

F-Structures, QLFs and UDRSs

Josef van Genabith and Richard Crouch*

July 23, 1996

1 Abstract

Lexical Functional Grammar (LFG) f-structures are “high-level” *syntactic* representations; Quasi-Logical Forms (QLFs) and Underspecified Discourse Representation Structures (UDRSs) are recent underspecified and truth-conditionally interpreted *semantic* representations. It turns out that there are a number of striking structural similarities between f-structures, QLFs and UDRSs, so much so that f-structures can be “read” as QLFs or UDRSs and hence be assigned either a direct or indirect underspecified truth-conditional interpretation. Indirect interpretations are defined in terms of homomorphic embeddings of f-structures into the QLF or UDRT formalism. Based on these we give a direct QLF-style semantics for f-structures and show how the UDRT inference system can be exploited by the translation images of f-structures. The translation functions can be shown to be truth-preserving with respect to an independent semantics (and hence with respect to each other ...) in the sense that the set of disambiguations obtained from a translation image of an f-structure coincides with the set of disambiguations obtained from the independent semantics for that f-structure. A number of grammatical interpretation components for LFG grammars have been proposed in the literature [Halvorsen, 1983; Fenstad *et al.*, 1987; Halvorsen and Kaplan, 1988; Dalrymple *et al.*, 1993; Wedekind and Kaplan, 1993; Dalrymple *et al.*, 1995b]. Our present proposal differs in several respects: unlike earlier proposals it associates f-structures with an explicit underspecified truth conditional semantics; unlike earlier proposals interpretation does not require levels of representation distinct from f-structure representations. Finally, the ease with which “syntactic” f-structure representations translate into the independently motivated “semantic” QLF and UDRT representations provides independent support for a level of representation such as LFG f-structure.

*Josef van Genabith: Dublin City University, School of Computer Applications, Ireland, Josef.Van.Genabith@CompApp.DCU.IE; Richard Crouch: DRA, Malvern, U.K., crouch@signal.dra.hmg.gb. We would like to thank Anette Frank, Jürgen Wedekind, Mary Dalrymple, Ron Kaplan, Louisa Sadler, Doug Arnold and our FraCaS colleagues Jan Jaspars, Steve Pulman, Manfred Pinkal, Robin Cooper and Hans Kamp for discussion. Errors and opinions are our own.

2 Introduction

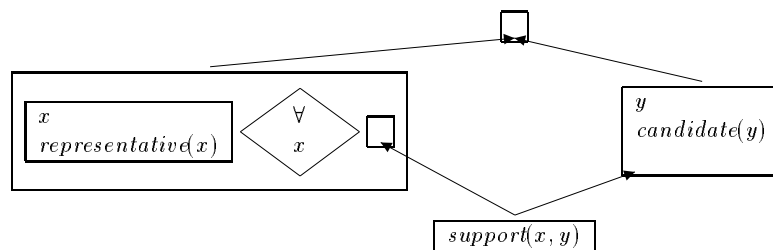
Lexical Functional Grammar (LFG) f-structures [Kaplan and Bresnan, 1982; Dalrymple *et al.*, 1995a] are designed to encode abstract syntactic information. In LFG this is unpacked in terms of an inventory of grammatical functions and encoded in the form of attribute-value structures (f-structures) related to surface structure trees in terms of a piecewise function mapping nodes in trees into f-structure components. The f-structure associated with “*Every representative supported a candidate.*” would look something like

$$\left[\begin{array}{l} \text{SUBJ} \left[\begin{array}{l} \text{PRED 'representative'} \\ \text{NUM SG} \\ \text{SPEC EVERY} \end{array} \right] \\ \text{PRED 'support } (\uparrow \text{SUBJ}, \uparrow \text{OBJ})' \\ \text{OBJ} \left[\begin{array}{l} \text{PRED 'candidate'} \\ \text{NUM SG} \\ \text{SPEC A} \end{array} \right] \end{array} \right]$$

Lexical, syntactic and semantic ambiguity in natural language rules out simple generate and test strategies in natural language processing on the grounds of the forbidding computational complexity involved. As an alternative, semantic representation formalisms have been developed which - in the absence of disambiguating information - allow one to remain uncommitted as to the scope of e.g. quantifiers and operators while at the same time providing for monotonic integration of further disambiguating information. Quasi-Logical Forms (QLFs) [Alshawi, 1992; Alshawi and Crouch, 1992] and Underspecified Discourse Representation Structures (UDRSs) [Reyle, 1993; Reyle, 1995] are truth conditionally interpreted semantic representations which allow different degrees of underspecification. A QLF associated with our English example sentence above might be

