ¹⁹

¹⁷ For Hintikka's rejoinder, see Hintikka (1979a).

¹⁸ Barwise (1979) defined these concepts as follows:

A quantifier Q is *monotone increasing* if for all predicates A, B
 $QxA(x) \ \& \ \forall x[Ax \supset Bx]$
 implies
 $QxB(x)$
 A quantifier Q is *monotone decreasing* if for all A, B
 $QxB(x) \ \& \ \forall x[Ax \supset Bx]$
 implies
 $QxA(x)$

¹⁹ Cf. Barwise (1979) for details in discussions on semantic interpretations.

$$(36) \quad \begin{array}{c} Q_1x \\ \quad \searrow \\ \quad A(x, y) \\ \quad \nearrow \\ Q_2y \end{array}$$

Sher (1991) made a further classification of BQ's into *independent BQ's* and *complex BQ's* in terms of their logical properties that also have linguistic consequences. Independent quantification is of the form (37) or (more generally), (38):

$$(37) \quad \begin{array}{c} (Q_1x) \\ (Q_2y) \end{array} \left| \Phi(x, y) =_{df} (Q_1x)(\exists y)\Phi(x, y) \& (Q_2y)(\exists x)\Phi(x, y).^{20} \right.$$

$$(38) \quad \begin{array}{c} (Q_1x_1) \\ \vdots \\ (Q_nx_n) \end{array} \left| \Phi(x_1, \dots, x_n) =_{df} \begin{array}{l} (Q_1x_1)(\exists x_2) \dots (\exists x_n)\Phi(x_1, \dots, x_n) \& \dots \& \\ (Q_nx_n)(\exists x_1) \dots (\exists x_{n-1})\Phi(x_1, \dots, x_n). \end{array} \right.$$

According to Sher, *independent quantification* is essentially first-order and does not involve commitment to a *massive nucleus* or to any other complex structure of objects standing in the quantified relation.²¹ Sher takes it to represent cases in

²⁰ As an informal explanation, (37) says that for every member of Q_1x , there is a y and for every member of Q_2y , there is an x such that $\Phi(x, y)$. That is to say, it is sufficient for each x to be paired with one y , and vice versa.

²¹ The term *massive nucleus* is used by Sher (1991) while discussing Fauconnier (1975). Suppose there are two sets of individuals. If each and every member of one set interacts with each and every member of the other set, then there results a massive nucleus of the complex interaction relationships. On the other hand if, given a certain relation which takes the first set as the domain and the second set as the range, each and every member of the first set simply maps onto one unique value in the second set, and vice versa, with the second set as the domain and the first as the range, then

natural language which have a *cumulative reading*, of which some readings of (25 - 27) are good examples. To my mind, cumulative reading is equivalent to the *incomplete group reading* discussed in Kempson & Cormack (1981) and Kempson (1992b) or the *weak symmetric reading* discussed in Gil (1982).²² An LDS treatment to group readings will be reported in Chapter 4. *Complex quantification* is equated by Sher to Henkin quantifiers which are defined by Barwise (1979) in the following way:

$$(39) \quad \left. \begin{array}{l} (Q_1x) \\ (Q_2y) \end{array} \right\} \Phi_{xy} =_{df} (\exists X)(\exists Y)[(Q_1x)Xx \ \& \ (Q_2y)Yy \ \& \ (\forall x)(\forall y)(Xx \ \& \ Yy \rightarrow \Phi_{xy})].^{23}$$

It is obvious from the definition (39) that a massive nucleus is involved in the case of complex quantification.²⁴

2.4. Essential and Inessential Branching

Coming back to BQ cases in natural language, Barwise (1979) settled a dispute on the interpretation of Hintikka's examples such as (14). Although Hintikka meant

there is no massive nucleus and we have a case of independent quantification.

²² The representations proposed in Gil (1982) will be discussed towards the end of this chapter.

²³ X, Y stands for set variables. (39) can be informally paraphrased as: There exists a set X and a set Y and $x(\text{in } Q_1x) \in X$ and $y(\text{in } Q_2y) \in Y$ such that for all x and for all y ($x \in X$ and $y \in Y$), Φ_{xy} . That is, each x interacts with every y and vice versa.

²⁴ In the LDS treatment of quantification reported in Chapter 4, both complex and independent branching quantification will be dealt with. But I will mainly concentrate on cases involving standard quantifiers in FOPC and numerals.

(14) Some relative of each villager and some relative of each townsman hate each other.

(14') $(\exists f)(\exists g)(\forall x)(\forall y)[(x \text{ is a villager} \wedge y \text{ is a townsman}) \rightarrow (f(x) \text{ is a relative of } x \wedge g(y) \text{ is a relative of } y \wedge f(x) \text{ and } g(y) \text{ hate each other})]$

Barwise (1979) thought that both Hintikka and Stenius had a point. He demonstrated, with the construction of a model, that (14) can also have a weaker reading, in which the choice of the value of each existential quantifier not only depends on the universal quantifier in its own branch but also on the one in the other branch, as shown in (41).

$$(41) \quad \begin{array}{ccc} \forall x & \xleftarrow{\text{dashed}} & \exists y \\ & \swarrow \quad \searrow & \\ \forall z & \xleftarrow{\text{dashed}} & \exists w \end{array} \quad \left. \vphantom{\begin{array}{ccc} \forall x & \xleftarrow{\text{dashed}} & \exists y \\ & \swarrow \quad \searrow & \\ \forall z & \xleftarrow{\text{dashed}} & \exists w \end{array}} \right\} P(x, y, z, w)$$

Under this construal, a possible situation can be such that each villager is paired with a unique townsman and vice versa, neither hating the other and only these pairs of people's relatives hate each other. Yet (41) is equivalent to the first-order representation (40). So (41) is a case of *inessential branching reading*. The paradigm example of BQ for Hintikka, i.e. (14), is therefore shown to be not a convincing example. According to Barwise, only non-standard quantifiers fulfilling the BQ definitions given in Section 2.3 constitute cases of *essential branching reading*.

2.5. Testing the Essential BQ Interpretation

Barwise (1979) proposed one test for essential BQ in contrast to the inessential ones. A paraphrased version of the testing method (according to my understanding) is given here as (42):

(42) TEST FOR ESSENTIAL BQ:

An unambiguous example of essential BQ cannot have its negated form paraphrased by a *negation normal* sentence without using a universal quantifier over abstract objects -- functions, sets, 'ways', 'assignments', 'choices', etc. (A sentence is *negation normal* (with respect to subject position) if no quantifier in subject position occurs within the scope of a negation. In English, for example, a sentence is negation normal if the negation operator occurs between the subject and the verb. An English sentence which is not negation normal usually has the form *It is not ... that S.*)

Thus for (14), its negation normal sentence (43) below does not involve higher-order quantification, which means (14) is not a case of essential BQ. If (14) were a case of essential BQ, it would have its negated form paraphrased by (44), which does not correspond to the model described by the negated form of (14). But in (45), whose negation normal sentence (46) does involve universal quantification over an abstract object of ways matching two entities, we find a true case of essential BQ.

- (14) Some relative of each villager and some relative of each townsman hate each other.
- (43) There is a villager and a townsman that have no relatives that hate each other.
- (44) Any way of assigning relatives to each villager and to each townsman will result in some villager and some townsman being assigned relatives that do not hate each other.
- (45) The richer the country, the more powerful one of its officials.
- (46) There is no way for the richness of any country and the power of one of its officials to be matched.

Although (45) is in Barwise (1979) and so is the 'There is no way...' heading of (46), Barwise did not supply the exact negation version of (45). (46) is my construction. I think the BQ representation of (45) ought to have such a form:

$$\begin{array}{lcl}
 & \forall x (x \text{ country}) \rightarrow \exists y (y \text{ richness}) & \\
 (47) & & \Big) F(x, y(x), z, w(z)). \\
 & \forall z (z \text{ official}) \rightarrow \exists w (w \text{ power}) &
 \end{array}$$

The underlying logical principle for such a test was given by Barwise as a Proposition, quoted here as (48):

- (48) If ϕ is a sentence of FPO and if its negation $\sim\phi$ is logically equivalent to an FPO sentence, then ϕ is logically equivalent to some first-order sentence.²⁵

Both (14) and (43) are FPO sentences, but not (44), which involves a higher-order predication over an FPO sentence. On the other hand, (45) is an FPO sentence, but not (46).

Given (42) and (48), it is obvious that (42) cannot be used to draw the division line between the BQ and the non-BQ readings. The antecedent of (48) states that the sentence under the test should have an FPO formula in the first place. It is therefore not possible to determine by (42) whether any given structure has a BQ reading or not. As discussed above, (1) has two readings, given here again as (1'a,b) in the form of restricted quantification.

- (1') Every student admires some professor.
- a. $(\forall x, \text{student } x) (\exists y, \text{professor } y) \text{Admire}(x, y)$
 - b. $(\exists y, \text{professor } y) (\forall x, \text{student } x) \text{Admire}(x, y)$

(1'b) is in fact equivalent to the branching reading, as observed by Hintikka (1974), Barwise (1979), and further explained in Section 4 of this chapter. Applying

²⁵ Proof for (48) is supplied in Barwise (1979: Appendix 4).

the test (42) to (1') will yield two versions of negation normal sentences:

- (49) Every student does not admire a professor.
- (50) Any way of assigning a professor to each student will result in the professor being not admired by the student.

(49) is the negated version of (1'b). As (49) is negation normal, (1'b) is a case of inessential branching. This is true because the non-linear reading of (1') has two logical forms that are equivalent to each other: the first-order form (1'b), and the BQ form (8) (to be discussed in Section 4). So far so good. But the negated version of (1'a), in the form of negation normal, can only be (50), a form involving higher functions. This, however, does not entail that (1'a) is a case of essential branching, because it is an out-and-out example of linear dependency. We can therefore conclude that (42) and (48) can never be tested on non-FPO sequences.

2.6. BQ and Compositionality

Barwise (1979) related the study of BQ to its implications for Frege's principle of compositionality. He argued that the meaning of a BQ expression of logic cannot be defined inductively in terms of simpler formulas, by explaining away one quantifier at a time in a first order fashion. Rather, the whole BQ block must be treated at once. Barwise thought that some use of higher-type abstract objects is essential. Although Gabbay & Moravcsik (1974) introduced a Montague-type grammar to accomodate BQ cases compositionally, which is stronger than the semantics for FOPC, it is shown to

be just an interpretation of inessential BQ, which has an equivalent FOPC version. While proving that FPO is mathematically definable, Barwise left open the issue of interpreting BQ structures 'in a linguistically natural way, one that respects the basic categories and syntactic structures of English'.

However, in the light of Sher's division of BQ into independent and complex quantification, it can be argued that the principle of compositionality is challenged only by cases of complex quantification. Independent quantification is essentially first-order and can be interpreted in a compositional manner. In this thesis, the BQ cases that I will analyse in the framework of Labelled Deductive Systems will be of three types: A. BQ cases involving standard first-order quantifiers; B. BQ cases involving numeric expressions, which are cases of (B1) complete group reading, and (B2) incomplete group reading. It is easy to establish that none of the three types defy compositionality. Type A, being cases of inessential branching, is convertible into first-order formulae. Type B1 can be taken as cases of inessential branching, for sentences falling under this category can be negated in a negation normal way. So they can also be represented by equivalent first-order formulae. Type B2, being cases of cumulative reading, is first-order as well.

This leads to a further issue. According to Barwise, inessential BQ cases can all be represented in equivalent FOPC formulae. Does it also hold that all the FOPC formulae which admit an equal FPO reading are cases of inessential branching? Barwise's study leads to an affirmative answer. But recall that there is one type of BQ (i.e. independent quantification) discovered by Sher (1991) which was not discussed

in Barwise (1979). Sher indicated that the BQ cases of Barwise were all cases of a different type: i.e. complex quantification. Therefore, it is still not clear whether Barwise's test for essential BQ, i.e. (42), can give the right prediction when tested on the cases of independent branching. My preliminary experimentation with the data seems to indicate that no independent readings can admit a negation normal form without using higher functions, for that would result in a non-cumulative reading (i.e. a complete group reading). For example, while the cumulative reading of (51) can be of a scenario in which one dog chased four boys and the other two dogs chased one boy, (52) seems to only admit a reading by which three dogs as a group did not chase a group of five boys:²⁶

(51) Three dogs chased five boys.

(52) Three dogs did not chase five boys.

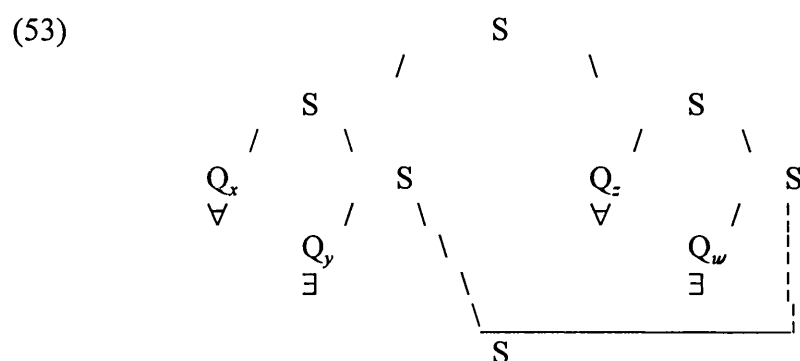
If my judgment is right, then we have cases of essential BQ which are cases of independent branching, the latter interpretable in a first-order way, i.e. in a compositional way. This means that at least some cases of essential branching do not defy compositionality. It also means that some first-order structures can have essential BQ equivalents.

²⁶ Ruth Kempson (p.c.) brought to my notice the following example, which does allow a cumulative reading:

- (i) Three dogs can't have been chasing five boys.

It is not yet known whether it is the role of the modal *can* that leads to such an interpretation.

McCawley (1993: Chpt.8, fn.14) raised doubts about Barwise's comment on the anti-compositionality nature of BQ. If BQ structures are represented as (53), he argued, then it is possible to treat the branched formulae as conjoined constituents, in the form of (54).



- (54) $(\forall x)(\exists y) F(x, y, z, w)$
 CONJ.
 $(\forall z)(\exists w) F(x, y, z, w)$

That is to say, given $[[Q_x Q_y] \text{ conj. } [Q_z Q_w] F(x, y, z, w)]$, it is possible to interpret it as $[[Q_x Q_y] F(x, y, z, w)] \text{ conj. } [[Q_z Q_w] F(x, y, z, w)]$. An explicit example in natural language that I can think of is (55):

- (55) Some relatives of each villager hated some people, and some relatives of each townsman hated some other people, in such a way that the haters in one situation became the hated in the other.

(55) is interpretable in a first-order way. But McCawley was not sure 'how one

puts together meanings of two formulas in which the bound variables of the one occur free in the other' (McCawley: 1993).

2.7. A Short Summary

The above discussion on BQ has its relevance to our present study in several respects. First, the phenomenon of BQ itself calls for a unitary theory of quantification that will cover both the linear and the branching cases of quantification. Second, the discussion of treatments of BQ provides an excellent introduction to some syntactic and semantic properties of FOPL and higher order logic. The acquaintance of notions such as *Skolem constants*, *dependency relations*, and *group readings* will help us to understand many technical details in the LDS approach to be introduced in the later chapters. In this sense, the discussions of BQ cases are more than considerations of the BQ phenomenon itself. Third, the studies on the logical properties of BQ and their relations to natural language make it possible for us to look at natural language syntax and semantics from a new vantage point. It sharpens our awareness of the logico-semantic issues of natural language understanding, making us realize the importance of re-examining the well-known linguistic facts from a logical point of view. In the next two sections, the proposal of BQ analysis as well as the examples given in these studies will be carefully compared to May's QR cum Scope Principle-based approach.

3. On the Interpretive Adequacy of LF Representations on Complex Structures

The BQ structures received treatment in May (1985), though not in May (1977). Although Hintikka (1974; 1979a) argued that the phenomenon of BQ in natural language can only be captured by a logic of a higher order than FOPC, it is clear from the discussion of the previous section that this is true only if the quantifiers involved meet Barwise's definition for essential BQ. Nevertheless, as soon as May (1985) incorporated branching quantifiers into his Scope Principle as one of the possible scope interpretations, the Scope Principle plus the QR at LF as a whole has acquired an expressive power higher than FOPC. However, there still seems to be quite some technically dubious points with regard to May's treatment. I will use Hintikka's example (14) as a testing case, in spite of its being an inessential case of BQ, because it is the one which May (1985) used in his discussion. Any points reached in the following discussion should, in this context, apply to the essential BQ cases as well.

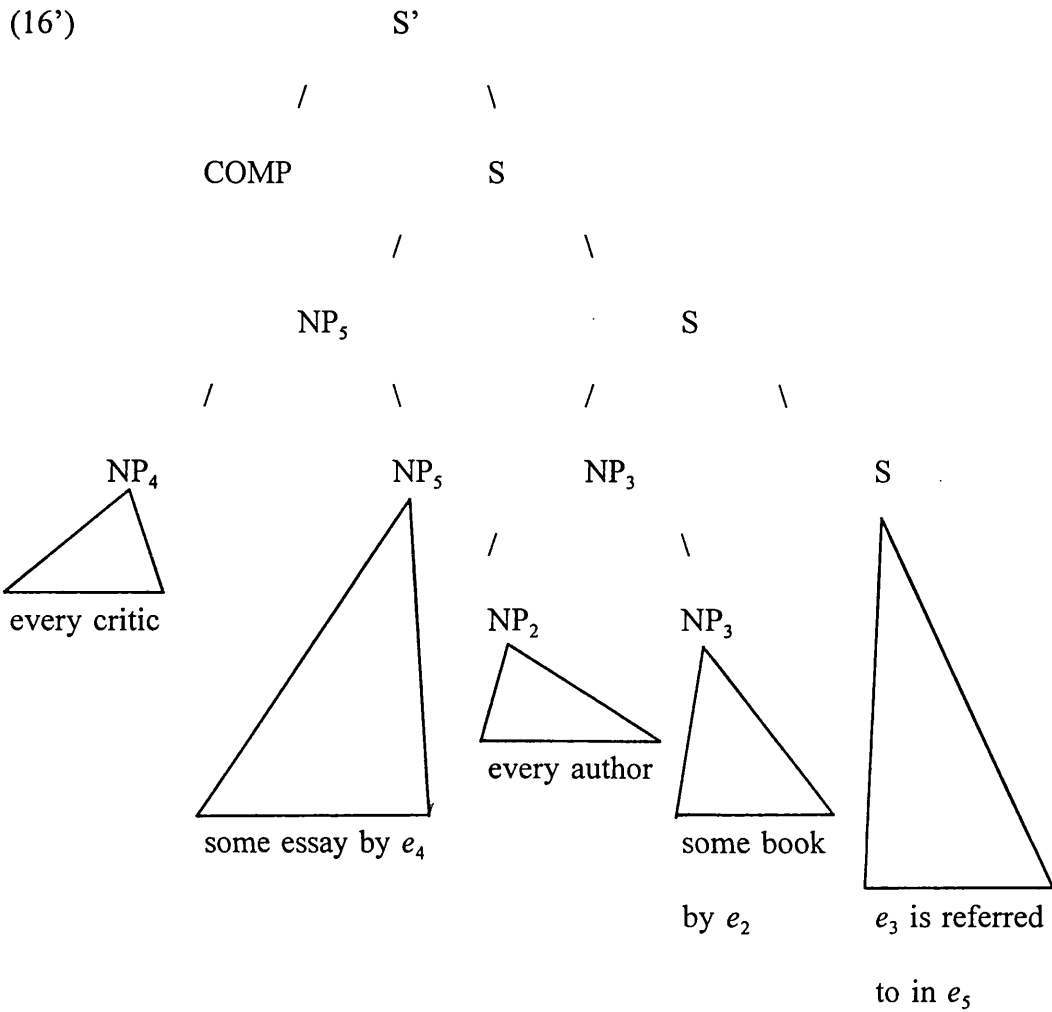
Let's look at the complex cases first. Recall that the Scope Principle tells us that any two operators (i.e. phrases in A-bar positions at LF) in a Σ -sequence can assume any forms of scope relation to each other, viz. one can be dependent on the other, or vice versa, or they can be independent to each other. It is thus possible to capture the BQ interpretation of (26) by letting the two quantifiers be independent of each other, while two other interpretations, by which either one of the quantifiers takes the wide scope, can also be obtained.²⁷

²⁷ May (1985) admitted that his approach could not cover the incomplete group reading (i.e. the cumulative reading, or the weak symmetric reading).

- (26) Three directors have made five movies.
- a. Three directors have each made five movies.
[*five movies* depends on *three directors*, i.e. 3 directors, 15 movies]
 - b. Each of the five movies have been made by three different directors.
[*three directors* depends on *five movies*, i.e. 5 movies, 15 directors]
 - c. Three directors as a group have made five movies together.
[the BQ reading(the complete group reading), i.e. 3 directors, 5 movies]

With regard to the cases involving four or more quantifiers, the same principle seems to be applicable. Thus for May, example (16) involves a complex Σ -sequence consisting of two pairs of quantifiers each of which is a Σ -sequence in itself. Its LF-representation is given as (16'):

- (16) Some book by every author is referred to in some essay by every critic.



In (16'), both NP₅ and NP₃ are in A-bar positions. Let's call {NP₃, NP₅} Σ -sequence 1, or Σ_1 for short. {NP₄, NP₅} forms Σ_2 , in which NP₄ is in an A-bar position because, through inverse linking, it is adjoined to NP₅, which is already in an A-bar position. Similarly, {NP₂, NP₃} forms Σ_3 .

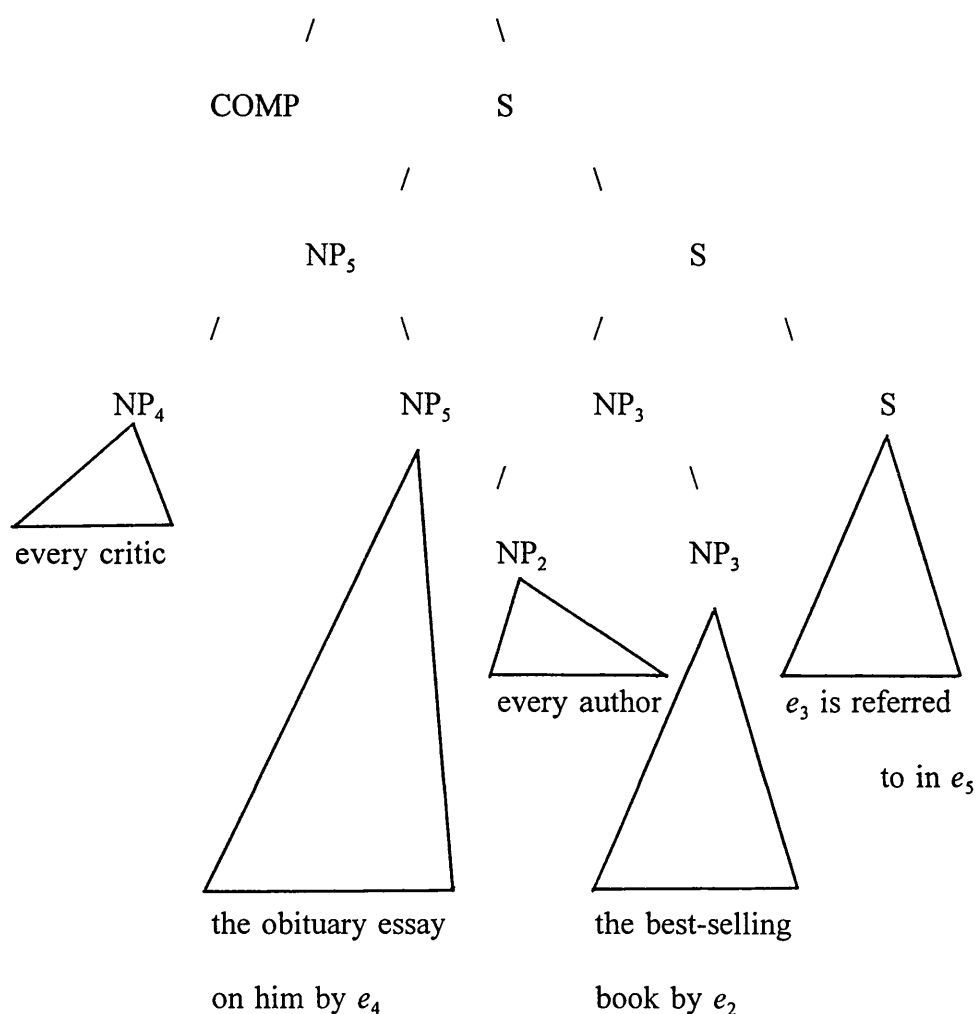
Now in terms of the interpretation intended by (16), the quantifiers in Σ_1 should be independent of each other. That is, NP₃ and NP₅ should branch. Σ_2 and Σ_3 should each constitute a dependent sequence according to the order represented in (16'). By the Scope Principle, given the LF-representation (16'), the above

interpretation can be derived successfully. Likewise, the BQ interpretation of all the other examples from (14) to (27) can be correctly derived, although the syntactic representations of some of them remain an open issue.

However, it is the dependent interpretation of the complex cases which seems to me to cause some technical difficulties. Suppose we have a structure similar to (16') yet involving dependency in a linear fashion, like (56)(from Hintikka 1974), with its representation given as (56'):

- (56) The best-selling book by every author is referred to in the obituary essay on him by every critic.

S'



In (56'), the lower NP₅ in Σ_2 should be dependent on both NP₄ in its own Σ -sequence and NP₂ in Σ_3 . May argued that this is also allowed by the Scope Principle, if we allow the higher NP₅ to be dependent on the higher NP₃, both in Σ_1 . To me, this is a dubious solution. The correct interpretation, when represented by indices of dependency, will assume the following form:²⁸

²⁸ Superscripts as category types; parenthesized subscripts as elements depended on.

$$(57) \quad \langle \text{NP}_2, \text{NP}_{3(\text{NP}_2)} \rangle^{\text{NP}_3-\Sigma_3} \dots \langle \text{NP}_4, \text{NP}_{5(\text{NP}_2, \text{NP}_4)} \rangle^{\text{NP}_5-\Sigma_2}$$

which is also what May meant to represent. But by the Scope Principle, what we *can* directly derive from (16') is actually (58):

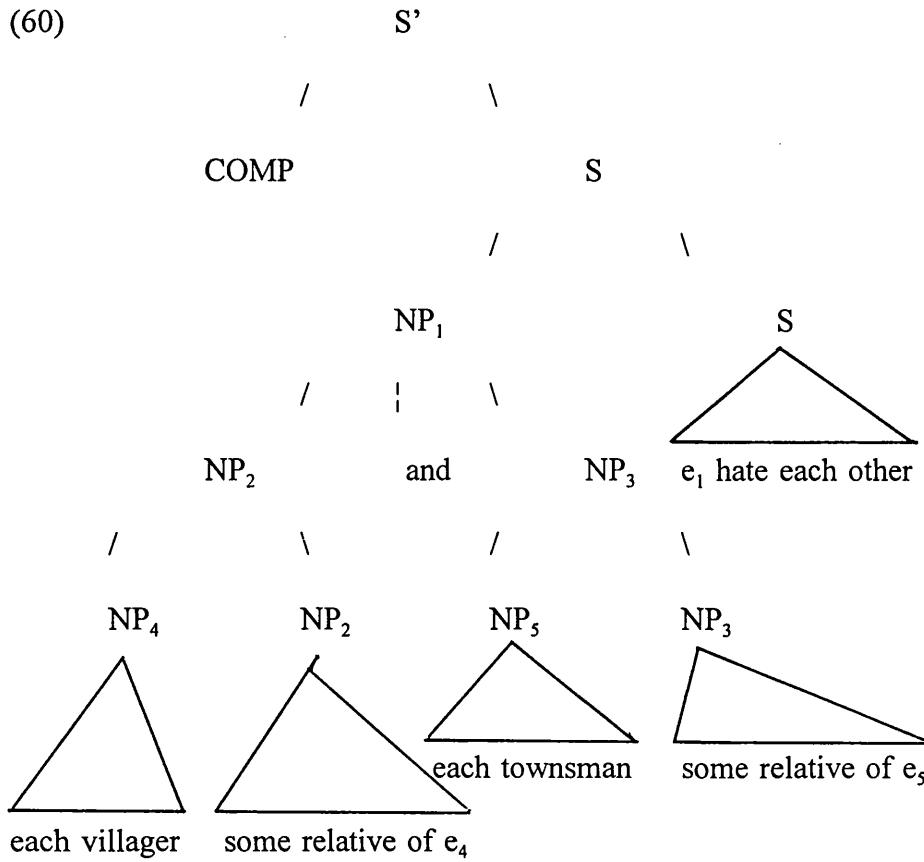
$$(58) \quad \langle \text{NP}_2, \text{NP}_{3(\text{NP}_2)} \rangle^{\text{NP}_3-\Sigma_3} \dots \langle \text{NP}_4, \text{NP}_{5(\text{NP}_4)} \rangle^{\text{NP}_5-\Sigma_2}_{(\text{NP}_3-\Sigma_3)}$$

which does not specify the dependent relationship between the lower NP_5 and NP_2 . We can probably get round to this difficulty by pointing out the fact that NP_5 can still be dependent on NP_2 through transitivity, because Σ_2 is dependent on Σ_3 . However, I do not see any semantic motivation to invoke such a dependency -- it doesn't make much sense to say that Σ_2 , *as a combined single unit*, is dependent on Σ_3 , *as another combined single unit*; if we take the LF-representation as the direct input to semantic interpretation and so long as we believe in the compositional nature of semantic interpretation. We might still make it work by arguing that, from a logical point of view, if Σ_2 is dependent on Σ_3 , what makes sense is only the dependency between NP_5 and the lower NP_2 through transitivity. After all, NP_5 has already established its dependency with NP_4 within its own Σ -sequence; and NP_4 , as a universal quantifier, does not depend on any other quantifier anyhow. But this argument will only hold if the members of Σ_1 , i.e. the higher NP_3 and NP_5 , are not taken as combined units, the opposite of which is what an LF-representation seems to convey. I can certainly appreciate the point of having hierarchically-structured representations, but what we need here is in fact a mechanism to merge the two Σ -sequences so that they form one single sequence, not one super sequence with two conjoined sub-sequences.

In his treatment of the *inessential branching* originally given in Barwise (1979), May adopted a technicality that can be turned to support my arguments. Recall that Barwise pointed out that (14) can also have a weaker reading, in which the choice of the value of each existential quantifier not only depends on the universal quantifier in its own branch but also on the one in the other branch, as shown in (59):

$$(59) \quad \begin{array}{ccc} \forall x & \leftarrow \cdots & \exists y \\ & \swarrow & \searrow \\ & \forall z & \leftarrow \cdots & \exists w \end{array} \quad \left. \vphantom{\begin{array}{ccc} \forall x & \leftarrow \cdots & \exists y \\ & \swarrow & \searrow \\ & \forall z & \leftarrow \cdots & \exists w \end{array}} \right\} P(x, y, z, w)$$

In this construal, a possible situation can be such that each villager is paired with a unique townsman and vice versa, neither hating the other and only these pairs of people's relatives hate each other. (14), with (59) as an interpretation, can also be regarded as forming complex Σ -sequences like (16'): each conjunct forms a sub- Σ -sequence, and the two conjuncts form one more Σ -sequence:



We have thus three Σ -sequences: $\Sigma_1 = \{NP_2, NP_3\}$, $\Sigma_2 = \{NP_4, NP_2\}$, and $\Sigma_3 = \{NP_5, NP_3\}$. To arrive at the intended interpretation, Σ_1 should allow its members to branch; the lower NP_2 should be dependent on both NP_4 and NP_5 , and the lower NP_3 , on NP_4 and NP_5 as well. May argued that we can allow inter-branch connections as a free option of interpretation, as the Scope Principle says nothing about this dependency in a Σ -sequence. This gives us (59), which is equivalent to the linear, FOPC representation (61):

$$(61) \quad \forall x \forall z \exists y \exists w P(x, y, z, w)$$

To me, inter-branch connections are more than a free option of choice of

dependency. To allow this type of dependency will considerably weaken any arguments motivating the treatment of the linear dependency of the members of Σ_1 in the previous case, i.e. (16'). What is the point of constructing dependency via Σ -sequences, if the free option of interpretation for inter-branching cases is available after all? Given that the two groups of quantifiers in Σ_1 of (16') do not reflect the right mode of dependency when they are construed in a linear fashion, we should certainly not allow them to branch either -- that would give us a different reading. At the level of Σ_1 in (16') and (60), only BQ cases get an adequate interpretation, not the linear ones. For these complex cases where four or more quantifiers are involved, the linearly-dependent cases need a representation which merges the two sub- Σ -sequences, and the choice of dependency is made by free choice of dependency, not by following the Scope Principle.²⁹ On the other hand, why shouldn't cases of inter-branch quantification be covered by May's Scope Principle? As shown by its first-order equivalent (59), it is just a simple case of multiple quantification. If the Scope Principle has zero explanatory power over (59) and at the same time turns out to be unsatisfactory with regard to (56), it seems clear that May's approach simply cannot handle adequately multiple quantification in general, when linear interpretation is called for.

May's offered solution to (60) suffers from one more flaw. If inter-branch connections are interpreted as a free option for the QNP's in their choices of dependency, as May suggested, then why can't we let one existentially quantified QNP

²⁹ This *free* choice of dependency is actually constrained by many important factors relating to word order, domain of inference, and nature of arbitrary individuals concerned, which will be explored in detail in the following chapters.

depend on another existentially quantified QNP ? Indeed, why can't we let them depend on each other? That is, in (60), why can't we let NP_2 depend on NP_3 ? Or vice versa?

It might be tempting to set off the above criticism against the LF approach by re-introducing the rule of Absorption which May (1985) proposed when dealing with the Bach-Peters sentences:

Absorption:

Absorption takes the structures in which one NP immediately c-commands another NP, and derives structures in which they form something like a conjoined constituent:

... $[NP_i [NP_j \dots \rightarrow \dots [NP_i NP_j]_i]_j \dots$

May's purpose in introducing the above rule was to turn asymmetrically c-commanding constituents into symmetrically c-commanding ones. As this role can now be played by the Scope Principle, May did not think it necessary to keep Absorption anymore.

Given our present concern of merging two c-commanding constituents, Absorption seems to provide a good solution. After the application of Absorption, Σ_1 will be converted into a conjoined constituent, thereby allowing indefinites to make choices of dependency at this level. But the immediate adverse effect is that this move will also destroy the structural representation of the BQ cases, unless we make further

amendments by stating the circumstances under which Absorption can apply (which should be only restricted to the dependent cases). A further disadvantage is that through QR, the resulting Σ -sequences are reversely linked, in terms of the relative position of subject and object. To convert them into conjoined constituents by Absorption would lead to the situation in which many dependent interpretations are constructed through inverse (contra-linear) dependency, mixing up with some linear cases of dependency. Take (56') as an example, the lower NP_5 has to depend on NP_4 , to its left, and on NP_2 , to its right. The order of such dependencies is unspecified, nor is its directionality.

4. Branching Quantifiers and the Scope of Standard Quantifiers

In this section, I will extend the points made by Hintikka (1974) and Liu (1990) that the BQ analysis has effects on the studies of the scope construals of standard quantifiers (in FOPC) in simple structures of quantification as well. I will put forward a strong thesis that the BQ analysis is indispensable even for these cases, which have always been considered to be cases that are equivalent to FOPC representations.

Among the logical forms of BQ structures in logic given by Hintikka (1974) and cited here as (8) to (11), (8) involves only two quantifiers, one existential and one universal, which are the only two quantifiers in FOPC. With the BQ analysis, we can now assign (8) to (1) and (2) as well, as a possible interpretation. For convenience of

discussion, I give the relevant cases again with new numbers:

$$(62) \quad \begin{array}{l} (\exists x) \\ \quad \quad \quad \left. \vphantom{\begin{array}{l} (\exists x) \\ (\forall y) \end{array}} \right\} F(x, y) \\ (\forall y) \end{array}$$

(63) Every student admires some professor.

a. $(\forall x, \text{student } x) (\exists y, \text{professor } y) \text{Admire}(x, y)$

b. $(\exists y, \text{professor } y) (\forall x, \text{student } x) \text{Admire}(x, y)$

c. $\begin{array}{l} \text{every student}_x \\ \quad \quad \quad \left. \vphantom{\text{every student}_x} \right\} \text{Admire}(x, y) \\ \text{some professor}_y \end{array}$

(64) Some student admires every professor.

a. $(\exists x, \text{student } x) (\forall y, \text{professor } y) \text{Admire}(x, y)$

b. $(\forall y, \text{professor } y) (\exists x, \text{student } x) \text{Admire}(x, y)$

c. $\begin{array}{l} \text{some student}_x \\ \quad \quad \quad \left. \vphantom{\text{some student}_x} \right\} \text{Admire}(x, y) \\ \text{every professor}_y \end{array}$

(63c) means that every student admires ^{and the} ~~one~~ [^] same professor, i.e., the value of *some professor* is independent of the value of *every student*. This interpretation is in fact equivalent to the object wide scope construal (63b). Likewise, the BQ representation of (64c) is equal to the subject wide scope construal (64a). That is why May (1985) thought (62) is not of much interest, as it is equivalent to some linear

structure in FOPC. Hintikka (1974), Liu (1990), and especially Barwise (1979) also pointed out this equivalence.

I will unfold my arguments in steps. We start by examining the manner of dependency in the simpler structures of quantification, using as examples (63) and (64).

A matter of definition comes into focus immediately. In a sentence involving less than four standard quantifiers, if a quantifier falls within the scope of another, does it necessarily follow that the value of the former will be dependent on the latter? The way quantifier-scope is discussed in some works of syntax³⁰ gives one the impression that an affirmative answer to the above question is taken for granted. But this is not to be taken in an absolute sense. We look at the dependency relations exhibited in (63) and (64) in detail:

- (63') a. subj. wide scope: obj.dep.subj. + subj.indep.obj.
 b. obj. wide scope?: obj.indep.subj. + subj.indep.obj.

- (64') a. subj. wide scope?: subj.indep.obj. + obj.indep.subj.
 b. obj. wide scope: subj.dep.obj. + obj.indep.subj.

[subj.= subject; obj.= object; dep.= dependent; indep.= independent]

³⁰ Hintikka (1974), for example, put it like this: '... in first-order logic a quantifier which lies in the scope of another depends on the latter in the sense that the move[to be understood in terms of Game-Theoretic Semantics, cf. Chapter 3 of this thesis] connected with the former depends on that associated with the latter.'

In (63a), the subject takes the wide scope, and the object, being an existentially quantified phrase, depends on the universally quantified subject for its value. The subject here is of course not dependent on the object, for two reasons. One reason being that it is not within the scope of the object. The other reason will be discussed with regard to (63b). In (63b), the existential object takes the wide scope, which should be independent of the subject. But what is the dependency status of the universal subject? A scope-based approach, if one is taken in by its superficial form, would give one the wrong idea that the value of the universal subject should be dependent on the value of the existential object. But this does not make sense. In terms of the semantic interpretation of a universal quantifier in set theory, x ranges over the whole domain of the relevant set and in fact should not depend on any other quantifier, be it universal or existential, for its interpretation. It still makes sense to say that relative to another quantifier, say $\exists y$, $\forall x$ is within the scope of $\exists y$. But it simply states that $\forall x$ and the ensuing formula (which ought to contain at least one occurrence of the variable y), is a propositional function in y . No dependency follows in this case. In fact, so far as FOPC is concerned, so long as each variable is closed off (i.e. bound) by an operator and so long as each quantifier gets a proper semantic interpretation in terms of set theory, then everything is fine. Scope domain does not necessarily entail dependency. Dependency relations are made clear only in a logic of a higher order because, as May (1985) put it, FOPC 'lacks the ability to "comment" upon its own syntax'. In the same spirit, McCawley (1981) pointed out that 'when the existential quantifiers precede the universal quantifiers, the variables bound by the latter are not dependent on those bound by the former' (Unless, as McCawley noted, we have an existential quantifier binding a time variable or the existential quantifier being an

adverb of quantification. These are special cases in the logic of natural language which, given the right treatment, do not invalidate the above claim.

When considering the natural language cases on an empirical level, the above argument in pure logical considerations follows as well. Therefore, the domain of *everyone* does not seem to vary in (65) and (66), which makes sense if and only if *everyone* does not depend on the preceding quantifier. Otherwise, *everyone* in (65) would be understood as all men in the world minus the misanthrope, while in (66) it would be understood as all men in the world minus the two misanthropes.

(65) A misanthrope hates everyone in the world.

(66) Two misanthropes, who love each other, hate everyone in the world.

So for the universally quantified structures in (63a) and (64b) to be independent because they take the wide scope, this dependency property is trivial here. Universal quantifiers are by definition independent, whether they take wide scope or not and no matter in subject or in object positions. But for the existentially quantified phrases in (63b) and (64a), they are really the cases worth noting. These phrases can either be dependent or independent depending on whether they take narrow scope or wide scope but not depending on whether they are in subject or object positions.

Although scope-domain does not entail any fixed dependency relations, it seems that independent readings in sentences containing less than four standard quantifiers need not be specially marked, as they are equivalent to a linear scope-

domain representation/interpretation. This seems to be the case for English.

However, in Chinese, we find cases in which independent readings of existentially quantified phrases are not fully compatible with a linear scope-oriented interpretation. We have good reasons to argue that although Chinese does not allow objects to take wide scope at all, indefinites and numerals in both subject and object positions can have an independent reading.³¹ Let us look at some examples:³²

- (67) Měi gè rén mǎi le yì běn shū
 every CL man buy ASP one CL book

"Everyone bought a book."

(CL = classifier; ASP=aspect marker)

a. obj. dep. subj. + subj. indep. obj.

b. obj. indep. subj. + subj. indep. obj.

- (68) Yí gè rén mǎi le shūdiàn lǐ de měi běn shū
 one CL man buy ASP bookshop-in DE every CL book

"Someone bought every book in the bookshop."

a. subj. indep. obj. + obj. indep. subj.

³¹ A brief survey of the current GB studies on Chinese quantification and a detailed analysis of the relevant data is presented in Chapter 5, where a treatment of Chinese quantification in LDS_{NL} is also given.

³² I am aware that the data and the interpretation given here is under strong debate among people working on Chinese quantification. See Chapter 5 for detailed discussions.

b. *subj. dep. obj. + obj. indep. subj.

(DE = modifier marker)

(69) Liǎng gè lǎoshī gāi le liù fèn kǎojiàn
two CL teacher mark ASP six CL scripts

"Two teachers marked six scripts."

a. obj. dep. subj. : 2 teachers, 12 scripts

b. obj. indep. subj. : 2 teachers, 6 scripts

c. *subj. dep. obj. : 12 teachers, 6 scripts

Now we see the advantage of introducing the BQ analysis even in simple cases of quantification involving less than four standard quantifiers. It will give us a clearer picture of quantification in Chinese. Taking note of the fact that in Chinese, sentences with an existentially quantified phrase as the subject followed by a universal one in object position like (68) does not exhibit scope ambiguity, most studies claim that no ambiguity exists in Chinese quantification, at least when adjuncts of various types do not come into play. As (67b) entails (67a), due to the quantifier rule given below as (70), (67) is not rated as a safe test of ambiguity but as only a type similarity of the indefinite whose value depends on the universal quantifier. So (68) is left as the usual safe test. Since it is not ambiguous and since it does not have object taking wide scope, (67) is, by analogy, taken as unambiguous as well.