?Scope : support (term (+r, <num=sg, spec=every>, representative, ?Q, ?X),
term (+g, <num=sg, spec=a>, candidate, ?P, ?R)).

while a corresponding UDRS would be



Note that both the QLF and the UDRS given here do not specify the scope of the quantified NPs in the example sentence.¹ It is obvious that there are some striking similarities between the f-structure, the QLF and the UDRS above: first, like the underspecified semantic representations the f-structure does not commit itself to the scope of the NP representations; second, like the semantic

¹They could, of course ...

representations the f-structure encodes the basic predicate - argument relations in the semantic form value of the f-structure's PRED function. Furthermore, it is easy to see how to get from one representation to another: to go e.g. from f-structure to QLF we first plug in the values of subcategorizable grammatical functions in the f-structure into the designated slots in the semantic form²

$$?Scope: support \left(\begin{bmatrix} \text{PRED} & \text{'representative'} \\ \text{NUM} & \text{SG} \\ \text{SPEC} & \text{EVERY} \end{bmatrix}, \begin{bmatrix} \text{PRED} & \text{'candidate'} \\ \text{NUM} & \text{SG} \\ \text{SPEC} & \text{A} \end{bmatrix} \right)$$

and then we apply a translation to the f-structure pieces in the argument positions of the semantic form to yield QLF terms.³ In the present paper we spell out some of these intuitions in terms of translation functions between the representations involved. We will briefly sketch the QLF and UDRF formalisms. Strictly speaking, f-structures are canonical representations of minimal models satisfying sets of constraints (i.e. sentences in an equality logic). In what follows, however, we will simply define f-structures as a language that we are going to interpret.⁴ Once we have defined a language of well-formed f-structures *wff-s* we interpret it in terms of a homomorphic embedding τ_q into the QLF formalism. A f-structure inherits the underspecified semantics of its translation image under τ_q . Once the translation function τ_q is in place we show how it can be eliminated by giving a direct underspecified truth conditional semantics for f-structures. Once τ_q is eliminated we define a reverse mapping τ_q^{-1} from QLFs back into f-structures and establish isomorphic subsets of QLF and f-structure representations. We then present an outline of a similar exercise in terms of an embedding τ_u of f-structures into UDRSs. As we see it the highlight of the f-structure - QLF correspondence is the direct underspecified QLF-style interpretation of f-structures. The highlight of the UDRS mapping is the exploitation of the UDRS reasoning component for the translation images of f-structures. τ_q and τ_u can be shown to be truth-preserving with respect to an independent semantics (and with respect to each other ...) in the sense that the set of disambiguations obtained from a translation image of an f-structure coincides with the set of disambiguations obtained from the independent semantics for that f-structure. Finally, here is a quote from [Kaplan and Bresnan, 1982] on the semantic import of f-structures:

The functional structure for a sentence encodes its meaningful grammatical relations and provides sufficient information for the semantic component to determine the appropriate predicate-argument formulas. ... The f-structure is the sole input to the semantic component, which may either translate the f-structure into the appropriate formulas in some logical language or provide an immediate model-theoretic interpretation for it.

²In a sense that where they are anyway - on that view a f-structure is just a somewhat unusual way of writing down a formula.

³Similarly, to obtain a UDRS representation we rotate the f-structure by +90 degrees and put in some arrows from the semantic form to subcategorizable grammatical functions and from them to the first bracket of the enclosing f-structure ... This is not to be taken entirely seriously! As we will see later the UDRS translation of an f-structure is obtained by simply taking the union of the translations of its component parts.

⁴This dual way of looking at f-structures is not really novel, in fact it is common practice to regard f-structures as objects in their own right and as canonical representations of minimal models.

In a sense what we are doing is a way of spelling this out.

3 Quasi Logical Form

QLF [Alshawi, 1990; Alshawi, 1992; Alshawi *et al.*, 1992; Alshawi and Crouch, 1992; Cooper *et al.*, 1996] is the semantic representation formalism developed for the Core Language Engine (CLE), a large scale natural language processing system developed at SRI, Cambridge. A lot of the QLF design decisions are directly informed by computational concerns. QLF provides an underspecified truth conditionally interpreted representation formalism with context modeling, resolution against context and monotonic interpretation. The semantics of an underspecified representation is given in terms of a supervaluation construction over the set of fully specified representations that can be obtained from the underspecified representation. Technically the interpretation function $\llbracket \cdot \rrbracket$ is defined in terms of a valuation relation \mathcal{V} which unpacks an underspecified representation into its set of disambiguated representations. \mathcal{V} may resolve an underspecified representation into a more specific one in terms of a salience relation \mathcal{S} between a context C and (part of) a QLF representation R (c.f. Q11, Q12, Q16). Quantifier scope is treated in Q14 and Q15. The QLF formalism is monotonic in a number of respects: first, the construction of QLFs does not involve destructive operations but proceeds through cumulative gathering of constraints; second, the addition of constraints to a QLF reduces its set of readings.⁵ Compared to other underspecified semantic representation formalisms it is worth noticing that QLF allows for a greater variety of semantic phenomena to be underspecified. The phenomena include (amongst others): quantifier and operator scope, vague relations and predication instances. Below we give (parts of) a syntax and semantics for a QLF language. The definitions are mainly from [Alshawi and Crouch, 1992; Cooper *et al.*, 1996]. A QLF term must be one of the following

- a term variable: x, y, \dots
- a term index: $+i, +j, \dots$
- a constant term: $7, \text{mary1}, \dots$
- an expressions of the form: $\text{term}(\text{Idx}, \text{Cat}, \text{Restr}, \text{Quant}, \text{Reft})$

A QLF formula must be one of the following

- the application of a predicate to arguments: $\text{Predicate}(\text{Arg}_1, \dots, \text{Arg}_n)$
- an expression of the form: $\text{form}(\text{Idx}, \text{Category}, \text{Restriction}, \text{Resolution})$
- a formula with scoping constraints: $\text{Scope}:\text{Formula}$

The semantics is given by

- $\llbracket \phi \rrbracket^{M,g} = 1$ iff $\mathcal{V}(\phi, 1)$ but not $\mathcal{V}(\phi, 0)$
- $\llbracket \phi \rrbracket^{M,g} = 0$ iff $\mathcal{V}(\phi, 0)$ but not $\mathcal{V}(\phi, 1)$
- $\llbracket \phi \rrbracket^{M,g}$ *undefined* iff $\mathcal{V}(\phi, 1)$ and $\mathcal{V}(\phi, 0)$
- $\llbracket \phi \rrbracket^{M,g}$ *uninterpretable* iff neither $\mathcal{V}(\phi, 1)$ or $\mathcal{V}(\phi, 0)$

⁵It is indeed possible to give a semantics for QLFs based on a subsumption relation where more specific versions of a QLF are subsumed by less specific ones.