(70) $(\exists x)(\forall y)\varphi(x, y) \Rightarrow (\forall y)(\exists x)\varphi(x, y)$

But the supressing of (67b) as a valid interpretation can give rise to a series of counter-intuitive results. While leaving the detailed analysis and argumentation to Chapter 5, I will here simply point out that the admission of the BQ reading will lead to the acknowledgement of (67) as being ambiguous without committing us to the impossible object-wide-scope reading of the sentence.

The above discussion on Chinese quantification has yet one more moral for us to draw: if no object-wide-scope reading can be found in Chinese, and if independent reading of a quantifier w.r.t. another is always possible either by definition(as in the case of universal quantifiers) or by choice(indefinites), then subject-taking-wide-scope needs not be marked out any more. In cases where a universal quantifier takes the subject position and an existential, the object position, then of course it is subject-wide-scope reading if no independence of value is given to the interpretation of the indefinite. A universal quantifier in object position does not care anyway which is in the wide scope and which the narrow scope. This conclusion can be derived from Chinese because the language does not have a subject-narrow-scope interpretation at all.

There is one more theoretical issue to be discussed. If we have a BQ interpretation in which quantifiers are independently interpreted, is interaction of quantifier scope involved? If not, then syntacticians might argue that a scope-domain approach does not have to have anything to say about an interpretation where no scopes interact. May (1985) did not think scope interaction takes place in the BQ cases. I think any answer to this question will inevitably lead to trivial consequences.

Suppose we argue, in the first place, that interaction of scope always involves one quantifier being dependent on the other, then the BQ case obviously does not involve scope interaction. But the BQ case, in the simple structures of quantification, is shown to be equivalent to a first-order linear interpretation, which *is* unanimously cited as a case of scope interaction. So the same example with the same construal both involves and does not involve scope interaction. To put the story in another way, if we have a logical form with a linear interpretation where a universal quantifier follows an existential quantifier, again a case of scope interaction by conventional standards, then the same case is convertible into the BQ reading, because the universal quantifier does not depend on anything and the existential quantifier has nothing wider in scope than itself to depend on. Other considerations seem to support this argument as well. If we have a structural case in which both the quantifiers are universal or both are existential, then the scope domain of each quantifier can commute with that of the other. In these cases, again they are no different from a BQ construal, and again they seem at once to confirm and refute the scope-interaction claim. We may be forced to conclude that only representations where a universal quantifier is followed by an existential one involves scope interaction. But this only constitutes a third of the 'standard' interaction cases and would make the study of scope interaction uninteresting, because we can no longer give a complete account of scope ambiguity by looking exclusively at these limited cases of quantification. The thesis can be demonstrated one more time. By a rule of quantification, we know that an existential quantifier followed by a universal one in a logical representation entails the reverse scope representation because of possible type similarities. If we take the former to be a non-interaction case due to its equivalence to the BQ cases, we have to conclude that

a non-interaction case entails an interaction interpretation, again a paradox. Empirically, it also seems to me that the BQ cases are very different from the cases where clause boundaries make the scope-interaction impossible, for example, (71):

- (71) The football scout, who discovered every star for the Spurs, still believes that some young talents are to be found in every season.

Obviously, the universal quantifier in the non-restrictive clause does not have scope interaction with the existential quantifier in the subordinate clause. While (71) gives a case of true non-interaction, the BQ cases do involve interaction. In the case of (62), it is a 'same-per story', to use the term given by Emms (1992a), i.e. all the members of the set specified by the universal quantifier interact with the identical individual(s) specified by another quantifier (existential quantifier in our context). In the cases of BQ discussed in Section 2, all should involve interaction of scope.

The dilemma we encountered when discussing the (non)-interaction of quantifier-scope with regard to BQ is not accidental. Recall that when we introduced the BQ reading, we actually extended the descriptive logic to a higher order. As FOPC cannot 'comment' on its own syntax, it cannot therefore represent BQ in its full complexity. Likewise, the technicalities of FOPC such as scope domain and scope-interaction, cannot be employed to discuss representations of a higher logic either, because of the lack of expressive power of the former.

This is a convenient place for me to make a digression to compare the

conclusions hitherto reached with the study of Gil (1982). Based on data in English, Dutch, and Hebrew, Gil argued that for a sentence like (72) involving two numeric expressions, there ought to be four interpretations: (i) object dependent on subject; (ii) subject dependent on object;³³ (iii) subject and object independent of each other, with each member of the set denoted by the subject interacting with each member of the set denoted by the object and vice versa; (iv) subject and object independent of each other, with each member of the set denoted by the subject interacting with one member of the set denoted by the object and vice versa. (i) and (ii) are the scope-dependent readings, which Gil termed *asymmetric reading*. (iii) and (iv) are termed by Gil as *symmetric reading*,³⁴ with (iii) being the *strong symmetric reading*³⁵ and (iv) being the *weak symmetric reading*.³⁶

(72) Three boys saw two girls.

Gil further argued that many treatments cannot offer an adequate representation to all the four readings. FOPC could only capture (i) and (ii). BQ theory could not distinguish between (iii) and (iv). And Montague and Keenan-Faltz logical forms were shown to be (representationally) equivalent to FOPC. Gil thought that the only adequate representation was quantification over sets such as the one proposed by Kempson & Cormack (1981):

³³ Note that this reading is not available for Chinese.

³⁴ Also termed the *group reading*, or the *branching reading*.

³⁵ Or the complete group reading.

³⁶ Or incomplete group reading.

- (72') a. $\exists B_3 \forall b \in B_3 \exists G_2 \forall g \in G_2 S(b, g)$
 b. $\exists G_2 \forall g \in G_2 \exists B_3 \forall b \in B_3 S(b, g)$
 c. $\exists B_3 \exists G_2 \forall b \in B_3 \forall g \in G_2 S(b, g)$
 d. $\exists B_3 \exists G_2 [\forall b \in B_3 \exists g \in G_2 S(b, g) \ \& \ \forall g \in G_2 \exists b \in B_3 S(b, g)]$

In (72'), B_3 stands for a set variable ranging over the set BOY with a cardinality of 3, and G_2 stands for a set variable ranging over the set GIRL with a cardinality of 2. The informal paraphrases are as follows:

- (72'') a. There exists a set B of three boys such that for every $b, b \in B_3$, there is a set G of two girls such that for every $g, g \in G_2$, b saw g . (G_2 depends on B_3)
 b. The reverse of (a), i.e. B_3 depends on G_2 .
 c. There exists a set B of three boys and a set G of two girls such that for every $b, b \in B_3$ and for every $g, g \in G_2$, b saw g . (strong symmetric reading: each boy saw every girl and vice verse).
 d. There exists a set B of three boys and a set G of two girls such that for every $b, b \in B_3$, there is a $g, g \in G_2$ such that b saw g and for every $g, g \in G_2$, there is a $b, b \in B_3$ such that b saw g . (weak symmetric reading: each boy saw one girl and each girl was seen by a boy).

Note here that (72'c, d) correspond exactly to the two definitions of Branching Quantifiers. (72'c) is equivalent to (39) and (72'd) to (37). This justifies Sher's definition of independent (branching) quantification (37) and Barwise's definition of

complex (branching) quantification (39).

Note also that quantification over sets, though first-order in appearance, in fact exceeds FOPC. Without giving detailed proofs, I simply remark that quantification over sets already has the expressive power of second-order logic.

Gil (1982) was right in his observation that only quantification over sets can supply the distinct representations for the four possible readings in (72). But this does not mean that the other approaches could not offer a correct interpretation of the readings. FOPC does not give explicit representation of dependency, but it can make use of the semantic interpretive device of Skolemization to reach the correct interpretation, at least for (72 a-c). Although BQ theory cannot give distinct representations to (72c,d), it can choose to interpret the relevant structures according to either of its two definitions, (37) or (39), thereby reaching the incomplete or the complete group readings. As to treatments in terms of Montague semantics, it is also possible to reformulate Cooper's NP-Storage and NP-Retrieval Rules to incorporate the cases of (72c,d).³⁷ However, Gil's quest for a clear and distinct representation of the logical forms of multiple quantification is still educational. In the first place, the LDS approach will try to create a parsed syntactic representation prior to the model-theoretic interpretations. We therefore will also try to see to what extent distinct representation is possible. Second, Gil at least showed us what are the available readings that any theory ought to be able to handle. We will compare our treatments

³⁷ Cooper (1983) did advocate for a simplification of syntactic representation and shift the burden of disambiguation to semantic interpretive rules. Cf. May (1986) for comments.

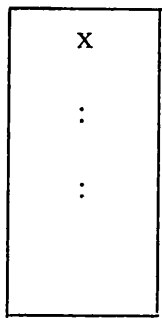
with Gil's (72') at the end of Chapter 4. In fact, the treatment of numeric expressions in LDS has close links to the representations of (72'). Third, Gil pointed out that even quantification over the sets is not adequate because it failed to reveal the varying degrees of preference over the readings of (72). I think no answers to such a question can be provided without a modelling of the construction of the dependency relations involved in (72). In this sense, the LDS treatment to quantification does provide a dynamic, parsing-as-deduction model in which Gil's concern can be further investigated.³⁸

5. On the Heterogeneity of the Notion of *Scope* in Natural Language

The discussion so far indicates that the concept of scope in natural language does not seem to be a homogeneous one. On the one hand, there is the notion of scope related to a one-place operator. In this case, the operator takes everything in the formula to its right within its scope, i.e. everything from the point of its introduction to the end of the formula. Examples of such operators are: (I) expressions related to the universal quantifier \forall (e.g. *everything*, *everyone*...), which in LDS_{NL} will be treated as free variables,³⁹ in the form of

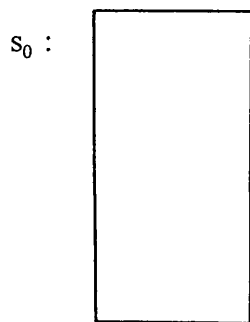
³⁸ I come to Gil (1982) again in Chapter 5, when I discuss the interpretation of Chinese data.

³⁹ Detailed introduction to LDS_{NL} is given in the next chapter.

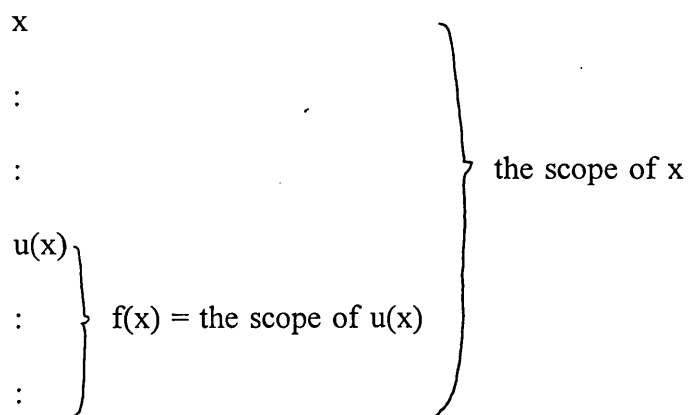


(where the box demarcates a local proof domain in which x is to be free, i.e. independent)

(II) expressions related to time, world, 'aboutness' topic, etc. (e.g. *yesterday*, *In Japan...*, *Talking about linguistics*, ...), which in LDS_{NL} will be represented as database labels (e.g. s_0, s_1, s_2, \dots) of the form



On the other hand, as indefinites are not genuine operators, the scope of an indefinite is unique in the sense that it is a function of the proof-domain of the element on which the indefinite is dependent. For example, we have



The heterogeneity of the concept of scope in natural language can be demonstrated with regard to another case: the scope of internal negation. In logic, negation is expressed through the logical operator \neg , which has scope over the formula to its right. But in natural language, the scope of a negative word is much more complicated. According to the studies made by Horn (1989) and Hofmann (1993), negation in natural language can be divided into two types: external logical negation and narrow or focused negation. The behaviour of the former is not different from the logical operator \neg and in English is usually given the form "It is not ... that ...", or by stressing the negation word *not* as shown in (73) and (74), in which *not* denies the whole sentence. That is, *not* has scope over the whole sentence.

(73) It is not true that the king of France is bald.

(74) The king of France is not\ bald.

(\ stands for stress)

So, external negation behaves like the one-place operators and are also to be represented by database labels. By negating a proposition, an external negator is actually negating a conjunction of the propositions related to the original proposition,

$$\neg(P \wedge Q \wedge R \wedge \dots)^{40}$$

⁴⁰ A proposition may entail a set of propositions, as originally observed by Russell. For example, (i) can be understood as entailing a conjunction of propositions (ii) - (iv):

- (i) The present king of France is bald.
- (ii) There exists an individual x.
- (iii) x is the king of France.
- (iv) x is bald.

Narrow/focused negation behaves quite differently from logical/external negation. It assumes a negative form which neither prefixes a sentence with "It is not ... that ..." nor stresses the negation word. The scope of the negation falls on the part that is stressed or focused. That is, any part of the sentence other than the negation word. Therefore, the scope of the negation is not the formula/constituent to its right. Rather, it is only attracted to the focused part, either to its right or to its left, as shown by the following array of cases:

- (75) John didn't call his brother yesterday\
(He called him the day before yesterday.)
- (76) John didn't call his brother\ yesterday.
(He called his wife.)
- (77) John didn't call his\ brother yesterday.
(He called Peter's brother.)
- (78) John didn't call\ his brother yesterday.
(He e-mailed his brother.)
- (79) John did\n't call his brother yesterday.
(It is not true that ... = logical negation.)
- (80) John\ didn't call his brother yesterday.
(His brother called him.)
- (81) I don't think John will come\
(I think he will not come.)
- (82) I don't\ think John will come.
(It is not true that ...)

(83) I don't think\ John will come.

(I do not "think" that -- "think" is not the exact word. Also = (81).)

So we have a different notion of scope related to focused negation. It simply chooses the focused bit to be within its domain and the exact position of the negation word usually does not indicate the boundary of its scope.⁴¹

By now, we can conclude that the behaviour of scope is not homogeneous in natural language interpretation and it is also inexplicit in dependency constructions. We see it as inadequate and imprecise for our study of quantification in natural language. This is in accord with Hintikka's claim when discussing the BQ quantifiers, that 'the concept of scope is not alone sufficient to unravel the interplay of quantifiers in English'.

In our novel attempt in the search for more precise notions for the study of the logical properties of natural language, we rely more on the notion of dependency, to be constructed according to the individual nature of quantifiers plus any structural and inferential constraints. We hope to use dependency relations to capture not only what

⁴¹ In Chinese, the negation word often appears immediately before the negated formula, making the scope of negation more logical, as shown by Y.R. Chao (1955, 1959). But there are also cases in which the negation word has a scope to its left, making it necessary to raise the negation word to a higher clause to obtain the right interpretation, e.g.

(i) wǒ bú rènwéi tā huì lái
 I not think he will come
 "I don't think he will come."

Moreover, focused negation is also used in Chinese to achieve contrastive effects.

a scope-based approach can account for, but also what the latter cannot deal with satisfactorily. As I will show in the later chapters, such a move no longer treats quantifiers as operators. Instead, it directly represents QNP's as meta-variables, to be instantiated in the process of labelled deduction. Gabbay & Kempson (1992b) reached the similar stand of dispensing with operators through a different route. They wanted to do away with the operators because they found the notion *operator* to be generating a proliferation of conceptual ambiguities and complexities that lacked a unified solution. So G&K reached this conclusion in a cut-the-Gordian-Knot spirit.

2

Labelled Deductive Systems for Natural Language

0. Preamble

Attempts at explaining linguistic facts almost always boil down to questions of proper representation and interpretation. By committing ourselves to the meta-logical discipline of Labelled Deductive Systems as applied to natural language understanding (LDS_{NL} for short), we hope to spell out the lexically under-determined natural language content with the aid of a powerful set of logical apparatus that comes at relatively little cost, for the framework is not only a theory for natural language, but primarily a theory of logic and computation. Within this adopted framework, we also hope to be able to achieve greater explanatory adequacy in analyzing linguistic phenomena. The more specific task in this thesis is to show how the LDS approach can give a unitary account of the quantificational properties of natural language in a way that makes it possible to cover all the possible manners of scope construal as well as providing a principled account of cross-linguistic differences between English and Chinese. This chapter outlines the basics of LDS_{NL}. My aim is twofold: A. to give a straightforward presentation of the system at work in natural language understanding; B. to supplement this working knowledge of LDS for natural language with knowledge

of its logical motivations, its philosophical backgrounds, its correlations with and its many departures from the standard practices of model-theoretic semantics. While examining the logical basis of the LDS_{NL} , the relationship between the purely logical considerations of LDS and their linguistic relevance in LDS_{NL} will be explored in detail. To fulfill this goal, I present in Section 2 an introduction to LDS in pure logic studies. Assuming knowledge of first-order predicate logic, I will trace some logic studies leading to the important underpinnings of LDS: formulae as types and labelled deduction. Turning then to LDS_{NL} , I will bring out some discrepancies between the LDS_{NL} ontology of logical types and the standard treatments in formal semantics. Finally, I draw up a sketchy outline of the LDS_{NL} enterprise, discussing its conceptions of language and linguistic theory and listing some research results and focal issues. While these theoretical examinations are by no means exhaustive nor constructive, I hope to cast the LDS_{NL} approach in a broader context so that its technicalities will be shown to be well-motivated and its results better appreciated. Detailed treatments of quantification in this model will be presented in the following chapters, again with much discussions on its logical underpinnings and linguistic consequences.

1. The Labelling Algebra -- A Common Sense View

An entity or object of any sort can be further described in various ways. One possible way to add accumulated information onto some entity is in terms of labels. Mr. Chris Patten, as we know, is the present Governor of Hong Kong. Taking Mr. Patten as an individual, we can use *Governor of HK* as a label to further describe him.

Thus in (1), what appears to the left of the colon is the label; to the right, the object of description. Putting a meta-box around it, we obtain a constructed database:

(1)

Governor of HK : Chris Patten

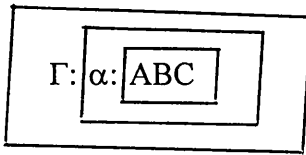
Further information can be added to this database in the form of labels in a recursive way, by taking as the basic unit the meta-box (1), and the databases constructed at each stage henceforth. Again taking Mr. Patten as an example, we also know that he started his present office in 1992, that he used to be the chairman of the Conservative Party until 1992, that he used to study at Oxford, etc. All these can be represented in a database with multiply structured labels, as in (2):

(2)

Oxford:	<table border="1"> <tr> <td>Tory Chair₍₋₁₉₉₂₎:</td> <td> <table border="1"> <tr> <td>G.HK₍₁₉₉₂₊₎:</td> <td>C. Patten</td> </tr> </table> </td> </tr> </table>	Tory Chair ₍₋₁₉₉₂₎ :	<table border="1"> <tr> <td>G.HK₍₁₉₉₂₊₎:</td> <td>C. Patten</td> </tr> </table>	G.HK ₍₁₉₉₂₊₎ :	C. Patten
Tory Chair ₍₋₁₉₉₂₎ :	<table border="1"> <tr> <td>G.HK₍₁₉₉₂₊₎:</td> <td>C. Patten</td> </tr> </table>	G.HK ₍₁₉₉₂₊₎ :	C. Patten		
G.HK ₍₁₉₉₂₊₎ :	C. Patten				

It is obvious that the labelling algebra can handle abstract symbols as well.

Thus (3) is another labelled database:

(3) 

Virtually anything can label and be labelled. It depends on what content we put into the algebraic system.

2. Labelled Deduction: Logical Considerations

2.1. Formulae as Types

The labelling algebra was proposed primarily to enrich proof systems in logic. According to Frege (1879), the now familiar assertion sign \vdash can in fact be broken down into two parts: the horizontal stroke and the vertical one. The horizontal stroke, as an operator of one arity, combines with a following formula signifying the content of such a formula. Frege called it the *content-stroke*.¹ Thus (4) means 'the proposition that A':

(4) $\text{——} A$

The vertical stroke is what Frege termed as the *judgment-stroke*. It combines

¹ We can distinguish this content sign from the negation sign by lengthening the horizontal stroke for the former, as done in Frege (1879).

with the whole formula in (4) to yield an assertion of A. Hence (5) means 'the judgment that (the proposition) A is true':

(5) $\vdash A$

But to say that A is true, we must have already assumed the existence of a proof of the proposition A. In view of the semantic commitment of (5), Frege claimed that 'the content of what follows the content-stroke must always be content of possible judgment.'

In the same spirit, Gabbay & de Queiroz (1993) made the following remark:

Contrary to the classical view, a proposition is not the same as a truth value. And in contrast to the traditional proof-theoretic account of propositions and inference rules, a logical inference is to be made from *judgment(s)* to *judgment*, and not from *proposition(s)* to *proposition*. Both premises and conclusions of inference rules are not *propositions* as in the usual case even in traditional natural deduction presentations of logics, but *judgments*. This seems to be a highly relevant refinement of the usual formalisation of mathematical procedures into rules of inference, such as e.g., natural deduction style à la Gentzen.

Given the traditional natural deduction presentation in a Gentzen style, a simple proof of &-introduction can assume the form of (6):

(6) A, B

A & B

But in the light of the above discussions, the proof should in fact take the form of (7):

(7) $\vdash A$ $\vdash B$

$\vdash A \& B$

Therefore, rules of inference operate on judgments as objects of deduction.² But we should not infer from the above conclusion that the notion of proposition will be simply subsumed by the notion of judgment. The notion of judgment applies not to propositions per se but to the process of establishing propositions. The relevance of judgments is its provision of the metalevel specifications of a logical inference. With this understanding of viewing formulae as judgments instead of mere propositions, there reached an important new conception of the definition of logical objects.³ The meaning of a logical constant is standardly defined in terms of its truth-

² Frege (1879) pointed out that while judgment cannot be made on an idea of an object (as in contrast to propositions), they can be made on circumstance of there being an object. Hence the formulae are not restricted to propositions, so long as entities are interpreted in the existential sense.

³ The contributors to this new understanding are, according to de Queiroz & Gabbay (1995), Gottlob Frege, Arend Heyting, Gerhard Gentzen, Michael Dummett, and Per Martin-Löf. Cf. de Queiroz & Gabbay (1995) for detailed references.

conditions. But taking formulae as judgments, it is possible for us to define a constant in terms of its proof conditions. De Queiroz & Gabbay (1995) quoted an observation by Dummett: "The meaning of each [logical] constant is to be given by specifying, for any sentence in which that constant is the main operator, what is to count as a proof of that sentence ..." One way to achieve this new manner of evaluation of logical constants is to use labels.

It is possible to use a labelling mechanism to enrich a formula so as to construct a formal representation of a judgment (of a formula) together with its justification (in the form of labels). According to Gabbay & de Queiroz (1992), by ' $a \in A$ ', we mean ' A is true because of a '. So a is a label which acts as a 'witness' to the judgment of the proposition A . Treating ' $a \in A$ ' as one unit, we now have metalevel features built into the object language of logical deduction. Here the object language is the proposition A , which according to Frege entails the implicit metalevel feature -- the judgment of A when serving as a premiss (i.e. $\vdash A$), while a is the explicitly represented metalevel feature -- the justification for the judgment that A is true.

There is, on the other hand, a different motive for using labels to supply metalevel features to the object language. Curry (1934), Curry & Feys (1958), Howard (1980), and Tait (1965, 1967) proposed to identify propositions with types of their proofs. We now move on to an introduction to the concept of logical types and type theory.

As an informal definition, type theory sets out with some designated entities or values as prime terms and recursively constructs formulae using these prime terms, aided by logical connectives, and rules of abstraction and application. The resulting formulae are therefore manifestations of types of proof construction. Hence the identification of formulae(propositions) with types. Here we shall concentrate on type theory in systems of logic, leaving discussions on type theory in formal semantics of natural language to later sections.

In Gabbay & de Queiroz (1993), at least four type systems were discussed, each one differing from the other in technical details and each named after its proponent: Curry's, Howard's, Girard's, and Martin-Löf's. As we are not concerned with logical consequences derived from the adoption of one particular system, I simply quote here Girard's type system for the sake of illustration:⁴

First, *formulae* become *types*:

Types are defined starting from *atomic types* T_1, \dots, T_n , and *type variables* X, Y, Z, \dots by means of the following operations:

1. Atomic types T_1, \dots, T_n are types.
2. if U and V are types, then $U \rightarrow V$ is a type.
3. if V is a type, and X a type variable, then $\Pi X.V$ is a type. [Π is some

⁴ From (Girard: 1989), and Gabbay & de Queiroz (1993), with omissions.

form of abstractor.]

4. Nothing else is a type.

Second, '*proofs* become *terms*; more precisely, *a proof of A* (on the formula side) becomes *a term of type A* (which can be represented as labels)' (Girard 1989).

Here are some selected schemes for forming *terms*:

1. *variables*: x^T, y^T, z^T, \dots are terms of type T ,
2. *application*: tu is a term of type V , where t is of type $U \rightarrow V$ and u is of type U ,
3. *λ -abstraction*: $\lambda x^U . v$ is a term of type $U \rightarrow V$, where x^U is a variable of type U and v is of type V .
- ...

Definition of *abstraction* is important here because, as Gabbay & de Queiroz (1993) put it, 'the idea of reading a formula as a type ... is used to give a λ -calculus interpretation of an intuitionistic theorem,... [which] is a theorem if and only if, when read as a type, it can be shown to be non-empty using the rules of term-construction, namely *abstraction* and *application*.'

As a further explanation, it was Frege who originally pointed out that a formula is true(valid) if and only if a deduction of it can be constructed with a self-contained proof-construction. That is, the truth of the formula relies on no assumptions. Such formulae qualify themselves as theorems because they are true regardless of other

formulae being true. This leads to attempts to formulate rules in order to discharge assumptions in proof construction. One way to do this is to make use of the rule of \rightarrow -introduction, which puts back an assumption into the conclusion, thus withdrawing the assumption on which the conclusion originally depends. As a result, we have 'assumption implying conclusion', rather than the original 'arriving at a conclusion, given the assumption'. Another way to discharge assumptions is by λ -abstraction, which creates an abstractor to bind any variables occurring free in a formula, thus making the variable losing its own identity it used to have in the formula as an arbitrary name. Now the bound variable is no more than a place-holder, being locally bound by the operator/abstractor. Combining these two assumption-discharging methods, we use \rightarrow -introduction on the side of typed formulae, while using λ -abstraction on the labelling side.

This is related to what we said earlier that Curry and others gave a λ -calculus interpretation of an intuitionistic theorem. Curry discovered that the constructed \rightarrow -types turned out to be of exactly the same set as the set of axioms in intuitionistic logic.⁵ Gabbay & de Queiroz (1993) remarked that 'Within the propositions-are-types paradigm there is a correspondence between axioms of implication and \rightarrow -types which contain λ -terms as elements or proofs/constructions of the corresponding axioms. ... Our "raw data", so to speak, is made by the λ -abstraction rule rather than by the axioms. So, e.g., instead of saying that "it seems plausible to consider the following axiomatic systems as capturing the notion of relevance ...", we shall rather say

⁵ Note that in Hilbert's system of intuitionistic logic, the only logical constants are \forall , \exists , \rightarrow , and \dagger (the *false*) (Cf. Ramsay 1988 for an introduction). As formulae related to other connectives in a Gentzen system, e.g. \wedge , \vee , \neg can all be transformed into formulae using \rightarrow and \dagger , it is enough to consider formulae of the \rightarrow -types.

something like "it seems reasonable to adopt non-vacuous λ -abstractions for relevant implication."⁶

What we can learn from the type systems of Girard is that we can use formulae as types and labels as terms. Thus the identification of propositions with types (typed λ -terms) is again correlated with the realization that a logical inference is to be made from judgment(s) (of propositions) to judgment. We now have instruments to deal with judgments which include its justification: in ' $a \in A$ ' we are basically saying that ' A is true because of a '. (E.g. in ' $\lambda x.x \in A \rightarrow A$ ' we say that ' $A \rightarrow A$ ' is true because we have a closed term ' $\lambda x.x$ ' which inhabits it).

When implementing the above findings in designing rules of inference, we can obtain the following reformulated rule of \rightarrow -introduction:

$$(8) \quad \frac{\begin{array}{c} [x \in A] \\ \cdot \\ \cdot \\ \cdot \\ b(x) \in B \end{array}}{\lambda x.b(x) \in A \rightarrow B}$$

What we have now is in fact a juxtaposition of two systems. On the right hand side, the proofs/constructions in the object language; on the left, the meta-logical

⁶ For more details, cf. Gabbay (1994a) and Morrill (1994).

features of such proofs in the forms of 'reasons',⁷ 'records', 'witnesses', 'history', 'order and manner of combination', 'controller', 'abstractions', etc. On the right hand of (8), we have an application of \rightarrow -introduction, possibly among other steps of deductive proofs being omitted here by the dots; on the left, a record of functional accumulation of indices of records of each formula in use and a final extraction of one index in an application of λ -abstraction, in correspondence to the withdrawing of an assumption on the formula. The moral is: any theorem ought to end with an application of \rightarrow -introduction on its formula side and a corresponding step of abstraction on its labelling side so as to make sure that all assumptions are discharged.⁸

2.2. Labelled Deduction

Gabbay (1994a), and Gabbay & de Queiroz (1993) proposed a labelling algebra to systematize the meta-logical information accompanying typed deductions. Such information is now defined under the term *labels* of formulae. As each premiss is labelled, deduction becomes labelled deduction, with the effect that what is obtained is not only the final conclusion of a deductive process, but also the accumulated labels reflecting the history or the manner of the deductive exercise. In a Fitch-styled natural deduction, for example, Modus Ponendo Ponens(MPP) or Conditional Elimination is presented as (9):

⁷ Again, Gabbay & de Queiroz noted that the 'reason' is represented by the witnessing of a closed λ -term (such as, e.g., ' $\lambda x.x \in A \rightarrow A$ ').

⁸ Cf. de Queiroz & Gabbay (1993, 1995) and Gabbay & de Queiroz (1993) for more details.

(9)	Assumption(ASS)	Formula	Rule	Premiss
	1	P	ASS.	1
	2	$P \rightarrow Q$	ASS.	2
	1, 2	$\frac{P \quad P \rightarrow Q}{Q}$	MPP.	1, 2

By labelling each of the logical formulae in (9), we obtain (10):

(10)	$\alpha:$	P
	$\beta:$	$P \rightarrow Q$
	$\frac{\alpha: \quad \beta:}{\beta(\alpha):}$	$\frac{P \quad P \rightarrow Q}{Q}$

The labels in (10) can serve various purposes. They take the place of the less expressive way of using numbers to note down the assumptions used in proofs, as in (9). They can make a record of the history of the deductive process, i.e. how Q is reached. But once the labelling algebra is invented and generalized to an abstract level, it can be shown to have many other possible applications, depending on the semantic content being assigned to it. In logic, labels can be substantiated to relate the classical system to various other systems, e.g. temporal logic. (11), for example, adds a temporal dimension to the classical natural deductive system. Labels can also be occupied by a system very much different from the system they label, thus having two parallel systems of inference working side by side.

(11)	$t_i:$	P
	$t_i:$	$P \rightarrow Q$
	$\frac{t_i: \quad t_i:}{t_i:}$	$\frac{P \quad P \rightarrow Q}{Q}$

(t_i : P to be read as 'P is true at time t_i ')

(12) is a more complex example to this effect, making use of MPP, and Conditional Proof(CP)(= \rightarrow -introduction) on the deduction of logical formulae, and functional combination plus λ -abstraction on the accumulating process of the labels, while specifying the goal of the whole proof and each of the sub-goals:⁹

$$(12) \quad P \rightarrow (Q \rightarrow R) \vdash Q \rightarrow (P \rightarrow R)$$

1.	$\alpha: P \rightarrow (Q \rightarrow R)$	GOAL $Q \rightarrow (P \rightarrow R)$
2.	$\beta: Q$	GOAL $Q \rightarrow (P \rightarrow R)$ GOAL $P \rightarrow R$
3.	$\gamma: P$	GOAL $Q \rightarrow (P \rightarrow R)$ GOAL $P \rightarrow R$ GOAL R
4.	$\alpha(\gamma):$	$Q \rightarrow R$ MPP 1,3
5.	$\alpha(\gamma)(\beta):$	R MPP 2,4
6.	$\lambda x \alpha(x)(\beta):$	$P \rightarrow R$ CP 3,5
7.	$\lambda y \lambda x \alpha(x)(y):$	$Q \rightarrow (P \rightarrow R)$ CP 2,6

At Step 1, we lay down the given assumption as a premiss and label it with a

⁹ Both (11) and (12) are taken from Kempson (1994a).

symbol α , at the same time putting down the goal of the proof on the right hand side. But there is no direct rule of inference applicable at the moment. So we look ahead and, adopting the standard technique of assuming the antecedent of the conclusion, assume Q at Step 2, which is labelled by β . So we have entered a sub-proof with two goals: one is the sub-goal $P \rightarrow Q$ to be attempted, the other being the ultimate goal previously un-reached but carried forward into this sub-proof. Likewise, we enter yet another sub-proof by assuming $\gamma: P$ at 3 with the sub-goal of proving R , the other two goals being carried forward into this twice-embedded meta-box. Now we can apply the rules of deduction and obtain $Q \rightarrow R$ at 4. On the labelling side, we have the functional application of labels, yielding $\alpha(\gamma)$, which records the proof of the formula. Likewise, we reach $\alpha(\gamma)(\beta): R$ at Step 5. Now that we have fulfilled the last goal, we exit the inner-most box to see if the other goals can now be met. By Conditional Proof (\rightarrow -introduction) at 6, we fulfill the second goal. On the labelling side, we perform a step of λ -abstraction discharging the label of γ . Exiting yet another box, we meet the first goal through similar processes. For this proof, the inferences on the formulae are standard first-order proofs, in the style of Lemmon (1965). What is novel is the labelling side, which works in consonance with the formulae yet on accord with its own rules of application and abstraction.

Each unit of the label-cum-formula pair is called a declarative unit, which can form a database with some other declarative units. A database can also be further labelled to form larger databases. For visual convenience, each database is marked by a box called meta-box, as shown in the last example.

Yet one more innovative force of the labelling algebra lies in the possibility

for it to provide means to manipulate or control the proof construction. For example, by imposing on the labels the constraint of using every premiss for once and once only, we can derive the characteristics of linear and relevant logics. It is thus possible to couple the meta-logical features with the object language in a unified format of logical statement, which hitherto has not been closely connected to each other in good harmony.¹⁰ Labelled Deductive Systems, in which this new form of deduction is embedded, is a meta-logical system attempting to unify different branches of contemporary logics. Our focus of interest in this study lies in its application to the study of natural language understanding.

3. Natural Language Understanding as Labelled Natural Deduction

In this section, I will first present the basic content of LDS_{NL} in steps, dealing with one aspect of the framework in each sub-section while comparing it with some other models when necessary. I will devote the last part to a general outline of the goals of the theory as having been hitherto conceived in the literature since its inception in 1991. I will reserve the discussion on the representation and treatment of quantified expressions to Chapter 4.

From the perspective of LDS_{NL} (Labelled Deductive Systems for Natural

¹⁰ Gabbay (1994c) pointed out that it was not that no previous logical studies had made use of labels but that no previous studies used labels in a systematic way, developing it into an algebraic system in itself. It is as if using two fists in a coordinated way, instead of relying mainly on the right fist while using the left haphazardly.

Language),¹¹ natural language understanding is viewed as a goal-directed, dynamic process of data-base construction involving inferences made by the hearer over the information supplied by the lexical entries as each one of them is inputted into the database under construction. The concept of a word is usually represented as a label, while the semantic type of some lexical categories is given as a typed formula subject to logical inferences.

With concepts of words serving as labels and their types as formulae, we create declarative units somewhat paralleling the ones we introduced in our discussion on the logical system of LDS in the last section, as exemplified by (10) - (12). If we specify the goal of a hearer as an attempt to construct a propositional form which can be evaluated in terms of truth-conditions at a later stage, then utterance interpretation can be readily modelled as a weakly goal-directed inferential process.¹² The concepts as labels get accumulated in steps of functional application, paralleling the logical deduction, in the form of \rightarrow -elimination (Modus Ponendo Ponens), over their formulae as types. The final outcome is a constructed database containing a composite label labelling a logical formula, the latter being the conclusion of a proof construction. The goal of the utterance interpretation would sanction the composite label as a wff structure if and only if its labelled formula is of the type t , t standing for truth value, in a type theory to be introduced shortly.

¹¹ As developed by G&K (1991; 1992a,b; 1993a,b) and Kempson (1992a,c; 1994a,b; 1995b,c).

¹² 'Weakly goal-directed' because the hearer cannot foresee what definite results he can achieve in the process of utterance interpretation, which may lead to misunderstandings and even total break-downs.

3.1. Assigning Logical Types to Lexical Categories

To present the type theory specific to G&K's LDS_{NL} , we start with some general sketches of type theory in linguistics. Type theory for natural language semantics has as its basis the type theory in logic we introduced in the last section.¹³ Recall that such a theory in logic starts with some prime types and recursively construct formulae out of those prime types over which rules of logical inference operate. We start by taking two fixed objects as prime types and name them as, for example, *e* and *t*, respectively. *e* and *t* in this logical context does not have to denote anything, the only requirement being that they be distinct. We might as well have named them as 0 and 1. Then the logical formulae can be constructed in the following way:

- a) *e* and *t* are basic categories CAT.
- b) If $A \in \text{CAT}$, and $B \in \text{CAT}$, then $(A \rightarrow B) \in \text{CAT}$.
- c) Rule of Conditional Elimination(MPP): Given A , $A \in \text{CAT}$, and $A \rightarrow B$, $(A \rightarrow B) \in \text{CAT}$, we can derive B , $B \in \text{CAT}$.

When implementing type theory into studies of semantics and syntax, the fundamental issues are (I) what ontological status to give to the prime types(basic categories) and (II) how to assign logical types(categories) to the lexical categories for a language. Taking *e* to denote individuals or entities and *t* to denote truth-values, as proposed by Montague (1974)(i.e. PTQ), it is possible to assign a semantic type to the

¹³ Cf. Montague (1974), Thomason (1974), Dowty et al.(1981), Bach (1989), Partee et al.(1990), Cann (1993), and Wood (1993).

concept of every word, which can be defined in set-theoretic terms.¹⁴ Semantic types are what words denote and can be viewed separately from logical types.¹⁵ The latter only play the role of logical deduction. We use angle brackets $\langle A, B \rangle$ to represent semantic types and conditionals $(A \rightarrow B)$ or slashes B/A to represent logical types. All the lexical categories in natural language carry a semantic type. But it is up to us to choose which of these categories get logical types for syntactic computations and which logical type should be assigned to a lexical category. Logical types therefore constitute a proper subset of semantic types. In the practice of Montague Semantics, all lexical categories get assigned logical types. That is, all semantic types have corresponding logical types. The types in Montague semantics are given in Table 1.

¹⁴ A notably different theory is Chierchia's property theory, which takes p as a basic type, denoting property, besides e and t . Cf. Chierchia (1985).

¹⁵ Many theories use the same symbols as prime types for both semantic and logical types. But it is possible to make a distinction by using S and N for logical types and reserving e and t for semantic types.

TABLE 1: Types in Montague Semantics

<u>Lexical Cat.</u>	<u>Cat. Name</u>	<u>Logical Type</u> & <u>Semantic Type</u>	<u>Semantic Def.</u>
Proper Name	Term-	t/IV	set of properties
	Phrase(T)	$\langle\langle e, t \rangle, t \rangle$	of individuals ■
Pronoun	T		
Bare NP	T		
Common Noun	CN	t/e	set of
		$\langle e, t \rangle$	individuals ■
Determiner	DET	T/CN	functions from
		$\langle\langle e, t \rangle,$	properties of
		$\langle\langle e, t \rangle, t \rangle\rangle$	individuals to sets
			of properties of individuals ■
QNP	T		
Definite NP	T		
Sentence	t	t	truth value ■
Verb(int.)	IV	t/e	set of
		$\langle e, t \rangle$	individuals ■
Verb(t.)	TV	IV/T	function from
		$\langle\langle\langle e, t \rangle, t \rangle,$	properties of
		$\langle e, t \rangle\rangle$	properties of
			individuals to sets of individuals ■

TABLE 1 (continued)

<u>Lexical Cat.</u>	<u>Cat.Name</u>	<u>Logical Type</u>	<u>Semantic Def.</u>
S-complement	IV/t	IV/t	function from
Verb		$\langle t, \langle e, t \rangle \rangle$	propositions to sets of individuals ■
VP	IV		
VP Adv.	IAV	IV/IV	function from
		$\langle \langle e, t \rangle ,$	properties of
		$\langle e, t \rangle \rangle$	individuals to sets of individuals ■
S Adv.	t/t	t/t	set of
		$\langle t, t \rangle$	propositions ■
Adj.		T/T	
Prep. -- for	IAV/T	(IV/IV)/T	function from
PP as IAV		$\langle \langle \langle e, t \rangle , t \rangle ,$	properties of
		$\langle \langle e, t \rangle ,$	properties of
		$\langle e, t \rangle \rangle \rangle$	individuals to
Prep. -- for PP as t/t		(t/t)/T	functions from
Prep. -- for PP			properties of
as T/T		(T/T)/T	individuals to sets of individuals ■

Table 1 is compiled drawing from Montague (1974), Thomason (1974), Bach (1989), and especially Dowty et al.(1981). Where there are lexical categories that are assigned logical types in Montague semantics but are not adopted in LDS_{NL} , these categories are bolded. I have chosen not to include in Table 1 the intensional dimension of the types. That is, I have omitted all the occurrences of the index $\langle s \rangle$. The only reason is for ease of comparison. Therefore, the semantic definitions in Table 1 do not match the given formulae in a strict sense. The ■ sign stands for the end of a definition. The double slash in A/B is used to distinguish different lexical categories sharing a same type that would otherwise have been all represented as A/B .

G&K's type assignment is presented in Table 2:

TABLE 2: **Type Classification in LDS_{NL}**

<u>Lexical Category</u>	<u>Logical Type</u>	<u>Basic Expressions</u>
Proper Name	e	John, Mary, ...
Pronoun	e	he, him, they,...
Bare NP	e	men, oil, people...
Quantified NP	e	every man, six boys...
Definite NP	e	the dog, that ship...
Sentence	t	[Syntax is easy.]...
Intransitive Verb	$e \rightarrow t$	sleep, talk, run...
Transitive Verb	$e \rightarrow (e \rightarrow t)$	find, eat, love...
S-complement Verb	$t \rightarrow (e \rightarrow t)$	believe, say, think...
VP	$e \rightarrow t$	[write a thesis]...

A comparison between the two tables reveals much difference between the LDS_{NL} type theory and that of Montague semantics. The most striking difference is that in LDS_{NL} , all the syntactic NP's have e as their logical type, whereas all NPs are given the category *Term Phrase* $(e \rightarrow t) \rightarrow t$ in Montague semantics, in which the logical type e has no corresponding basic expressions. In Montague semantics, CN, DET, Adj. and Adv. are provided with their logical types, whereas LDS_{NL} does not mark them out as syntactic categories. LDS_{NL} views these categories as semantic functions which take in some semantic types as arguments and return with a logical type, as given in Table 3:

TABLE 3: Semantic Functions in LDS_{NL}

<u>Lexical Category</u>	<u>Semantic Function</u>
Determiner	$D, \star(D) : e$
Common Noun	$\star, CN(\star) : e$
Adj.	$\alpha, [ADJ, ADJ(\star)](\alpha) : e$
Prep.	$Prep.(o) : VP Adv.$
	$: \alpha, [ADJ, ADJ(\star)](\alpha) : e$
VP Adverb	$ADV. (o) : e \rightarrow t$

The structure of an NP is such that it consists of a common noun preceded by a determiner. In between, there may be one or more adjectives. Neither the determiner nor the common noun nor the adjectives can stand by themselves in a sentence. They are locked up together in the fixed structure of (Det) - (Adj.) - (CN). So we can view each of these three categories as occupying certain positions in the NP grid, while

other positions are simply marked by dummy variables to be filled by either of the other two remaining categories. When these categories meet, the variables are unified and the NP structure is gradually saturated. So when the determiner meets a common noun, unification takes place in the following manner:

D,	*	(D) :	e	the,	*	(the):	e
↕	↕	↕		↕	↕	↕	
,	CN	() :	e	*	man	(*) :	e

(where CN is a restrictor of D, D as Determiner)

Adjectives combine with common nouns and determiners to yield the type e . So its semantic function allows two kinds of dummy variables to occur i.e. \square and $*$, one to be unified with common nouns, the other with determiners. Multiple adjectives means recursive combinations of adjectives with common nouns, which itself may contain adjectives and common nouns.

But the preposition and the VP adverb work rather differently. In the case of preposition, it takes in an e as a logical type and returns either a logical function (VP Adv.) or a semantic function $[\square, [\text{ADJ}, \text{ADJ}(*)]](\square): e$ as an adjectival phrase.¹⁶ A VP adverb takes in a logical type of $(e \rightarrow t)$ and returns another logical type $(e \rightarrow t)$.

As a result, the lexical categories of these semantic functions get combined,

¹⁶ It remains to be worked out how PP's as attributives are to be represented in LDS_{NL} in a precise way.

either with each other in the form of variable unification or with other lexical categories as arguments and yield a composite label with a logical type.

Sentential adverbials project themselves directly as database labels and have nothing to do with either the logical types or the semantic functions.

The whole point of this strategy is to keep the logical type of the verb as the major premiss in the local proof domain. LDS_{NL} does not have *direct* use for many lexical categories in the actual inferential process of *database construction* because these categories involve higher-order logical types in Montague Semantics and if introduced into the database as premisses, will have to be taken as the major premisses. These categories do get assigned some semantic functions or semantic types, but they combine with some others in a process of unification which presents them as pre-packaged units serving as premisses in the database construction. By preserving the verb type as the major premiss, it is possible to control the deductive process so that a goal with the type t can be reached in finite, deterministic steps which solely involve combination of the verb premiss with its argument premisses. If we add in more complex types as premisses, such as determiners, common nouns, and adverbials, some of them would assume the same types as the verb; others would project more complex ones. If that happened in LDS_{NL} , then the construction of the database would not be goal-directed and would not be in accord with relevant and linear logics, for we would be forced to take the formulae with the most complex type as the major premiss, which is not necessarily the predicate verb, and we would not be able to identify subjects as being a premiss used last in the minimal inference

involving a major premiss and some minor ones reaching a type t . By simplifying the typed formulae and projecting some lexical categories directly as database labels, LDS_{NL} avoids the added complexity in Montague semantics, where it is necessary to postulate type hierarchy and type ambiguity for single syntactic categories.¹⁷ This is a principled distinction that underlies all the differences in type assignment between the two theories.

3.2. A Sample Analysis

With the lexical expressions being assigned their logical types, let us look at an example to see how a simple sentence is parsed and interpreted in LDS_{NL} :

(13) John likes Chris.

(13') M

1.	Goal: ($[Label:Formula]_{w1}, [L:F]_{w2}, \dots$) $\vdash s_i, a:t$	
2.	$s_i \quad \langle w_i, t_i \mid [5a. \Theta t_i = t_{utt}] \rangle$	
3.	John', [5b. USE LAST] :	e ASS.
4.	like' :	$e \rightarrow (e \rightarrow t)$ ASS.
6.	Chris' :	e ASS.
7.	like'(Chris') :	$e \rightarrow t$ MPP. 4,6
8.	like'(Chris')(John') :	t MPP. 3,7

$s_i \langle w_i, t_i \mid [\Theta t_i = t_{utt}] \rangle :$

like'(Chris')(John'): t

¹⁷ Cf. Partee & Rooth (1983), Partee (1992), and Kempson (1994c).

We start by building a database at a starting point M . At Step 1, the goal of utterance interpretation is laid down according to which each word should contribute to the building of the database till a t is reached. At 2, a database label s_i is given which, in the context of utterance interpretation, is further split into an ordered pair of indices: world (w) and time (t), whose values remain to be instantiated at relevant moments of database construction.¹⁸ At 3, the concept the word *John* stands for is entered into s_i as a label (prime here indicates labels instead of actual words, representing the concepts such words denote),¹⁹ with its type given as e , the whole declarative unit serving as an assumption in the logical proof under way. Likewise, at 4 and 6, *like* and *Chris* are entered together with their types. But after 4, some more information is read into the database. As the word *like* ends with *-s*, we know that the tense is simple present. This indicates that the time the event reported by the proposition happened at the same time as the time of utterance of the proposition. Hence 5a, in which Θ is an instantiation function. Also from the *-s* ending of the verb, we know the nominal element immediately preceding this tensed verb must be the subject. We thus have 5b, which caused this premiss to be used last in the minimal process of inference leading towards a t . The aim of this move is to yield a proposition which distinguishes a subject from an object so as to yield the correct interpretation, in accordance with the principle of compositionality.²⁰ Following the

¹⁸ Explanations to these indices will be given in 3.6.

¹⁹ This characterization is a simplification, ignoring problems of there being many people named *John*. What the hearer ought to perceive here is an identified person named *John*. For example, *John*₁₈, cf. Kempson (1994a). A more detailed representation is given in Chapter 4.

²⁰ More discussions related to this important issue is given in 3.5 and Chapter 5.

recent convention adopted in Kempson (1995b,c), I will use the resource label \mathcal{G} to stand for this [USE LAST] specification in the later analyses. (5a) and (5b) are not necessarily ordered in such a sequence. We can take it as two tasks being simultaneously performed. At Step 7, with all the words being scanned, the inference goes under way. By two steps of MPP, a t is reached, and the labels accumulated, yielding an interpreted sentence -- a proposition.

3.3. Logical Deduction over Types

With the sample analysis of (13) in hand, we can now present the mechanism of LDS_{NL} with more ease. The discussion in this section and the ensuing ones will also provide more motivations for the technicalities introduced in 3.2.

Given the logical formulae as premisses, deduction goes in a simple manner using \rightarrow -Elimination (to be precise, only MPP but not MTT). \rightarrow -Introduction (Conditional Proof, CP) is only employed in the study of ellipsis.²¹ So the inference rules usually involves no more than MPP and CP. The deduction is type-driven and goal-directed, in the sense that given the typed formulae, the major premiss (the ticket) will combine with the minor premiss(es) in a mechanical way until the goal of deduction is met. As a result, the deduction will stop only if the following conditions are met: A. All the \rightarrow are eliminated. That is, the ticket is all saturated. B. A t is reached. A is the prerequisite of B. If the minor premisses are all used up and yet the major premiss is not saturated, then the resulting formula is ill-formed. If all the

²¹ Kempson (1994a,b; 1995c).

minors are used and the resulting formula is not a *t*, then the resulting formula is not a wff either. In fact, what is to be sanctioned is not only the ultimate logical type, but also the composite label which labels the formula. For example, all the variables in the labels should be properly instantiated. But we leave this issue to the next chapter.

Some extra assumptions in the present approach should be explicated. As shown by (13'), each premiss should be used once and once only, as required by linear logic, while every premiss should be used, in the spirit of relevant logic.

Also partially revealed by the simple example (13) is the different kinds of natural language content projected by the lexical items. A word may project a label, which stands for the concept of the word together with its logical formula.²² It may project no label at all, nor ^a type formula, but some control features (or *resource labels* in the terminology of LDS), which dictate the order of logical deduction, like Step 5b. It must be indicated at this point that some logical formulae, being a major premiss and a functor, also control the order of deduction. The verb *like* in (13) for example, has a type $e \rightarrow (e \rightarrow t)$, which will consciously look for formulae with an *e* to combine with, and will not halt the mechanism of inference until both *e*'s have been discharged. The process of utterance interpretation is therefore modelled as a type-driven, proof-theoretic process. Instead of projecting a unique label, a lexical form may contribute to the instantiation of a database label, as shown in Step 5a in (13'), where *-s* helped setting the right features of *s_i*. We will see in the next chapter that some words will project some other information, some meta-variables as labels, to be

²² In the case of verbs in English, the labels appear as primed un-inflected cognates.

instantiated at a later stage.

3.4. Functional Application over Labels

As the deduction over the typed formulae gets under way, the labels labelling each of the formulae also undergo a functional application with the result that each step of deduction over the premisses simultaneously results in the accumulation of the related labels, in accordance with the following rule of functional application:

- (14) Given $\alpha: A$, and $\beta: B$, α and β being labels, A being the major premiss and B being the minor premiss, then the combination of labels will yield $\alpha(\beta):C$, C being the result of applying B to A .

Note here that α is acting as a functor and β , an argument, in accordance with the logical type they each label. Thus the concepts denoted by words as labels will combine together in a structured way, yielding an interpreted string which is a proposition if it labels a t . Computation over the labels mainly involves functional combination. But when dealing with ellipsis, λ -Abstraction is also employed, paralleling the process of \rightarrow -Introduction on the related formula.

3.5. Manipulating Deduction: the Resource Labels

Thus we have two systems working in tandem: deduction over types, and functional application over labels. They form integral parts of one and the same process of utterance interpretation, yet are kept distinctly apart, so that what we get

as the result of operation over one system may also acquire some independent status of its own. Another advantage is that we can introduce extra controlling features into one system that may or may not have repercussions over the other system without messing up the format and the operation of the latter. As a direct consequence, meta-features of logic will be encoded into the same declarative unit as the object language, yet are still kept distinctly apart. This makes it possible to manipulate over the labels to exercise control over the deductive process, or simply to enrich the labelling system itself. We look at the first case in this section and the second case in 3.6.

One resource label we have already encountered is the \mathfrak{E} symbol encoding the [USE LAST] instruction. Every theory of semantic interpretation has to make the distinction between the subject and the object. And if it is believed that the object combines with the verb first to form the VP as a constituent, then the subject should be combined with the VP as a later step. So in LDS_{NL} , the subject, although most often introduced as a premiss well before the verb and the object, actually has to be used much later, even though the major premiss projected by the verb is available before the object and MPP is applicable at an earlier stage. To implement this strategy of holding back the subject premiss till a later stage, \mathfrak{E} is attached to the subject premiss as a resource label, so that the application of conditional elimination to that premiss is delayed till the last step of deduction.

The remaining issue is that, given the parsing as deduction nature of the LDS_{NL} model, how is the subject to be identified. I leave this issue to Chapter 5. Other uses of resource labels, especially with regard to variable instantiation, will be discussed

in Chapter 3.

3.6. Adding a Temporal-Spatial Dimension

As a system of its own, labels may also be further enriched in ways which reflect finer aspects of utterance interpretation without having much to do with the deduction on the formulae.

In this sub-section, I look at how LDS_{NL} represents two important factors in natural language semantics: time and world. The content of a proposition is always time-related. The truth of a proposition is always evaluated with reference to time. Even an eternal truth is time-related, because its eternity lies in its being true all the time. A proposition can be true with reference to one time, but false to another. For example, sentence (15) can be extended to form (16) and (17) with explicit reference to time. (16) is true, but (17) is false:

- (15) Margaret Thatcher was the Prime Minister of U.K.
- (16) Margaret Thatcher was the Prime Minister of U.K. in 1989.
- (17) Margaret Thatcher was the Prime Minister of U.K. in 1993.

Moreover, a proposition can be true when uttered at one time and false when uttered at another time. (18) is true while (19) is false.

- (18) John Major is the Prime Minister of U.K.

[Time of utterance: December 31st, 1994]

(19) John Major is the Prime Minister of U.K.

[Time of utterance: May 31st, 1990]

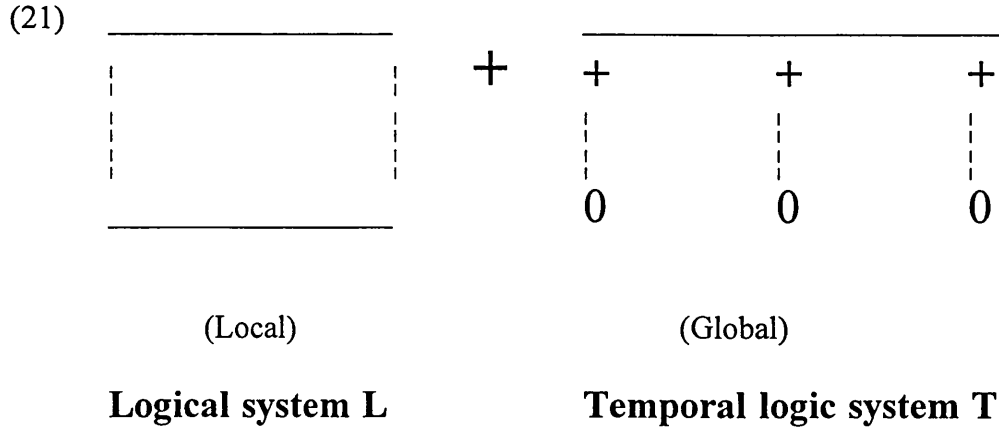
So what a semantic theory ought to capture about time are at least two elements: the time related to the content of the proposition and the time the proposition is uttered.

Language users do not only have the ability to make their utterances refer back and forth in time, they can also refer to worlds that are distinct from the world they are in. That is, they can talk about possible worlds. The classic example is (20):

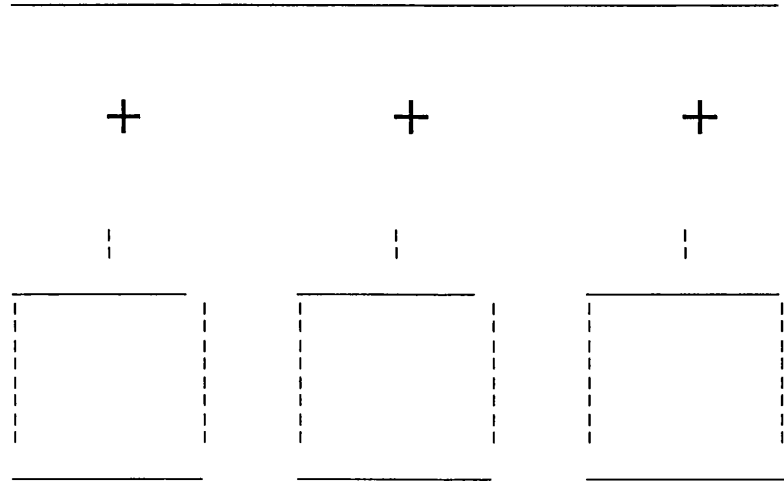
(20) If Cleopatra's nose had been longer, the history of the world would have been different.

This makes it possible for us to make utterances that are factual as well as counter-factual.

Finger & Gabbay (1994) presented, among others, an external method of describing how a system S , specified in a logic L , changes over time. According to this external method, different states of S are related to different moments of time. A temporal system can therefore be externally added to S , which can be decomposed into $S_{t1}....S_{tn}$. A visual representation is like (21):



→



The logic system T(L)

Adopting the external method of time representation, LDS_{NL} takes the local logical system S as the database Δ and posits the temporal logic system as a database label T , which has its own internal structure.²³ T can be realized into a cluster of time variables t_1, \dots, t_n , which are sequentially connected forming a time sequence by the

²³ The following version is my adaptation of Finger & Gabbay (1994), with extensive modifications.

connective $<$. The temporal logic system T , as a database label, can acquire a logical life of its own. According to Gabbay et al.(1994), the structure $(t_n, <)$ is considered temporal if it has an '(irreflexive transitive) ordering $<'$. That is to say, if $t_1 < t_2$ and $t_2 < t_3$, then $t_1 < t_3$ (transitivity). But if $t_1 < t_2$, then it is not the case that $t_2 < t_1$ (irreflexivity). The time of utterance $t_{utterance}$ (shortened as t_{utt}) is related to t_i , the time index internal to the proposition, by $<$ and $=$. t_{utt} is identified with one member of $t_1 \dots t_n$ and so is t_i . t_{utt} can precede t_i ($t_{utt} < t_i$) or follow it ($t_i < t_{utt}$) or it can be identified with t_i ($t_{utt} = t_i$).

The metavariable $\langle t \rangle$ is instantiated procedurally in the process of utterance interpretation, by picking out time-related information encoded in the lexical items as each of them are input into the database. These pieces of information may be highly language-specific. For example, in English, the time-related information is encoded in the verb suffixes, in the auxiliary words, and in the time adverbials. Each English sentence gives explicit information about tense. Contextual information will also give indications for a finer specification of time. For example, a sentence may carry a past tense which may not be different from the tense carried by the preceding sentence. But contextual information will specify the order of time between these two snapshots of event reported by the two sentences. So verb suffixes directly mark the tense in English and contextual information coordinates the sequential order of time. In Chinese, however, verb suffixes carry little information about tense. A lot of information about time is carried by time adverbials and by contextual information. When no verb suffixes nor time adverbials appear in a sentence, which is not rare in Chinese, then the contextual information takes up the whole burden of specifying the time of the proposition. For both English and Chinese, and perhaps for all languages,

the time of utterance is always easier to fix -- it is always to be construed as NOW. Even in the case of reading, the time we read these words, i.e. NOW, can be taken as the time the author communicates his message to the reader.²⁴

The above considerations about time can be implemented into mechanisms of LDS_{NL} in the following ways:

When interpreting an utterance, after the goal is set, we put into the imaginary stack a symbol $\langle t \rangle$, whose value is to be instantiated. When dealing with a Chinese sentence, $\langle t \rangle$ is then instantiated by carrying over the time index specified for the last utterance or, with the lack of a preceding utterance, the time index which the hearer synchronizes with one of his assumptions. Any later time-related lexical information will either confirm or alter the instantiated $\langle t \rangle$. The result of this instantiation, represented as Θ , is formally stated by relating $\langle t \rangle$ to $\langle t_{utt} \rangle$ by the connective $<$ or $=$, that is, by specifying the temporal order between the $\langle t \rangle$ and $\langle t_{utt} \rangle$. In the case of English, the empty symbol $\langle t \rangle$ will be instantiated when the information on tense centering around the verb is accessed. Contextual information does not play a determinant role in the initial instantiation of $\langle t \rangle$ for English. Hence the instantiated $\langle t \rangle$ will not be liable for any alteration, although it is still subject to modifications by contextual information for a fine-grained temporal representation.

The world label is introduced into the database by putting into the imaginary

²⁴ It may be a better idea to term it 'the time the sentence is being processed' or 'time of processing'.

stack a symbol $\langle w \rangle$, which is generally instantiated as $\langle w_{\text{now}} \rangle$ unless a counterfactual utterance is being made. In that case, for English, lexical information will indicate the counterfactuality, which results in the instantiation of a world different from the world we are in: $\langle w_i \neq w_{\text{now}} \rangle$.²⁵ In the case for Chinese, contextual information will indicate the counterfactuality, again resulting in the proper instantiation of the $\langle w \rangle$ label.²⁶ The world label should also be closely related to the representation of modal aspects of the language, leading to a structured system W that may have a logical life of its own. But this remains to be worked out in LDS_{NL}.

4. LDS_{NL} -- Goals

Generally speaking, the task of linguistics is to describe and explain how people produce and understand natural language. That is, how can human beings utter sentences to reflect their thoughts, to mean what they mean, and how can human beings recover meaning, given a string of sounds. Areas of linguistics were drawn to reflect hypothesized stages of natural language understanding:²⁷ such as phonology, morphology, syntax, semantics, and pragmatics. The hearer partitions a string of sounds, identifies morphemes and words, reconstructs the sentence structure, assigns the sentential meaning, and finally recovers the propositional meaning.

²⁵ For details, see Gabbay & Kempson (1992b).

²⁶ For discussions on relevant facts in Chinese, see A. Bloom (1981), which initiated a series of studies in its wake.

²⁷ The production side either conceived as the same procedure in reverse order or relatively ignored because of its psychological, neurological, and physiological complexities.

Linguistic theories vary in their scope of coverage. Some concentrate on special areas while interfacing other theories for other areas; some are more exclusive because of their ontological commitments towards their conception of the nature of language. Generative Grammar represented by the works of Noam Chomsky concentrates on the study of syntax, morphology, and phonology. Semantic and pragmatic studies are considered not part of the quest for the rule-governed properties of human language that are biologically endowed and form an encapsulated body of knowledge inherent in the human mind. Knowledge of grammar(encompassing the above mentioned three areas) thus forms an autonomous region for investigation, through which it is expected that we can learn indirectly about the working of the human mind.²⁸ But the generative enterprise can at best offer a partial understanding of the working of the human mind, what is related to the processing of language.

On the other hand, Jerry Fodor's theory of the Modularity of Mind is a theory of the mind in general.²⁹ The working of the mind is divided into two bodies of systems by Fodor: input systems and the central cognitive processes. The input systems are individually encapsulated bodies of rule systems which are task-specific, such as the language system, the visual system, etc. The language module as an input system is considered to be syntactic in nature. That is, its properties are best studied in terms of its structures. The language module processes and assigns syntactic structures and

²⁸ This is a miniature summary of Chomsky's views as reflected in Chomsky (1968, 1975, 1986). Chomsky did speculate the possibility that language competence in terms of the abstract principles currently under investigation may be ascribed to the general ability of computation of the human mind, Cf. Huybregts & Riemsdijk (1982).

²⁹ Cf. Fodor (1983, 1990a).

structural meaning to sound strings and input the results into the central cognitive system, where the mind computes over all the input information from all the input systems. Speaking of natural language understanding, the full recovery of propositional meaning is only possible as a result of the working of the central cognitive system. Because of the heterogenous nature of the information involved, the working of the central cognitive processes are equally heterogenous: anything can interact with anything to yield something else, in unpredictable ways. Fodor therefore thought it impossible to derive any principled theorization over the central cognitive processes.

So Chomsky did not inquire into the central cognitive processes because the issue is beyond his concern, while Fodor did not make principled claims about that area because he considered it an impossible task.

In contrast to the above two schools, Relevance Theory proposed by Sperber & Wilson (1986, 1995) does make explicit claims on the working of the central cognitive processes in a principled way. The Principle of Relevance formulated by Sperber and Wilson claims that cognitively speaking, the human beings aim at obtaining maximal cognitive effects with minimal cognitive efforts, and that in terms of verbal communication, people search for the optimal contextual effects with no undue processing effort.³⁰ Taking into consideration the fact that both the speaker and the hearer are unconscious observers of this principle, the first interpretation that comes into the mind of the hearer becomes the interpretation the hearer takes the

³⁰ Relevance Theory is therefore both a theory of cognition and a theory of verbal communication(pragmatics).

speaker to have intended to communicate. Misunderstanding does not refute the principle but should rather be ascribed to the failure of one party in recognizing the mutually manifested assumptions from which inferences are drawn under the guidance of the principle of relevance to obtain the relevant propositions. Relevance Theory thus makes emphasis on three aspects of verbal communication: First, the structural meaning of a sentence is vastly underdetermined, which needs to be enriched to qualify as the proposition expressed by the speaker(The Underdeterminacy Thesis). Second, enrichment of sentence meaning is carried out through inferences over assumptions made manifest by lexical, sentential and contextual information(The Inference Model of Communication). Third, communication is cooperative, cost-effective, and principle-governed(The Principle of Relevance). In the light of Relevance Theory, many pragmatic issues such as implicature and explicature, presupposition, reference assignment, rhetorical effects, bridging, etc. get an adequate explanation.

The Labelled Deductive Systems for Natural Language Understanding set out to formalize the insights of Relevance Theory in proof-deductive terms,³¹ but has evolved into a distinct theory of its own, because it has made claims not only about pragmatics, but about syntax and semantics as well, with its conception of the nature of natural language understanding being similar to neither that of Chomsky nor that of Fodor.

³¹ A direct result is Gabbay & Kempson (1991) on relevance reasoning in verbal communication.

The Generative Grammarian's conception of syntax(hitherto abbreviated as the GB stand) is sentence-oriented and does not address context-dependent issues. Anything of the latter kind, such as ambiguity of reference assignment, bridging cross-reference, bare-argument ellipsis, etc. is ascribed to the realm of pragmatics. Formal semantics treats cases of a context-dependent nature in the same way as semantic interpretation of simple sentences -- through direct model-theoretic interpretation over strings through which fine-grained and even finer-grained indices of world, time, event, situation, etc. can eventually hook the sentence to its context.³² Both these approaches fail to capture the fact that these cases, though context dependent, can yet often be subject to syntactic constraints at the same time. As Kempson (1994a) indicated, those context-dependent cases should best be treated in a way that strings receive an initial interpretation together with algorithms which build up the syntactic structures, which both pays attention to the context-dependent factors and attend to issues of a syntactic nature.

LDS_{NL} as an inferential system applied to natural language understanding turns out to be an ideal theory to capture the context-dependence of language. Because of its rich expressive power in using labels coupled with formulae, it is able to add an extra semantic dimension in parallel to the structures. Therefore, it can put semantic interpretation into the structure building of strings and process strings in a combination of parsing, deduction, and interpretation. And because of its stringent way of structure building which is rooted in the logical discipline, it is also able to capture the purely

³² Cf. Lewis (1972), Montague (1974), Dowty et al (1981), Bach (1989), and Chierchia & McConnell-Ginet (1990).

structural properties of natural language. As labelled deduction involves both deduction and abduction, the mechanisms of LDS_{NL} can use techniques such as the choice functions to update databases and incorporate contextual information when necessary, in the middle of the structure building itself.

We have seen that LDS_{NL} mechanisms have potentials to deal with issues in several areas: syntax, semantics and pragmatics, and it shows its special power when dealing with cases where the three areas interact: cases of a context-dependent nature. The framework therefore seems to be working in a way that pays no tribute to the standard division of labour among syntax, semantics, and pragmatics. More importantly, as LDS_{NL} is a sub-system of the Labelled Deductive Systems which is a meta-logical system, it lays the strong claim that the mechanisms for the characterization of natural language understanding can well be a specialised sub-system of the mechanisms for the characterization of human reasoning in general. Therefore, the language faculty is likely to be only partially encapsulated, and the dichotomy between the input systems and the central cognitive processes is also very much blurred from the LDS perspective.³³ All can be eventually captured by systems of logic.

Such a claim is revolutionary, to say the least, and calls for investigations that offer detailed analyses of linguistic facts in the LDS framework, so that specific claims can be substantiated in support or refutation of aspects of the theory. The research

³³ Fodor (1990a) admits that there are rules that are at work both in input systems and in the central cognitive processes. The dichotomy of the two types of systems holds only in so far as some rules working for one do not appear in the other.

reported in this thesis is one initial attempt towards this direction.

3

Procedural Accounts of Quantification in Logic

0. Preamble

Before we present treatment of quantification in natural language in LDS_{NL} , we need to be acquainted with the present state of the art in the treatment of quantification in logic. In particular, we need to know how quantification in pure logic is analysed in LDS. We also want to know some other treatments of quantification from which the LDS_{NL} draws sources.

This chapter constitutes a search for the optimally appropriate techniques in logic that can be employed in the analysis of natural language quantification in LDS_{NL} .

I will first take a look at Hintikka's Game-theoretic Semantics, especially its treatment of quantification, which is one of the very few theories that assumed underdeterminacy and proposed a procedural account of natural language understanding. Since underdeterminacy and procedural interpretation are also assumed by LDS_{NL} , we want to see to what extent techniques in game theory can be borrowed for the LDS_{NL} analysis. The answer is negative, since game theory turns out to be a verification process, not a deductive one. And there are efficiency problems in the

verification process itself.

In Section 2, we turn to the studies on the ε -term. From Hilbert's ε -Calculus to the η -variables of Gabbay (1994a), we find means to reason with quantified expressions without the first-order quantifiers. This enables us to discard the notion of scope. From studies on the functional interpretation of quantifiers by de Queiroz & Gabbay (1995), we learn the logical basis for putting the ε -symbol in the labels, which makes it possible to project QNP's in natural language as meta-variables over the labels without using quantifiers.

Reducing the meta-variables into arbitrary individuals, we can construct dependency relations between them. We examine in Section 3 studies on dependency and value instantiation. Fine's discussions on *arbitrary objects* (Fine 1985) give the background knowledge on the need to construct dependency as well as the explicit object(A-objects) to reason with. Looking for more syntactic alternatives, we choose the *assignment statements* from Meyer-Viol (1995).

But we do not want to borrow Fine's notion of arbitrary objects, because we do not want to be committed to the unique logico-philosophical implications of that notion. What we use for the labelled analysis is the Skolem variables(or η -variables). Therefore, the finished product is not Fine's instantiated A-objects but Skolem constants. A discussion on the status of Skolem constants is given in Section 4. The purpose is to reveal the relationship between Skolem constants and the Skolem function.

1. Game-theoretical Semantics and Quantification

The game-theoretic approach to natural language quantification embodies Hintikka's underdeterminacy thesis. Hintikka (1979a) noted that in natural language quantification, absolute scope does not matter, for it can be extended absolutely far in a sentence or discourse.¹ But relative scopes of multiple quantifiers are vitally important for the understanding of such sentences.

However, it is not easy to study the relative scopes of quantifiers in ordinary discourse. The exact scopes are not indicated by brackets, parentheses, dots, or by any comparable devices. They are underdetermined. We cannot model the semantics for natural language after the semantics of formalized languages, which interprets a formula recursively out of its subparts in a truth-theoretic manner. The reason is that to interpret a quantified expression compositionally, we have to first construct the whole component over which the relevant quantifier has the scope. But as the scope of a quantifier can in principle be arbitrarily extended and as no scope is explicitly marked by any syntactic device, we have no way of specifying the relevant component in relation to a Q-expression. The way out of this difficulty, according to Hintikka, is to interpret a sentence procedurally from outside-in, which is in contrast to the inside-out mode of interpretation of truth-conditional semantics. In this way, we do not have to specify the scope beforehand. Instead, we choose an arbitrary individual for the Q-

¹ Witness the possibility of introducing an existential Q-expression and keeping on to refer to that randomly chosen individual by using pronouns and definite expressions:

(i) *A man* came into the shop. *He* leafed through the magazines. Then *he* played with the cat. After that *he* attempted to feed the bird. Finally, *the man* was asked to leave.

expression and carry on with it in interpreting the rest of the discourse. Each step of interpretation affects the following steps. And the formal way to realize the above idea is through Game Theory.

In this section, we look at both the game theory in logic and its extension in natural language understanding. The aim is not to give a comprehensive presentation of the theory but to find out parallels between the game-theoretic approach and the LDS_{NL} approach to natural language quantification.

1.1. Game-theoretic Interpretation of First-Order Formulae

Hintikka and others² made use of game theory in mathematics to discuss logical and linguistic phenomena. Game theoretic semantics provided procedural accounts to issues such as quantifier interpretation and reference assignment for anaphora in natural language, and that makes the theory worth our attention.

Game theory takes the interpretation of first-order logical formulae as a hypothetical game between two parties: Nature and Myself or I.³ The game is a zero-sum game(i.e. a win-or-lose game). Given a formula S , the game is played with each

² Hintikka (1974, 1976a,b, 1979a,b,c, 1982) and papers by others which appeared in Saarinen (ed) (1979), and Hintikka & Kulas (1983, 1985).

³ These two parties can be personified by other names or do not have to be personified at all.

party taking turns in reducing S into simpler structures S' , S'' , etc.,⁴ eventually leading to variable-free and operator/connective-free atomic sentences. Each party tries to beat the other, in the case of I , by trying to produce a true atomic sentence, and in the case of Nature, by producing a false one. A successful theory of semantic interpretation lies in building a winning strategy for I in every circumstance, in face of each type of logical formulae. The winning strategies ensure that if the truth of a formula can be verified, then I will always win. If I lose, then the formula cannot be true. Here are some winning strategies given by Hintikka (1974, 1976a):

Given a domain of individuals D on which all the predicates of the language in question (L) are interpreted and assuming that the only free singular terms of L are proper names of members of D . This in turn means that each atomic sentence built up of the predicates of L and of the names of the members of D has a definite truth-value, true or false.

In the games $G(S)$, (G standing for game and S , a first-order sentence of L), at each stage, a sentence S' is being considered (S' belonging to L or to a slight extension of L obtained by adding to it a finite number of names of members of D).

- (1) (G.E) If S' is $(\exists x)F(x)$, I choose a member of D , give it a proper name (if it does not have one already that can be used), say ' b '. The result being

⁴ S' and S'' stand for simpler sentences derived from more complex ones. They are not to be understood in the terms of X' -syntax in GB theory.

$F(b/x)$. The game is then continued with respect to $F(b/x)$.

- (2) (G.U) If S' is $(x)F(x)$, the same happens except that Nature chooses b [i.e. Nature makes the first choice].
- (3)(G.V) If S' is $(F \vee G)$, I choose F or G , and the game is continued with respect to it.
- (4)(G. \wedge) If S' is $(F \wedge G)$, the same happens except that Nature makes the choice.
- (5)(G. \sim) If S' is $\sim F$, the roles of the two players (as defined by the rules (G. \exists), (G.U), (G.V), (G. \wedge), (G. \sim), and (G.A)) are reversed and the game is continued with respect of F .
- (6)(G.A) If A is true, I have won and Nature lost; if A is false, vice versa [A = an atomic sentence].
- (7)(G.T) S is true iff I have a winning strategy in $G(S)$ [T = truth].

Other complexities can be derived from the above rules. For example, S' of the form $P \rightarrow Q$ can yield $\sim P \vee Q$. Games dealing with multiple quantifications can be played by applying rules to each of the quantifiers in turn, from outside in. That is, given S of the form

$$(8) \quad \forall x \exists y F(x, y)$$

then $\forall x$ is dealt with first. Applying the (G.U) rule, Nature chooses a member from D , say, b , producing S' of the form

$$(9) \quad \exists y F(b/x, y).$$

Then it is my turn. Applying the (G.E) rule, I choose a member from D, e.g. c, yielding S":

$$(10) \quad F(b/x, c/y) \Rightarrow \\ F(b, c).$$

But in making this move, I am making a conscious choice, with the full knowledge of what Nature's last move is. The c I chose is therefore dependent on Nature's choice in the last move. Whenever a name, e.g. n_i is chosen by Nature with regard to S, I return him with a name n_j . The game then goes on. If the value of n_j does depend on n_i , then I win. If whatever individual that Nature comes up with, I can always produce a compatible individual satisfying the truth of the atomic $F(n_i, n_j)$, then the formula $\forall x \exists y F(x, y)$ is true. What results from this case is an interpretation that gives us exactly the same result as Skolemization:

$$(11) \quad \exists f \forall x (x, f(x)).$$

In the case of

$$(12) \quad \exists x \forall y F(x, y),$$

I make the first move, producing

$$(13) \quad \forall y F(b/x, y).$$

(14) $F(b/x, c/y)$,

In the last two cases of multiple quantification, each party chooses with the complete knowledge of all the previous moves. But if one only gets partial information, then he chooses with reference to the incomplete information he has about the game. That gives us cases of branching quantification. For example, given

the game can be played in a way that the two parties deal with one branch at a time.

Nature first produces

Then I produce

⁵ Alternatively, Nature can come up with a different name for the value of y in (14), e.g. d/y , e/y , etc. But under each choice of Nature, I always win, for $\{c, d, e \dots\} \subseteq D$.

Nature produces

I in turn come up with

The dependency relations are equivalent to the Skolemized form

When dealing with the inter-branch reading of the same structure,⁶ Nature may choose individuals for both of the universal quantifiers at the same time, producing

I then substitute u , and w with individuals, with the complete knowledge of what Nature's twin moves are, producing

⁶ Cf. the discussions in Chapter 1 of this thesis.

$$(22) \quad F(b/x, c/u, d/y, e/w)$$

But this time, the dependency relations are different. It is an inter-branch interpretation of the form

$$(23) \quad \exists f \exists g \forall x \forall y F(x, f(x, y), y, g(x, y))$$

That is, it is equivalent to

$$(24) \quad \forall x \forall y \exists u \exists w F(x, u, y, w)$$

1.2. Game-theoretic Semantics and the Interpretation of Quantifiers in Natural Language

Hintikka applied game theory to the study of natural language quantification, establishing Game-theoretical Semantics. The application is straightforward. Some of the details are quoted here:

- (25) (G.some) X - some Y who Z - W [My Choice]
 \Rightarrow X - b - W , b is a(n) Y , and b Z .
 (X -- W marks an arbitrary syntactic environment)
- (26) (G.every) X - every Y who Z - W [Nature's Choice]
 \Rightarrow X - d - W if d is a(n) Y and if d Z .
- (27) (G.and) X and Y [Nature's Choice]

- \Rightarrow X, or Y. [the clausal *and*]
- (28) (G.or) X or Y [My choice]
- \Rightarrow X, or Y.
- (29) (G.neg) $\text{neg}^+[X]$ [Players shift roles as defined by the game rules, and
the game is continued w.r.t. X.]
- (30) (G.if) X if Y [My Choice]
- $\Rightarrow \sim Y$ or X.

Rules (6)(G.A) and (7)(G.T) apply to the study of natural language as well. Quantifiers and other operators in natural language are used with constraints related to their lexical properties. Many more details have been worked out in the literature cited in Footnote 2, including the use of *any*, *a certain*, *the*, anaphora and non-standard quantifiers.

To see how Game-theoretical Semantics deal with multiple quantification in natural language with standard quantifiers, here is an example provided in Hodges (1983):⁷

- (31) Everybody in Croydon owns a dog.

Applying rule (26)(G.every), Nature makes the first move by producing someone who lives in Croydon, say, Bill. Then we have

⁷ Detailed steps are my formulation. Hodges (1983) explained the game procedure in a simplified way, similar to the pure logical study introduced in Section 1.1 in this chapter.

(32) Bill, if Bill is in Croydon, owns a dog.

Applying rule (30)(G.if), I produce a further disjunctive choice between

(33) Bill is not in Croydon.

and

(34) Bill owns a dog.

Applying rule (28)(G.or), I choose (34). Applying rule (25)(G.some), I make a move by producing a dog, say *Fido*. So we reach the following sentence:

(35) Bill owns Fido and Fido is a dog.

Applying rule (27)(G.and), Nature produces

(36) Bill owns Fido.

which is an atomic sentence.

Rule (6)(G.A) now applies. I win if and only if the dog I produced belongs to the person Nature produced. If each time Nature brings up a person living in Croydon, I can always name a dog that belongs to him, then by rule (7)(G.T), my winning

strategy works and the truth of (31) is proved.

In the next case (37), it is pragmatically easier to find another reading by which everyone in Croydon loves the same dog.

(37) Everyone in Croydon loves a dog.

In this case, in order to derive the wide scope effect of the indefinite, I believe there are two ways of playing the game. According to the first way, I take the initiative by applying rule (25)(G.some) and produce a sentence with *Fido* substituting *a dog*, then the game will move on. And I win if and only if each and every individual Nature names loves *Fido*. According to the second way, Nature takes the first step by applying rule (26)(G.every). I will eventually produce *Fido* by applying rule (25)(G.some) no matter which individual Nature named in the previous move. Again I win if *Fido* is unanimously loved. This second method can be viewed from a different perspective. My move in applying (G.some) can be made without taking notice of the individual Nature names in applying (G.every). Now with the first method, I set out with the wide-scope reading of the existential QNP. With the second method, if I look at the issue from one angle, then I set out by assuming the wide-scope reading of the universal QNP, but end up with a type similarity of the variable binding construal of the existential QNP, which is similar to the wide-scope reading of the existential QNP. If, with the second method, I look at the issue from a different angle, in relation to incomplete information, then I established a branching reading of (37). All the three readings are equivalent. That is why both ways worked, and both

versions of interpretation in the second method worked as well.⁸

Branching quantifiers in natural language create added complexities for the conducting of language games. Although no exact details seem to have been worked out with regard to the famous branching cases supplied by Hintikka (1974), it is possible to propose some rough sketches here, along the lines by which other issues are tackled in the theory. We look at two cases here:

(38) Every writer likes a book of his almost as much as every critic dislikes some book he has reviewed.

(39) Some relative of each villager and some relative of each townsman hate each other.

In the case of (38), Nature makes the first move by rule (26)(G.every) and replaces *every writer* with an individual, say, *J.R.R. Tolkien*. Steps later, I apply rule

⁸ Hintikka (1979a) proposed two general principles of ordering of rules:

(i) (O.comm) A game rule must not be applied to a phrase in a lower clause if some rule can be applied to a higher one(i.e., to a phrase in a clause dominating the former).

(ii) (O.LR) When two phrases occur in the same clause a rule must not be applied to the one on the right if a rule can be applied to the one on the left.

Principle (i) strengthens the outside-in order of interpretation, i.e. from higher clauses to lower ones. Hintikka thought principle (ii) helps explain why (31) has a preferred linear reading. If (ii) is to be observed, then only the second way of game playing that I gave can be adopted. Although Hintikka also gave some special principles of ordering that can overrule the general ones, they do not apply to our case here, as they are related to the relative orders between rules for *any*, *some*, *each*, on the one hand, and rules for *not*, *if*, *and*, on the other.

(G.a)(which is equivalent to (25) (G.some)) and choose a particular book, say, *Lord of the Rings*. Nature later chooses a critic, say, *Noam Chomsky*, in place of *every critic*. I then come up with *Verbal Behaviour*, in place of *some book*. The rest part of the game is of no more interest to us here.⁹ What is important here is that, unlike case (15) in pure logic, the two branching clusters of QNP's can be separately introduced, according to their relative argument positions in a sentence. The second cluster is dealt with much later. So an interpretation of branching cases is possible without having to actually interpret the structure in a parallel, simultaneous way, as the branching formula of (15) seems to suggest.

But (39) does require us to interpret the two branched clusters of QNP's first, in a parallel way, before moving on to the rest part of the sentence, since the two branches are conjoined by a phrasal *and*. A tentative formulation of the game goes like this:¹⁰

In the sentence S for (39), we first deal with the conjoined structure *Some relative of each villager and some relative of each townsman*. Nature produces the first conjunct. Then Nature goes into a sub-game and produces an individual in place of *each villager*,¹¹ I make the corresponding move by giving an individual for *some*

⁹ I omit discussion on how pronouns are interpreted here.

¹⁰ 'tentative' because Hintikka did not provide an explicit rule regarding the use of phrasal *and*.

¹¹ Here the Universal QNP is dealt with first, rather than the existential QNP because of the role played by the word *of*, which creates inversely-linked structures in English. It is possible to compose a rule (G.of) requiring the rule related to the QNP to the right of *of* be applied first. Exact details are not our concern here.

relative. We then exit this sub-game. I choose the second conjunct. We go into the second sub-game. When emerging from that sub-game, the game moves on, eventually dealing with the anaphor *each other* and finally yielding an atomic sentence.