- Q1:** $\mathcal{V}_g(\text{and}(\phi, \psi), 1)$ if $\mathcal{V}_g(\phi, 1)$ and $\mathcal{V}_g(\psi, 1)$
- Q2:** $\mathcal{V}_g(\text{and}(\phi, \psi), 0)$ if $\mathcal{V}_g(\phi, 0)$ or $\mathcal{V}_g(\psi, 0)$
- Q3-Q10:** disjunction, implication, negation, abstraction, predication
- Q11:** if ϕ is a formula containing a term $\text{term}(\mathbf{I}, \mathbf{C}, \mathbf{R}, ?\mathbf{Q}, ?\mathbf{R})$ and T is a term such that $\mathcal{S}(\mathbf{C}, T)$ then $\mathcal{V}_g(\phi, v)$ if $\mathcal{V}_g(\phi[\text{exists}/?\mathbf{Q}, T/?\mathbf{R}], v)$ and $\mathcal{V}_g(\mathbf{R}(T), 1)$
- Q12:** if ϕ is a formula containing a term $\text{term}(\mathbf{I}, \mathbf{C}, \mathbf{R}, ?\mathbf{Q}, ?\mathbf{R})$ and Q is a quantifier such that $\mathcal{S}(\mathbf{C}, Q)$ then $\mathcal{V}_g(\phi, v)$ if $\mathcal{V}_g(\phi[Q/?\mathbf{Q}, I/?\mathbf{R}], v)$
- Q13:** $\mathcal{V}_g(?Scope:\phi, v)$ if $\mathcal{V}_g(\phi, v)$
- Q14:** if ϕ is a formula containing a term $T = \text{term}(\mathbf{I}, \mathbf{C}, \mathbf{R}, \mathbf{Q}, \mathbf{A})$ then $\mathcal{V}_g(\phi, v)$ if $\mathcal{V}_g(\mathbf{Q}(\mathbf{R}', \mathbf{F}'), v)$ where \mathbf{R}' is $X^\wedge(\text{and}(\mathbf{R}(X), X=\mathbf{A})) [X/\mathbf{I}]$, and \mathbf{F}' is $X^\wedge(\text{and}(\phi, X=\mathbf{A})) [X/T, X/\mathbf{I}]$
- Q15:** if $[\mathbf{I}, \mathbf{J}, \dots] : \phi$ is a formula containing a term $T = \text{term}(\mathbf{I}, \mathbf{C}, \mathbf{R}, \mathbf{Q}, \mathbf{A})$ then $\mathcal{V}_g([\mathbf{I}, \mathbf{J}, \dots] : \phi, v)$ if $\mathcal{V}_g(\mathbf{Q}(\mathbf{R}', \mathbf{F}'), v)$ where \mathbf{R}' is $X^\wedge(\text{and}(\mathbf{R}(X), X=\mathbf{A})) [X/\mathbf{I}]$, and \mathbf{F}' is $X^\wedge([\mathbf{J}, \dots] : \text{and}(\phi, X=\mathbf{A})) [X/T, X/\mathbf{I}]$
- Q16:** $\mathcal{V}_g(\text{form}(\mathbf{I}, \mathbf{C}, \mathbf{R}, ?\mathbf{R}), v)$ if $\mathcal{V}_g(\text{form}(\mathbf{C}, \mathbf{R}, ?\mathbf{R}) [\mathbf{R}(\mathbf{P})/?\mathbf{R}], v)$ where $\mathcal{S}(\mathbf{C}, \mathbf{P})$
- Q17:** $\mathcal{V}_g(\text{form}(\mathbf{I}, \mathbf{C}, \mathbf{R}, \phi), v)$ if $\mathcal{V}_g(\phi, v)$ where ϕ is a QLF formula

4 Underspecified Discourse Representation Theory

In the graphical representations of standard DRT [Kamp and Reyle, 1993] scope relations between quantificational structures and operators are unambiguously specified in terms of the structure and nesting of boxes. UDRT [Reyle, 1993; Reyle, 1995] allows partial specification of scope relations, graphical representations of which are lattice-like structures as shown in the introduction above. Formally UDRSs are tuples of a set of labeled conditions with a set of ordering constraints on the labels such that the ordering constraints define an upper semi-lattice with a top element. Simplifying somewhat the semantics of a UDRS is defined in terms of its disambiguations as $\forall \delta (\Gamma^\delta \models \alpha^\delta)$.⁶ Disambiguations are all consistent extensions of the partial ordering theory resulting in a total order. Unlike the QLF approach outlined above UDRT features an associated proof system. The system operates directly on underspecified representations without the need to consider disambiguated cases.⁷ UDRT is monotonic in the senses outlined in the QLF section above. Its syntactic consequence relation is classical: it is reflexive, transitive and monotonic. The language of UDRSs consists of a set L of labels, a set Ref of discourse referents, a set Rel of n -place relation symbols and a set Sym of logical symbols. It features two types of conditions:⁸

1.
 - if $l \in L$ and $x \in Ref$ then $l : x$ is a condition
 - if $l \in L$, $R \in Rel$ a n -place relation and $x_1, \dots, x_n \in Ref$ then $l : P(x_1, \dots, x_n)$ is a condition

⁶In the earlier approach [Reyle, 1993] the semantics was given in terms of an object level disjunction of disambiguations: $\forall \delta \exists \delta' (\Gamma^\delta \models \alpha^{\delta'})$.

⁷Soundness and completeness theorems are proved for the approach in [Reyle, 1993]

⁸The definition abstracts away from some of the complexities in the full definitions of the UDRS language [Reyle, 1993].

- if $l_i, l_j \in L$ then $l_i : \neg l_j$ is a condition
 - if $l_i, l_j, l_k \in L$ then $l_i : l_j \Rightarrow l_k$ is a condition
 - if $l, l_1, \dots, l_n \in L$ then $l : \vee(l_1, \dots, l_n)$ is a condition
2. if $l_i, l_j \in L$ then $l_i \leq l_j$ is a condition where \leq is a partial ordering defining an upper semi-lattice with a top element.

UDRSs are pairs of a set of type 1 conditions⁹ with a set of type 2 conditions.

- A UDRS \mathcal{K} is a pair $\langle \mathcal{L}, \mathcal{D} \rangle$ where $\mathcal{L} = \langle L, \leq \rangle$ is an upper semi-lattice of labels and \mathcal{D} a set of conditions of type 1 above such that if $l_i : \neg l_j \in \mathcal{D}$ then $l_j : \leq l_i \in \mathcal{L}$ and if $l_i : l_j \Rightarrow l_k \in \mathcal{D}$ then $l_j \leq l_i, l_k \leq l_i \in \mathcal{L}$.¹⁰

The construction of UDRSs is constrained by a set of meta-level constraints (principles). They ensure, e.g., that verbs are subordinated with respect to their scope inducing arguments, that scope sensitive elements obey the restrictions postulated by whatever syntactic theory is adopted, that potential antecedents are scoped with respect to their anaphoric potential, etc. Below we list some examples principles:

- Clause Boundedness: the scope of genuinely quantificational structures is clause bounded. If l_q and l_{cl} are the labels associated with the quantificational structure and the containing clause, respectively, then the constraint $l_q \leq l_{cl}$ enforces clause boundedness.
- Scope of Indefinites: indefinites labeled l_i may take arbitrarily wide scope in the representation. They cannot exceed the top-level DRS l_\top , i.e. $l_i \leq l_\top$.
- Proper Names: proper names, π , always end up in the top-level DRS, l_\top . This is specified lexically by $l_\top : \pi$

5 A Language *wff-s* of Well-Formed F-Structures

In order to be able to interpret f-structures as semantic representations we define them as expressions in a language *wff-s*. The basic vocabulary comprises a set of subcategorizable grammatical functions GF_s , non-subcategorizable grammatical functions GF_n , semantic forms SF , attributes ATR and atomic values $ATOM$:

- $GF_s = \{\text{SUBJ, OBJ, OBJ2, OBL}_\theta, \text{COMP, XCOMP, POSS, ...}\}$
- $GF_n = \{\text{ADJUNCTS, XADJUNCTS, RELMODS, ADJMODS, ...}\}$
- $SF = \{\text{candidate}\langle \rangle, \text{mary}\langle \rangle, \dots, \text{leave}\langle \uparrow \text{SUBJ} \rangle, \dots, \text{support}\langle \uparrow \text{SUBJ}, \uparrow \text{OBJ} \rangle, \dots\}$
- $ATR = \{\text{SPEC, NUM, PER, GEN ...}\}$
- $ATOM = \{\text{A, SOME, EVERY, MOST, ...}, \text{SG, PL, 1, 2, 3, MASC, FEM, ...}\}$

The basic formation rules pivot on the semantic form PRED values. Tags $\boxed{}$ are used to represent reentrancies and will often appear vacuously. The first clause defines “non-recursive” f-structures, the second clause “recursive” f-structures, the third clause covers non-subcategorizable grammatical functions, the fourth clause atomic attribute-value pairs. The side condition in the second and third clause ensures that only identical substructures can have identical tags.

⁹The full language also contains type 1 conditions of the form $l : \sigma(l_1, \dots, l_n)$ indicating that (l_1, \dots, l_n) are contributed by a single sentence.

¹⁰This simply closes \mathcal{L} under the subordination relations induced by complex conditions of the form $\neg K$ and $K_i \Rightarrow K_j$.