1.3. Principal Features of the Game-Theoretical Approach

Some principal features of the game-theoretical approach emerge from the above discussions. From a general point of view, taking into consideration of the approach in dealing with quantification both for pure logic formulae and natural language sentences, game theory offers a procedural account of the semantics of quantification. It systematically eliminates the quantifiers and replaces the quantified variables with names for individuals as constants. This process involves conscious searching and finding of an individual with reference to contextual information available to a player of the game. Perfect information of previous moves yields dependency between names; imperfect information weakens or prevents the construction of dependency links. Hence the outcome is a functional interpretation of the quantified structures in first-order logic and in natural language that are directly representable in a second-order interpretive form with Skolem functions. Such a process involves eliminating a complex structure to its atomic ones. In doing this, game theory assigns a non-trivial and formally explicit role to the concept of a stepwise evaluation process which proceeds from outside in. That is, it is carried out by dealing with the most inclusive quantifier first, going stepwise to the embedded ones. Therefore, it is markedly different from the Tarskian-styled inside out process of interpretation, whereby the most embedded quantifier-free formula is assigned some

tentative value first, moving stepwise outward. Hintikka thought that only the outside-in approach can give an adequate account of finite partially-ordered formulas, i.e. branching quantifiers, because an inside out operation is carried out in total oblivion of the branching structure that lies ahead of it. Therefore, the inside out approach, based on strict compositionality, cannot handle branching quantification, which in the game-theoretic approach, poses no problem.

From a linguistic point of view, game-theoretical semantics is, as its name suggests, purely semantic, in the sense that it is not related to any structure building process that reconstructs the syntactic structure of the formula involved. It is a rule-governed replacement process that breaks the given sentence into its atomic parts. Language variations are directly encoded into the rules of the game and into the order of rule application. Semantic interpretations are directly carried out as proof steps on logical formulae, which are built up according to the truth conditions of each of the logical operators involved.

But the procedural aspect of game theory is not to be taken as an absolutely natural series of procedures. As semantic interpretation is not related to syntactic structure building, there is no indication that economy in the processing of linguistic data can be maintained. If syntactic construction is a procedural process as well, then we will have possible repetitions. That is, we might have two separate procedures, one for syntax, one for semantics. On the other hand, the concept of procedure in semantic interpretation in game theory seems to have lost its force somewhat as well. Due to theory-internal reasons, turn-taking in the playing of games is related to particular

quantifiers or other operators we are dealing with. Each rule of the game will specify who takes the initiative. That takes away the naturalness of a procedure and makes it extremely difficult for a structure-building procedure to be constructed that will be compatible with this semantic procedure.

Hintikka (1979c) took his games as 'games of exploring the world, of verifying and falsifying sentences...' The technicality behind the game theory is identical to some other methods of truth verification. An examination of the verification aspect of the game theory is provided in Appendix A.

It is now known that verification procedures suffer from computational efficiency problems and therefore cannot be psychologically real. Demonstrative examples are given in Appendix A.¹² Moreover, from our point of view, natural language understanding is a deductive process, not a verificational one. In the case of quantification in natural language, the target is to formulate a procedural theory that predicts the right dependency relation without having to go into actual verification processes by exhaustive variable-replacement and without having to construct a refutation procedure looking for negation-by-failure outcomes. For this reason, we do not think Hintikka's approach is in the right direction, although we take side with him in assuming underdeterminacy of natural language content and in endeavouring to

¹² de Queiroz (1994) also remarked that

"Despite [the] great merits [of Game-Theoretical Semantics] in clarifying a number of issues regarding the semantics of the language of mathematics and the role of the explanation of the (immediate) consequences one can draw from a proposition in determining its meaning, this view does not seem to reflect the truly individual nature of the mathematician's activity."

construct procedural accounts of natural language understanding, especially with reference to branching quantifiers.

2. From the ϵ -Symbol to the η -Symbol

This section presents an important technique: to use alternative symbols in place of standard quantifiers for deductive purposes. We trace the evolvement of the notion ϵ -symbol in logic studies, beginning from its inception in Hilbert's ϵ -calculus, to its transformation into an abstractor over the labels in de Queiroz & Gabbay (1995), to the related η -symbol as a metavariable over Skolem constants in Gabbay (1994a), the last symbol being adopted by Gabbay & Kempson (1992b) in the study of natural language quantification.

2.1. The ϵ -Calculus

In the procedural analysis of quantification in the game-theoretic approach, quantifiers are dropped and the variables are substituted by individual constants. This practice can be traced back to Hilbert & Bernays (1934, 1939), who proposed to replace $\exists x\phi$ by the sentence $\phi[\epsilon x\phi/x]$, where ' $\epsilon x\phi$ ' is interpreted as 'the element I choose among those that satisfy ϕ '.¹³ The $\epsilon x\phi$ is called the *epsilon term* and can be seen as a triple $\langle \epsilon, x, \phi \rangle$, of a control parameter ϵ (the ϵ -symbol), a variable x and a formula ϕ in which x occurs free: ' $\epsilon x\phi$ ' then characterizes a variable x existentially bound in ϕ ' (Meyer Viol 1995). Hilbert also invented *the tau term* to replace $\forall x\phi$:

¹³ Hilbert & Bernays (1934, 1939), requoted from Hodges (1983).

$\tau x\phi$, in which τ is a control parameter different from ε and x is universally bound in ϕ . In fact, we can use the ε -symbol in place of both \exists and \forall quantifiers, as the latter can be expressed by existential terms as a matter of conversion in predicate logic, i.e. $\forall x\phi = \sim\exists x\sim\phi$. In de Queiroz & Gabbay (1995), the form ' $\varepsilon x.(f(x), a)$ ' is used as a dual form to the ' $\Lambda x.f(x)$ ' terms of ' $\forall x^D.F(x)$ ', (a being the witness chosen at the time of assertion; the superscripted **D** denoting the domain of x). We will have more to say about the Q&G convention later.

Operations on ε -terms constitute the ε -calculus. According to Leisenring (1969), Hilbert and Bernays (1934, 1939) used the ε -calculus only in a subsidiary role to prove that certain deductions in the predicate calculus can be rewritten in a simpler form. ε -calculus, according to the Second ε -Theorem of Hilbert and Bernays, is an 'inessential extension' of the predicate calculus, in the sense that if A is deducible from a set of formulae X in some language L_ε , then A is deducible from X in the predicate calculus. But if the system L_ε can be proven to be sound and complete, then ε -calculus exists on its own.¹⁴ Following Leisenring (1969) and the references cited therein, we take the ε -calculus as a formal system in its own right.

Simply put, the ε -calculus is first-order predicate calculus adjoined by the ε -symbol as a new logical constant. The ε -calculus in the version presented by Leisenring (1969), has two characteristics: First, the notion *arbitrary individual symbols* is used, in the form of a_1, a_2, \dots , denoted by a, b , and c , instead of the notion of *free variables* used by others (as contrary to *bound variables*), for example, Quine

¹⁴ Cf. Leisenring (1969) and the literature cited therein for the actual proofs.

(1952).¹⁵ Like the predicate system in Lemmon (1965), *arbitrary symbols* are never bound by the operators. Second, the logical constants, in addition to the familiar ones, include the ϵ -symbol, the formation rule for the ϵ -term, i.e. $\epsilon x\phi$, and its well-formedness condition.

ϵ -terms, relate themselves to standard quantifiers in the following way:

$$(40) \quad \exists x\phi \leftrightarrow \phi(\epsilon x\phi)$$

$$(41) \quad \forall x\phi \leftrightarrow \phi(\epsilon x\sim\phi)$$

According to Leisenring (1969), the ϵ -term $\epsilon x\phi$ says 'an x such that if anything has the property ϕ , then x has that property.' Leisenring pointed out that since the ϵ -symbol selects an arbitrary member from a set of objects having some given property, this symbol is often referred to as a 'logical choice function'. Carnap (1961) also remarked that the meaning of ϵ is specified only to the extent that any non-empty set has exactly one representative which is an element of the set. 'If the set has more than one element, then nothing is said... as to which of the elements is the representative, either officially or unofficially,... Thus, for example, $\epsilon x(x = 1 \vee x = 2 \vee x = 3)$ must be either 1, or 2, or 3; but there is no way of finding out which it is.'

With this conception of the ϵ -term, there is no further attempt to construct dependency relations between the term and other logical objects. Hilbert introduced

¹⁵ Also named as *arbitrary symbols*, *arbitrary constants*, *arbitrary names*, or simply as *individual symbols*. This last term is not to be confused with *names* or *proper names*, i.e. names of definite objects in Lemmon's system. In Leisenring's system, there is not a category for *proper names*, which is included in (*arbitrary*) *individual names*. Their difference from Fine's notion of *arbitrary objects* will be given shortly.

the ϵ -symbol for the purpose of facilitating proof-theoretic investigations of logic and mathematics, with the ultimate purpose of axiomatizing the whole ^{of} \wedge mathematics. In Leisenring's words, 'the significance of his ϵ -Theorems is that a given deduction in the predicate calculus can be converted, using the ϵ -calculus, into another deduction of a certain special form in the predicate calculus.' The ϵ -symbol, therefore, only plays an interim role, and that role is purely syntactic. Consequently, the interpretation of the ϵ -symbol is unimportant in Hilbert's program. Leisenring (1969), drawing results from others, did formulate a semantic interpretation for the ϵ -symbol, his choice function Φ . But his efforts did not go beyond finding a proper interpretation for the ϵ -term. So long as the ϵ -term is interpreted in a model by being assigned a value through the choice function Φ , then no more task is imminent. For in ϵ -calculus, there is no way of knowing which individual is being selected by Φ . Any attempt in specifying the chosen arbitrary individual will have to involve further selections of value and specifications of value dependency for the ϵ -term. But such type of 'choice after the choice', i.e. after the choice function Φ is not available in the ϵ -calculus.¹⁶

2.2. The ϵ -Symbol in the Labelling Algebra

In the ϵ -calculus, the ϵ -term substitutes Q -expressions in the logical formulae. In de Queiroz & Gabbay (1995), which provides a functional interpretation of quantified formulae, the ϵ -symbol is used in a new sense. The ϵ -symbol is now used as an abstractor in the labelling algebra, in a dual form to the Λ -symbol representing in the labels the \exists - and \forall - quantifiers, side by side to the standard Q -expressions which reside in the formula side. First-order deduction over the Q -expressions in terms

¹⁶ Fine (1985) talked about the possibility of developing a generic semantics for the ϵ -calculus, but to my knowledge, that has not yet come out. Cf. Section 2.3 for discussions on the relationship between Hilbert's ϵ -symbol and Gabbay's η -symbol.

of elimination or introduction is mirrored by functional application over the labels involving arbitrary individuals, the abstractors, and other operators. The labelling algebra thus adds a semantic dimension to the syntactic operations in the formulae. The details of such operations are not our concern here and are included in Appendix B for reference. What we want to note here is the shifting of the role of the ε -symbol from a logical constant in the formula to a symbol in the labels. We also take note of the introduction of the Λ -symbol as the dual form of ε , thus typographically making a distinction between symbols related to different Q-expressions.

In de Queiroz & Gabbay's system, standard quantifiers still have their place in the formulae. But if the formulae side is assumed by semantic types as in LDS_{NL} , then there will be no place for the first-order quantifiers at all. We will have to project QNP's directly as terms on the labelling side. That is what Gabbay & Kempson (1992b) did, which we will examine in the next chapter.

2.3. The η -Symbol

It was in Gabbay (1994a) that a new form of ε -term was introduced, which formed the basis of the treatment of quantification in natural language in Gabbay & Kempson (1992b). Working on the formula side, Gabbay introduced the η -function for \exists -elimination:

$$\begin{array}{c}
 (42) \quad \exists x \phi(x) \\
 \hline
 \phi(\eta)
 \end{array}$$

where η is a Skolem constant subject to some rules and restrictions. Gabbay considered η a generalised Skolem operator which can be realized as η -variables: u, v, w, \dots η -variables are metavariables over the labels. The η -function is a generalised sort of ε -function developed especially for deduction in LDS, having the general form $\phi(\eta x \phi(x, y), y)$. The η variables get instantiated as arbitrary names which directly participate in the proof deduction and through Skolemization, we can obtain arbitrary names having their dependency relations fixed: Skolem constants.

Gabbay's η -function as a generalised sort of ε -function can be traced back to Hilbert & Bernays (1934, 1939). As briefly mentioned in Leisenring (1969), Hilbert & Bernays initially defined the ε -symbol in terms of the η -symbol. Leisenring mentioned a η -rule which goes as follows:

(43) **The η -rule**

If a formula $\exists x A$ is an axiom or is derivable, then $\eta x A$ can be introduced as a term, and the formula $A(\eta x A)$ can be taken as an initial formula, i.e. from $\exists x A$, one can infer $A(\eta x A)$.

The ε -symbol is then defined as (44):

$$(44) \quad \varepsilon x A =_{\text{Df}} \eta x (\exists y [A]_{xy} \rightarrow A).$$

From (44), we can derive (45):

$$(45) \quad \exists x A \rightarrow A(\varepsilon x A)$$

Therefore, Hilbert & Bernays dispensed with the η -symbol and took the ε -symbol as a primitive. Hence the ε -Calculus. So we see that the η -function in Gabbay (1994a) is a re-defined notion, reassociating the discarded η -symbol in Hilbert & Bernays (1939) to the ε -symbol and putting the former as a generalised form of the latter.

In the system of Gabbay (1994a), the η -symbol and the Skolem constant reside in the formulae, not in the labels. The predicate language of the formulae contains two types of variables: ordinary variables for the quantifiers denoted by $\{x, y, z, \dots\}$ and η -variables for Skolem constants denoted by $\{u, v, w, \dots\}$. The η -symbol as the Skolem functor is also included in the predicate language. Omitting other details, the relevant well-formed^{ness} _{Δ} conditions are:

- (46) If $\alpha: A(x, y)$ is a labelled formula, x an ordinary variable and u is a set of η -variables, then $\eta[\alpha: A(x, y), u]$ is a term.

Gabbay's system operates on a labelled metabox system. I quote the definition for quantified metabox system:

- (47) A quantified metabox system is comprised of the following components:

A finite partially ordered system of metabox names $\{a_i, <\}$. In addition, with

each metabox name \mathbf{a} , a finite set of η - variables $\mathbf{U}(\mathbf{a})$ is associated, together with a substitution [function] $\theta_{\mathbf{a}}$ to these variables (e.g. we can allow $\theta_{\mathbf{a}}(u) = t$ subject to certain restrictions.)

The rules of quantifiers now take the following new forms:

$$(48) \quad \forall I \quad \frac{\alpha: \quad A(\eta x [A(x), \mathbf{U}(\mathbf{a})])}{\alpha: \quad \forall x A(x)}$$

$$(49) \quad \forall E \quad \frac{\alpha: \quad \forall x A(x)}{\alpha: \quad A(t)}$$

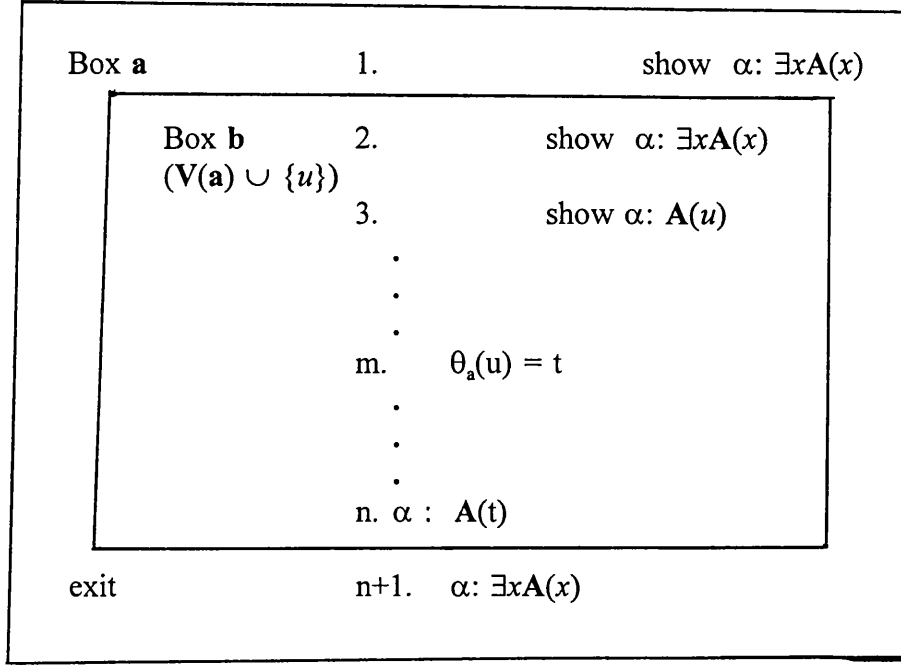
$$(50) \quad \exists I \quad \frac{\alpha: \quad A(t)}{\alpha: \quad \exists x A(x)}$$

$$(51) \quad \exists E \quad \frac{\alpha: \quad \exists x A(x)}{A(\eta x [\alpha: A(x), \mathbf{U}(\mathbf{a})])}$$

To see how the quantifier rules work in a metabox system, I present $\exists I$ as one example:¹⁷

¹⁷ Adapted from Gabbay (1994a) and enriched with my understanding.

(52) $\exists I \quad \dots \vdash \alpha : \exists x A(x)$



Imagine we are at a certain line in a box **a**, with a goal to show $\alpha : \exists x A(x)$. We open a new box **b** and choose a new η -variable u , with the new goal of showing $\alpha : A(u)$. If this new goal can be fulfilled, then by the rule $\exists I$, the original goal can also be proven. We associate $V(a) \cup \{u\}$ with **b**. The original (unproven) goal is carried forward into **b**. At some later stage m , we instantiate the η -variable u by making its value relevant to the metabox **a** be equivalent to t , t a Skolem constant serving as a term. We therefore reach $\alpha : A(t)$ at Step n . Hence we exit box **b** at $n+1$ with the original goal fulfilled.

For linguistic utilities in LDS_{NL} , it is possible to plant the η -function into the labelling algebra, while keeping the formula side for the types. The η -variables then take the place of the Q -expressions in natural language. They are to be reduced to arbitrary individuals which are later instantiated into Skolem constants through the θ -

function, as shown in (52).

We now turn to a survey of techniques related to variable instantiation and value assignment in logic, which directly relates to the interpretation of arbitrary individuals reduced from the η -variables.

3. Constructing Dependency Relations

Explicit formulations of instantiation mechanisms were proposed in Fine (1985) in conjunction with his studies on *arbitrary objects*. Fine's techniques got enriched in Meyer Viol (1995). Value instantiation assumes the existence of arbitrary individuals. We survey Fine's theory of arbitrary objects in 3.1 and the instantiation mechanisms in 3.2.

3.1. Reasoning with Arbitrary Objects

In Fine (1985), we see another approach to the study of quantification without the sole reliance on technicalities in first-order predicate logic. Fine's theory is constructed on the novel concept of *arbitrary objects* (A-objects for short). Given a set of individual objects (I-objects), an A-object is an entity abstracted out of the I-objects. Its value is associated with an appropriate range of I-objects. It has those properties common to the I-objects in its range. An A-object can be used as an individual in an abstract sense. So we can talk about an arbitrary number a having properties such as divisibility by a number n , $n > 1$ and $n \neq a$ itself. But we are not talking about specific

numbers such as 4, 144, or 275. Likewise, we can talk about an arbitrary professor *PF* at Oxford who met with others to discuss fantasy writing every week in the early forties. We can include *PF* into a group called *the Inklings*. We can talk about the ways *PF* influenced English literature with his activities. But we are not talking about a specific person, be it *J.R.R. Tolkien* or *C.S. Lewis*, or any others. In fact, given the generic and abstract nature of an A-object, we cannot reduce it into a specific individual, unless, by happenstance, the A-object asserts a set which is a singleton. But this is by pure coincidence, by which the level of abstraction and the level of specific objects happen to be isomorphic. Conceptually, the distinction between an A-object and an actual object should be clearly maintained. So we can talk about an arbitrary (living) professor, but we cannot have tea with him. This makes the A-object semantically different from an arbitrary individual symbol, which an ϵ -term stands for (in ϵ -calculus) or an arbitrary name (in Lemmon's system). An arbitrary individual is arbitrary in the sense that it is arbitrarily chosen from a given set, as a representative, but an arbitrary object is arbitrary in the sense that it is an abstraction of the individuals in the given set. From an arbitrary individual symbol a , we cannot come down to a designated individual, because a is indeterminable. But we can talk of it as being either a_1 , or a_2 , or a_3 , ..., a_{1-3} being the members of the set. From an A-object a , we cannot narrow down to an individual because a is by nature abstract. It is therefore, a fallacy to try and find a designated individual for an A-object, whereas it is not incoherent to talk about the possibility of constructing a theory to determine the exact value of an arbitrary symbol with reference to a particular system, e.g. mathematical, computational, or linguistic, depending on the information and procedure characteristic of the system.

On the other hand, an A-object is not to be equated to a generic term in philosophical or linguistic analysis, by which I mean the name of a genus, name of a kind. A generic term abstracts from all members of its kind, but an A-object abstracts from any given set of individuals. Ontologically, a generic term is the name of a kind, not an individual name, while an A-object is an individual, albeit an individual of an abstract nature. An A-object is arbitrary in at least one sense: the way it is given a name in logical deduction, i.e. either *a*, or *b*, or *c* will do. But a generic term cannot be named this way, as it is never an individual. To treat a generic term as an individual symbol is to equate the name for a set to the name of a member of that set. In first-order logic, generic terms do not exist as distinct logical categories. They are always translated into universally quantified formulae. A-objects, as we will soon see, get represented as A-names in the syntax of first-order logic as a distinct category.

We can now see that A-objects are conceived as posing a level between actual and arbitrarily chosen individuals on the one hand, and generic terms on the other. A given A-object presupposes the existence of a set of individuals, be it finite or non-finite, carrying specific names or not. As an individual itself, an A-object can be given an arbitrary name.

A first-order predicate logic incorporating the semantic concept of the A-object turns out to be similar in syntax to a ϵ -free system that uses arbitrary names instead of free variables, e.g. Lemmon (1965). According to Fine (1985), A-objects have their counterparts in syntax as A-names. A-names in Fine's system are used in the same way as arbitrary names in Lemmon's system in the sense that while quantifier-

elimination yields arbitrary names in the latter, it yields A-names in the former. Both the A-names and arbitrary names are treated as individual symbols. But as we have already seen, the two constructs are completely different in semantic content. The similarity of the two constructs in syntactic behaviour is not by coincidence. Logicians adopting a separate set of individual symbols, what Fine termed as 'instantial terms', in place of the 'free variables' are clear about the role such symbols should play in syntax, even though the way they formulate the syntactic rules may be very different. But they can differ a lot on the semantic content of such instancial terms. According to Fine (1985), instancial terms have been differently construed as meaningless marks, as variables, as names of ordinary individuals, as schematic or ambiguous names, or as A-objects. As a result, Fine can implement his A-objects to other standard logic systems with only slight modifications to the syntax, but a lot more has to be added in semantics.

Fine (1985) took three notions to be at the heart of his theory of A-objects. One is the notion of an A-object itself. The second is the notion of dependence. The third, the notion of a value assignment. An A-object takes as its value all the individuals in the set. Moreover, the value one A-object takes may depend on the value of another A-object. Conversely, the value one A-object receives may constrain the values of some other A-objects. Some A-objects can be independent in value-assignment; some dependent. Some can receive one value at a time; some can take multiple values simultaneously. This web of relationship among A-objects calls for a theory of dependency and value assignment. Fine (1985) formulated generic semantics to address the above issues.

In contrast to Hilbert's ε -Calculus, which emphasizes operation on syntactic formulae and is minimal in semantics, Fine's system is scanty in syntax and rich in semantics. Fine's system of dependency and instantiation is defined model-theoretically and are semantic in nature. However, the mechanisms we are looking for are syntactic, not semantic. Therefore we only want to borrow Fine's ideas of reasoning with A-objects. The special meaning Fine read into the A-objects does not need to be held by us wholly. In ^{the} syntax of logic, A-objects are similar to A-individuals, so what we learn _^ about the manipulation of the A-objects can be applied to systems where no A-objects appear as semantic entities.

3.2. Proof-Theoretic Treatment of Assignments

The syntactic mechanism for dependency construction in logic has been worked out by Meyer Viol (1995). The logic system L designed by Meyer Viol (1995) aims at giving assignments of valuation of terms in the formulae of the logic language, which are amenable to proof-theoretic manipulation. The system is a standard first-order language with some additional features. For our purpose, we only note down the assignment predicate $:=$, which is a binary predicate operating on the first-order formulae containing A-objects and the ε -term. As one of its functions, the predicate $:=$ can take an instancial variable to its left and a term to its right, thereby assigning a value to the variable.

I now briefly exemplify how assignment statements, dependency relations, the ε -term, and Fine's arbitrary objects are put together in Meyer Viol's system. The

example is the ϵ E- Rule:

(53) The ϵ -Elimination Rule (ϵ E):

$$\frac{\exists x\phi \qquad \epsilon x\phi := a}{\phi[a/x]}$$

This was illustrated by Meyer Viol with a well-known example from Fine (1985):

- (54) A. "There exists a bisector to the angle α " $\Rightarrow_{tr} \exists x\phi$ [There is a ϕ -er]; ¹⁸
 B. "Call it a " $\Rightarrow_{tr} \epsilon x\phi := a$;
 C. "So a is a bisector to angle α " $\Rightarrow_{tr} \phi[a/x]$

Here A is the major premiss and B, the minor one. Meyer-Viol pointed out that (53) is different from the standard \exists E rule because in the latter, C would be taken as an assumption, not a conclusion.

According to Meyer Viol, semantically, the assignment $\epsilon x\phi := a$ represents a "friendly" choice of value to the variable x which has to satisfy ϕ . Given the premise $\exists x\phi$, such a friendly choice can find such an element. This justifies the conclusion. The ϵ -term represents an A-object in the sense of Fine (1985) -- a generic proper term in the proof discourse to which reference is possible in the subsequent proof (by using 'it', or 'that ϕ -er').

¹⁸ "A \Rightarrow_{tr} B" means A translates into B.

Assignments lead to choices of dependency relations. According to Meyer-Viol, assignment statements always incorporate a choice: they assign a value to a (meta)variable. And this choice is made for a specific purpose. Once we have introduced the notion of a 'considered' choice to eliminate quantifiers, it may even be possible to describe a quantifier exhaustively in terms of assignment statements with the appropriate argument. He also mentioned the possibility of describing some quantifiers which 'differ essentially in their attention to dependencies'. These are insights which we can readily incorporate into our study of natural language quantification.

There is more in (53) than meets the eye. Meyer Viol pointed out that from a proof-theoretic point of view, the proper term a in the assignment $\exists x\varphi := a$ should depend on all the individual constants occurring in $\exists x\varphi$. By consequence, the conclusion $\varphi[a/x]$ of the \exists E-rule does not hold for arbitrary a satisfying φ , but only for those that depend on the parameters in φ . Therefore, assignment leads to value dependency within a given proof-domain. Given multiple quantification, assignment of values to one A-object may also depend on the values or conditions of another Quantifier or ε -term introduced into the local proof-domain.

What Meyer Viol aims at here is to construct valuations as statements within a proof-theoretic context, which allows assignments as formulas of the language, thereby internalizing semantics into proof theory (Meyer Viol 1995). As will be shown in the next chapter, we can use the $:=$ operator (in variant forms) in the labelling algebra to instantiate values to the A-individuals. And the dependency conditions will

be made explicit with overt indexing. This is what Skolem constants are capable of, which we consider in the next section.

4. On The Status of Skolem Constants

As the notion of A-objects carries special logical-philosophical commitments, what we can choose as an alternative is to use Meyer Viol's assignment statements on Gabbay's η -variables, not on A-objects. The computational procedure is not different from a syntactic point of view. Only that the final product is a Skolem constant, not an instantiated A-object. Therefore, it is necessary for us to look into the concept of Skolem constant before we close this chapter.

From the discussion in Chapter 1 about the Skolem function, we know that because of the second-order existential quantification in (55), Skolemization usually yields only one result.

$$(55) \quad \exists f \forall x A(x, f(x))$$

Therefore, it may sound a bit weird to talk about Skolem constants, whose value may not be fixed and may vary according to the element it depends on. If that is the case, then an instantiated A-individual cannot be equated to the result of Skolemization since the former can be multi-valued. However, Fine (1984) admitted the possibility of having "multi-valued Skolem functions". In the new version of Skolemization, as presented in Gabbay (1994a), there does not simply exist a single

function with one single outcome of Skolemization. We have in fact a family of Skolemizations depending on the inputting value of the argument in the functor. Therefore, in the new version, we have a Skolem functor η standing for an array of values, and η can be realised as η variables for Skolem constants denoted by $\{u, v, w, \dots\}$. Through value assignment, an η -variable is instantiated into a Skolem constant c . In the LDS system, the Skolem functor η is presented without the Skolem function with second-order quantification in the form $\exists f \forall x A(x, f(x))$. So the new Skolem functor η can be multi-valued. Following Gabbay (1994a: 15.5), we can let the Skolem constant c take a more explicit form: c^α , meaning c depending on α .

5. Conclusion

In search for logical techniques suited for linguistic analysis, I went through several approaches to quantification in logic studies that are all procedural, among which some are also proof-theoretic, and of the latter, some adopt labelled-deductive techniques. These approaches are distinct in their offered techniques but are also closely related. De Queiroz & Gabbay (1995) observed the similarity between their functional interpretation and Hintikka's game-theoretic treatments. Hilbert's ε -calculus resurfaced in the studies of de Queiroz & Gabbay (1995), Gabbay (1994a), and Meyer Viol (1995). And Fine's A-objects are incorporated into Meyer Viol's system of assignment logic. The close link among these approaches makes it possible for us to conceive ways to unite selected aspects of these studies into our LDS_{NL} formulations. For example, we can implant Meyer Viol's assignment statements and dependency algorithms into Gabbay's η -function. And we can follow the practice of de Queiroz & Gabbay in putting operations on the η -variables and A-individuals into the labelling

algebra, and maintain the typographical as well as the interpretive distinction between the \forall - and \exists - quantifiers. The result is a new model of proof-theoretic treatment of quantifiers. This turns out to be the position of Gabbay & Kempson (1992b), which we will examine in the next chapter.

Quantification in LDS_{NL}

0. Preamble

In chapter 1, I discussed treatments of quantification in logic and natural language syntax which are modelled on first-order logic. I pointed out inadequacies of such treatments in unravelling the complexities of quantification with special reference to properties of quantification in natural language. A scope-based analysis of quantification in logic is not adequate because it cannot give an account of branching quantification, which can only be properly represented by making use of branching structures which have roots in the second-order logic with Skolem functions. But once we introduce multi-valued Skolemization in Chapter 3, we also bring in η -variables, Skolem constants and the choice of dependency. It is the different modes of dependency construal which result in the interpretation of linear and branching quantification. But given dependency, there is still one area which needs to be worked out: the reasons and procedures by which one choice of dependency is made instead of others. Now the issue seems a lot clearer: There is nothing *incorrect* with the scope-oriented representation of quantification in first-order logic. Its only shortcoming is its inexplicitness. Skolemization-based second-order representation is a lot more expressive. But in itself it still appears as a static end-product. In this sense it is still

not explicit enough. What remains to be revealed in a second-order representation is the procedural steps that lead to choices of dependency. This will be the key to our understanding of quantification. Choices are not made in total anarchy. They are constrained by logical factors and, in the case of natural language understanding, by structural and lexical factors as well. Therefore, by spelling out the exact procedures for the representation and interpretation of quantification in natural language, we also hope to reveal facts about the structure of language itself.

The QR-based approach in GB syntax (May 1985) does not live up to our expectation, even though it does make use of second-order properties (by implementing a branching structure in Σ -sequences) and loosely delimits the choices to be made in Σ -sequences, because, for theory-internal reasons, it opts for a scope-based representation in the first place, by invoking QR to form Σ -sequences. Such permutations of quantifiers are not procedurally motivated and turn out to handicap rather than facilitate the proper interpretation of quantified structures.

This chapter presents the procedural treatment of quantification in LDS_{NL} . The backbone of the analysis I will present here is Gabbay & Kempson (1992b) and Kempson (1992b), supplemented by Kempson (1994a) and Kempson (1995c). My contribution lies in the study of four topics. The first is expository: to provide the linguistic motivation to the analysis of LDS_{NL} . The second is supplementary: to associate in an explicit way the techniques of Gabbay & Kempson (1992b) with the procedural treatments of quantification in logic in the last chapter, so as to supply the logical motivations to the LDS_{NL} analysis given here. The third is comparative: to

make an evaluative comparison between the LDS_{NL} treatment of quantification and the treatments in Categorical Grammars (Pereira 1990, Morrill 1994, 1995, and Carpenter n.d.a, b) and Discourse Representation Theory (Kamp & Reyle 1993). The fourth is inter-lingual: to conduct a parallel analysis on Mandarin Chinese. The first two topics will be covered in this chapter, and I will deal with the other two topics in Chapters 5 and 6.

1. Underdeterminacy and the Referential Properties of Noun Phrases

By *underdeterminacy*, we mean the lexical and structural meaning of language does not supply adequate information for the recovery of the propositional content. This phenomenon exhibits itself in many aspects.¹ Focusing on the referential aspects of noun phrases, we can claim that no NP is fully determinable in referential content solely in terms of its lexical content.

To start with, we look at the proper names. Take (1) for example:

(1) John loves Mary.

The content seems to be well-determined. There is a person *John* and a person *Mary* such that *John* is in love with *Mary*, which translates into (1'):

(1') $L(j, m)$.

¹ Cf. Sperber & Wilson (1986, 1995) for comprehensive discussions.

And we know that names such as j or m denote particular individuals.

But natural language is not the same as logic. (1) is ambiguous in the sense that there may be more than one man named *John*, and there may be more than one woman named *Mary*. Adding surnames won't eliminate ambiguities, as there may be people sharing both surnames and given names. It depends on the world, time, location and situation ^{in which} we utter (1). Or in logic terms, it depends on the universe of discourse, which can be equated ^{with} everything in the world across all the time, present, past, and future, or it can be hooked to the individuals in a seminar room at No. 20, Gordon square on the afternoon of July 31st, 1995. Using indices to reflect these factors, (1) and (1') will have to be roughly represented as (2) and (2'):

(2) John₁₆₈₈^(w = now; t = now) loves Mary₅₈^(w = now; t = now)

(2') L(j_{1688} ^(w = now; t = now), m_{58} ^(w = now; t = now)).

(L = love)

Definite NP's are more underdetermined:

(3) John loves Mary. The man is crazy about the woman.

Taken in isolation, *the man* and *the woman* can be used to refer to people other than *John* or *Mary*. Even the deictic use of definite NP's cannot prove its determinacy. The non-ambiguity of the deictic NP is due to the use of gestures or contextual saliency in figurative use of deixis, not because of the NP itself.

To represent the second sentence in (3) in terms of logic, we can use the analysis proposed by Russell:

$$(3') \quad \exists x[Mx \wedge (\forall y(My \rightarrow (y=x)) \wedge (\exists z (Wz \wedge (\forall u (Wu \rightarrow (u=z)) \wedge C(x, z))))))] \\ (M = \text{man}; W = \text{woman}; C = \text{is-crazy-about})$$

(3') is so under-determined that it did not reflect our understanding that *the man* in the present context should refer to *John* and *the woman, Mary*.

A more complex case is the bridging-cross reference (4):

- (4) John's computer broke down again. The disk-drive won't boot up.

Here *the disk-drive* should refer to [(the disk-drive) of John's computer]. So the definite NP is to be first enriched into [(the disk-drive)_A of (one's computer)_B]_C, with *B* choosing *John's computer* as its antecedent.

Pronominals and reflexives provide even stronger cases of under-determinancy:

- (5) John loves Mary. *He* is crazy about *her*.

- (6) Zhāngsān_i yǐwéi Lìsì_j xǐhuān zìjǐ_{ij}.
Zhangsan think Lisi like self.
"Zhangsan_i thinks Lisi_j likes himself_{ij}."

In (5), *he* and *her* should refer to *John* and *Mary* respectively. The pronominals can also refer to another man and woman in another interpretation. When used non-deictically, pronominals act as place-holders (variables) in logic which need to be instantiated for their reference:

(5') $L(j, m)$.

$$\exists x \exists y F(x, y) \Rightarrow F(j/x, m/y)$$

In (6), the anaphor *ziji* (self) in Chinese can refer to either *Zhangsan* or *Lisi*, but it cannot refer to a person not mentioned in the sentence.

The binding conditions of GB serve as filters, telling us the conditions when co-reference is not possible, but they cannot tell us what exact reference is to be chosen as the antecedent.²

Similar situations can be found in the cases of PRO and pro. Take PRO for example, some mechanisms usually termed control theory is responsible to determine the reference of the PRO in (7 - 9).

(7) Peter_i promised John_j PRO_i to come.

(8) Peter_i persuaded John_j PRO_j to come.

² Cf. Pan (1995) as a recent study of the binding of Chinese *ziji* ('self').

- (9) PRO to do a Ph.D with a full-time job is like hell.

(7) is a case of subject control; (8), object control, and (9), arbitrary control.

A theory of control³ often divides verbs into types of subject and object control. But when voice comes in, the rules will have to be readjusted:

- (10) John_i was persuaded by Peter_j to PRO_i leave.

At the end of this paradigm of NP's is the indefinite quantifier, whose content is least determined.

- (11) Every student hates a lecturer.

As extensively discussed in Chapter 1, *a lecturer* can depend on *every student* for its interpretation, or it can be independent. The meaning of an indefinite is not solely reliant on its dependee. Although *a lecturer* can depend on *every student*, its lexical meaning is partially supplied by itself: *u*, lecturer (*u*). In this respect, indefinites are unlike the other types of NP's discussed above, the latter all to be *identified* or *unified* with some other individuals. But indefinites only functionally *depend* on some other NP's for interpretation. Indefinites in a given sentence cannot be reduced to a named individual and are non-reducible in nature. As this dependence is not solely specified by the encoded rules of syntax, indefinites are under-determined as well.

³ Cf. Chomsky (1980, 1981), Chomsky & Lasnik (1977), Manzini (1983).

Looking at the paradigm of NP's which are underdetermined in their referential content, we can see that all these NP's need to be represented in an underdetermined form at an initial stage. And we can also conclude that there calls for a mechanism to enrich the content of the NP's, to assign more specific reference to them by choosing some related antecedents or dependees for them.

2. Representing NP's in LDS_{NL}

The LDS_{NL} mechanism of NP interpretation as presented in Gabbay & Kempson (1992b) and Kempson (1992b, 1994a, 1995b,c) draws inspirations and techniques eclectively from the proof-theoretic approaches in logic discussed in the previous chapters. To put it in the simplest way, all underdetermined NP's project labels into the database in the form of η -variables $\{u, v, w, \dots\}$ in the sense of Gabbay (1994a), which are called meta-variables in the works of LDS_{NL} cited above. On the formula side, these meta-variables unanimously get assigned the type e . The η -variables then get enriched in several different ways, depending on the inherent specifications each meta-variable contains. The details will be presented shortly. The enriching process is procedural within the proof-theoretic discipline of LDS. In this section, I briefly outline the treatment of names, definite NP's, pronominals, reflexives, and PRO, leaving the treatment of indefinites and universally quantified NP's to the next section.

2.1. Names

The treatment of names in a sentence like (1) is given below:

(12) John loves Mary.

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) \vdash s _i , $\alpha : t$	
2.	$s_i < w_i, t_i$ [5a. $\Theta t_i = t_{utt}$] >	
3.	u_{name} , John(u) [5b. \mathcal{G}] :	e ASS.
	CHOOSE $u_j =:$ John ₁₆₈₈	
	John ₁₆₈₈ :	e
4.	love' :	$e \rightarrow (e \rightarrow t)$ ASS.
6.	v_{name} , Mary(v) :	e ASS.
	CHOOSE $v_m =:$ Mary ₅₈	
	Mary ₅₈ :	e
7.	love(Mary ₅₈) :	$e \rightarrow t$ MPP.4,6
8.	love(Mary ₅₈)(John ₁₆₈₈) :	t MPP.3,7

The interpretation of names involves picking out an exact individual bearing the proper name concerned. We first project the name as a meta-variable with the type e , with a resource specification $John(u)$ in which the name *John* predicates over the variable. Then using the CHOICE function, we identify the name with a particular individual. Finally we instantiate the meta-variable into the proper name with a fully enriched content, using a number index as a simplified symbol indicating the particular individual. Here the CHOICE function has the syntactic form of **CHOOSE** as a meta-level predicate taking the rest of the formula as its argument. The argument of **CHOOSE** predicate is an assignment statement as discussed in the light of Meyer Viol (1995) in Section 3 of Chapter 3. What **CHOOSE** does is to make an abductive on-line choice of value as an enriching process, while the assignment statement effects the instantiation of value onto the underdetermined meta-variable. Besides the instantiation of NP's, deduction over the types is routine work, as explained in Chapter

2.

In the case of names, the CHOICE is made on-line, immediately after the meta-variable is introduced. The assignment statement effects a direct identification between the variable and a chosen individual. When projected, the variable has already a side condition specifying its lexical content, which should bear a proper name. In this case, the object of choice is obviously outside the language proper, as a cognitively salient individual predicated by *John*.

2.2. Definite NP's

(13) John loves Mary.

The man is crazy about the woman.

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...)	$\vdash s_i, \alpha : t$	
2.	$s_i < w_i, t_i$ [5a. $\Theta t_i = t_{\text{utt}}$] >		
3.	$u_{\text{name}}, \text{John}(u)$ [5b. \mathcal{C}]	:	e ASS.
	CHOOSE $u_j =: \text{John}_{1688}$		
	John_{1688}	:	e
4.	love'	:	$e \rightarrow (e \rightarrow t)$ ASS.
6.	$v_{\text{name}}, \text{Mary}(v)$:	e ASS.
	CHOOSE $v_m =: \text{Mary}_{58}$		
	Mary_{58}	:	e
7.	love(Mary_{58})	:	$e \rightarrow t$ MPP.4,6
8.	love(Mary_{58})(John_{1688})	:	t MPP.3,7

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) \vdash $s_i, \alpha : t$	
2.	$s_j < w_i, t_i$ [5a. $\Theta t_i = t_{utt}$] >	
3.	w_{the} [5b. \mathcal{C}] : e $\text{man}(w) \wedge [\forall x(\text{man}(x) \rightarrow (x = w))]$ $\Theta w \notin s_j$ CHOOSE $w_{the} =: \text{John}_{1688}$	ASS.
4.	w_{JOHN} : e is'-crazy'-about' : $e \rightarrow (e \rightarrow t)$	ASS.
6.	z_{the} : e $\text{woman}(z) \wedge [\forall x(\text{woman}(x) \rightarrow (x = z))]$ $\Theta z \notin s_j$ CHOOSE $z =: \text{Mary}_{58}$	ASS.
7.	z_{MARY} : e is'-crazy'-about'(z _{MARY}) : $e \rightarrow t$	MPP.4,6
8.	is'-crazy'-about'(z _{MARY})(w _{JOHN}) : t	MPP.3,7

In (13) S_i is the same as (12). S_j involves the interpretation of definite NP's. At Step 3, the η -variable w is introduced, which has the side condition that its referent should be a man and that it has a definite referent.⁴ " $\Theta w \notin s_j$ " means its referent is not to be chosen from its own database. We then choose w to be equivalent to *John* in S_i . w is hence instantiated as w_{JOHN} . This instantiation is a bit different from a parallel instantiation in (12). There the η -variable is replaced by the chosen name *John*₁₆₈₈. But in (13), after the choice of referent is made, the η -variable is not removed, it is merely indexed with a subscript. This difference is meant to maintain the difference between names and definite NP's. Names, once identified, to assume the role of the identified object in total, and will be thus used consistently in the same situation or even many other situations. But $\underset{\wedge}{\exists}$ definite NP _{i} even if identified with a

⁴ In the formula " $\text{man}(w) \wedge [\exists x(\text{man}(x) \rightarrow (x = w))]$ ", w is an η -variable in the sense of Gabbay (1994a), which co-occurs with the ordinary variables of first-order predicate logic. η -variables are not bound in the formula.

name, does not thereby get transformed into a name in content. There is no direct correspondence. Moreover, a definite NP remains underdetermined in its very next occurrence. We will have to make another choice for its referent. So we want to keep this less determinate nature of definite NP's in notational form.

2.3. Pronominals

(14) John loves Mary.

He is crazy about her.

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...)	$\vdash s_i, \alpha : t$	
2.	$s_i < w_i, t_i [5a. \Theta t_i = t_{utt}] >$		
3.	$u_{name},$ John(u) [5b. \mathcal{C}]	:	e ASS.
	CHOOSE $u_j =:$ John ₁₆₈₈		
	John ₁₆₈₈	:	e
4.	love'	:	$e \rightarrow (e \rightarrow t)$ ASS.
6.	$v_{name},$ Mary(v)	:	e ASS.
	CHOOSE $v_m =:$ Mary ₅₈		
	Mary ₅₈	:	e
7.	love(Mary ₅₈)	:	$e \rightarrow t$ MPP.4,6
8.	love(Mary ₅₈)(John ₁₆₈₈)	:	t MPP.3,7

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) \vdash s_i , $\alpha : t$			
2.	$s_j < w_i$, t_i [5a. $\Theta t_i = t_{utt}$] >			
3.	w_{he} ,	[5b. \mathcal{C}]	:	e ASS.
	man(w)			
	$\theta w \notin s_j$			
	CHOOSE $w_{he} =: John_{1688}$			
	w_{JOHN}	:	e	
4.	is'-crazy'-about'	:	$e \rightarrow (e \rightarrow t)$	ASS.
6.	z_{her} ,	:	e	ASS.
	woman(z)			
	$\theta z \notin s_j$			
	CHOOSE $z_{her} =: Mary_{58}$			
	z_{MARY}	:	e	
7.	is'-crazy'-about'(z_{MARY})	:	$e \rightarrow t$	MPP.4,6
8.	is'-crazy'-about'(z_{MARY})(w_{JOHN})	:	t	MPP.3,7

The representation of pronominals in the present case does not look much different from the representation of definite NP's except for lack of the control features. That is, pronominals do not need to be specified as carrying definite information. But the reasons are more complex than meets the eye. Definite NP's are definite in reference, as compared to indefinite NP's such as *a man* or plurals like *men*. But the discourse antecedent of a definite NP can either be definite, e.g. *John*, or indefinite, e.g. *an actor*. Likewise, pronouns are by nature definite, although their antecedents can be definite or indefinite, e.g. *a man* or *John*. But we do not need to specify the definiteness of pronouns because their lexical form is self-explanatory. A related, deeper motivation is that the definiteness information of a definite NP is expressed by its determiner, which has to be represented. But pronouns do not contain such a marker of definiteness. So the lexical information does not give us the definiteness of pronouns. Names, on the other hand, must be encoded to denote specific individuals. So there is no need to specify their definiteness either. We learn

about the non-indefiniteness of pronouns only by observing their use, not from the lexical information. But in the case of pronouns, the other piece of use information put down as resource labels, the one telling us where to pick out the antecedent, suffices to tell us that it is not indefinite. This resource label is indispensable for the reference assignment of pronouns, hence its inclusion renders the definiteness information redundant. In the case of names, since their choice of referent is outside the linguistic context, so we do not need to lay down their choice constraints. If we wanted to do that, we would have to say, quoting Chomsky, that names are free(non-coreferential with another linguistic term) everywhere (in the linguistic context).

2.4. Anaphors

- (15) Zhāngsān yǐwéi Lǐsì xǐhuān zìjǐ
 Zhangsan think Lisi like self

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , α : t	
2.	s _i < w _i , t _i [5a. Θt _i = t _{utt}] >	
3.	u _{name} , Zhangsan(u) [5b. Ⓔ] : e	ASS.
	CHOOSE u _z =: Zhangsan ₁₉₉₇	
	Zhangsan ₁₉₉₇ : e	
4.	yiwei' : t → (e → t)	ASS.
6.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _j , β : t	
7.	s _j < w _j , t _j [10a. Θt _j = t _i] >	
8.	v _{name} , Lisi(v), [10b. Ⓔ] : e	ASS
	CHOOSE v _i =: Lisi ₂₅₀	
	Lisi ₂₅₀ : e	
9.	xihuan' : e → (e → t)	ASS
11.	w _{ziji} , θw = <L, Ⓔ> : e	
	CHOOSE w _{ziji} =: Lisi ₂₅₀	
	w _{LISI} : e	
12.	xihuan(w _{LISI}) : e → t	MPP 9, 11
13.	xihuan(w _{LISI})(Lisi ₂₅₀) : t	MPP 8, 12
14.	yiwei'[xihuan(w _{LISI})(Lisi ₂₅₀)] : e → t	MPP 4, 13
15.	yiwei'[xihuan(w _{LISI})(Lisi ₂₅₀)](Zhangsan ₁₉₉₇) : t	MPP 3, 14

Alternatively, **CHOOSE** w_{ziji} =: Zhangsan₁₉₉₇ ,

Result: yiwei'[xihuan(w_{ZHANGSAN})(Lisi₂₅₀)](Zhangsan₁₉₉₇) : t

Anaphors in English would be labelled by a resource label $\theta w \in s_j$. But their counterparts in Chinese are less constrained in reference assignment, with the only requirement that it be a grammatical subject.⁵ That is why I chose the Chinese

⁵ The reference assignment for anaphor in Chinese is still under subtle constraints. Cf. Pan (1995) for a recent study.

example (15) so as to show more options the meta-predicate **CHOOSE** has in anaphor resolution. The condition $[\theta w = \langle L, \mathbb{G} \rangle : e](L \text{ as a label})$ in (15) serves to specify the subject searching nature of the reflexive.

2.5. PRO

(16) John promised Bill [PRO_{JOHN}] to come.

M

1.	Goal: $([Label:Formula]_{w_1}, [L:F]_{w_2}, \dots) \vdash s_i, \alpha : t$	
2.	$s_i < w_i, t_i [5a. \Theta t_i = t_{utt}] >$	
3.	$u_{name}, \text{John}(u) [5b. \mathbb{G}] :$	e ASS.
	CHOOSE $u_j =: \text{John}_{158}$	
	$\text{John}_{158} :$	e
4.	promise' :	$t \rightarrow [e \rightarrow (e \rightarrow t)]$ ASS.
6.	$v_{name}, \text{Bill}(v) :$	e ASS.
	CHOOSE $v_j =: \text{Bill}_{302}$	
	$\text{Bill}_{302} :$	e
7.	Goal: $([Label:Formula]_{w_1}, [L:F]_{w_2}, \dots) \vdash s_j, \beta : t$	
8.	$s_j < w_j, t_j [10. \Theta t_j = t_i] >$	
11.	$w_{PRO}, [12. \mathbb{G}] :$	e ASS
	$w_{PRO} = \text{subject of } s_i$	
	CHOOSE $w_{PRO} =: \text{John}_{158}$	
	$w_{JOHN} :$	e
9.	come' :	$e \rightarrow t$ ASS
13.	come'(w_{JOHN}) :	t MPP 9, 11
14.	promise'[come'(w_{JOHN})] :	$e \rightarrow (e \rightarrow t)$ MPP 4, 13
15.	promise'[come'(w_{JOHN})](Bill_{302}) :	$e \rightarrow t$ MPP 6, 14
16.	promise'[come'(w_{JOHN})](Bill_{302})(John_{158}) :	t MPP 3, 15

In (16), we have a case of empty category PRO in the terms of the GB

literature. In LDS_{NL} , no empty categories are explicitly represented^{in the system}. If the typed formula of a verb requires an argument e which cannot be found, we have to insert one, which again involves the choice of a suitable candidate. The type of the verb *promise* is projected as " $t \rightarrow [e \rightarrow (e \rightarrow t)]$ ". At Step 7, we create an embedded metabox s_j with the goal of reaching s_j , $\beta: t$. When coming to Step 9, we input the verb *come*. The morphological properties of the verb lead to Step 10.⁶ But *come* is also in need of an argument of type e before it as the subject. We therefore create an η -variable w at Step 11. According to the requirement of the verb *promise*, PRO is to be controlled by the subject of *promise*. Hence the resource label " $w = \text{subject of } s_i$ ". The tracing of the subject of s_i is easy, since the \mathcal{C} sign gives us the clue. Thus w is identified with the subject of s_i : *John*. At Step 12, we mark w as the subject. When we reach a t at Step 13, we exit s_j and the inference continues till we reach a t in s_i . The practice of making the matrix verb *promise* combine with s_j first rather than the matrix object *Bill* is evidenced by the fact that the latter is optional but the embedded proposition is obligatory. Thus we see a closer link between s_j and the matrix verb *promise*.⁷

3. Quantification and Dependency in LDS_{NL}

Now we come to the treatment of quantification proper. As discussed in

⁶ I presume that if the verb is in infinitive form, then it is to carry over the tense of a previous metabox or one in which the present box is embedded.

⁷ If the matrix object does not occur, we have to project a different type for the verb *promise*: $t \rightarrow (e \rightarrow t)$. Or we can assign a unified type $t \rightarrow ([e] \rightarrow (e \rightarrow t))$, where $[e]$ is optional.

Section 1, quantifiers also give us underdetermined semantic content. In terms of standard quantifiers, an indefinite or existentially quantified NP may ^{denote} \wedge an individual, but it does not have an antecedent to be identified with. Nevertheless, an indefinite can be interpreted with reference to some other linguistic objects in its proof domain. In doing this, the indefinite, being the dependant, is dependent on something else (the dependee). But the indefinite is not identified with its dependee. An indefinite has its inherent meaning specified by its lexical content and does not act like an (ordinary) variable. It only needs to have its dependency link constructed. Therefore, the proof-theoretic enrichment of an indefinite is bound to be rather different from other NP's. In Gabbay & Kempson (1992b), the treatment of indefinites follows such a procedure: First, project an indefinite as an η -variable (also called meta-variable). Second, reduce the variable into an arbitrary name depending on an unspecified element α . Third, choose the exact value for α for the arbitrary name to depend on. Finally, instantiate the arbitrary name into a Skolem constant.

The story with a universally quantified NP is a different one. A universally quantified NP does not depend on any other elements for its interpretation. It denotes an arbitrary member of a ^{set satisfying} \wedge a certain condition. In Gabbay & Kempson's system, a universally quantified NP is first projected into an η -variable, which stands ^{den} independently in itself. When the proposition is constructed, the η -variable is closed off by a rule called *universal closure*, so that what we get is no longer one proposition, but a conjunction of propositions each of which is a α substitution instance for each member of the set of the universally quantified NP in its relevant argument

position.⁸ To make a distinction in typological convention, we use $\{u, v, w\}$ for the η -variables needing dependency, and index them with a subscripted *dep*, marking the variable to be a dependent one. We use $\{x, y, z\}$ for the independent variables and call them *free variables*, free in the sense that they do not need to depend on other elements for interpretation. So we effect a dichotomy of two types of η -variables to reflect the difference between the \forall - and \exists - quantifiers, just like de Queiroz & Gabbay (1995) in their typographical distinction between an ε -term and a Λ -term. Besides the typographical distinction, the inherent difference between the two types of quantified NP's is revealed in LDS_{NL} as resource labels indicating different instructions to interpret the two quantifiers proof-theoretically. This treatment again parallels the approach in de Queiroz & Gabbay (1995), where the distinction between the ε - and Λ -terms is reflected through the argument structures of the labels. In the case of the ε -Abstraction Rule, the specific individual a resides within the ε -abtractor, in the form of $\varepsilon x.(f(x).a)$, a being a specific individual. In the case of the Λ -Abstraction, a may reside in the EXTR predicate but outside the Λ -term and hence should be taken as an arbitrary individual: $EXTR(\Lambda x. f(x), a)$.

Note that a stands for the record of a proof step on the side of the formula.

Hence it encodes procedural information rather than merely the structural information

⁸ A proposition with a universal quantifier can be considered as being equivalent to the multiple conjunction of propositions each of which is a substitution instance by the members of the set quantified^{over} by the universal quantifier. In this sense, a universally quantified formula is considered *closed* with reference to the \forall -quantifier when it is reduced into the multiple conjunction formula. In the same vein, a proposition with an existential quantifier is equated to the multiple disjunction of propositions and the quantified formula is *closed* with reference to the \exists -quantifier when it is reduced into the disjunction formula. But an existentially quantified formula can also be considered *closed* when its value is specified as interpretively dependent on some other elements.

in the labelling algebra.

Let us see how the following two sentences are interpreted in LDS_{NL} :

(17) Every student admires a professor.

a $(\forall x, \text{student } x) (\exists y, \text{professor } y) \text{Admire}(x, y)$

b $(\exists y, \text{professor } y) (\forall x, \text{student } x) \text{Admire}(x, y)$

(18) Some student admires every professor.

a $(\exists x, Sx) (\forall y, Py) A(x,y)$

b $(\forall y, Py) (\exists x, Sx) A(x,y)$

The LDS analyses of (17-18) are given as the following:

(17a')

M

1.	Goal: $([Label:Formula]_{w_1}, [L:F]_{w_2}, \dots) \vdash s_i, a : t$		
2.	$s_i < w_i, t_i [5a. \Theta t_i = t_{utt}] >$		
3.	$x, \text{student}(x) [5b. \mathbb{C}]$:	e ASS.
4.	admire'	:	$e \rightarrow (e \rightarrow t)$ ASS.
6.	$u_{dep}, \Theta u = p^\alpha, \text{professor}(p^\alpha)$:	e ASS.
	CHOOSE $\Theta \alpha = x$		
	p^x	:	e
7.	$\text{admire}'(p^x)$:	$e \rightarrow t$ MPP.4,6
8.	$\text{admire}'(p^x)(x)$:	t MPP.3,7

Universal Closure

9. $\bigwedge x, x \in \{x \mid \text{student}(x)\}$

$\text{admire}'(p^x)(x) : t$

(17b')

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) \vdash s _i , a : t		
2.	s _i < w _i , t _i [5a. $\Theta t_i = t_{utt}$] >		
3.	x, student(x), [5b. \mathcal{G}]	:	e ASS.
4.	admire'	:	e \rightarrow (e \rightarrow t) ASS.
6.	u _{dep} , $\Theta u = p^\alpha$, professor(p ^α)	:	e ASS.
	CHOOSE $\Theta \alpha = w_i$		
	p ^{w_i}	:	e
7.	admire'(p ^{w_i})	:	e \rightarrow t MPP.4,6
8.	admire'(p ^{w_i})(x)	:	t MPP.3,7

Universal Closure

9. $\wedge x, x \in \{x \mid \text{student}(x)\}$ admire'(p^{w_i})(x) : t

(18a')

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) \vdash s _i , a : t		
2.	s _i < w _i , t _i [5a. $\Theta t_i = t_{utt}$] >		
3.	u _{dep} , $\Theta u = s^\alpha$, student(s ^α)	:	e ASS.
	CHOOSE $\Theta \alpha = w_i$		
	s ^{w_i} , [5b. \mathcal{G}]	:	e
4.	admire'	:	e \rightarrow (e \rightarrow t) ASS.
6.	x, professor(x)	:	e ASS.
7.	admire'(x)	:	e \rightarrow t MPP.4,6
8.	admire'(x)(s ^{w_i})	:	t MPP.3,7

Universal Closure

9. $\wedge x, x \in \{x \mid \text{professor}(x)\}$ admire'(x)(s^{w_i}) : t

(18b')

M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) \vdash s _i , a : t		
2.	s _i < w _i , t _i [5a. $\Theta t_i = t_{unt}$] >		
3.	u _{dep} , $\Theta u = s^\alpha$, <i>student</i> (s ^α) [5b.Ⓔ]	:	e ASS.
4.	admire'	:	e \rightarrow (e \rightarrow t) ASS.
6.	x, <i>professor</i> (x)	:	e ASS.
	CHOOSE $\Theta \alpha = x$		
	s ^x	:	e
7.	admire'(x)	:	e \rightarrow t MPP.4,6
8.	admire'(x)(s ^x)	:	t MPP.3,7

Universal Closure:

9. $\wedge x, x \in \{x \mid \text{professor}(x)\}$ admire'(x)(s^x) : t

(17a') differs from our analysis of non-quantificational examples at Step 3 and onwards. At 3, *every student* projects a free variable x , which is restricted within the universe of students, hence the resource label *student*(x). At 6, *a professor* projects a dependent variable u_{dep} whose value is underdetermined except that it be a professor. Hence the value of u_{dep} , which is an η -variable, is instantiated as p , an arbitrary individual depending on an element α whose value is to be chosen on line. Once we work out the dependency relation between the dependant p and its dependee α in the proof domain, the value of p will be instantiated. And an arbitrary individual, once instantiated in terms of its dependency, is no different from a multi-valued Skolem constant.⁹ The instantiation of the η -variable u is stated by the Θ -function, and choice of the dependee for the arbitrary individual p is stated in terms of the CHOICE function, both formalized under the name of assignment statements in Meyer Viol (1995). Back at Step 6, we now reach $\Theta u = p(\alpha)$. Then, x , the value of the free variable given at 3, is chosen to be the value of α . ^{The} dependency relation is thereby shown to be p^x . We re-instantiate p into the Skolem constant p^x labelling the type e .

⁹ Cf. Fine (1984, 1985) and de Queiroz & Gabbay (1995).

With all the premisses entered, the deduction gets under way, and the result is given at Step 8. To ensure that each and every member of x plays a role in the proposition reached, we have the rule of universal closure (19), of which Step 9 in (17a') is an application.

(19) **Rule of universal closure**

$$\begin{array}{l} \alpha: \Delta(x) \quad \Delta = \text{a database} \\ \hline \alpha: \bigwedge \Delta(x_i) \quad \text{for all substitution instances } x_i \end{array}$$

In (19), $\Delta(x)$ means Δ contains one or more instances of x . \bigwedge is a generalized form for the multiple conjunction of each of the substitution case of x_i , x_i a member of the set x . So we end up with a multiple conjunction of propositions, each one with a different member from the set X . Without the introduction of such a rule, x would not have been interpreted as a universally quantified NP.

However, at Step 6 of (17a'), the dependee available for p is not only x . Another candidate is the database label w . As an alternative, $\Theta\alpha$ can also be w . Hence we have representation (17b'), in which the value of p is instantiated as p^{wi} : e . The semantic consequence of this dependency is that, being dependent on the database label 'world', p is interpreted as a single entity, for Θu is taken as a function from the world label w , which is a singleton. Here the label 'world' is obviously a simplification. What we really want is the universe of discourse, which can be either bigger or smaller than the contingent world we are in. The set denoted by the free variable is also to be interpreted in relation to the universe of discourse.

(18a') is not much different from (17a'b'). At Step 4, the dependee available is w_i . Hence s is set to depend on w_i . However, by the assumption of Gabbay & Kempson (1992b), the logic of English is such that an arbitrary individual does not have to find a dependee as soon as it is chosen, i.e. at the time when the metavariable is input into the database. As an alternative, the arbitrary individual can wait till some other premisses are input before looking for a dependee. Hence in (18b'), s waits until Step 6, when the free variable x is entered into the database. s then chooses to depend on x . This results in an object-wide-scope reading. We thus postulate in English a delaying mechanism which gives more freedom to the instantiation process of dependent variables.

Although the delaying mechanism can hold back the dependency of an arbitrary individual till a later stage, there are constraints on the delaying. The study of this issue will be a major concern in the remaining part of this thesis.

4. Numeric Expressions and Group Readings

The motivation of the LDS_{NL} representation of numerals as informally presented in Kempson (1992b) is from the representation of the similar cases in Kempson & Cormack (1981) and Gil (1982), in which quantification over sets is used to represent numerals.¹⁰ In fact, the representational notation in LDS_{NL} is directly translatable into the representation of Kempson & Cormack (1982) and Gil (1982). But what the LDS_{NL} account can reveal while the representation of K&C(using

¹⁰ The latter representations are included here under each of the related examples.

quantification over sets) cannot be the interpretive procedure of quantifiers. Quantification over the sets is no more than a static end product.

Like other NP's, we project numerals as dependent η -variables. But this time, the variables are over sets, hence the capital letters standing for sets. Such η -variables are then reduced to arbitrary set names. When the dependee of an arbitrary name is chosen, we instantiate the arbitrary name into a Skolem constant for a set. We then create a free variable of type e ranging over the set. When the deduction is over, we apply the rule of universal closure so that each member of the set will act as substitution instances in the proposition constructed. The treatment of numerals therefore involves two stages: (I) From dependent η -variables over sets to arbitrary set names to Skolem constants over sets; (II) Re-project the Skolem constants over sets as free η -variables and close off after the database is constructed.

Now we proceed to the details, using the one single sentence (20), whose different interpretations are represented as (21) - (24):

(20) Two examiners marked six scripts.

(21) a. "Two examiners each marked six scripts."

b. $\exists E_2 \forall e \in E_2 \exists S_6 \forall s \in S_6 M(e, s)$

(21') M

- | | | |
|----|--|--|
| 1. | Goal: $([Label:Formula]_{w_1}, [L:F]_{w_2}, \dots) \vdash s_i, a : t$ | |
| 2. | $s_i < w_i, t_i [5a. \Theta t_i = t_{utt}] >$ | |
| 3. | $U_{dep}, [5b. \mathbb{C}] :$ <div style="float: right; text-align: right;">e
ASS.</div> | |
| | $\Theta U = E^\alpha, Examiner(E^\alpha), U_{dep} = 2$ | |
| | CHOOSE $\theta\alpha = w_i$ | |
| | $E^{w_i} :$ e | |
| | $x, x \in E^{w_i} :$ e | |
| 4. | mark' : | e \rightarrow (e \rightarrow t) ASS. |
| 6. | $V_{dep} :$ e | ASS. |
| | $\Theta V = S^\beta, Script(S^\beta), V_{dep} = 6$ | |
| | CHOOSE $\theta\beta = x$ | |
| | $S^x :$ e | |
| | $y, y \in S^x :$ e | |
| 7. | mark(y) : | e \rightarrow t MPP. 4, 6 |
| 8. | mark(y)(x) : | \dagger MPP. 3, 7 |

 $\wedge y, y \in S_{script}^x$

mark(y)(x) : t

 $\wedge x, x \in E_{examiner}^{w_i}$ $\wedge y, y \in S_{script}^x$

mark(y)(x) : t

In (21'), we project *two examiners* as a dependent η -variable U_{dep} . We then reduce it into an arbitrary name E^α , with the resource labels indicating that E^α be a set of examiners and that the members of the set are two. Then we choose the value of α to be w_i . We thus instantiate E as being dependent on w_i . Now we re-project E^{w_i} into a free η -variable x , x being an arbitrary member of E^{w_i} . Likewise, we deal with the numeral *six scripts*, and make it depend on x . The rest is routine. Finally we get an asymmetric dependency with the object dependent on the subject.

(22) a. "Six scripts were each marked by two examiners."

b. $\exists S_6 \forall s \in S_6 \exists E_2 \forall e \in E_2 M(e, s)$

(22')

M

- | | | |
|----|---|---|
| 1. | Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) $\vdash s_i, a : t$ | |
| 2. | $s_i < w_i, t_i [5a. \Theta t_i = t_{utt}] >$ | |
| 3. | $U_{dep}, [5b. \mathbb{C}] :$ | $\frac{e}{\Theta U = E^\alpha, Examiner(E^\alpha), U_{dep} = 2} \text{ ASS.}$ |
| 4. | mark' : | $\frac{e}{e \rightarrow (e \rightarrow t)} \text{ ASS.}$ |
| 6. | $V_{dep} :$ | $\frac{e}{\Theta V = S^\beta, Script(S^\beta), V_{dep} = 6} \text{ ASS.}$ |
| | CHOOSE $\theta\beta = w_i$ | |
| | $S^{wi} :$ | e |
| | $y, y \in S^{wi} :$ | e |
| | CHOOSE $\theta\alpha = y$ | |
| | $E^y :$ | e |
| | $x, x \in E^y :$ | e |
| 7. | mark(y) : | $\frac{e \rightarrow t}{\text{MPP. 4, 6}}$ |
| 8. | mark(y)(x) : | $\frac{t}{\text{MPP. 3, 7}}$ |

$\wedge y, y \in S_{script}^{wi}$

mark(y)(x) : t

$\wedge x, x \in E_{examiner}^y$

$\wedge y, y \in S_{script}^{wi}$

mark(y)(x) : t

In (22'), we make E^α depend on y , therefore reaching an asymmetric dependency relation in which the subject depends on the object.

Now we come to (23) and (24), the real group readings. The first issue is the representation of Branching Quantification(BQ). Looking at the quantification cases

we have dealt with so far, we see that when we want to interpret a dependent element in terms of another QP, we make the former depend on the latter. But if we want to interpret a dependent element as independent of another QP, we make the former depend on the world label, so that it is interpreted only in terms of the universe of discourse and nothing else. BQ entails that both the quantifiers are to be interpreted independently. Hence we make both of them depend on the w label. So notationally speaking, in LDS_{NL} , all indefinites and numerals are made to be obligatorily dependent. Group readings are taken as cases of branching reading. As discussed in Chapter 1, there are two types of branching quantification: the complex reading and the independent reading. The complex reading is also referred to as the complete group reading, and the independent reading, as the incomplete group reading. The distinction is to be drawn on the applicability of the closure rule (19). If we apply the closure rule on a BQ representation, we reach a state in which each and every member of set 1 interacts with each and every member of set 2 and vice versa. This gives us the complete group reading, shown below as (23) and (23'):

- (23) a. "Two examiners each marked the same six scripts."
 b. $\exists E_2 \exists S_6 \forall e \in E_2 \forall s \in S_6 M(e, s)$

(23')

M

- | | | |
|----|--|------------------|
| 1. | Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , a : t | |
| 2. | s _i < w _i , t _i [5a. Θt _i = t _{utt}] > | |
| 3. | U _{dep} , [5b. Ⓔ] : e | ASS. |
| | ΘU = E ^α , Examiner(E ^α), U _{dep} = 2 | |
| | CHOOSE θα = w _i | |
| | E ^{wi} : | e |
| | x, x ∈ E ^{wi} : | e |
| 4. | mark' : | e → (e → t) ASS. |
| 6. | V _{dep} : | e ASS. |
| | ΘV = S ^β , Script(S ^β), V _{dep} = 6 | |
| | CHOOSE θβ = w _i | |
| | S ^{wi} : | e |
| | y, y ∈ S ^{wi} : | e |
| 7. | mark(y) : | e → t MPP. 4, 6 |
| 8. | mark(y)(x) : | t MPP. 3, 7 |

 $\wedge y, y \in S_{\text{script}}^{wi}$

mark(y)(x) : t

 $\wedge x, x \in E_{\text{examiner}}^{wi}$ $\wedge y, y \in S_{\text{script}}$

mark(y)(x) : t

On the contrary, if we do not apply the closure rule, then we only know that the two groups interact. And each member of set 1 interacts with at least one member of set 2, and vice verse. So we reach the incomplete group reading, given here as (24) and (24'):

- (24) a. "Two examiners marked six scripts between themselves, in the sense that one may have marked five and the other just one."
- b. $\exists E_2 \exists S_6 [\forall e \in E_2 \exists s \in S_6 M(e, s) \ \& \ \forall s \in S_6 \exists e \in E_2 M(e, s)]$

M

- | | | |
|----|---|-----------|
| 1. | Goal: $([Label:Formula]_{w_1}, [L:F]_{w_2}, \dots) \vdash s_i, a : t$ | |
| 2. | $s_i < w_i, t_i [5a. \Theta t_i = t_{utt}] >$ | |
| 3. | $U_{dep}, [5b. \mathcal{G}] : \quad \quad \quad e$ | ASS. |
| | $\Theta U = E^\alpha, Examiner(E^\alpha), U_{dep} = 2$ | |
| | CHOOSE $\theta\alpha = w_i$ | |
| | $E^{w_i} : \quad \quad \quad e$ | |
| | $x, \quad x \in E^{w_i} : \quad \quad \quad e$ | |
| 4. | mark' : $e \rightarrow (e \rightarrow t)$ | ASS. |
| 6. | $V_{dep} : \quad \quad \quad e$ | ASS. |
| | $\Theta V = S^\beta, Script(S^\beta), V_{dep} = 6$ | |
| | CHOOSE $\theta\beta = w_i$ | |
| | $S^{w_i} : \quad \quad \quad e$ | |
| | $y, \quad y \in S^{w_i} : \quad \quad \quad e$ | |
| 7. | mark(y) : $e \rightarrow t$ | MPP. 4, 6 |
| 8. | mark(y)(x) : t | MPP. 3, 7 |

5. Summing Up

Now let us sum up the correlations between the LDS_{NL} treatment of quantification and the procedural studies of quantification in logic as presented in Chapter 3.

The LDS_{NL} 's practice of using a system different from predicate calculus on the labels to interpret quantifiers is akin to the work of de Queiroz & Gabbay (1995), but LDS_{NL} dispenses with the standard quantifiers altogether, while de Queiroz & Gabbay (1995) still keeps them intact on the formulae side, which is a standard first-order predicate system. The use of meta-variables in LDS_{NL} is to be traced to the η -variables and Skolem constants in Gabbay (1994a), which in turn is to be traced back to the ε -calculus in Hilbert & Bernays (1939), and Leisenring (1969). But LDS_{NL}

differs from Gabbay (1994a) in the sense that Gabbay's η -variables co-occur with standard quantifiers on the formulae side. The use of A-individuals is to be related to Fine (1985) and Meyer Viol (1995). Specifically, the reasoning with A-individuals and the choice of dependency is borrowed from Meyer Viol (1995) and to a less extent, Fine (1985). But A-individuals are not the A-objects in the sense of Fine and Meyer Viol. A-individuals are used in the sense of Lemmon (1965), de Queiroz & Gabbay (1995), and Gabbay (1994a). A-objects never reduce to specific individuals and poses a level between η -variables and A-individuals. We might use the concept of A-objects when dealing with *any*. But further investigations are in order.¹¹

The use of the terms for dependency is almost identical to that of Fine (1985) and Meyer Viol (1995). And the representation of dependency relations in superscripted form is borrowed from Gabbay (1994a). Assignment statements as the basis of the CHOICE function and the θ -function are from Meyer Viol (1995).¹²

One more association is to be made between the procedural treatment of quantification and the analysis of temporal sequences in LDS. In Gabbay et al. (1994), it was pointed out that the importance of the concept of time not only lies in the moments when a time factor is introduced into the database. It is also important to study the sequential, relative order when an element of a non-temporal nature is entered into the database. The construction of $\overset{\Delta}{\wedge}$ dependency between a dependant and

¹¹ As mentioned in Chapter 3, A-objects are still to be distinguished from generics. The former are individuals, albeit abstract ones; the latter are names of kinds. Generics have to be names of natural classes of objects, but A-objects do not have to be so.

¹² LDS_{NL} differs from Meyer Viol in that the latter put the ε -term in the formulae, together with the standard quantifiers.

a dependee is very much a temporal issue. The choice of dependee is related to the relative time when the dependant and the dependee are respectively introduced. This is the heart of procedural interpretation of NP's.

6. Constraints on Delaying

The delaying mechanism formulated in this chapter seems to apply quite freely in English. However, there should be constraints on delaying. Take for example, the following case involving a clause boundary:

(25) Someone believes that everyone hates him.

which cannot be understood with *someone* dependent on *everyone*. It has been claimed that quantifiers in different clauses do not interact. May (1985) further substantiated this claim by observing that quantified arguments in different clauses cannot form a Σ -sequence and are therefore always independent of each other. Hence no interaction exists. If delaying were freely applied in LDS_{NL} , (25) would be interpreted as ambiguous as well. I propose the delaying mechanism be modified¹³ by a single constraint:

Constraint on Delaying¹³

A dependent variable should be instantiated within its own database.

¹³ As will be shown in Chapter 5, with the Kempson & Jiang Hypothesis, the present constraint will be made redundant.

As a result, when *someone* in (25) has to wait till another embedded database is constructed, the constraint will come into force and the whole parsing process will halt. But the constraint will not come into play in (18b'), when delaying takes place within its own database.

The present proposal does not make use of the concept of clause boundary and is not equivalent to the claim using such a notion. In the procedural approach of LDS_{NL} , what matters more is the kind of information already input and the type of structure already constructed. Two variables belonging to a pair of linked databases cannot construct a dependency relation. Nor can a dependency be constructed if a variable is input into the database s_0 and needs to depend on another variable which has just been input into the database s_1 which is embedded in s_0 . These two cases are equivalent to the clause-boundary cases. But a variable in s_1 can depend on a variable in s_0 (s_0 embedding s_1) even if they are separated by a clause boundary. In the dynamics of database construction, as s_1 is embedded in s_0 , any information already inputted into s_0 can be made accessible to the choice function in s_1 . This is reflected in the geometry of the LDS meta-box discipline. A database s_1 embedded in s_0 can be viewed as residing in s_0 , serving as one element in s_0 . From s_1 a unique declarative unit can be derived. s_0 incorporating s_1 forms a meta-database(metabase). Therefore, in spite of the alleged clause-boundary restriction, a variable in s_1 can depend on a variable in s_0 . What is more, no delaying is involved. However, any element in s_0 , at the point of its introduction, can only be taken as being in a database different from s_1 , which is yet to be constructed. So any delaying from s_0 into s_1 is made illicit by the constraint I proposed.

The above difference in treatments leads to divergence in the analysis when dealing with the following sentence:

- (26) Every boy believes that some girl will fall in love with him one day.

In the LDS_{NL} treatment I am expanding on, *some girl* is allowed to depend on *every boy*. But such a dependency does not seem to be sanctioned by the clause-boundary argument. We therefore find Hornstein (1984) arguing for the lack of quantifier ambiguity in the following sentences:

- (27) Everyone believes that a pretty woman loves him.

- (28) Someone believes that everyone ate well.

Hornstein's judgment is questionable. Given that (26) and (27) are ambiguous while (28) is not, the LDS_{NL} treatment clearly wins over the clause-boundary thesis.

7. The Case of Mutual Dependency

Recall that in Chapter 1, I pointed out the unavailability, in natural language semantics, of an interpretation in which two quantified expressions are mutually dependent. This may happen when two dependent variables are involved, i.e. indefinites or numeric expressions. The way to debar this type of dependency comes for free in the framework of LDS_{NL} . When two variables need to find their respective value in the other, we will expect to see a loop. As analogous to a Prolog program,

when such a loop occurs, the process of database construction will grind to a halt. No further steps of logical deduction can be executed. Therefore, the goal of natural language understanding will never be attained, as a t can never be reached. Consequently, such a dependency, though not inconceivable, is disallowed. For the same reason, example (29), with a cross-binding interpretation, is also deemed ill-formed:¹⁴

(29) His wife saw her husband.

8. Remaining Issues

The treatment of quantification formulated in the present chapter is preliminary in the sense that we have yet to apply it to the analyses of a host of more complex structures of quantification as well as interactions between quantification and other phenomena such as anaphora-binding, ellipsis, control, and donkey sentences. But these issues will have to be dealt with at a later stage. In the remaining chapters, I will extend the present analysis to Chinese and compare the overall results to the treatments in Categorical Grammar and Discourse Representation Theory.

¹⁴ From May (1985), who in turn quoted from Jacobson (1977).

Extending the LDS_{NL} Approach to Chinese Quantification

0. Preamble

This chapter is an extension of the LDS_{NL} approach to Chinese quantification. The aim is twofold: A. to give an adequate account of Chinese quantification, predicting the right construal of dependency relations for various structures; B. to make a comparative study between quantification in English and Chinese, deriving typological generalizations on the syntactic and semantic structures of the two languages in the framework of LDS_{NL}.

After a survey of the study of Chinese quantification in Section 1, we set off with a straightforward application of the LDS_{NL} mechanisms to the analysis of the simplex cases in Chinese and reach a major distinction between English and Chinese: the exploiting of the *delaying mechanism* in the former and its absence in the latter. Following more discussions on the nature of the delaying mechanism, we attribute it to the difference in the status of the *subject* in the two languages and rephrase the primary discovery into the *Kempson & Jiang Hypothesis*. If the distinction between

the two languages is only related to the *subject*, then we would not expect the K&J Hypothesis to affect the quantified expressions in double object constructions, which seems to be on accord with the data in English and Chinese. But the quantificational properties related to the dative construction raise complexities that call for further investigation. A preliminary analysis of quantification involving dative constructions is thereby given. In this stepwise characterization of more complex structures of quantification, we cover more data in the two languages. But the main focus is on the development of an adequate LDS_{NL} treatment of quantification which also accounts for language variations.

1. Quantification in Chinese -- A General Survey

This first section is a general survey of the studies on Chinese quantification. In Section 1, I will give an intensive analysis of the data, in which I propose my own interpretations and which presents a clearer picture of the relevant facts in the study of Chinese quantification. Section 2 is a sketchy summary of the major literature. In the last section, I will outline the general concerns and present what I perceive to be the main issues in Chinese quantification that ought to be addressed in the LDS_{NL} approach.

1.1. The Data

In the literature on Chinese quantification, there have been more disputes over the judgments of the data than consensus. It is therefore of primary importance to re-

examine the relevant data, and to sharpen our intuition if necessary. This is all the more important in the present context, because my interpretation of data differs from the majority of the views in the current literature in one crucial aspect, which I will present in detail. Reliable judgments are hard to come by in this case, as informants have to be tested on the ambiguity rather than the well-formedness of the quantified structures. Most well-circulated claims on the ambiguity status of Chinese quantified sentences are found to be based on the author's shaky judgments for just a few sentences. The author's own intuition became the only criteria on the ambiguity of quantified structures. Some studies did solicit judgments from informants, yet in such an informal way that informants were asked to comment directly on the ambiguity status of given sentences, sometimes with their intended interpretations provided. The findings therefore cannot obtain authenticity. Scientific psycholinguistic experiments or surveys in Chinese quantification approximating those of Gil (1982) and Kurtzman & MacDonald (1993) are rare, with the notable exception of T.Lee (1986, 1989). However, the primary target of Lee's experiments was to study the children's acquisition of quantified structures. Adult's understanding of quantification may be more sophisticated than children. Therefore, ^{an}authentic study on the data interpretation _^of Chinese quantification on a comprehensive scale is still wanting. This accounts for the heterogeneity of data judgment in the literature, which has been too frequently attributed to regional variations, again without systematic analysis.¹

In this section, I will present a new picture of Chinese quantification in terms

¹ Cf. Y.Li (1995).

of data interpretation. I will argue that due to the lack of authentic experiments, the present literature does not even make the correct generalisations over the data judgments obtained through informal tests. I will trace some standard lines of argumentation in the literature leading to the choice of specific data interpretations and show them to be on shaky grounds. My strategy is that, when faced with a certain claim, I will attempt to reveal its logical implications to the semantic properties of Chinese. If some claims make unacceptable predictions, I will propose to drop them and consider the alternatives. In cases where no obvious logical implications can be derived, I will rely on my intuition to make a tentative choice, if I find my judgments to be clear-cut.

Current studies on Chinese quantification have been focusing on the following types of examples:

- (1) Měi gè rén (dōu) mǎi le yì běn shū
every CL man all buy ASP one CL book

[CL = classifier, ASP = aspect marker]

a. "For all x, x human, there is some y, y a book, such that x bought y."

b. "There is some y, y a book, such that for all x, x human, x bought y."

- (2) Zuótiān, yí gè rén mǎi le shūdiànlǐ
yesterday, one CL man buy ASP bookshop-in

de měi yì běn shū
DE every one CL book

"There is some x, x human, such that for all y, y a book in the bookshop, x bought y yesterday."

- (3) Liǎng gè lǎoshī gǎi le liù fēn kǎojiàn
two CL teacher mark ASP six CL scripts

"Two teachers marked six scripts."

- (4) Měi gè rén dōu bèi yí gè nǚrén zhuāzǒu le.
every CL man all by one CL woman arrest ASP

"Everyone was arrested by a woman."

- (5) Yàoshì liǎng tiáo xiànsuǒ bèi měi gè rén
if two CL clue by every CL man
zhǎodào le...
find ASP

"If two clues are/were found by everyone..."

- (6) Zhāngsān fàng le liǎng zhǒng shìjì zài² měi gè
Zhangsan put ASP two type acid at every CL

shìguǎnlǐ
test-tube-in

- a. "There are two types of acid x such that for every test-tube y, Zhangsan put x into y."
b. "For every test-tube y, there are two types of acid x such that Zhangsan put x into y."

- (7) Zhāngsān bǎ³ liǎng zhǒng shìjì fàng zài měi gè
Zhangsan BA two type acid put at every CL

shìguǎnlǐ
test-tube-in

² *zai* is generally considered a preposition of time, place and location, see Lü (1980). Sometimes, its object can take another postpositional word which further specifies the directionality of *zai*, as is shown by the *zai...li* sequence in (6). The reason why I did not mark out the category of *postposition* is because it is very often treated as part of the noun phrase it is attached to, for an NP plus a postposition functions exactly like an NP in terms of distribution. The postpositional word *li* also appears after the noun *shūdiàn*[bookshop], where again the combined phrase functions like an NP syntactically. Cf. A.Li (1990) for detailed discussions on the NP status of the construction NP + Postpositional Word.

³ *ba* is usually considered a preposition which, together with a noun, appears before a verb, the latter subcategorizing the noun which is preposed to form part of the *ba* construction.

(Gloss same as (6).)

- (8) Zhāngsān zài liǎng gè shìguǎnlǐ fàng le měi
 Zhangsan at two CL test-tube-in put ASP every
 zhǒng shìjī
 type acid

"There are two testtubes x such that for every acid y, Zhangsan put y into x."

- (9) Shàng gè xuéqī liǎng mén kǎoshì sānshí gè xuéshēng
 last CL term two CL exam thirty CL student
 (dōu) tōngguò le
 all pass ASP

"Last term, of the two exams, thirty students passed [them]."

- (10) Zhāngsān sònggěi le měi gè xuéshēng yì běn
 Zhangsan give ASP every CL student one CL
 shū
 book

"Zhangsan gave every student a book."

- (11) Zhāngsān bǎ měi běn shū dōu fàng zài yì
 Zhangsan BA every CL book all put on one
 zhāng zhuōzi shàng
 CL table on

"Zhangsan put every book on a table."

We start our analysis of the data from (2), which is one of the few cases in which unanimity of judgments has been reached both among the linguists working on the topic and among the native-speaker informants consulted. The sentence, with an indefinite(which in Chinese assumes the form of a numeral plus a classifier plus a bare noun) as the subject and a universally quantified NP as an object, is alleged to be not in common use. By starting the sentence with an adverb of time(which is said to serve

as the topic here, as in T.Lee (1986)) and prefixing the object with a modifying phrase (thus emphasizing the *each and every* aspect of the meaning,⁴ making it different from an object with *suoyou* ('all') or *quanbu* ('all')⁵ as the quantifier), the sentence is judged to be acceptable.⁶ In the GB literature or in the language of first-order logic, the indefinite subject is said to enjoy wide scope, and the universal object, narrow scope. From the points of view of branching quantifier analysis and second-order logic with Skolemization, the indefinite subject is considered to be independent of the universal object.⁷ The point of agreement is that the subject in (2) should never depend on the object, yielding a reading by which for each different book, there was a different person who bought it. The subject is to be understood as being definite: there was only one person who bought each and every copy of the book, either in one transaction or through multiple purchases. This marks a major linguistic variation from English. Contrary to Chinese, the equivalent English structure, such as "Someone bought every book", can be construed in two ways, with the possibility of the subject being dependent on the object. Based on this critical example, it has been widely held that Chinese does not exhibit object wide scope reading.⁸ (3) further supports this claim. The two numeric expressions in the subject and object positions can be

⁴ Cf. Vendler (1962).

⁵ Both *suoyou* and *quanbu* can be glossed as "all". Both have a collective reading, in the sense of Vendler (1962).

⁶ Cf. Lee (1986), Xu & Lee (1989), and Shen (1989) for detailed discussions on this issue.

⁷ Cf. Chapter 1 for details.

⁸ E.g. J.Huang (1982, 1983), T.Lee (1986), Gao (1989), Xu & Lee (1989), Liu (1990), Duanmu (1988), Aoun & Li (1993).

construed in 3 ways: object depending on subject, object independent of subject with the complete group reading, or with the incomplete group reading. But it never admits the reading by which the subject depends on the object, i.e. the object wide scope reading. This is again in contrast to the case in English, i.e. (12), which allows four readings.

(12) Two dogs chased three children.

The above cases led to a generalized hypothesis that in Chinese, quantifier scope is purely determined by linear order.⁹ It does extend to some cases where quantifiers take positions other than subjects and objects. (9), for example, is of the structure [TOPIC₁, TOPIC₂, SUBJECT Verb [e₂]_{NP}], where the first topic is an NP functioning as a time adverbial and the second topic can be taken as the preposed object of the verb. Only the second topic and the subject are taken by QP's. The QP in TOPIC₂ enjoys scope wider than the subject QP. In other words, the subject QP depends on the topic QP.¹⁰ (4) is another case in which the subject can also take

⁹ e.g. S.F.Huang (1981).

¹⁰ It certainly allows another reading by which the two QP's are independent of each other. In fact the independent reading is more easily available than the dependent reading, which is rather hard to get, unless used in a contrastive context, in a scenario when for each of the two exams, thirty students passed, whereas for each of the other three exams, only 15 students passed. Putting *you*[there be] between the two QPs would make the dependent reading easier to obtain, but that will change the structure of the sentence. Cf. Duanmu (1988) and Gao (1989) for discussion on the relationship between *you* and quantification in Chinese. Adding an adverbial quantifier *dou*[all] still yields the branching reading.

wider scope than the QP in the *bei*[by]-phrase to the right of the subject.¹¹ In our terms, the latter depends on the former. Likewise, most native speakers consider (5) as unambiguous, though Aoun & Li (1993) reached the contrary conclusion. But the linear-precedence argument is not a fail-safe criterion. In J.Huang (1983), Aoun & Li (1989), Shen (1989) and Xu & Lee (1989), cases involving two QPs in a [V-QP-P-QP]_{VP} structure are found to be ambiguous, as shown in (6). In (7), which parallels (6) but introduces a *ba*-construction, ambiguity is equally detected. In both cases, the QP as the object of P can take wide scope, i.e. the QP following *ba* or the verb can depend on the object of P, against the linear criterion. Nevertheless, if the PP precedes the Verb chunk, then the sentence is again found to be unambiguous, as shown in (8).

Before we deal with the remaining Chinese cases, a digression into the structurally equivalent English cases will provide the background information. As has been discussed in Chapter 1, the equivalent of (1) in English, i.e. with a universally quantified subject and an existentially quantified object, is mostly judged to be ambiguous. The example is given here as (13):

(13) Every student admires some professor.

In (13), the subject can take wide scope with the object depending on it. Or the object can take wide scope, but the subject does not depend on it, since a universally quantified phrase should not depend on anything. The object can also be independent

¹¹ (4) also admits an object-wide-scope reading, as pointed out by Aoun & Li (1993). In my understanding, such a reading is equivalent to a branching reading.

of the subject, in a branching interpretation. But as can be proved in logic, when a sentence only involves a universal QP and an existential QP, the latter following the former, then a branching interpretation is equivalent to the object-wide—scope interpretation. Summarising, the English example is 3-way ambiguous, two of which can be collapsed into one. But with a sentence containing two numeric expressions such as "Two examiners marked six scripts", the 3-way ambiguity is distinct. However, some native speakers of English can only get the subject wide scope reading of (13), as reported by Lee (1986), so the data in English does not really get a consensus interpretation. On the other hand, as is standard in first-order predicate logic, in cases where an existential QP follows a universal one, of which (13) is an example, it can be proven that of the two available interpretations of such a structure, the $\exists y \forall x P(x, y)$ reading entails the $\forall x \exists y P(x, y)$ one. That is, the former reading is included in the latter. For the latter may have an interpretation by which the value of y as dependent on x may happen to be the same. It may happen to be the token variation of the same type. Let us illustrate it in graphic form:

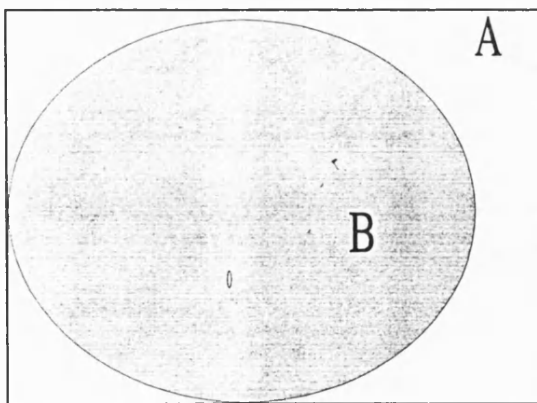


Figure 1.

In Figure 1, if Set A includes Set B, then B entails A. So the mentioning of a member in Set B would entail the mentioning of Set A, but the reverse does not hold. This forms the basis of the Entailment Thesis, which argued that, since $\exists\forall \rightarrow \forall\exists$, it is enough just to recognize the $\forall\exists$ reading in the case of (13) and take $\exists\forall$ as a special instance of $\forall\exists$. Linguists such as Ioup (1976) and Reinhart (1983), among others, noticed this fact and argued that it is not necessary to take a sentence like (13) as ambiguous. Still, it is now common practice to keep treating (13) as ambiguous. Only that it is sometimes agreed that (13) is not an ideal case to examine scope interpretations in a language. The best case is a sentence with the reverse ordering of the two quantifiers, in which an indefinite subject precedes a universal object. An example is given as (14):

(14) Some student admires every professor.

It was mainly from examples like (14) that linguists concluded that English can have object-wide-scope reading.

The Entailment Thesis arguing for the non-ambiguity of (13) was attacked by Chierchia & McConnell-Ginet (1990) from a logical point of view. They pointed out that negation reverses ^{the} entailment relationship. This is because that given A includes B, then $\neg B$ includes $\neg A$. Thus $\neg B$ does not entail $\neg A$. Now it is $\neg A$ that entails $\neg B$. The relationship is shown in Figure 2:

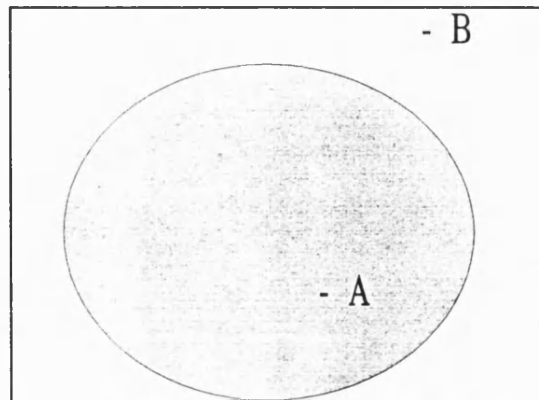


Figure 2.

So on the one hand, since B entails A in Figure 1, therefore $\exists y \forall x P(x, y)$ entails $\forall x \exists y P(x, y)$. So $\forall x \exists y P(x, y)$ is to be set as the generalized formula. On the other hand, since $\neg A$ entails $\neg B$ in Figure 2, therefore $\neg(\forall x \exists y P(x, y))$ entails $\neg(\exists y \forall x P(x, y))$. Thus the latter concatenation of quantifiers is to be set as the generalized formula. Moreover, when we look at concatenation of quantifiers only, we do not have to pay attention to the \neg sign, which can be shifted to the predicate P, especially in natural language, where an external negation is often equivalent to an internal negation.¹² The conclusion is that it is just not possible to posit one ordering of two quantifiers and derive the other ordering from it. Applying this anti-thesis to natural language, we have (15):

- (15) *It is not the case that every student admires some professor.*

¹² Cf. Hofmann (1993).

(15) is a case of logical negation¹³ in which (13) is embedded. If we interpret it in a compositional way, then ^{the}Entailment Thesis would give us only the $\forall\exists$ reading of the embedded clause. However, negating the embedded sentence would give us $\neg\forall\exists$, which entails $\neg\exists\forall$. This means that $\neg\forall\exists$ is not the more inclusive reading, so by taking $\forall\exists$ as the generalized reading, we are also made to treat $\neg\forall\exists$ as the generalized one, with the result that we lose another possible reading, the $\neg\exists\forall$ reading. What is captured by the Entailment Thesis in the case of (15) is the reading that "For each student-professor pair, it is not the case that the student admires the professor." . But the thesis cannot capture the other reading: "It is not the case that there is one professor such that every student admires him".

Coming back to the Chinese example (1), native speakers are divided in their judgments. All agree that there is a subject wide scope reading, while many detect a reading with object independent of subject. The availability of this second reading is reported in J.Shen (1985), Lee (1986), Xu & Lee (1989), Yeh (1989), Pan (1991) and S.Z.Huang (1993).¹⁴ This second reading has been understood as object taking wide scope (not as the branching reading), as the discussions were mainly conducted in the context of first-order predicate logic. Now there is a dilemma. If we admit the object wide scope reading of (1), we can no longer generalize from the crucial case (2) and maintain the thesis that Chinese does not allow object taking wide scope, which has been hypothesized as a major distinction between Chinese and English. Therefore,

¹³ Cf. Chapter 1, Section 5.

¹⁴ But Lee (1986) and Xu & Lee (1989) chose to dismiss this reading in preference for the Entailment Thesis.

linguists opted for the Entailment Thesis and dismissed the ambiguity of (1) as spurious.¹⁵ The object-wide-scope reading (1b) entails the subject-wide-scope reading (1a). In other words, (1a) includes (1b). Therefore (1) is not taken to be ambiguous. It was enough to give it a linear interpretation, which includes the object-wide-scope interpretation as a special, non-distinct case of the variable-binding reading of (1). As for (2), it should be understood in a linear way all the time. Its interpretation, with the existential subject taking wide scope and the universal object taking narrow scope, certainly entails the reverse reading, with the same existential QP interacting with all the members of the universal QP. In this sense, the subject QP is still independent of the object QP. But (2) does not have a variable-binding reading in which the subject depends on the object. So the object-wide-scope reading is not available. Thus a linear interpretation of (2) also gives the right result. Some linguists put things more weakly and observed that, because of the entailment possibility, (1) is just not an ideal case to study quantification in Chinese. For the same reason, (4) is also argued to be unambiguous, although Aoun & Li (1993) presented it as a case of ambiguity. Although in this case, the second QP is not in the object position, with a universal QP in the subject position, (4) tends to elicit the same interpretation as (1).

In spite of the common practice in Chinese syntax to treat (1) and (4) as unambiguous, there are good reasons to challenge this convention. The logical considerations of Chierchia & McConnell-Ginet (1990) are enough to invalidate the Entailment Thesis which is believed by most students of Chinese quantification. Here

¹⁵ Xu & Lee (1989) is the most explicit.

are some more arguments against those who might still insist that their intuition tells them that (1) is not ambiguous.

First, although it is an established law of quantifier dependence that $(\exists x)(\forall y)\varphi(x,y) \Rightarrow (\forall y)(\exists x)\varphi(x,y)$,¹⁶ it does not make it absolutely necessary to let the other reading evaporate. The law is stated in first-order predicate logic and the first proposals to invalidate the object-wide-scope reading of (13) were made with reference to English. Yet it is still widely held that (13) is ambiguous, even for those who believe that the Chinese case (1) is not ambiguous. It seems that just for the reason of consistency, if one believes that (1) is not ambiguous, then he should equally buy the faith that (13) is not either. The motivations for the non-ambiguity of (13) and (1) are exactly the same. It doesn't make sense to apply the law to one language while ignoring it in another, yet at the same time making contrasts between the two languages based on this erratic strategy.

Second, from the insights in Russell (1905), we learn the distinction between a *primary* occurrence and a *secondary* occurrence of denoting phrases. The distinction was also studied in Quine (1955) under the dichotomy of *relational* and *notional* senses. A primary/relational interpretation of a denoting phrase carries existential commitment, while a secondary/notional one does not, both in an opaque context. There seems to me to be cases in Chinese which admit such a dichotomy of interpretations as well, such as in the following sentence:

¹⁶ Cf. Partee et al.(1990).

- (16) Zhāngsān xiāngxìn měi gè rén dōu mòngjiàn le
 Zhangsan believe every CL man all dream ASP
 yí gè nǚhái.
 one CL girl

"Zhangsan believed everyone dreamt of a girl."

(16), there ought to be at least four interpretations. (A) Everyone dreamt of a different, non-existent girl; (B) For each man, there is a particular girl whom he dreamt of; (C) Zhangsan had in mind one particular girl whom he believed that everyone dreamt of, (D) The speaker, not Zhangsan, had in mind a particular girl whom he believed that everyone dreamt of. If the object could not be independent of the embedded subject, (C) and (D) would not be possible for Chinese.

We can extend the relevance of such notions from the study of denoting phrases in opaque contexts to the question of *specificity*. As defined in Cormack and Kempson (1991), an indefinite carries a specific sense if it denotes a specific individual or entity in the mind of the speaker or in the mind of an individual that assumes the subject position of an opaque context. If we deny the ambiguity of (1), we will have to admit the lack of a specific reading of the indefinite in the sentence, since with the subject taking the wide scope, the interpretation of the indefinite concerned depends on the value of the universal quantifier and cannot be taken as a fixed constant. But it is not difficult to imagine a situation in which the speaker is aware of the type similarity of the indefinite being dependent on the universal subject and has therefore a specific entity in mind. He may even emphasize this similarity by stressing the word *yí ge* ('one'). In this light, it is not advisable to exclude this

interpretation from (1).¹⁷ What is more, for a proper semantic representation of Chinese quantification, it is necessary to be able to represent this reading even if it is a type similarity. After all, when looking at (2), we will realize the major difference between (1) and (2), in that for (2), it is black and white unambiguous. The subject never depends on the object in Chinese.

Third, there seems to be a hidden worry that if we admit (1) into the ambiguous cases, we will lose an important generalization that Chinese does not have object taking wide scope, as typically exemplified by (2). However, in the light of the branching quantifier analysis, it is not accurate to take (1b) as object taking wide scope, since the subject does not depend on the object. It is in fact a branching reading in which the two QP's are independent of each other, in the following form:

$$(17) \quad \left\langle \begin{array}{l} Q_1 \\ Q_2 \end{array} \right.$$

What our intuition tells us about (2) remains solid. In (2), if the object were to take wide scope, then indeed the subject would have to depend on it, as shown in the English example (14). So we can now argue that in Chinese, although object taking wide scope is never possible, it is still possible for it to have a branching reading in

¹⁷ There is a further complexity involved here. While interpreting an indefinite some predicate verbs may only allow different types or tokens of the same type to be paired with members of a universal QP (e.g. Every man wore a tuxedo [at once]), but some other verbs can allow one copy be related to all members of a set at the same time (e.g. Everyone watched a film from 9 to 11). Cf. Croft (1984) for some mathematical characterizations.

relation to another QP. In representing the branching quantifier reading, we have to make use of the notions in higher-order logic. But the notion of scope-domain in first-order logic does not give us a precise guideline to the real dependence relations in natural language, since first-order predicate logic is not powerful enough to describe quantification in natural language, as indicated by Hintikka (1974) and May (1985). This new conclusion can also serve to explain cases where two numeric phrases occur in a sentence. In (3), for example, the object can depend on the subject. It can also be independent of the subject. But the sentence does not admit an object-wide-scope reading, by which the subject depends on the object. In the case of (3), the object-wide-scope reading cannot be collapsed with the branching case, because it does not involve just the two standard quantifiers in first-order logic: the universal and the existential quantifiers. If the distinction between the branching reading and the object-wide-scope reading is maintained throughout, either in (1), (2), or (3), then the ambiguity of (1) and (3) as well as the unambiguity of (2) can all be maintained, while the difference between Chinese and English in this respect can also be kept. In fact, emphasis on the dependency relations between quantifiers can also reveal that whenever there is a universal quantifier followed by an existential one, even if they are not in subject and object positions, it is always possible for the latter to either depend on the former or be independent of it. Therefore, it is no wonder that (4) is found to be ambiguous. It would also be logical to find a double object construction to be ambiguous, if the first object is a universal one followed by an indefinite as the second object, such as (10). So will be the case for the structure of a direct object followed by locative, benefactive, or dative constructions such as (11).

A controversial consequence follows from the above argument. If (13) is found to be ambiguous, then the independent interpretation of the indefinite in the sentence will yield a reading in which the indefinite is not bound as a variable by the universal subject. The former therefore can be co-indexed by a singular pronoun in a following sentence, which I term as pronominal binding, like (18):

(18) Every student admires some professor. He is Professor X.

Does it follow that, in Chinese, we can admit the same interpretation, assuming my above argumentation is on the right track? The answer, to my mind, is positive. Syntactically, the Chinese indefinite marker is a numeral such as *yi* + CL.¹⁸ It can admit two interpretations: (i) as *some/a*; (ii) as *one*. In the (i) case, we would expect to have a reading paralleling the English case (18). In the (ii) case, we would expect to have a reading emphasizing the numeric aspect of *yi* + CL. Both seem to be borne out by examples:

Pronominal Binding (19a) vs. Variable Binding(19b):

(19)

a.	zài	wǒmén	dānwèilǐ,	měi	gè	nánrén	dōu	ài
	at	our	unit-in	every	CL	man	all	love

¹⁸ In my understanding, the concept of *definiteness* vs. *indefiniteness* should be understood in two ways: in syntactic form and in semantic content. What appears syntactically with an indefinite determiner in Chinese(in fact, a numeral) can be interpreted semantically either as definite or as indefinite, the latter can be construed as either specific or non-specific.

zhe yí gè nǚrén. Tā jiù shì Lǐ xiáojiě.
ASP one CL woman. she EM be Li miss.

"In our working unit, there is a woman whom everyone loves. She is Miss Li."
(EM = emphatic marker)

b. zài wǒmén dānwèili, měi gè nánrén dōu ài
at our unit-in every CL man all love

zhe yí gè nǚrén. Zhāngsān ài Lǐ xiáojiě,
ASP one CL woman. Zhangsan love Li miss,

Lǐsì ài Wáng xiáojiě,
Lisi love Wang miss, ...

"In our working unit, every man is in love with a woman. Zhangsan loves Miss Li. Lisi loves Miss Wang. ..."

Emphatic Reading plus Pronominal Binding (20a) and Simple Emphatic Reading (20b):

(20)

a. měi gè rén dōu niàn le yì běn shū.
every CL man all read ASP one CL book

Nèi běn shū jiù shì << Hóng Lóu Mèng>>.
that CL book EM be red mansion dream

"There is one book which everyone read. That book is *Dream of the Red Mansions*."

b. měi gè rén dōu niàn le yì běn shū.
every CL man all read ASP one CL book

Ér bú shì liǎng běn.
but not be two CL

"Everyone read one book each, instead of two."

These two paradigms of examples whose ambiguity affects cross-sentential coreferential properties clearly demand explanation. They will have to be explained

by a theory which assumes their ambiguous status. Yet the controversial point is that example (19a) is rejected by most linguists working on Chinese quantification, the same people who refused to admit the ambiguity of (1), while example (20a) is not considered to be a proper case either, as it involves suprasegmental features which may over-ride syntactic generalizations. As to the first objection, the crucial point is whether (19a) is acceptable. On my side, there are two more sources of support: Pan (1991) and S.Z.Huang (1993). As to the second objection, unless a coherent theory is given concerning the interaction between phonological factors and semantic interpretation, I will not exclude (20a) as a valid case of study.

In Y. Li (1995), the following two cases are considered ambiguous while (1) isn't:

- (21) Tā jiāo guò de měi gè xuéshēng dōu kàn guò
 he teach ASP DE every CL student all read ASP
 yì běn shū
 one CL book

"Every student he taught read a book."

- (22) Měi gè tā jiāo guò de xuéshēng dōu kàn guò
 every CL he teach ASP DE student all read ASP
 yì běn shū
 one CL book

"Gloss same as (21)."

The crucial point here is that in (21)-(22), the subject is modified by a relative clause, while (1) is not. I do not share Li's intuition and would take both (21)-(22) and

(1) to be similarly ambiguous. My judgment aside, at least we learn that (21) and (22) *can* be ambiguous, which would not be possible given the Entailment Thesis.¹⁹

As a final argument for the ambiguity of (1), I cite research findings in Farkas (1994) and Abusch (1994). Farkas (1994) observed that the scope of indefinites is *upward unlimited*. Abusch (1994) also noted the existence of intermediate scope of indefinites in object position. If we take (1) as ambiguous, then Farkas' point will be immediately accommodated, and the applicability of the findings of Abusch (1994) to Chinese will be an empirical issue. But taking (1) as unambiguous will straightforwardly dismiss the findings of Farkas and Abusch as inapplicable to Chinese.

1.2. Studies in Chinese Quantification: A Brief Outline

In a series of papers on the working of formal logic in Chinese language, Chao (1955, 1959) initiated the study of quantifying properties in Chinese. He noted some language-specific ways to express standard logical categories such as existential and universal statements in Chinese. What is more important is his remarks that ^{the} Chinese language observes a linear order in the determination of the scope of a logical operator. S.F. Huang (1981) further demonstrated the close link between linear order and scope domain in Chinese. In the GB framework, James Huang (1982, 1983) pointed out that hierarchical order and c-command are the underlying factors that

¹⁹ And I believe that many linguists who do not take (1) to be ambiguous may not take (21) and (22) to be ambiguous either.

determine the scope domain in Chinese. These findings were further modified in T.Lee (1986), Yeh (1986), Duanmu (1988), and Aoun & Li (1989). While most cases in Chinese do not seem to exhibit scope ambiguity, J.Huang (1983), T.Lee (1986) and Aoun & Li found cases in Chinese that do contain ambiguity of scope. Aoun & Li (1989) proposed a theory which centres on the Minimal Binding Requirement, which they further developed into Aoun & Li (1993). T.Lee (1986) did the first detailed study on the quantifying properties of the floating quantifier *dou* in Chinese. He also revised J. Huang's criteria, arguing for the adoption of command and g-command as well as precedence relations to account for scope interpretation in Chinese. Moreover, T.Lee (1986, 1989) conducted psycholinguistic studies on children's acquisition of Chinese quantification. Yeh (1986) basically argued for a parallelism between English and Chinese quantification in terms of data interpretation as well as theoretical treatments. Duanmu (1988) tried to generalize on the well-recognised tendency for Chinese pre-verbal elements to be definite and post-verbal elements to be indefinite, so as to explain the lack of scope ambiguity in Chinese. Shen (1989) explored the relationship between Chinese topic structures and the scope interpretation. Xu & Lee (1989) made the first detailed analysis on the factors that affected interpretations of the Chinese data. Recognizing the ambiguity of some cases, they proposed a thematic hierarchy to account for the phenomenon. Drawing on the studies on branching quantifiers and generalized quantifier theory, Liu (1990) proposed a typology of Chinese NP's that makes divisions between generalised-specific and non-specific NP's, by which she hoped to reveal the quantificational properties of Chinese NP expressions. Gao (1989) associated *dou*('all') with universal quantification and *you*('there exists') with existential quantification in Chinese. This briefly outlines the

works done in this area.

1.3. The Main Issues

Assuming the discussion in Section 1.1 has given us a sharpened data and reliable judgments, I now outline what I take to be the main issues in the study of Chinese quantification.

First and foremost, we should endeavour to give a principled theoretical account to the data hereby given. We ought to be able to predict which structures are ambiguous and which are not. More important, the explanation ought to be a unitary one, in the sense that it uses one theory to explain systematically variations of interpretations in various structures. For example, we ought to give a well-motivated account why (1), (3), (4), (6), (7), (10), and (11) are ambiguous, and why (2), (5), (8) and (9) are not.

Second, provided the first issue is successfully addressed, we ought to give a principled account to the difference between Chinese and other languages ^{with respect to} this phenomenon. What is more, we ought to seek to uncover the relationship between the difference in this area and some other typological or parametric differences between Chinese and other languages.

Third, we ought to extend the analysis to some other related structures that have received relatively less attention. For example, the role of *dou* in quantified

structures,²⁰ the quantification properties within NP structures, including both simple modifications and relativized structures.²¹

The fourth important task, in my understanding, is to relate the structural analysis of quantification to the semantic studies of the referential properties of Chinese NPs. For example, how can studies mentioned in the above three points lead to a further studies on the well-known impression of the definiteness effect of pre-verbal elements in Chinese ? Is it possible to provide a motivated distinction among concepts like referential/non-referential, definite/indefinite, specific/non-specific, unique/non-unique, and generic/individual properties, or is it necessary to collapse some of these notions ? While some interesting investigations have been made in this area,²² it seems that there exists more conceptual divergence on the categorial distinctions in such studies. What is more, few results are extendable to other related issues. More systematic accounts are called for.

In the remaining part of this chapter, I will take up the first two issues. My own response is formulated within the framework of LDS_{NL} as introduced in the previous chapters.

²⁰ Lee (1986) and J.Xu (1993) are among some primary studies on this topic.

²¹ J.Huang (1982, 83) and Lee (1986) examined cases with simple modification, while Wu (1985) is one of the very few studies on relativized structures.

²² For example, J.Fan (1985), Lee (1986), Duanmu (1988), Liu (1990), Chen (1991), Okochi (1993), Sanui (1993), and Uchida (1993).

2. LDS_{NL} Account of Chinese Quantification and Language Variations

2.1. Simplex Cases

This section is devoted to the 'simpler' cases in Chinese, which involve quantification in subject and direct object positions only. The best example in Chinese illustrating its difference from English in quantification is (1), which has only one reading:

- (1) Zuótiān, yí gè rén mǎi le shūdiànlǐ de
 yesterday, one CL man buy ASP bookshop-in DE
 měi běn shū
 every CL book

"Someone bought every book in the bookshop yesterday"

(CL = classifier, ASP = aspect marker, DE = modifier marker)

An LDS_{NL} procedural representation will give us (1'), omitting the NP modifiers and adjuncts:

(1') M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , a : t	
2.	s _i < w _i , t _i [5a. $\Theta t_i < t_{utt}$] >	
3.	u _{dep} , $\Theta u = r^\alpha$, ren(r ^α), [5b. \mathcal{C}] :	e ASS.
	CHOOSE $\Theta \alpha = w_i$	
	r ^{wi} :	e
4.	mai'	e → (e → t) ASS.
6.	x, shu'(x)	e ASS.
7.	mai'(x)	e → t MPP. 4,6
8.	mai'(x)(r ^{wi})	t MPP. 3,7

Universal Closure

9. $\wedge x, x \in \{x \mid \text{shu}(x)\}$ mai(x)(r^{wi}) : t

(1') resembles the related English example analysed in Chapter 4. The unavailability of a subject-depending-on-object reading for Chinese can be explained away in the present model simply by suppressing the delaying mechanism. But this treatment for Chinese will also predict that the Chinese example (2) is ambiguous just as its English equivalent:

(2) Měi gè rén mǎi le yì běn shū
 every CL man buy ASP one CL book

"Everyone bought a book."

a. "For all x, x a man, there is some y, y a book, such that x bought y."

b. "There is some y, y a book, such that for all x, x a man, x bought y."

(2a') M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , a : t		
2.	s _i < w _i , t _i [5a. Θt _i = t _{utt}] >		
3.	x, ren(x) [5b.Ⓒ]	:	e ASS.
4.	mai'	:	e → (e → t) ASS.
6.	u _{dep} , Θu = s ^α , shu(s ^α)	:	e ASS.
	CHOOSE Θα = x		
	s ^x	:	e
7.	mai'(s ^x)	:	e → t MPP.4,6
8.	mai'(s ^x)(x)	:	t MPP.3,7

Universal Closure

9. $\wedge x, x \in \{x \mid \text{ren}(x)\}$ mai'(s^x)(x) : t

(2b') M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , a : t		
2.	s _i < w _i , t _i [5a. Θt _i = t _{utt}] >		
3.	x, ren(x), [5b.Ⓒ]	:	e ASS.
4.	mai'	:	e → (e → t) ASS.
6.	u _{dep} , Θu = s ^α , shu(s ^α)	:	e ASS.
	CHOOSE Θα = w _i		
	s ^{w_i}	:	e
7.	mai'(s ^{w_i})	:	e → t MPP.4,6
8.	mai'(s ^{w_i})(x)	:	t MPP.3,7

Universal Closure

9. $\wedge x, x \in \{x \mid \text{ren}(x)\}$ mai'(s^{w_i})(x) : t

So in the light of the proof-theoretic approach of LDS_{NL}, the difference in dependency construals between English and Chinese is now reduced to the exploiting of the delaying mechanism in the former and its absence in the latter.

2.2. The Delaying Mechanism and the Kempson & Jiang Hypothesis

In this section, I would like to explore a little bit more the consequences of the analyses so far given. Observing the fact that English allows greater freedom in establishing dependent relations, Gabbay & Kempson (1992b) proposed that a delaying mechanism operates in English. With this mechanism at work, a dependent variable does not have to be instantiated as soon as it is projected. It can choose to delay its instantiation till more lexical items are input into the database. For Chinese, however, I suggested in Section 2.1 that the delaying mechanism is not available. Hence the value of all the dependent variables must be instantiated on line. It seems that by postulating this mechanism, we succeed in giving a unitary account of multiple quantification in simplex sentences in English and Chinese, with their differences attributed to adjustments of this minimal device. Thus the availability of the delaying mechanism in English and the lack of it in Chinese draw up the distinction between the two languages in their dependency behaviours. The preliminary claim is that Chinese relies heavily on linear order in constructing dependency for dependent variables, whereas English is less order-sensitive. However, we are immediately left to wonder about the nature and scope of this delaying mechanism as a valid explanation of ambiguity in quantification, whether logical or linguistic. That is, we want to know whether this delaying mechanism reveals the difference in the body of logic rules that applies to a language, or whether it is parasitic on the idiosyncratic structure of a particular language, syntactic or semantic. This somewhat parallels the distinction drawn in Aoun & Li (1993) between the so-called difference in interpretive rules at LF between two languages or difference in terms of constituent

structures between the two. An answer was proposed in Gabbay & Kempson (1992b). They suggested that although it might be a universal fact that natural language understanding is a procedural process, making use of the logical principles characterisable in the framework of LDS, yet the inferential rules available to each language may be different. That is to say, although all languages make use of the inferential rules in LDS, the set of rules available for one language may not be the same set of rules for another. Thus the delaying mechanism, for example, is available for English but not for Chinese. This is merely a parametric variation in the general proof-theoretic approach to natural language and may well have deeper logical motivations that require more sophisticated characterisation in formalism. Z.Chen (1993) also made a general statement to the same effect that it is very likely for different languages to employ different bodies of logic rules. However, further studies in this direction seem to reveal that the nature of the delaying mechanism involves linguistic motivations and has interesting linguistic consequences. Research into this issue by Ruth Kempson and ^{me}~~I~~_^ has reached a tentative proposal. As it centres around the notion of *grammatical subject* in English and Chinese,²³ I will first discuss briefly the notion of subject before presenting the proposal itself.

The status of the notion of grammatical subject varies from one type of language to another. Without trying to provide a precise definition of the notion, it is at least necessary for a theory to provide the optimally accurate means to identify the

²³ *Grammatical subjects* as conceptually distinct from *logical subjects* and *psychological subjects*, as discussed for example, in Halliday (1970).

subject as well as other functional notions.²⁴ In a highly inflected language like Latin, every NP receives a morphological case so that, to the extent that a subject makes its appearance in the sentence, it is always given the nominative case, which is reflected in its suffixation. So the subject in Latin is always easily identifiable even if it never has a fixed position in a sentence.²⁵

(23) Puella equum vidit.
 girl horse sees
 subj. obj.

(24) Puellam equus vidit.
 obj. subj.

(25) Equus puellam vidit.
 subj. obj.

The subject in English is identified through a different route, given the fact that natural case has de-generated to a great extent in the language except for the system of pronouns. Normally a nominative element other than the pronouns is indistinguishable from the accusative element or the dative element. However, there

²⁴ These can be considered as two separate issues, as noted by Anderson (1984), who distinguished between providing a definition of subject and offering a checklist of properties to identify a subject. The same distinction applies to the notion of object as well.

²⁵ Sometimes in Latin the subject does not appear in the sentence, because from the inflexion of the verb we can deduce the person and number of the subject, thereby relating a particular noun in the context to the omitted subject, like the famous saying quoted below:

(i) Veni uidi uici.
 "I came; I saw; I conquered"

does exist an algorithm for us to work out the subject of a given sentence, even if some syntactic theories do not state it in clear terms.²⁶ An algorithm of subject identification has been incorporated into the LDS_{NL} treatment so that the compositional process can reflect the argument structure of the sentence to facilitate semantic interpretation. In the LDS-motivated utterance interpretation, the English subject can be usually identified as the first nominal element immediately preceding the tensed verb in an affirmative sentence.²⁷

The subject position in English is therefore relatively fixed. No other nominal element can be inserted between the subject and the verb. English does allow a limited number of topicalisation but it does not affect the identifying process of the subject. In LDS_{NL}, the subject is not defined as the first NP in the sentence but as the first NP that precedes a tensed verb, as I have stated above. Therefore a topic and a subject can never be mixed up in the procedural approach. Moreover, it is also worth noting the extremely limited use of an argument as a topic in English. With the emphasis on the concept of an *argument topic*, I hope to distinguish between two types of topic structures in English, which is also found in Chinese. One is the very loose and

²⁶ Chomsky (1965) provided one way to identify a subject in configurational terms. In a phrase structure, the subject is the NP immediately dominated by S. Hence the notion of subject can be derived from the structural relation [NP, S].

²⁷ Of course there are deviations from this algorithm, for example, questions (in which subject can be identified as the first nominal element following a tensed auxiliary verb); inverted structures (in which the subject can be identified as the first nominal element following a tensed verb, but this is non-deterministic, as there are imperative forms in which the NP following the verb is in fact the object and the subject most often does not appear. But we can still draw the line by arguing that the verb in an imperative sentence is not a tensed verb).

general sense of topic, the "*aboutness*" topic, which usually appears as an adjunct and is not an NP in an argument position:

(26) As to John, he always thinks fish and chips is the best.

(27) Speaking of food, John thinks fish and chips is the best.

In LDS_{NL}, aboutness topics project themselves as database labels and do not enter into the deduction process, as they are not assigned types, in the following form:

$(\Omega: \Delta) : t$

where Ω is the aboutness topic as the database label labelling the database Δ , the two as a whole label the type t . From a pragmatic view, Ω introduces a set of assumptions that interact with the proposition in Δ and may yield some contextual effects as a consequence.

Another type of topic is the *argument topic*, which is related to an argument position in the sentence:

(28) Books I have, but wisdom I haven't.

(29) (I'm familiar with soccer, but) Australian football, I just can't figure out.²⁸

In LDS_{NL}, such argument topics are represented as *goals*, like the *wh* word.

²⁸ (9) is taken from Ernst & Wang (1995).

They are projected with a type *e* and a goal specification that a database be constructed in which the above-mentioned *e* is to be used as a premiss to reach a *t*.²⁹

I will henceforth refer to *argument topics* as *goals*.

So *wh* goals apart, English is rare in the use of goals, although the language makes frequent use of topics projected as database labels.³⁰

The picture of Chinese is much more complicated. Here I want to emphasize two points: A. The position of the subject is not fixed. B. Non-*wh* goals are frequently used in the language. Chinese verbs do not have grammatical inflexion relating to tense. They only take a few aspect morphemes which are not obligatory in occurrence. So quite often it is difficult to tell if a main verb is tensed or not. On the other hand, a predicate can also be assumed by an adjective or even a noun phrase.³¹ What is

²⁹ Cf. Kempson (1995b).

³⁰ Chinese is exactly the opposite. It makes heavy use of non-*wh* goals, but makes almost no use of *wh* goals. The only exception is some rare use of *wh* goals as informal echo questions.

³¹ Here are some examples:

- (i) Tā zuótiān xiǎng lái, Dàn méi lái chéng.
 he yesterday want come, but not come succeed
 "Although he wanted to come yesterday, he did not manage to come."
 [Main verb *xiang* (and the main verb *lai* in the second sentence)
 indistinguishable from the infinitive verb *lai*.]
- (ii) Tā hěn gāo.
 He very tall.
 "He is (very) tall."
 [Adjective as predicate.]

more, between the subject and the main verb of a sentence, other nominal elements can be inserted either as time adjuncts (some of which are assumed by NP's or by objects (NP's without *ba* serving as a premiss with type e), which is never possible for English.³² The pre-subject positions are also complex in Chinese. Before the subject there may be one topic or two topics or sometimes even three topics, which can be "aboutness" topics, or argument topics, as shown by the following examples:

(31) TOPIC SUBJECT VERB

Píngguǒ wǒ bù xǐhuān chī.
apple I not like eat
"Apples, I do not like to eat."

(11) TOP TOP SUB V

Zhèi cì kǎoshì sān dào tí wǒ zuò duì-le liǎng dào
this CL exam three CL item I do right two CL
"Of this exam, I did two items right, out of a total of three."

(12) TOP TOP SUB OBJ V

Zhèi cì kǎoshì sān dào tí wǒ liǎng dào zuò duìle
this CL exam three CL item I two CL do right
(Gloss same as (11).)

-
- (iii) Zhāngsān Shànghǎi rén, Jīnnián shí suì.
Zhangsan Shanghai man, this year ten year
"Zhangsan is from Shanghai. He is ten years old this year."
[NP as predicate.]

³² Linguists have not reached agreement on the exact status of this element. Ernst & Wang (1995) called it the *focus topic*.

As a result, the Chinese subject does not have a fixed position because it is surrounded by so many elements which may optionally appear either before or after the subject and which can be exactly the same in morphological forms. Or to put it in another way, the Chinese subject may have a very fixed position in the simplest cases when no topic nor focus topic appears (as compared to Latin) but many other elements can appear before or after it in complex cases, making it difficult to locate the subject. There is thus no stringent requirement for the position of the Chinese subject.³³

Based on these observations, Kempson and Jiang hypothesised that the delaying mechanism is employed in English because of the fixed position of the subject. As the subject must appear as the first NP preceding the tensed verb and as non-*wh* goals related to an object position ^{are} ~~is~~ extremely limited in English (and even more so if the sentence involves multiple quantification), no element of a type *e* can easily occupy a position before the subject for the quantified subject to linearly depend on it.³⁴ To make up for this structural limitation, the English subject, when it is assumed by a dependent variable, has to make use of the delaying mechanism as a compensation for its rigid distributional requirement. The delaying mechanism enables the value of the

³³ This leads to works querying the need for the notion of *subject* in Chinese and promoting the notion of *topic*, e.g. Chao (1968), Li & Thompson (1976), and L. Li (1985).

³⁴ Cf. the implausibility of such a sentence:

Every patient, some nurse takes care of.

the first QNP taken as the goal. Also note the implausibility of taking the second QNP as the preposed object, which would be downright ill-formed.

subject to be functionally dependent on some other elements like the object or a prepositional object. In Chinese, however, the delaying mechanism is not necessary because the language can exploit the many positions available before the subject. The result is that logical object, or some other elements that usually appear in a post-verbal position, can be easily promoted to a slot before the subject in the form of a goal for the subject to depend on so that linearity can still be preserved.³⁵

For ease of exposition, I will henceforth call the above hypothesis the *Kempson & Jiang Hypothesis* (*K&J Hypothesis* for short).

The K&J Hypothesis can be taken as providing a linguistic stipulation to account for the otherwise arbitrary delaying mechanism. In the following sections of this chapter, I will examine some related cases: the double-object and dative constructions in English and in Chinese. The linguistic facts related to the double-object construction provides justification to the K&J Hypothesis, but the uniqueness of quantification in dative constructions also calls for a special treatment.

3. Quantified Objects

The K&J Hypothesis traces the origin of the delaying mechanism to the different distributional properties of the subject and topic/goal in English and in

³⁵ This of course begs the question why linearity has to be preserved, or why linearity should be considered as the best mode of dependency for quantifiers. Although the question has been addressed by many studies, I have to leave it aside.

Chinese. This entails that quantified elements appearing in a non-subject position should not be subject to this mechanism. That is to say, dependency relations in English do not really make heavy use of delaying all the time and are not that freely established after all. This seems to receive empirical support in English. For one case, in chapter 4, I have already argued that the metavariable projected by the subject cannot delay its instantiation until another database is created, either in the form of embedding or linking. This observation receives further support in the present context. A subject, in the usual grammatical sense, is a subject only with relation to the other elements in the same minimal database. Therefore a subject for one database no longer assumes the part of a subject when it is carried over to another database. The latter should have its own subject within its syntactic environment. When looking at subordinate clauses embedded in a matrix clause, the subordinate one should have its own grammatical functions such as subject, predicate and object, distinct from the ones in the matrix clause. Even if the subordinate clause should act as a sub-element in the matrix clause in the sense that it may play the role of a single premiss(e.g. an object), it is the subordinate clause as a whole that plays such a role, not any one of its sub-constituents. It follows that the subject of a matrix clause cannot depend on anything within the subordinate clause, because what are grammatical functions in the latter are only fragments for the former.³⁶ In this sense, a subordinate clause does constitute

³⁶ For example, in (i), the subject of the matrix clause, *John*, has the syntactic function of subject relative to the other functions, i.e. the predicate verb *told*, and the object *Bill* as well as the clause serving as the object complement. But *John* is not a subject with relation to an element within the complement, e.g. *the moon*. The latter, although a subject in the complement clause, is only a fragment in relation to a grammatical function in the matrix clause.

(i) John told Bill that the moon is made of cheese.

a distinct database from its superordinate sentence. Nevertheless, the algorithm of logical dependency in LDS_{NL} is such that any element in the subordinate clause, i.e. embedded database, can choose freely elements in the matrix clause as dependees. For, from inside the embedded database, the matrix elements are certainly of the same database as the embedded elements, and no dependency on the matrix elements involves delaying.

Another source of empirical evidence supporting the conclusions reached in the last section is from the double-object construction. From Larson (1988, 1990) and Williams (1994), we know that English double-object constructions do not exhibit scope ambiguity when the indirect object is an indefinite and the direct object is a universal quantifier. For example, a sentence like (33) is considered to be unambiguous, in which *a man* necessarily takes wider scope than *every book*. In our terms, *a man* should never depend on *every book*.

(33) John gave a man every book.

However, there is the other side of the coin which is quite often neglected -- if the indirect object is a universal quantifier while the direct object is an indefinite, ambiguity is again possible. For example, in (34), both QNP's can take wide scope. That is, *a book* can either choose to depend on *every man* or be independent of it.

(34) John gave every man a book.

The ambiguity of (34) comes as no surprise in the light of the understanding reached in previous chapters. Recall that there are necessarily two possible routes to the establishing of dependency relations whenever an indefinite follows a universal quantifier. One route is to make the indefinite depend on the universal QP, whereas the other route is to let the indefinite be independent of the universal QP by making it dependent on the *w* label. These two alternatives are sometimes available even when the two QP's involved do not belong to the same minimal database, so long as one is embedded in the other. The rationale for such a possibility has already been explored in Chapter 4. It follows therefore that it is not precise either to view the double-object construction in English as simply ambiguous or as downright unambiguous, because it is not merely an issue of linear arrangements of the QP's, but also one related to the individual nature of each QP. The like constructions in Chinese seem to parallel the English cases in exactly the same semantic construals. With the K&J Hypothesis embedded in the LDS_{NL} approach, this comes as no surprise. For English, as the indirect object in the double object constructions is not a subject, the delaying mechanism doesn't apply. So it cannot wait till the direct object is entered into the database and choose the latter as the dependee. On the other hand, as the delaying mechanism never applies in Chinese, the outcome is the same. With relation to sentence (34), the ambiguity does not rise from any application of the delaying mechanism. The direct object simply has two possible dependable elements to choose from. Hence two dependency construals are possible, both for English and for Chinese.

Here is the implementation of the above arguments into the LDS_{NL}

representations with regards to double object constructions:³⁷

(33) John gave a man every book.

(33') M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...)	⊢ s _i , a : t	
2.	s _i < w _i , t _i [5a. $\Theta t_i < t_{utt}$]	>	
3.	John', [5b. \mathcal{C}]	:	e ASS.
4.	give'	:	e → (e → (e → t)) ASS.
6.	u _{dep} , $\Theta u = m^\alpha$, man(p ^α)	:	e ASS.
	CHOOSE $\Theta \alpha = w$		
	m ^w	:	e
7.	x, book(x)	:	e ASS
8.	give'(m ^w)	:	e → (e → t) MPP.4,6
9.	give'(m ^w)(x)	:	e → t MPP.7,8
10.	give'(m ^w)(x)(j)	:	t MPP.3,9

Universal Closure

11. $\wedge x, x \in \{x \mid \text{book}(x)\}$

give'(m ^w)(x)(j) : t

(34) John gave every man a book.

³⁷ For the sake of simplicity, I treat proper names as constants in this chapter.

(34'a) M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , a : t		
2.	s _i < w _i , t _i [5a. $\Theta t_i < t_{utt}$] >		
3.	John', [5b. \mathbb{C}]	:	e ASS.
4.	give'	:	$e \rightarrow (e \rightarrow (e \rightarrow t))$ ASS.
6.	x, man(x)	:	e ASS
7.	u_{dep} , $\Theta u = b^\alpha$, book(b^α)	:	e ASS.
	CHOOSE $\Theta \alpha = x$		
	b^x		
8.	give'(x)	:	$e \rightarrow (e \rightarrow t)$ MPP.4,6
9.	give'(x)(b ^x)	:	$e \rightarrow t$ MPP.7,8
10.	give'(x)(b ^x)(j)	:	t MPP.3,9

Universal Closure

11. $\Lambda x, x \in \{x \mid \text{man}(x)\}$ give'(x)(b^x)(j) : t

(34'b) M

1.	Goal: ([Label:Formula] _{w1} , [L:F] _{w2} , ...) ⊢ s _i , a : t		
2.	s _i < w _i , t _i [5a. $\Theta t_i < t_{utt}$] >		
3.	John', [5b. \mathbb{C}]	:	e ASS.
4.	give'	:	$e \rightarrow (e \rightarrow (e \rightarrow t))$ ASS.
6.	x, man(x)	:	e ASS
7.	u_{dep} , $\Theta u = b^\alpha$, book(b^α)	:	e ASS.
	CHOOSE $\Theta \alpha = w$		
	b^w		
8.	give'(x)	:	$e \rightarrow (e \rightarrow t)$ MPP.4,6
9.	give'(x)(b ^w)	:	$e \rightarrow t$ MPP.7,8
10.	give'(x)(b ^w)(j)	:	t MPP.3,9

Universal Closure

11. $\Lambda x, x \in \{x \mid \text{man}(x)\}$ give'(x)(b^w)(j) : t

I omit representation of the Chinese examples, which are of the same nature as the English ones.

Other varied situations related to the double-object construction ought to be predictable. If, for example, the subject and the indirect object are QNP's, then the subject should be able to depend on the indirect object or be independent of it by being dependent on the *w* label.³⁸ But in Chinese, the subject should only depend on the *w* label.

4. Dative and Locative Constructions

If the above reasoning is correct, how do we account for a related set of examples in which a dative or locative phrase appears after the direct object, exhibiting ambiguity of scope no matter how the linear arrangements of the quantifiers are? The examples are given in (35) to (38).

(35) John gave a book to everyone.

(36) John gave every book to someone.

(37) John put a book on every table.

³⁸ In Pica & Snyder (1995), however, the following sentence is claimed to be unambiguous:

- (i) Someone gave everyone his business card.

Here *someone* cannot depend on *everyone*. But there are similar cases which are ambiguous, for example (ii):

- (ii) Some journalist is supposed to show every politician his credentials.

So the claim by Pica & Snyder (1995) only works at random.

(I thank Ruth Kempson for bringing this point to my notice.)

(38) John put every book on a table.

Again, the Chinese cases given in Section 1 parallel the English ones. The K&J hypothesis doesn't appear to cover this interaction of quantifiers between the direct object and the dative/locative complement. And it shouldn't, since the K&J hypothesis bears no relations to such structures. Now we want to preserve the thesis of the K&J Hypothesis in arguing that the only case allowing delaying of dependency is in relation to the quantified subject. So we do not want to account for the ambiguity of (35) by invoking the delaying mechanism again. As I will argue in the present section, such cases are accountable because the dative/locative phrase, that is, the PP argument in (35) to (38) and its equivalent in Chinese, has its distinct mode of dependency construction.

In terms of LDS_{NL}, the preposition in the argument PP is a function $f(\cdot):e$, in the sense that it takes in a type e and returns with another e . For example, a preposition *to* can combine with an NP such as *John* and yield a PP argument *to-John*: e . I propose that when the PP argument combines with a three-place verb of the form $e \rightarrow (e \rightarrow (e \rightarrow t))$, there can be two orders of combinations. Either the verb combines with the direct object first, then with the PP argument, or the other way round. If that is the case, my proposed solution is that, when there are multiple routes of composition among some premisses, dependency construction among these elements is established according to the order of composition. Different orders of composition therefore give different choices for dependency. Hence the ambiguity. This manner of dependency construction only affects those premisses involving alternative routes of

composition, so the subject premiss should still be instantiated on-line or be subject to a delaying mechanism in English. But why should the PP argument be combined with the verb premiss in two different ways, while the two arguments of a direct object construction have to combine with the verb in one way only, in the linear order? This can probably be ascribed to the unique nature of prepositional phrases, in the sense that the PP arguments are not like the NP arguments. Their positions in sentences are much freer than their NP counterparts. They can either follow the direct object or precede it, either in English or in Chinese, as shown by the following examples:

- (39) a. I gave a Christmas gift to my friend.
 b. I gave to my friend a Christmas gift.
- (40) a. I put three bottles of whisky on the shelf.
 b. I put on the shelf three bottles of whisky.
- (41) a. wǒ sòng-le yí fèn lǐwù gěi wǒ péngyǒu
 I give-ASP one CL gift to my friend
 b. wǒ sòng gěi wǒ péngyǒu yí fèn lǐwù
 I give to my friend one CL gift
 "I gave a gift to my friend."

Whatever the order, it is always easy for us to tell the thematic roles of the PP and the post-verbal NP, both as premisses of type e. By the preposition marker, we know the the PP argument is the *recipient*. And the other NP argument is to assume the thematic role of *theme*. Therefore, we can allow a freer mode of composition for

the PP arguments. But given a different ordering of the double object construction, we have no way to tell which is the recipient and which, the theme, as there are no morphological markers to the effect. So we have to rely on the linear order in composition.

The picture we get now is this: We use the K&J Hypothesis to account for the interpretive differences between English and Chinese with regard to multiple quantification when QP's appear at subject and object positions. Quantification in double object positions in English and Chinese are not affected by the hypothesis and are therefore not different, both interpreted in a linear fashion. Quantification in PP arguments in dative and locative constructions has its special properties in that the dependency construction runs off the compositional process. And alternative orders of composition give rise to different dependency.

Admittedly, the proposed solution in relation to dative and locative constructions does not seem to be wholly compatible with the rest of the story. Other alternatives have been attempted and have turned out to be dead ends. For example, we can formulate meaning postulates so that, whenever we have dative constructions, we derive its double object counterpart and make dependency run off linear order. This may turn (42) into (43):

(42) I gave a book to every student.

(43) I gave every student a book.

The result is that *a book* can be made to depend on *every student*. This will correctly predict the dependency relations. But an adverse effect is that (44) can also be turned into (45):

(44) I gave every book to a student.

(45) I gave a student every book.

While (44) allows the indefinite to depend on *every book*, (45) does not. So this method can give wrong predictions.

In fact, the quantificational behaviour of dative constructions has been a puzzle to almost all the existing theories. To provide a better solution in LDS_{NL}, I believe a lot more studies have to be made on the properties of PP's, both as arguments and as adjuncts, which would be the major key to unravel the mystery of quantificational asymmetries in such cases.

Comparisons with Categorical Grammar & Discourse Representation Theory

0. Preamble

This final chapter compares the treatments of quantification in LDS_{NL} with the practices in Categorical Grammars (CG) and Discourse Representation Theory (DRT), both of the latter have provided influential formal analyses of aspects of natural language and in appearance are strikingly similar to LDS_{NL} in many respects. Through the comparative studies in this chapter, I want to point out that although the LDS_{NL} framework shares certain technical features with CG and DRT, the former is different from the latter in many substantial aspects, from ontological conception of natural language to technical achievements. As the focus of this thesis is on dependency relations in multiple quantification, I will restrict the comparisons to the treatments of the standard examples of multiple quantification. It should be noted that many works in CG and DRT go beyond the analysis of simple cases of multiple quantification and cover a wider spectrum of quantification structures in English, especially the cases involving interaction between quantifiers and other syntactic phenomena such as anaphora, lots of which have not been tackled by LDS_{NL} . But I have to concentrate on

the simple cases here and want to derive the major differences between LDS_{NL} and CG and DRT in terms of these restricted examples.

1. Treatments of Quantification in CG

The basic mechanisms of CG is presented in Appendix D for reference. We come to the central issues directly.

A recent practice in some CG studies which seems to be gaining popularity is the adoption of the LDS methodology.¹ Linguistic information, either as semantic information or as semantic information plus prosodic information, is put side by side to the typed formulae. The logical motivation is no different from that of LDS_{NL} introduced in Chapter 2, but the technical details are substantially different.

Studies of quantification in CG using labelled deduction can be found in Pereira (1990), Morrill (1994, 1995), and Carpenter (n.d.a, n.d.b.), which are similar in spirit, in spite of some notational differences. In these works, the logical mechanism dealing with quantification turns out to be a deductive version of Montague's quantifying-in. Pereira (1990), for example, formulated a derived rule like (1):

¹ Cf. Pereira (1990), Morrill (1994, 1995), and Carpenter (n.d.a, n.d.b.).

$$\begin{array}{c}
 (1) \quad q: \quad (e \rightarrow t) \rightarrow t \quad x: \text{quant}(q)^1 \\
 \hline
 \begin{array}{c}
 x : e \\
 (x: \text{quant}(q)) \\
 : \\
 : \\
 s : t
 \end{array} \\
 \hline
 \lambda x. s : e \rightarrow t^1 \quad q: (e \rightarrow t) \rightarrow t \\
 \hline
 q(\lambda x. s) : t
 \end{array}$$

In (1), the type of a quantified NP is constructed as $(e \rightarrow t) \rightarrow t$, following the practice of Montague (1974) and Barwise & Cooper (1981). Such a typed formula is introduced as an assumption. But due to its special nature, it does not combine immediately with other types. Simultaneously, an associated variable x with a type e is created. The latter then participates in the type deduction as an extra assumption which ought to be discharged at a later stage (hence the superscript number). Through Lambda Abstraction, the extra assumption is discharged (the superscript identifies the assumption discharged). On the formula side, an e is put back and on the labelling side, we have the corresponding lambda abstraction on the Q-variable x . Then the original type of QNP is combined with the abstracted formula, introducing the quantifier scope over the formula it combines with. However, the actual version of Q-Licensing and Q-abstraction used by Pereira as derived rules in the linguistic analysis is simplified as (2):

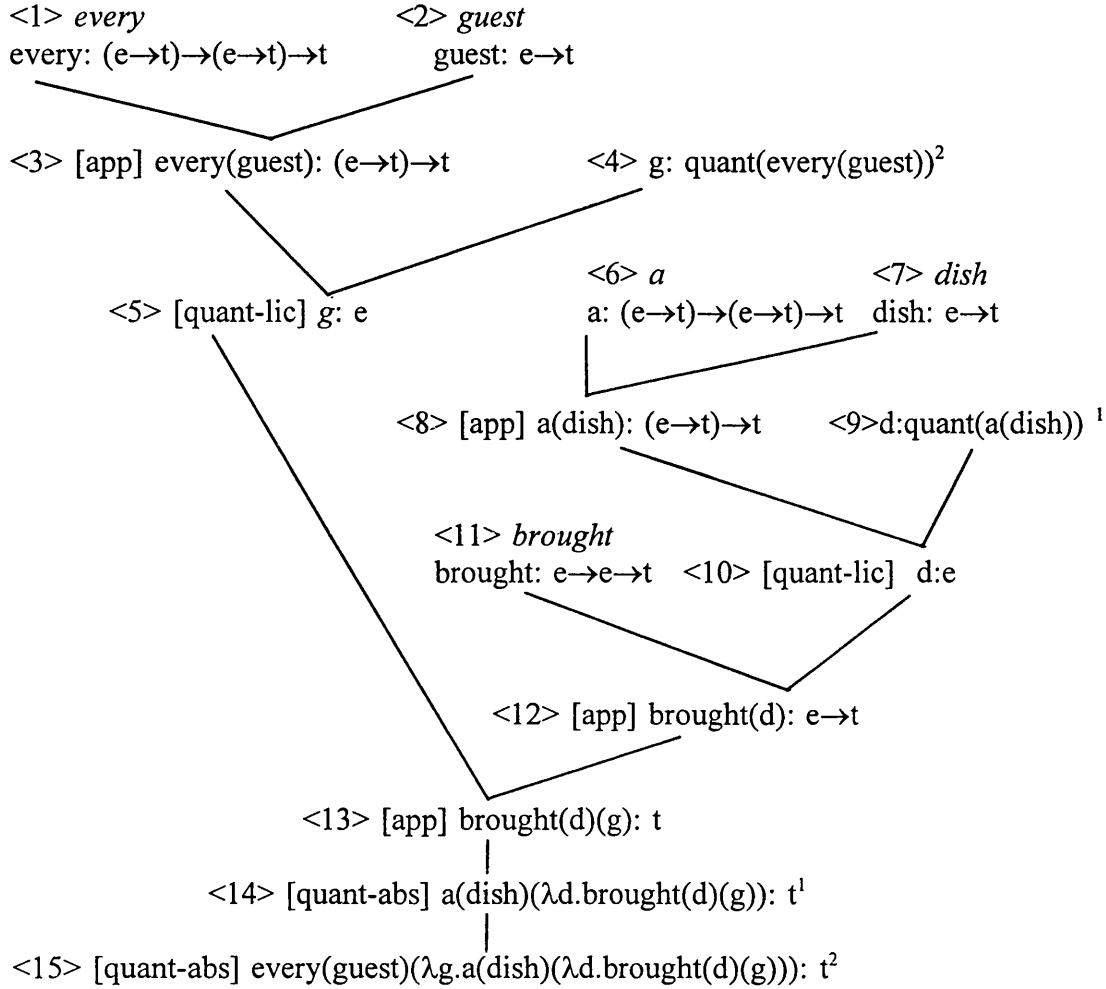
$$\begin{array}{c}
 (2) \quad [\text{quant-lic}]: \quad q: \quad (e \rightarrow t) \rightarrow t \qquad x: \quad \text{quant}(q)^1 \\
 \\
 \hline
 \begin{array}{c}
 x \quad : \quad e \\
 (x: \text{quant}(q)) \\
 : \\
 : \\
 : \\
 s \quad : \quad t
 \end{array}
 \\
 \\
 \hline
 q(\lambda x. s) \quad : \quad t^1
 \end{array}$$

In (2), the rule of Q-licensing reduces the QNP to its variable x with a type e and the rule of Q-abs incorporates the use of the premiss of QNP in (1). So in appearance, the type of QNP is never combined with other formulae. By this simplification, I think Pereira wants to ensure that no constructed higher-order type participates in the deduction, so as to avoid possible complexity when the type of the QNP combines with the wrong premisses. I come back to this point in Section 2.²

Now we look at the actual analysis:

² Rules similar to Pereira's Q-lic and Q-abs were formulated in Carpenter (n.d.a).

(3) Every guest brought a dish.



The numbers are added for ease of explanation. <1> introduces the lexical item *every*, with its corresponding semantic information given below as the label, and its type as formula. <2> introduces the word *guest*. <3> combines <1> and <2> to get the QNP. <4> is an extra assumption introducing a quantifier variable *g* (*g* as the first letter of *guest*). The application of Q-lic in <5> reduces the QNP to *g* with a type *e*. <6> to <10> constructs the type *e* out of the QNP *a dish* in the similar way. <11> introduces the verb and <12> to <13> constructs a proposition with the type *t* through two steps of application. The Q-abs in (14) discharges the assumption <9> and <14>

introduces the label of the related QNP (not the type). This establishes the scope domain of *a dish* over the proposition. Likewise <15> introduces the label *every (guest)* while discharging the assumption <4>. So we derive an interpretation with *every guest* having scope wider than *a dish*.

Reversing the order of [Quant-abs] <14> and <15> would enable us to derive the interpretation with *a dish* having scope wider than *every guest*. But we have to swap the order of the process <6> - <10> with <1> - <5>, so that the discharge of assumptions will still be in a last-in first-out fashion, which has important consequences for the treatment of other cases in CG.

Although Pereira did not use an order-sensitive calculus on the formula as commonly employed in CG, it is easy to convert his notation into an enriched Lambek calculus(as introduced in Appendix D).

In Morrill's Type-Logical Grammar, words project three parts of information: prosodic, semantic and logical. The first two are presented in the form of labels, with the prosodic form in the first position in italics, followed by the semantic form in bold, the two separated by a hyphen. The logical information appears as typed formulae.

Morrill's system uses the operators \uparrow and \downarrow . Quantified expressions are assigned the type $(S\uparrow N)\downarrow S$. With the introduction of each argument QNP, there is also an accompanying introduction of a variable with a type N as an extra hypothesis. The

type of the variable combines with the type of the main verb to create a proposition. Then the extra hypothesis is discharged in a step of $I\uparrow$ (\uparrow -introduction), creating a λ formula in the semantic label, a gapped prosodic label, and a formula of the type $S\uparrow N$. This formula is then combined with the related QNP to yield an S. And the QNP takes its scope from the point it is introduced. Multiple QNP's involve multiple operations according to the format outlined above, in a first-in last-out fashion, which in Morrill's system is made clearer in the form of sub-proofs.

Here are the detailed analysis of the ambiguous sentence (4):

(4) Everyone loves something.

(4'a)	1. <i>everyone</i> - $\lambda x\forall z[(\text{person } z \rightarrow (x \ z))]: (S\uparrow N)\downarrow S$	
	2. <i>loves</i> - love : $(N\backslash S)/N$	
	3. <i>something</i> - $\lambda x\exists w[(\text{thing } w) \wedge (x \ w)]: (S\uparrow N)\downarrow S$	
	4. $b - y: N$	H
	5. $a - x: N$	H
	6. $\text{loves} + a - (\text{love } x): N\backslash S$	E/ 2, 5
	7. $b + \text{loves} + a - ((\text{love } x) y): S$	E\ 4, 6
	8. $((b + \text{loves}, \in) W a) - ((\text{love } x) y): S$	= 7
	9. $(b + \text{loves}, \in) - \lambda x((\text{love } x) y): S\uparrow N$	$I\uparrow$ 5, 8
	10. $((b + \text{loves}, \in) W \text{ something}) -$	$E\downarrow$ 3, 9
	$(\lambda x\exists w[(\text{thing } w) \wedge (x \ w)] \lambda x((\text{love } x) y)): S$	
	11. $b + \text{loves} + \text{something} - \exists w[(\text{thing } w)$	
	$\wedge ((\text{love } w) y): S$	= 10
	12. $((\in, \text{loves} + \text{something}) W b) - \exists w[(\text{thing } w)$	
	$\wedge ((\text{love } w) y): S$	= 11
	13. $(\in, \text{loves} + \text{something}) - \lambda y\exists w[(\text{thing } w)$	
	$\wedge ((\text{love } w) y): S\uparrow N$	$I\uparrow$ 4, 12
	14. <i>everyone</i> + <i>loves</i> + <i>something</i> -	
	$\forall z[(\text{person } z) \rightarrow \exists w[(\text{thing } w) \wedge ((\text{love } w) z)]]: S$	$E\downarrow$ 1, 13

(4'b)	1.	<i>everyone</i> - $\lambda x\forall z[(\text{person } z \rightarrow (x \ z))]: (S\uparrow N)\downarrow S$	
	2.	<i>loves</i> - <i>love</i> : $(N\backslash S)/N$	
	3.	<i>something</i> - $\lambda x\exists w[(\text{thing } w) \wedge (x \ w)]: (S\uparrow N)\downarrow S$	
	4.	$a - x: N$	H
	5.	$b - y: N$	H
	6.	$\text{loves} + a - (\text{love } x): N\backslash S$	E/ 2, 4
	7.	$b + \text{loves} + a - ((\text{love } x)y): S$	E\ 5, 6
	8.	$((\in, \text{loves} + a) \ Wb) - ((\text{love } x) \ y): S$	= 7
	9.	$(\in, \text{loves} + a) - \lambda y((\text{love } x) \ y): S\uparrow N$	I\uparrow 5, 8
	10.	$((\in, \text{loves} + a) \ W \text{everyone}) -$ $(\lambda x\forall z[(\text{person } z) \rightarrow (x \ z)] \ \lambda y((\text{love } x) \ y)): S$	E\downarrow 1, 9
	11.	$\text{everyone} + \text{loves} + a - \forall z[(\text{person } z)$ $\rightarrow ((\text{love } x) \ z)]: S$	= 10
	12.	$((\text{everyone} + \text{loves}, \in) \ Wa - \forall z[(\text{person } z)$ $\rightarrow ((\text{love } x) \ z)]: S$	= 11
	13.	$(\text{everyone} + \text{loves}, \in) - \lambda x\forall z[(\text{person } z)$ $\rightarrow ((\text{love } x) \ z)]: S\uparrow N$	I\uparrow 4, 12
	14.	$\text{everyone} + \text{loves} + \text{something} -$ $\exists w[(\text{thing } w) \wedge \forall z[(\text{person } z) \rightarrow ((\text{love } w) \ z)]]: S$	E\downarrow 3, 13

In (4'a), at Step 1, the QNP *everyone* projects the prosodic label, the semantic label represented in the usual form of first-order logic, and its logical formula of type $(S\uparrow N)\downarrow S$, which means that the QNP is such that given a formula which wraps around a needed N to yield an S, it infixes itself into that formula to yield the S. 2 introduces the verb *loves* and 3 another QNP *something*. 4 and 5 bring into variables of the type N, as extra hypotheses. These variables combine with the verb in steps of slash eliminations (E/, E\) akin to order-sensitive \rightarrow -Elimination to yield the proposition of type S at Step 7. Step 8 involves operation over the prosodic labels. It moves the object argument out of the argument structure, leaving an empty slot \in . 9 discharges Hypothesis 5 in a step of \uparrow -introduction, with the corresponding λ -abstraction over the semantic label and the removal of the object argument Wa in the prosodic labels. Then the QNP in 3 is combined with 9 in a step of \downarrow elimination to yield 10. In 11, the newly introduced QNP assumes its positions in all the three dimensions: semantic(with

the introduction of $\exists w$ **thing** w), *logic*(where w replaces x), and *prosodic*(where *something* replaces ϵ). Similar steps lead to the introduction of the other QNP *everyone* at 14. Now we have the QNP's built into the S with their relative scopes specified according to the order in which the specific QNP is combined with $S \uparrow N$.

The other reading can be obtained in a similar way, as shown in (4'b). After the S is reached, we first discharge the hypothesis related to the subject variable, then build in the QNP *everyone* to bind the subject gap in S. Then *something* is built in. So the resulting S has *something* taking wider scope than *everyone*. In this instance, we first introduce the extra hypothesis related to the object variable, then the variable hypothesis related to the subject, in order to observe the first-in last-out principle.

2. Comparison between LDS_{NL} and CG

The Categorical approach outlined in the last section tries to achieve a Montagovian quantifying-in effect through labelled deduction. Each step of deduction over the formulae invokes a parallel functional operation over the labels. Labels and formulae act in strict harmony. And each operation takes place as a step of deduction, based on rules that are all motivated by logical rules of deduction. Therefore, all the operations are deductive in nature and the labels and the formulae work in tandem on a rule-to-rule basis. This entails strict restrictions over the whole operations that are permitted.

Although CG claims to model natural language understanding by means of

purely logical deductive mechanisms, it does not seem to be a natural reflection of natural language interpretation for the following reasons, when we look at its treatment of quantification:

First, by using notions like quantifying-in and linear arrangement of quantifier scope in first-order predicate logic, we observe the first point of unnaturalness. Although the syntactic structure only holds one position for each QNP, we are forced to treat them in two separate steps. The first involves using its variable in the compositional process of proposition construction. The second involves the introduction of the QNP itself over the proposition. But no syntactic structures would reflect this dual treatment and no natural compositional process based on the syntactic analysis would allow this type of double composition.

Second, although the whole process of quantifier interpretation in CG has been constructed on purely logical grounds with each rule motivated by the deductive rules of logic, there are derived rules that are constructed to amend technical pitfalls that render the system less logical than it claims to be. For example, the Q-licensing rule and Q-application rule in Pereira (1990) reduce a QNP of the type $(e \rightarrow t) \rightarrow t$ to a variable of type e and decree that the original type of the QNP should never participate in the type deduction. In fact, behind these derived rules, we see that the type of QNP can be allowed to take part in the deductive process, only that it cannot do so until the very last stage, when the relevant unquantified proposition has already been constructed. But to impose this added constraint is to introduce an extra unmotivated constraint on the logical deduction itself. We might consider how things

might go otherwise. If the type of QNP is allowed to combine with other types and there is no restriction on the timing of its composition, then we might not use it in a proper place, thus not getting what we wanted. To illustrate, the type of QNP $(e \rightarrow t) \rightarrow t$, if freely usable, can be combined either with a proposition withholding one premiss, e.g. $\lambda x A(x): e \rightarrow t$, or with a VP before it combines with another e to form a t , e.g. an $e \rightarrow t$ without the λ -abstraction over the labels. This means that in the case of (3), $\langle 3 \rangle$ would even be allowed to combine with $\langle 12 \rangle$, an unwanted result. Hence the derived rules are no more than a cover-up of this possible complexity by avoiding higher-order types and complex routes of compositionality.

Morrill's treatment appears not to suffer from this unnaturalness. But that is only because he made use of the $\uparrow\downarrow$ operators in assigning a type to QNP. Since other formulae do not have corresponding types of the same operator, the formula of a QNP is held up until the proposition is built and $I\uparrow$ applied to the type of the proposition. So the whole process is monitored in such a way to appear more naturally deductive, but the use of the $\uparrow\downarrow$ operators in forming $(S\uparrow N)\downarrow S$ is deliberate on the metalevel.

In Morrill's system, insertion of the QNP's into the constructed proposition does not only apply to the semantic constructs, but also to the prosodic strings at the same time. This introduces more unnaturalness. When the dummy variables were combined with the verb premiss to form the initial proposition on the semantic side, the prosodic strings were also constructed with arbitrary symbols (a, b, \dots) corresponding to the variables. However, in order to make room for the insertion of the QNP's, the arbitrary symbols have to be removed with special operations, leaving empty symbols in the form of ϵ , to be replaced by the Q-expressions eventually. This

is exemplified by lines 11 and 12 in (4'a). So the mechanism is unnatural both on the semantic side and on the prosodic side. And unlike the claims of the proponents of Type-Logical Grammar, the system is not purely logic-driven and deduction-driven, because in lines 11 and 12, there are no accompanying steps of deduction. That is to say, Morrill's system also involves pure manipulation over the labels.

Third, CG's treatment of other structures are all driven by syntactic reasons but in dealing with quantification it is driven more by semantic reasons. So even if it can be deductive and proof-theoretic, it cannot be naturally procedural. The most striking evidence is the order of the introduction of the quantifier variables which can be the reverse of the order of the QNP's themselves. Although the first-in last-out principle behind it is logically driven, the aim to reach a quantifying-in effect is semantically motivated.

Finally, unlike LDS_{NL} , CG does not make any assumptions about underdeterminacy and underspecification. It is a theory that directly interprets the given strings. There is no attempt of enrichment and there is no creation of any intermediate representation between the strings of words and the compositional meaning.

In contrast to the CG manipulations, the system of labels in LDS_{NL} does not have to act in strict co-ordination with the deductive steps of the formulae. Labels can lead an independent life of their own, as originally conceived by Gabbay (1994a). The link between the labels and the formulae can be looser in the sense that although

deductions over the formulae always lead to co-ordinated functional applications over the labels, there can be other operations over the labels that do not affect the formulae. For example, while steps of deduction over the formulae are accompanied by the incremental combination of the labels in LDS_{NL} , the introduction and the instantiation of the database labels such as $\langle t_i \rangle$ and $\langle w_i \rangle$ are not deduction-motivated. Such operations are originally motivated by considerations in temporal logic and modal logics, different from the first-order deductions. As another example, quantification in LDS_{NL} relies heavily on the manipulation over the labels, involving instantiation, the choice function and dependency construction. These mechanisms only work on the labels, not on the formulae. And they are not conducted in a wholly deductive manner. Some of the steps can be deductive, others are incremental and involve other logical mechanisms. The logical motivations for such moves have been traced in Chapter 3 to ε -calculus, the logic of value-assignment, and temporal logic.

In terms of technical details, the mechanisms of LDS_{NL} provides a unitary treatment of quantification, including multiple quantification, group readings, branching quantifiers, and language variations.

While mechanisms are being developed in CG to deal with most of these cases, e. g. in Carpenter (n.d.a, n.d.b), there are two issues which stand out as testing cases.

The first issue is on language variation. In the LDS_{NL} approach, the difference in quantification between English and Chinese has been shown to lie in the use of delaying mechanism, which is accounted for by the K&J Hypothesis. In CG, it is not

yet clear how such variation can be accounted for. It has been repeatedly stated in CG that all language variations should be built into the lexicon (e.g. Morrill (1994), Carpenter (n.d.a.)). But I see no way of encoding the behaviour of Chinese quantification into the lexicon, without generating a vast amount of complexities.

The second issue is on branching quantifiers(BQ). The conception of quantification in CG is linear and first-order in nature. No known solution has been offered to deal with the BQ cases, except Carpenter (n.d.b), which is about plurals and non-standard quantifiers. When dealing with standard quantifiers in English not exceeding three in the number of quantifiers involved, the BQ cases are not different from the linear cases, as shown in Chapter 1. But it is difficult for us to see how the cases involving four standard quantifiers that do call for a BQ treatment can be dealt with in CG and whether it is possible for CG to offer a unitary solution to both the linear and the BQ cases of quantification, as LDS_{NL} has succeeded. The fact that in Chinese, the BQ interpretation involving two standard quantifiers is acceptable while its equivalent linear interpretation is not seems to show that even with two standard quantifiers, BQ cases ought to be taken into consideration. Therefore, the treatment of Carpenter (n.d.b) which dealt with the BQ cases with plurals and non-standard quantifiers, seems to be incomplete in coverage.

3. Treatments of Quantification in DRT

Discourse Representation Theory(DRT) as presented in Spencer-Smith (1987), Asher (1993), Kamp & Reyle (1993), and FRACAS (1995) constructs *discourse*

representation structures(DRS) as semantic representations of linguistic units(sentences or larger constructions). DRS's are quasi-models subject to model-theoretic definitions.³ The building of the DRS's is incremental in the sense that information is constantly updated in the process of the construction of the DRS's. The representational process is therefore also a procedural one in that the order of the expansion of a certain construction can substantially affect the semantic structures being represented.

This procedural, incremental aspect of DRT is also characteristic of the LDS_{NL} approach. Both treat natural language understanding as a dynamic process which builds on the information previously accumulated. The object of analysis is not bound to single sentences but may extend to larger units such as discourse.

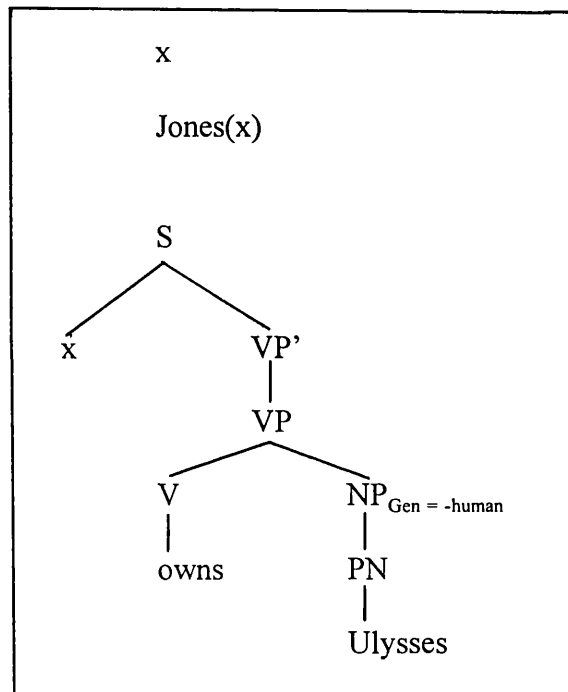
The construction of a DRS involves the gradual introduction of a set of discourse referents in the form of variables. Each of these referents are related to positions in the syntactic structures of a given sentence through triggering configurations, which specify the syntactic environments that sanction the insertion of the referents. Gradually, DRS's are built up as interpretations of given sentences with the interpreted NP's replaced by the discourse referents. At the same time, DRS-conditions are drawn for the discourse referents. These conditions are to be satisfied by the world(model) if the given sentence is to be true. A syntactic structure is assigned a semantic interpretation if and only if a relevant DRS can be built for it. In

³ According to Spencer-Smith (1987), a DRS will be true in a model if it can be mapped onto it in an appropriate way.

other words, a syntactic structure is semantically interpretable if and only if it can be enclosed in at least one DRS box. An example involving pronouns is given below for illustration:⁴

(5) Jones owns Ulysses. It fascinates him.

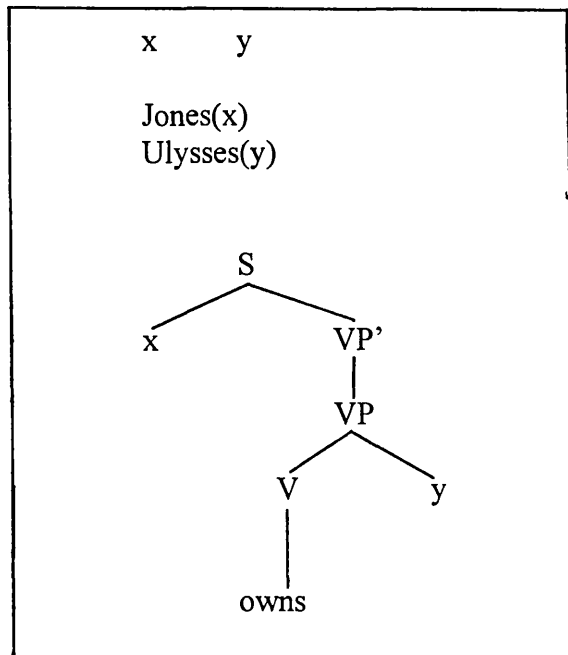
(5a)



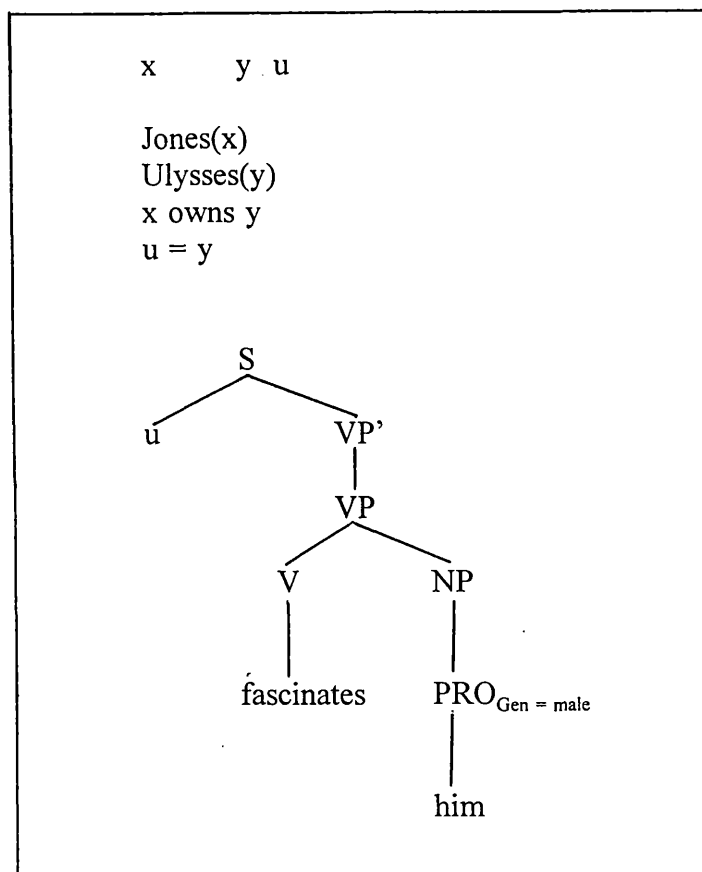
(PN = Proper Noun; Gen = Gender)

⁴ From Kamp & Reyle (1993).

(5b)

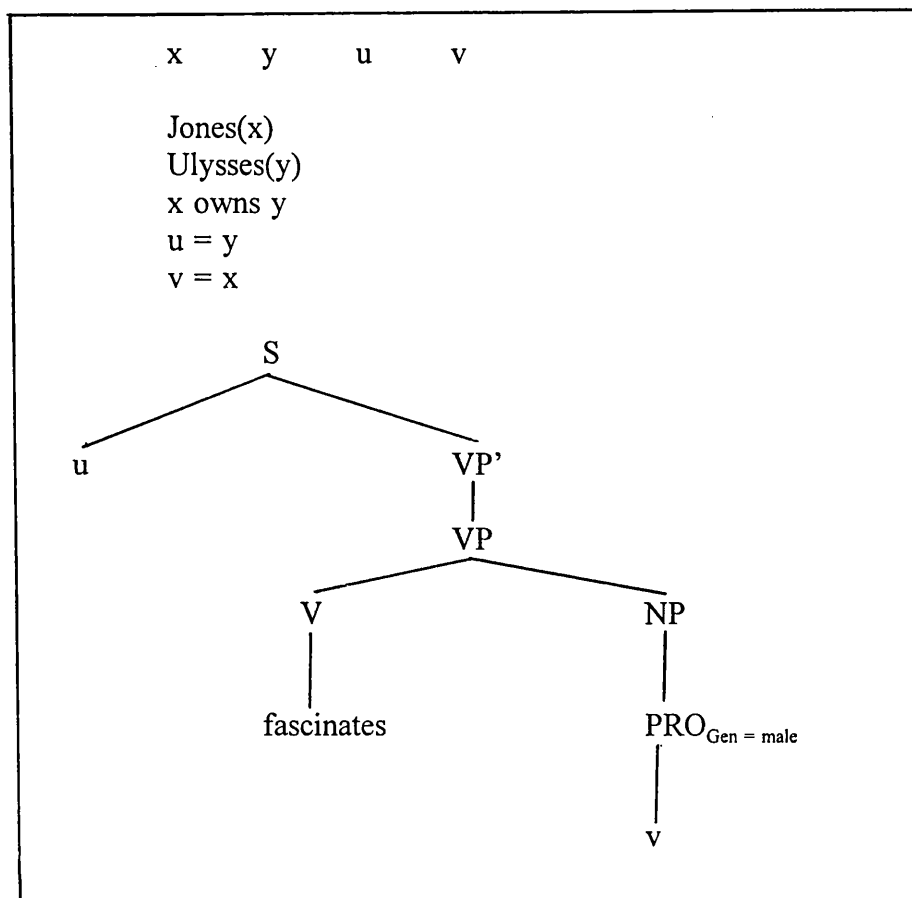


(5c)

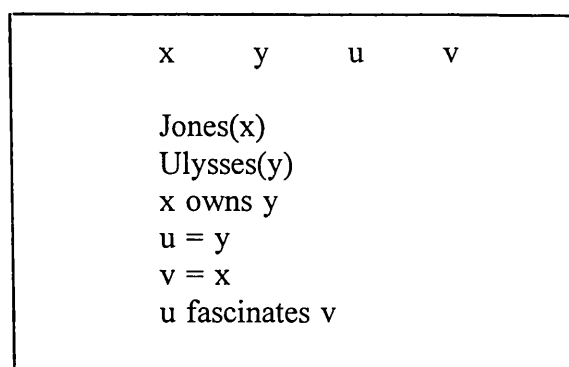


(PRO = pronoun)

(5d)



(5e)



Through steps of procedural representation of names and instantiation of pronouns, we reach the final result (5e), with the syntactic structures omitted for the sake of simplification.⁵

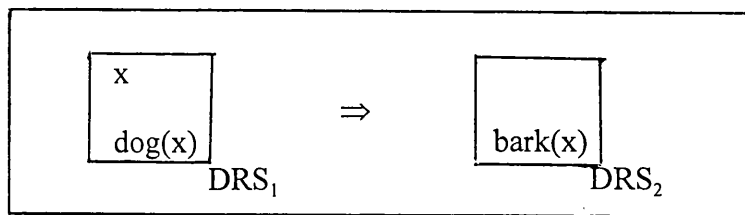
⁵ What have been ignored in this series of representations are the detailed construction algorithm and construction rules leading to the correct representation structures.

The above example reveals that, when dealing with names and pronouns, DRT also assumes the underdeterminacy thesis. Irrespective of the content of the NP in a given sentence, the discourse referent initially introduced into the DRS always takes the underspecified form of a variable. Later steps of information-updating enrich the variable by either providing a proper name for the variable⁶ or equating the variable to a named referent already present in the DRS. So DRT and LDS_{NL} are similar in assuming underdeterminacy and providing enrichment processes.

The treatment of quantification in DRT underwent two stages of development. According to the analysis of the first stage,⁷ quantifiers are dispensed with and QNP's are directly projected as discourse referents embedded in the truth-conditions of such logical expressions. A universally quantified expression introduces a pair of sub-DRS's linked by \Rightarrow embedded within a larger DRS, as shown in (6):

(6) Every dog barks.

(6')



The DRS in (6') will be true if for any embeddings of DRS_1 in the model, there must be at least one enclosure of DRS_2 in the same model. This is equivalent

⁶ This can be done by simple equation, e.g. $x = \text{Jones}$, or in the form of a predication, e.g. $\text{Jones}(x)$. Cf. Spencer-Smith (1987, II) for problem with the first option.

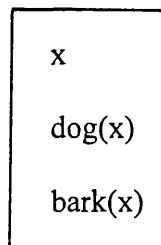
⁷ As exemplified by Spencer-Smith (1987).

to the truth-conditions of a universal quantifier.

An indefinite is projected as a variable(discourse referent). Its difference from proper names is brought out in the discourse conditions, where the variable is not equated to a named entity, as shown in (7):

(7) A dog barks.

(7')

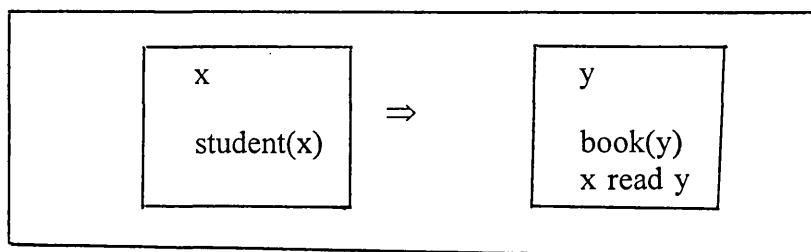


The DRS in (7') will be true if there is some way of embedding the DRS into a model. This gives us the existential force of the indefinite.

Relative scope in multiple quantification can be represented by different depths of embedding, as illustrated in (8):

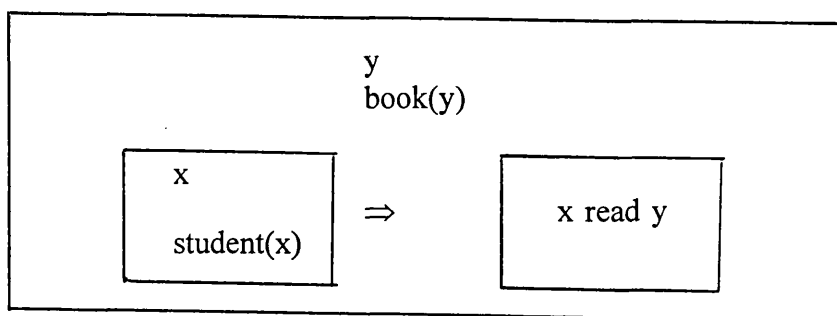
(8) Every student read a book.

(8'a)



(narrow scope for the indefinite)

(8'b)



(wide scope for the indefinite)

Both DRT and LDS_{NL} try to do away with the quantifiers and interpret the QNP's in a procedural way. The two treatments are similar in the sense that with the dispensing of quantifiers, the variables are not to be viewed as free-variables from the point of first-order predicate logic. In DRT, the DRS's containing these variables are not open sentences or propositional functions. They are semantically complete. Similarly, in LDS_{NL} , labels containing meta-variables(η -variables) are not equivalent to first-order formulae either.

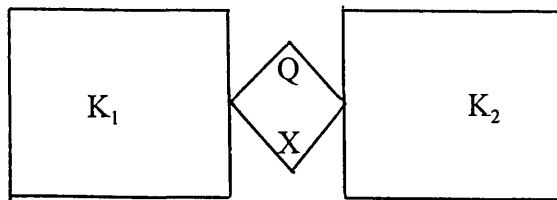
In the second stage of the DRT treatment of quantification,⁸ quantifiers are explicitly introduced into the DRS's. This is due to considerations of non-standard quantifiers such as *many* and *most*, which defy representation in first-order predicate calculus, and hence cannot be properly represented by the original DRT treatment either, whose conditional DRS is based on first-order logic.⁹ The way out is to adopt the generalised quantifier analysis of Barwise & Cooper (1981) for such non-standard quantifiers. For the sake of uniformity, standard quantifiers are then treated in the

⁸ Cf. Kamp & Reyle (1993).

⁹ Cf. Barwise & Cooper (1981) and McCawley (1993).

same way.

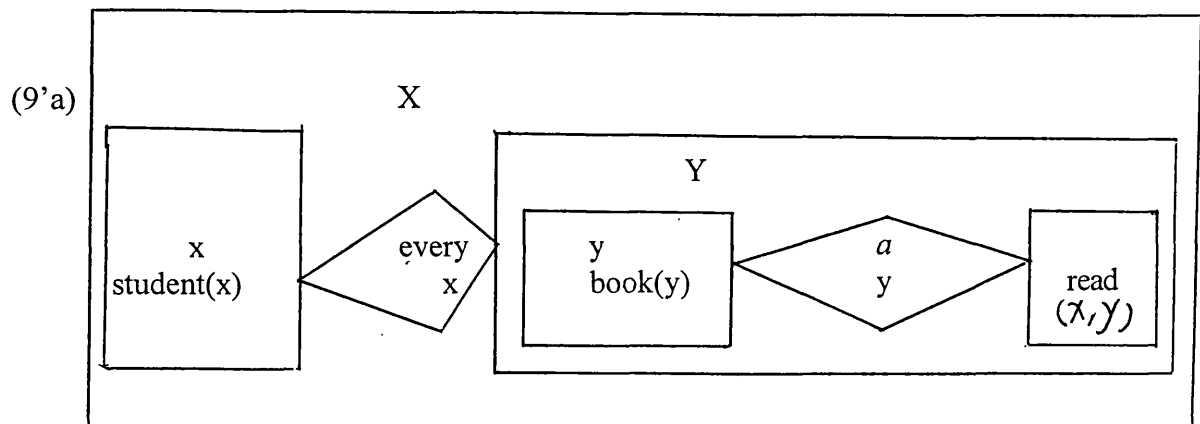
As generalised quantifiers, QNP's in the second-stage treatment of DRT are being represented as a relation between two sets. Thus a sentence containing a QNP is represented in a duplex form:



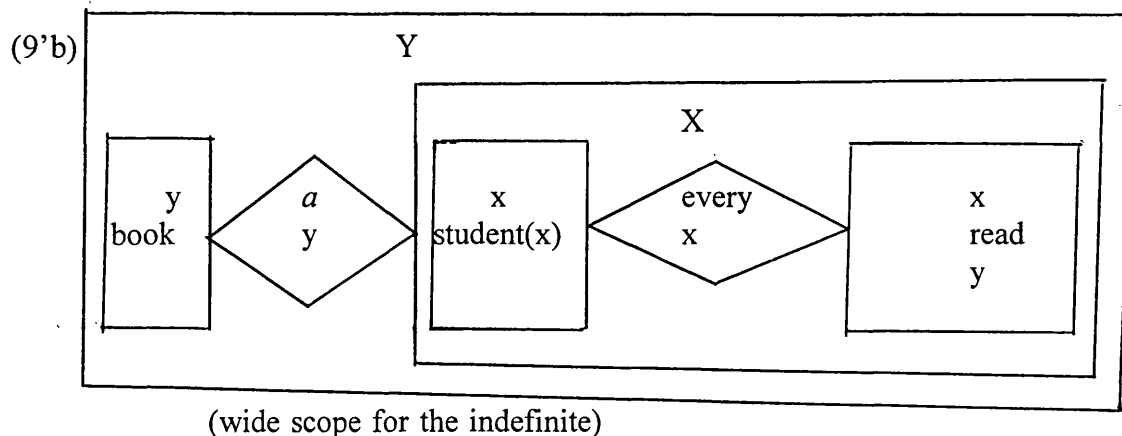
(K_n as discourse conditions, Q as the lexical form of the quantifier, and X as the set denoted by the Q)

Multiple quantification involves the embedding of one duplex form within another, as shown in (9):

(9) Every student read a book.



(narrow scope for the indefinite)



Q-expressions are taken as introducing set variables as discourse referents. The order of the introduction of such referents determines the relative scope of the QNP's under consideration.

The introduction of the quantifiers into the DRS means that DRT is no longer similar to LDS_{NL} in this respect, as no explicit quantifiers appear in the labels of the latter. However, LDS_{NL} has yet to deal with the non-standard quantifiers. We cannot evaluate the full import of such a difference until we find non-quantificational ways for LDS_{NL} to deal with the non-standard QNP's.

Although DRT's treatment of names and pronouns assumes underdeterminacy, its treatment of indefinites does not. Indefinites in DRT are assumed to be ambiguous between the specific sense and the bound-variable sense. Specific indefinites are always represented as taking the least embedded position in DRS, just like proper names. Bound variable indefinites take scope positions relative to their depth of embeddedness in a DRS. So there is no treatment of indefinites as a unitary phenomenon. But no ambiguity is assumed for pronouns in DRT. Whether as deictics

or pronominals or anaphors, they are all introduced as an underdetermined variable. This means that while the underdeterminacy thesis is held for some cases in DRT, it is not assumed for others. But in LDS_{NL} , underdeterminacy is consistently assumed both for the treatment of pronouns and for indefinites. In particular, specificity of indefinites is not taken as a semantically primitive notion which is distinct from the other uses of indefinites. Specificity is derived pragmatically from cases in which an indefinite is dependent on nothing except the database label of $\langle w \rangle$ and is linked to a particular individual in the mind of the speaker or the subject in a sentence containing an opaque context.¹⁰ Therefore, an underdetermined metavariable can be projected for indefinites and then interpreted either specifically or non-specifically at a later stage.

4. Comparison between LDS_{NL} and DRT

There are several other aspects about the DRT approach which are fundamentally different from the LDS_{NL} .

First, each operation in DRT is motivated by the triggering configurations which are part of the syntactic trees formulated by PS rules. Therefore, the construction of DRS's is a mapping process from phrase structures into semantic representations. In other words, DRS's are semantic interpretations on the phrase structures. Hence, the structural basis of DRS is no more than phrase structure grammar. Being model-theoretic, DRT does not build syntactic structures. It only

¹⁰ Cf. Cormack & Kempson (1991/1982).

builds semantic representations. DRT does not involve type-driven deduction processes. It does not use labelled formulae. And it is not a systematic construction of both syntactic and semantic structures, in contrast to LDS_{NL} and CG, both of which 'put semantics into syntax'.

Second, in DRT, discourse referents first introduced as variables are subsequently related to the phrase structures. But the variables as discourse referents are not really instantiated or enriched in terms of lexical content. Every noun gets represented as $\overset{\wedge}{\lambda}$ variable, be it names, or pronouns, or QNP's. Their distinctions are only drawn by the DRS conditions specifying their content in terms of predicates (e.g. $\text{John}(x)$, $\text{most}(x)$) or equations (e.g. $u = x$). Crucially, variables are not subsequently instantiated. They still appear as variables. And their dependency relations are never made explicit, in the case of quantification. In contrast, LDS_{NL} does provide instantiation mechanisms to enrich the metavariables so that the final output of structured interpretation no longer contains bare variables.

The third point again concerns language variation. The representation of multiple quantification involves the manipulation over the ordering of expansion of parts of phrase structures and the insertion of discourse referents. In dealing with the cases in Chinese, it is necessary to develop some meta-level mechanism similar to the delaying mechanism and the Kempson & Jiang Hypothesis to debar the expansion of certain structures ahead of the expansion of others. It remains to be seen how such a mechanism can be developed in DRT which is in harmony with the treatment of quantification in general and can be based on some syntactic motivations for such a

mechanism. The K&J Hypothesis, formulated in terms of dependency, does not seem to be directly translatable into the language of DRT(or CG).

The last aspect for comparison is on branching quantification. As DRT's treatment of multiple quantification is also linear and first-order, it does not seem to be able to handle the BQ cases well. The points I raised with reference to CG should also apply to DRT in this case.

5. Conclusion

The comparisons made in this chapter between LDS_{NL} on the one side and CG and DRT on the other help to make clear the links and the differences between LDS_{NL} and the latter two theories.

LDS_{NL} is similar to CG in the use of labels and deduction over the typed formulae. LDS_{NL} also shares similarities with DRT in formulating procedural, incremental interpretations of strings.

But LDS_{NL} is the only theory which consistently upholds the underdeterminacy thesis and constructs explicit mechanisms to enrich the lexical content. To achieve this goal, instantiation techniques have been borrowed from logic and operations are allowed to perform on labels alone, not on corresponding formulae.

With reference to quantification, LDS_{NL} provides an account which deals with

dependency ambiguity, branching quantification, group readings and language variation with uniformity. But more studies are needed in order to see if the same simple naturalness in the present analysis of quantification in LDS_{NL} can be achieved with minimal expansion when handling some more complex cases such as non-standard quantifiers and interaction between quantification and anaphora. So the issue of comparison between LDS_{NL} and CG, and between LDS_{NL} and DRT remains an open one.

Appendix A

Game Theory and Verification Procedures

Game theory is essentially a verification theory. In this appendix, we examine the relationship between game theory and the verification techniques in logic. After presenting the verification procedures, I will also briefly address the flaws of such techniques in terms of computational complexity, which devalues game theory as an efficient theory of natural language understanding.

First, we have a look at the Beth Tableaux. According to Hodges (1983), the logical basis of Beth-Tableaux is the following theorem:

$$(1) \quad \phi_1, \dots, \phi_n \models \psi \text{ iff } \phi_1, \dots, \phi_n, \sim\psi \not\models \perp.$$

Taking an example from Hodges (1983), we attempt to determine the validity of the following sequent,

$$(2) \quad p \wedge q, \sim(p \wedge r) \models \sim r.$$

By (1), (2) holds iff (3) holds,

$$(3) \quad p \wedge q, \sim(p \wedge r), \sim\sim r \not\models \perp$$

(3) says that there is no model such that the three formulae to the left of \models holds simultaneously. To verify the truth of (3), we try to refute it by constructing such a model. We break each of the formulae into its atomic parts according to the truth conditions they must satisfy for them to be true. If we can come up with a model that contains all the atomic formulae without any inconsistencies, then we have built up such a model without leading to absurdity. In that case, we have succeeded in proving that (3) is false. If the reverse happens, then we fail to refute (3). So (3) is true. Details are hereby provided with relation to (3):

$$\begin{array}{lcl}
 (4) & p \wedge q, \sim(p \wedge r), \sim\sim r & \models \perp \\
 & | & \text{[Double Negation]} \\
 & p \wedge q, \sim(p \wedge r), r & \models \perp \\
 & | & \text{[}\wedge\text{ Elimination]} \\
 & p, q, \sim(p \wedge r), r & \models \perp \\
 & / \qquad \qquad \backslash & \text{[Truth-condition(TC) for } \sim(A \wedge B)\text{]} \\
 & \underline{p, q, \sim p, r = \perp} & \underline{p, q, \sim r, r = \perp}
 \end{array}$$

In (4), as every possibility leads to absurdity, the formula (3) cannot be refuted. It is therefore correct.

Another example concerns an incorrect sequent, also from Hodges (1983):

$$(5) \quad p \vee \sim(q \rightarrow r), q \rightarrow r \models q.$$

$$\begin{array}{c}
 (6) \quad p \vee \sim(q \rightarrow r), q \rightarrow r, \sim q \vdash \perp \\
 \quad \quad \quad / \quad \quad \backslash \quad \quad \quad \text{[TC for } \vee\text{]} \\
 \quad \quad p, q \rightarrow r, \sim q \vdash \perp \quad \quad \underline{\sim(q \rightarrow r), q \rightarrow r, \sim q \vdash \perp} \\
 \quad \quad / \quad \quad \backslash \quad \quad \quad \text{[TC for } \rightarrow\text{]} \\
 p, \sim q, \sim q \vdash \perp \quad \quad p, r, \sim q \vdash \perp
 \end{array}$$

We can only show that the right-most branch in (6) leads to absurdity. The other two branches remain open. We conclude that in these two cases, we have successfully built models that do not lead to absurdity. We have thereby refuted (5).

But semantic tableaux only work for propositional formulae, just like truth tables. We therefore turn to a similar procedure that, with the aid of some more theorems and processes, can deal with predicate formulae as well. A more complex case with quantification is presented in Davis (1994), which is verified in a more complicated way but in the same spirit as Beth Tableaux and Game Theory. Davis (1994) called procedures for verifying logical inferences based on a theorem similar to (1) *refutation procedures* 'because they can be thought of as "refuting" the negation of the conclusion.'

Given (7), and its translated form (8), we want to show that (8) is true if and only if (9) is inconsistent.

- (7) John loves Mary, Everyone loves a lover \vdash Everyone loves John. \Rightarrow
 (8) $\text{LOVES}(\text{JOHN}, \text{MARY}), (\forall x)(\forall y)[(\exists z)\text{LOVES}(y, z) \rightarrow \text{LOVES}(x, y)] \vdash$
 $(\forall x)\text{LOVES}(x, \text{JOHN}).$

$$(9) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge (\forall x)(\forall y)[(\exists z)\text{LOVES}(y, z) \rightarrow \text{LOVES}(x, y)] \wedge \sim(\forall x)\text{LOVES}(x, \text{JOHN})].$$

I quote the steps of verification first, then supply the explanations:

$$(10) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge (\forall x)(\forall y)[\sim(\exists z)\text{LOVES}(y, z) \vee \text{LOVES}(x, y)] \wedge (\exists x)\sim\text{LOVES}(x, \text{JOHN})] \Rightarrow$$

$$(11) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge (\forall x)(\forall y)[(\forall z)\sim\text{LOVES}(y, z) \vee \text{LOVES}(x, y)] \wedge (\exists x)\sim\text{LOVES}(x, \text{JOHN})] \Rightarrow$$

$$(12) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge (\forall x)(\forall y)[(\forall z)\sim\text{LOVES}(y, z) \vee \text{LOVES}(x, y)] \wedge (\exists w)\sim\text{LOVES}(w, \text{JOHN})] \Rightarrow$$

$$(13) \quad (\exists w)(\forall x)(\forall y)(\forall z)[\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge [\sim\text{LOVES}(y, z) \vee \text{LOVES}(x, y)] \wedge \sim\text{LOVES}(w, \text{JOHN})] \Rightarrow$$

$$(14) \quad (\forall x)(\forall y)(\forall z)[\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge [\sim\text{LOVES}(y, z) \vee \text{LOVES}(x, y)] \wedge \sim\text{LOVES}(c, \text{JOHN})]$$

Reducing the conditional in (9) to its equivalent disjunction gave us (10). By rule of quantifier equivalence, we changed $(\sim(\exists z))$ to $((\forall z)\sim)$ and obtained (11). Then we relabelled the variable bound by the last \exists , changing it from x to w , so that no two quantifiers referred the same variable. This gave us (12). Steps of normalization yielded (13), which was in prenex normal form. When applying Skolemization to (13), we found the only 'Skolemizable' element was the Existential operator and its variable w . We wanted to delete $\exists w$ and replace all occurrences of w by $g(\alpha)$, α to be taken as the value w depends on. As (13) begins with $\exists w$, the α in $g(\alpha) = 0$. In this case, '...the term replacing the variable reduces to a constant symbol[like a name], which

... can be thought of as a function symbol of degree 0' (Davis 1994). This gave us (14), where w was replaced by the Skolem constant c . We pause here by introducing the Skolem-Herbrand Theorem and its related definitions.

- (15) **The Skolem-Herbrand Theorem.** Let α be a sentence of the vocabulary $\Lambda = \langle C, F, R, d \rangle$ of the form: $(\forall \xi_{i1}) \dots (\forall \xi_{in}) \zeta(\xi_{i1}, \dots, \xi_{in})$. Then, α is consistent if and only if its Herbrand support $S(\alpha)$ is truth-functionally consistent.
- (16) A Herbrand support of α is a set of sentences:
 $S(\alpha) = \{ \zeta(\mu_1, \dots, \mu_n) \mid \mu_1, \dots, \mu_n \in H(\alpha) \}$, where $H(\alpha)$ is the Herbrand universe of α .
- (17) The Herbrand universe of α is the set of all terms of Λ that contain no variables, where Λ is the vocabulary of α .

We construct a Herbrand universe for (14):

- (18) $H = \{ \text{JOHN, MARY, } c \}$

which contains three elements. As (14) contains three variables, we thus have

- (19) $\zeta(x, y, z) = [\text{LOVES}(\text{JOHN, MARY}) \wedge [\sim \text{LOVES}(y, z) \vee \text{LOVES}(x, y)] \wedge \sim \text{LOVES}(c, \text{JOHN})]^1$

Using the three individuals to substitute the three variables, we have 3^3

¹ The left of (19) says that the sentence is of an abstract form containing 3 variables; the right side is the sentence itself.

possibilities. Hence the Herbrand support of (14) contains $3^3 = 27$ sentences. One of these sentences is (20):

$$(20) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge [\sim \text{LOVES}(\text{JOHN}, \text{MARY}) \vee \text{LOVES}(\text{c}, \text{JOHN})] \\ \wedge \sim \text{LOVES}(\text{c}, \text{JOHN})]$$

which further reduces to two sentences:

$$(21) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge \sim \text{LOVES}(\text{JOHN}, \text{MARY}) \wedge \sim \text{LOVES}(\text{c}, \text{JOHN})]$$

$$(22) \quad [\text{LOVES}(\text{JOHN}, \text{MARY}) \wedge \text{LOVES}(\text{c}, \text{JOHN}) \wedge \sim \text{LOVES}(\text{c}, \text{JOHN})]$$

Both are inconsistent. Therefore, the entire Herbrand support is truth-functionally inconsistent. By the Skolem-Herbrand Theorem (15), (14) is inconsistent, so is (9). Having refuted (9), we can establish that (8) is a correct inference.

In the above example, we see mirror images of the game-theoretical approach, which proceeds via the same route of reduction, substitution, and refutation. Now we can conclude that game theory(including game-theoretic semantics), the semantic tableaux method, and the refutation procedures given in Davis (1994) share the same logical principle, i.e. the theorem (1), which we can either name as the Refutation Method, or the non-constructive technique² or Negation by Failure (the latter notion a more apt description from a procedural point of view and is widely used in logical

² Leisenring (1969) defined a 'non-constructive argument' as one in which the existence of something is proved by deducing a contradiction from the assumption that no such thing exists.

programming languages such as Prolog). In addition, the first and the third method, being capable of dealing with predicate formulae, are buttressed by the Skolem-Herbrand Theorem and Theorem of Skolemization (Detailed formulations can be found in Hodges (1983)).

In the case of the Herbrand universe of a sentence α being an infinite set, e.g. natural numbers, there will be no limit to the Herbrand support. That means the verification procedure will never go to an end, with the refutation steps recursively applied to each and every sentence generated as members of the Herbrand support. Both in logic and in natural language quantification, we might often want to refer to infinite sets. And we might as well want to make out the dependency relations among individuals occurring in a formula. But we do not need to wade through the whole set examining each and every case. That would be virtually impossible in the case of a set being infinite. What we want is simply the establishment of a relationship in terms of Skolem functions. No need for extra efforts of verification. What is more, verification by substitution sets out to reflect the deductive properties of the logic of quantification. But in practice it turns out to be an inductive process. Although winning strategies can be recursively applied, I cannot be sure whether the next example will turn out to be against the rule of winning. What if the rule is a bent rule, which works well with the first twenty thousand cases and goes wrong with the very next?³ Davis (1994) showed that if the Herbrand universe is not finite, and if the inference with regard to a formula is not correct, then we will not be able to discover inconsistency in our refutation procedure. As a result, the procedure will never

³ Cf. Peacocke (1979) and Blackburn (1984) for discussions.

terminate. From the point of view of computability theory, such cases are recursively enumerable and hence not computable. Even with a finite set, which is exhaustable and hence verifiable within a finite length of time, such a procedure is extremely inefficient. Hodges (1983) remarked that with regard to semantic tableaux method in propositional logic, it could be argued that 'for longer sequents the problem is too hard to be solved efficiently by a deterministic computer[for example, in polynomial time]'. Davis (1994) is of the same opinion.

But it is still not clear whether such problems in efficiency and computability are really inherent to any procedural approach. While it is yet to be shown that any current theory of linguistics can be as efficient as being able to process extremely complex sentences in polynomial time, we can at least try to bypass such traps by taking different routes.

Appendix B

Functional Interpretation of Quantifiers

This appendix contains the rules for quantifiers in de Queiroz & Gabbay (1995), with detailed explanations:

(1) \exists -introduction

$$\frac{a : \mathbf{D} \quad f(a) : \mathbf{F}(a)}{\varepsilon x.(f(x), a) : \exists x^{\mathbf{D}}.\mathbf{F}(x)}$$

Let a be an individual (a witness) from the domain \mathbf{D} , and let a satisfy the property $\mathbf{F}(a)$, we let $f(a)$ be a proof of $\mathbf{F}(a)$. With EI, we reach $\exists x^{\mathbf{D}}.\mathbf{F}(x)$ on the formula side. At the same time, we replace all the occurrences of a in $f(a)$ by a new variable x , which is bound by the ε -x.-abtractor. Here $f(a)$ serves as a record of the proof of $\mathbf{F}(a)$ (or the judgment of the proposition $\mathbf{F}(a)$). And we apply EI to obtain the indefiniteness of the formula by abstracting on $\mathbf{F}(a)$, yielding $\exists x^{\mathbf{D}}.\mathbf{F}(x)$. On the labelling side, we make a corresponding move by abstracting on $f(a)$. We introduce the εx -abtractor which binds the x in $f(x)$. However, the a in $\varepsilon x.(f(x), a)$ is neither within the domain of f nor bound by εx . a is kept here as a hidden argument, a record to remind us that $f(a) : \mathbf{F}(a)$ is true of a specific individual a , which is chosen at the time of assertion. a is here resident in the εx -abtractor because (1) does not involve the discharge of previous assumptions, since the introduction of the \exists -quantifier does

not assume that a is an arbitrary element from \mathbf{D} . That is why we allow a to reside in the ε -term.

(2) \exists -elimination

$$\frac{\begin{array}{c} [t : \mathbf{D}, \quad g(t) : \mathbf{F}(t)] \\ e : \exists x^{\mathbf{D}}. \mathbf{F}(x) \qquad \qquad \qquad d(g, t) : \mathbf{C} \end{array}}{\text{INST}(e, \sigma g. \sigma t. d(g, t)) : \mathbf{C}}$$

Q&G treats EE as indirect existential instantiation, in the same way as Lemmon (1965). That is, given $\exists x \mathbf{F}(x)$, and given $\mathbf{F}(a)$ as a new assumption, if \mathbf{C} can be inferred from $\mathbf{F}(a)$, we can conclude that \mathbf{C} can be inferred from $\exists x \mathbf{F}(x)$, so long as \mathbf{C} does not depend on any premisses other than $\mathbf{F}(a)$ that contain arbitrary individuals. In the LDS convention, given the labelled formula $e : \exists x^{\mathbf{D}}. \mathbf{F}(x)$, e an unanalysed term denoting the proof of the formula, we know from (1) that in e there ought to be a hidden argument a denoting a specific individual $a : \mathbf{D}$, from which we obtain $f(a) : \mathbf{F}(a)$ and $\varepsilon x. (f(x), a) : \exists x^{\mathbf{D}}. \mathbf{F}(x)$ in turn. But in $e : \exists x^{\mathbf{D}}. \mathbf{F}(x)$, the hidden argument is unavailable. That is, given $\exists x^{\mathbf{D}}. \mathbf{F}(x)$, we have no way of knowing who the individual is, which was chosen at an introduction inference prior to the present inference. So we hypothesize that there exists an individual $t : \mathbf{D}$, t being a new name different from a in e . We suppose t satisfies the property $\mathbf{F}(t)$ and we introduce a new assumption $g(t) : \mathbf{F}(t)$, in which g is a proof of $\mathbf{F}(t)$ and g depends on t . So $g(t)$ is a Skolem function. If, given $g(t) : \mathbf{F}(t)$, we can reach \mathbf{C} through finite steps of reasoning, we use $d(g, t)$ to label \mathbf{C} . d is a proof of \mathbf{C} and d depends on both g and t . Now we want to say that \mathbf{C} follows from $\exists x^{\mathbf{D}}. \mathbf{F}(x)$ anyway. To do this, we identify the premiss $d(g, t)$

: \mathbf{C} with $e : \exists x^{\mathbf{D}}. \mathbf{F}(x)$. The process is a complex one. We use a new abstractor σ to abstract on both g and t in d , yielding $\sigma g. \sigma t. d(g, t)$. This process of σ -abstraction discharges the assumption $d(g, t) : \mathbf{C}$. It makes g and t lose their identity in d . The result is that although we assumed $t : \mathbf{D}$ and reached $g(t) : \mathbf{F}(t)$ and $d(g, t) : \mathbf{C}$, we now claim that it does not really matter what individual we chose to start with. \mathbf{C} can be reached regardless of the status of t or g . Finally, we identify $d(g, t)$ with e by instantiation(INST). This means \mathbf{C} follows from e , given another proof $\sigma g. \sigma t. d(g, t)$ in its support.

(3) \forall -introduction

$$\frac{\begin{array}{l} [x : \mathbf{D}] \\ f(x) : \mathbf{F}(x) \end{array}}{\Lambda x. f(x) : \forall x^{\mathbf{D}}. \mathbf{F}(x)}$$

Suppose x is an arbitrary individual chosen from the domain \mathbf{D} . We let $f(x) : \mathbf{F}(x)$ be satisfied, $f(x)$ a proof of $\mathbf{F}(x)$. This means that $f(a)$ is a proof of $\mathbf{F}(a)$ provided a is an arbitrary individual chosen from \mathbf{D} . We can then reach $\forall x^{\mathbf{D}}. \mathbf{F}(x)$ through $\forall I$. Since this is an introduction process based on an assumption which mentions arbitrary individuals, we want to discharge the assumption $f(x) : \mathbf{F}(x)$. Hence we introduce Λ -abstraction on the labelling side, yielding $\Lambda x. f(x) : \forall x^{\mathbf{D}}. \mathbf{F}(x)$. In $\Lambda x. f(x)$, we do not have any hidden argument like the specific witness a in (1). x is freely chosen. This difference between the Λ -abstractor and the ε -abstractor reflects the difference between the \forall - and \exists -quantifiers in terms of **introduction** rules.

(4) \forall -elimination

$$\frac{a : \mathbf{D} \quad \Lambda x.f(x) : \forall x^{\mathbf{D}}.F(x)}{\text{EXTR}(\Lambda x.f(x), a) : F(a)}$$

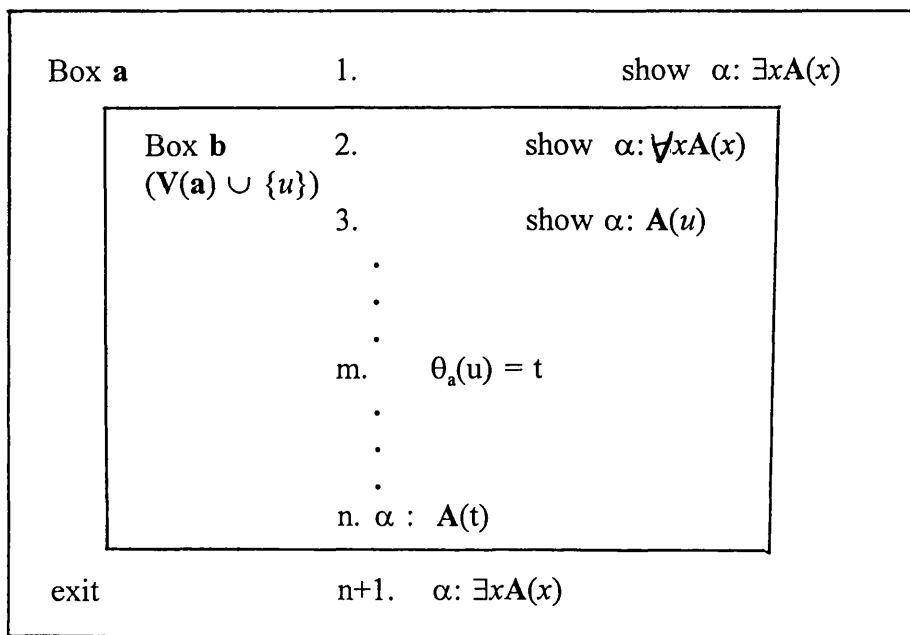
Let a be any individual in the domain \mathbf{D} . Given $\Lambda x.f(x) : \forall x^{\mathbf{D}}.F(x)$, we can substitute the x in $\forall x^{\mathbf{D}}.F(x)$ by an arbitrary individual a , yielding $F(a)$. On the labelling side, we introduce the individual a through a process called **EXTR**(action). When a is applied to $\Lambda x.f(x)$ by Λ -conversion, it gives us $f(a)$. Here again it should be noted that a is an argument of **EXTR**, but not an argument of $\Lambda x.f(x)$. So a is accessible to **EXTR**. Hence we can reach $f(a)$. Moreover, the Λ -term does not carry a particular witness with it. So the choice of witness a in **EXTR** is arbitrary. In contrast, a is an argument in ex in (1), so it is hidden in e in (2) and therefore not accessible as an argument to **INST** in (2).¹ Hence **C** is reached in (2) with no mention of the specific individual a , while (4) does mention an arbitrary a . This difference between the Λ -abstractor and the ε -abstractor reflects the difference between the \forall - and \exists -quantifiers in terms of **elimination** rules. We can perhaps view the use of a residing on the labelling side as an argument of the main functor on the last lines of relevant proofs (i.e. (1) and (4)) as resource labels stating the side conditions related to some rule application. a stands either as an arbitrary individual or a specific one, depending on the history of its introduction in the proofs.

¹ Even if we replace the unanalysed term e with $\text{ex}.f(x), a$, in (2), a is still unavailable to **INST** because it is not an argument of **INST**.

Appendix C

Quantifier Rules with η -Function

(1) $\exists I$... $\vdash \alpha : \exists x A(x)$



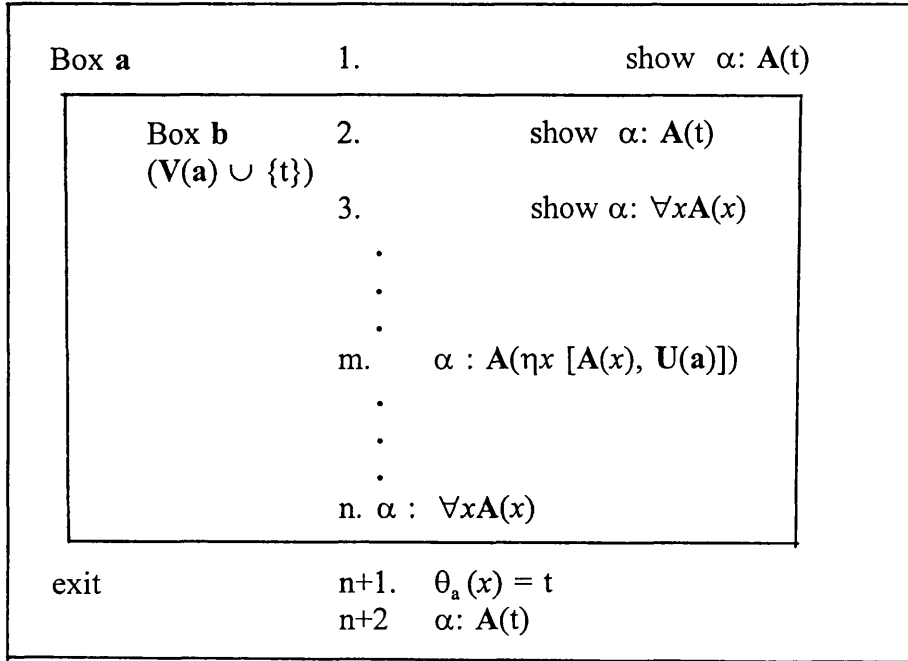
(See Chapter 3 for explanations of this example.)

(2) $\forall I \quad \dots \vdash \alpha : \forall x A(x)$

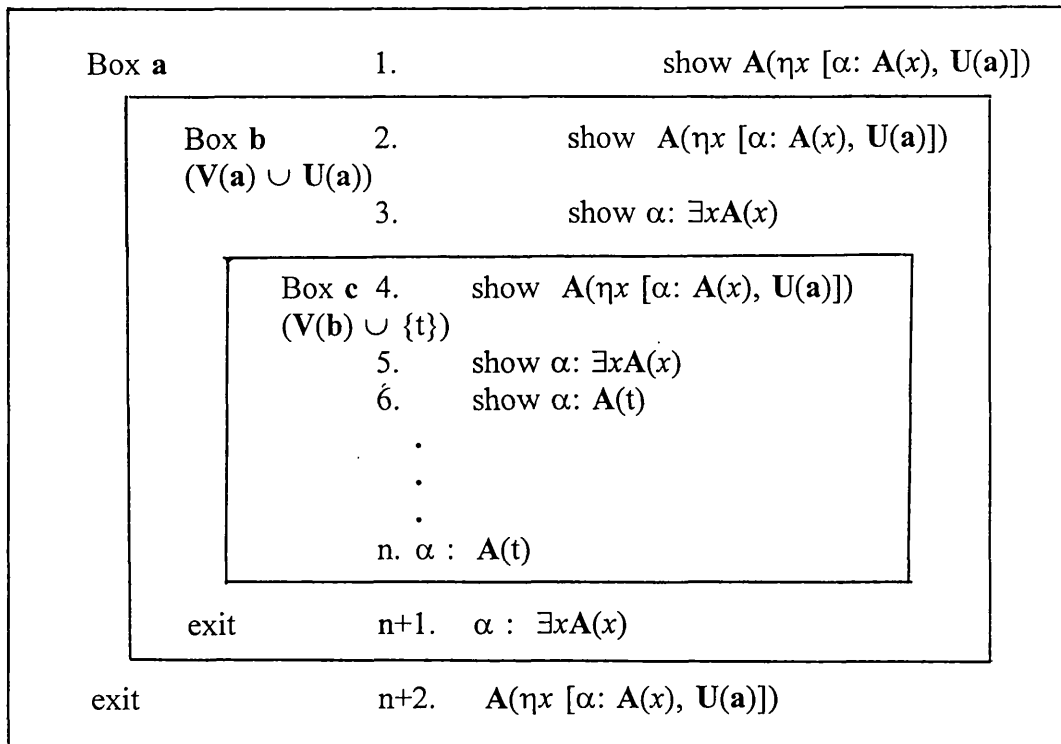
Box a	1.	show $\alpha : \forall x A(x)$
Box b	2.	show $\alpha : \exists x A(x)$
$(V(a) \cup U(a))$	3.	show $\alpha : A(\eta x [A(x), U(a)])$
	.	
	.	
	.	
	n.	$\alpha : A(\eta x [A(x), U(a)])$
exit	n+1.	$\alpha : \forall x A(x)$

An line 3 of (2), we put down the complete η -term: $A(\eta x[A(x), U(a)])$, in which $U(a)$, being a finite set of η - variables, resides as an argument. This contrasts with line 3 in (1), where a single Skolem variable u suffices. I think the reason for such a difference is that for $\forall I$, we want to make sure that the x in $A(\eta x A(x))$ should be an arbitrary individual picking out from the set $U(a)$. But for $\exists I$, the existence of one single specific individual suffices to lead to an existential commitment.

(3) $\forall E \quad \dots \vdash \alpha : A(t)$



(4) $\exists E \quad \dots \vdash A(\eta x [\alpha : A(x), U(a)])$



Note that Gabbay's formulation of $\exists E$ here is in the form of direct elimination, different from indirect elimination in de Queiroz & Gabbay (1995) or Lemmon (1965).

In (4), again we choose to eliminate the existential form into a complete η -term, where the presence of $U(\mathbf{a})$ as an argument shows that the η - term is reached relevant to a specific individual chosen from the set of η - variables, i.e. t in $\alpha : A(t)$. Since α stands for the proof of $A(t)$ [t later abstracted by the η - abstraction], we keep $\alpha : A(x)$ as a declarative unit serving as a bound argument within ηx .

Appendix D

The Basic Mechanisms of Categorical Grammars

This is not the place to give a detailed presentation of categorical grammars, which exist in various versions. I can only present some mechanisms common to most versions of CG to facilitate our discussions on the treatments of quantification in the text.

The core mechanism of CG is the Lambek Calculus, which consist of deduction rules operating over the syntactic types or categories projected by the words in the lexicon. Besides the rules and the types, the third integral element is the operators which connect the types to form formulae over which the rules apply. The minimal details are presented below. I adopt the convention of Lambek in putting the argument to the top of the operator, and the result to the bottom, if the related operator is order-sensitive (such as the slashes).²

Categorical Grammar

I. Types:

(a) Atomic Categories,

² More systematic presentations can be found in Wood (1993), Morrill (1994), Carpenter (fcmng), and literature cited therein.

e, t (or N, S)³

(b) Complex (Functor) Categories

If A, B are categories,

then $A \text{ op } B$ is also a category,

where op is an operator, and

A, B do not have to be atomic categories.

II. Infix Operators as Functors

(a) The forward slash A/B ,

[An element can take an argument B to the right of / and return a result A. e.g.

$(N \backslash S)/N$ is a transitive verb taking an object NP to its right and return a VP.]

(b) The backward slash $B \backslash A$,

[An element can take an argument B to the left of \ and return a result A, e.g.

$N \backslash S$ is a VP taking a subject NP to its left and return an S.]

(c) The extraction operator $B \uparrow A$ ('up arrow')

[An element can wrap around A to produce B. e.g. a sequence with a gap wrapping around the missing A to produce B.]

(d) The infixation operator $A \downarrow B$ ('down arrow')

[An element can infix itself into A to form B, being the counterpart of (c).]

(e) The constructor $A \uparrow \uparrow B$.

[An element can act as a B in the derivation of A, at which point it can be applied semantically, e.g. generalised quantifiers $S \uparrow \uparrow N$ which act as NP's in S

³ The type N(or e) stands for a semantic type and should not be equated to an N as a syntactic category. In fact, N as a type is usually associated with the syntactic category NP, as shown in the rest part of the fragment of CG.

and take semantic scope within the resulting S.]

$A \uparrow B$ is by definition equivalent to $(A \uparrow B) \downarrow A$, as stated in Carpenter (n.d.a).

III. The Rules (Using the slash operator for illustration)

(a) Application

$A/B, B \rightarrow A$

$B, B \backslash A \rightarrow A$

e.g. $N, N \backslash S \rightarrow S$

(b) Composition

$A/B, B/C \rightarrow A/C$

$C \backslash B, B \backslash A \rightarrow C \backslash A$

(c) Raising

$A \rightarrow B / (A \backslash B)$

e.g. $N \rightarrow S / (N \backslash S)$ (Subject NP)

$A \rightarrow (B/A) \backslash B$

e.g. $N \rightarrow (S/N) \backslash S$ (Object NP)⁴

The mechanisms of CG outlined above are employed by many current studies in CG's. Not all the studies make use of the same set of operators and rules, and some formulated additional derived rules and notations. This is characteristic of the current

⁴ I exclude other rules that do not play a role in our current discussion, such as Associativity, Division, etc. cf. Wood (1993).

categorical studies.

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VITAE

Yan Jiang(surname last) was born in Beijing on August 30th, 1962. He studied at the Department of Foreign Languages, Fudan University, Shanghai, between 1980 and 1986, where he got his BA degree(1984) in English language and literature and MA degree(1987) in modern English and linguistics. From 1986 to 1989, he worked in the same department as lecturer teaching English language and linguistics. From late 1989 to 1993, he studied at the Departments of Phonetics and Linguistics, University College, and the School of Oriental & African Studies, London University. Since October, 1993, he has been working as assistant professor in the Department of Chinese and Bilingual Studies, Hong Kong Polytechnic University. His main areas of interest are formal semantics, pragmatics and Chinese linguistics.