- if $\Pi\langle \rangle \in SF$ then $[\text{PRED } \Pi\langle \rangle] \mathbb{I} \in \text{wff-s}$
- if $\varphi_1 \mathbb{J}, \dots, \varphi_n \mathbb{K} \in \text{wff-s}$ and $\Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \in SF$ then $\varphi \mathbb{I} \in \text{wff-s}$ where $\varphi \mathbb{I}$ is of the form

$$\left[\begin{array}{c} \Gamma_1 \quad \varphi_1 \mathbb{J} \\ \dots \\ \text{PRED } \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \\ \dots \\ \Gamma_n \quad \varphi_n \mathbb{K} \end{array} \right] \mathbb{I}$$
 where for any two substructures $\psi \mathbb{I}$ and $\phi \mathbb{M}$ occurring in $\varphi \mathbb{I}$, $l \neq m$ except possibly where $\psi \equiv \phi$.
- if $\varphi_1 \mathbb{J}, \dots, \varphi_n \mathbb{K}, \psi \mathbb{I} \in \text{wff-s}$, where $\psi \mathbb{I}$ is of the form $\left[\begin{array}{c} \dots \\ \text{PRED } \Pi(\dots) \\ \dots \end{array} \right] \mathbb{I}$, $\Gamma \in GF_n$ and $\Gamma \notin \text{domain}(\psi \mathbb{I})$ then

$$\left[\begin{array}{c} \Gamma \quad \{\varphi_1 \mathbb{J}, \dots, \varphi_n \mathbb{K}\} \\ \dots \\ \text{PRED } \Pi(\dots) \\ \dots \end{array} \right] \mathbb{I}$$
 where for any two substructures $\phi \mathbb{I}$ and $\chi \mathbb{M}$ occurring in $\psi \mathbb{I}$, $l \neq m$ except possibly where $\phi \equiv \chi$.
- if $\alpha \in \text{ATR}$, $v \in \text{ATOM}$, $\varphi \mathbb{I} \in \text{wff-s}$ where $\varphi \mathbb{I}$ is of the form $\left[\begin{array}{c} \dots \\ \text{PRED } \Pi(\dots) \\ \dots \end{array} \right] \mathbb{I}$ and $\alpha \notin \text{domain}(\varphi \mathbb{I})$ then

$$\left[\begin{array}{c} \alpha \quad v \\ \dots \\ \text{PRED } \Pi(\dots) \\ \dots \end{array} \right] \mathbb{I} \in \text{wff-s}$$

Proposition: The definition captures f-structures that are complete, coherent and consistent. Proof: simple induction on the formation rules for *wff-s* using the definitions of completeness, coherence and consistency [Kaplan and Bresnan, 1982].¹¹

6 F-Structures \rightsquigarrow (unresolved) QLFs: τ_q

Now that we have defined the language *wff-s* we can interpret it. We will do this first indirectly in terms of a translation function τ_q which maps f-structures into QLFs. In this approach f-structures inherit the semantics associated with their translation image under τ_q . Non-recursive f-structures are mapped into **terms** while recursive f-structures are mapped into **form** expressions:

- $\tau_q(\Gamma, \left[\begin{array}{c} \alpha_1 \quad v_1 \\ \dots \\ \text{PRED } \Pi\langle \rangle \\ \dots \\ \alpha_n \quad v_n \end{array} \right] \mathbb{I}) := \text{term}(\mathbb{I}, \langle \text{gf}=\Gamma, \alpha_1 = v_1, \dots, \alpha_n = v_n \rangle, \Pi, ?Q_I, ?R_I)$

¹¹The notions of *substructure occurring in an f-structure* and *domain of an f-structure* can easily be spelled out formally. \equiv is syntactic identity modulo permutation. The definition given above uses graphical representations of f-structures. It can easily be recast in terms of hierarchical sets, finite functions, directed graphs etc.

$$\bullet \tau_q(\Gamma, \left[\begin{array}{c} \Gamma_1 \quad \varphi_1 \boxed{\mathbf{J}} \\ \alpha_1 \quad v_1 \\ \dots \\ \text{PRED} \quad \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \\ \dots \\ \Gamma_n \quad \varphi_n \boxed{\mathbf{K}} \\ \alpha_m \quad v_m \end{array} \right] \boxed{\mathbf{I}}) :=$$

?Scope:

$$\text{form}(\mathbf{I}, \langle \text{gf}=\Gamma, \text{pred}=\Pi(\Gamma_1, \dots, \Gamma_n) \quad \alpha_1=v_1, \dots, \alpha_m=v_m \rangle, \\ P \wedge P(\tau_q(\Gamma_1, \varphi_1 \boxed{\mathbf{J}}), \dots, \tau_q(\Gamma_n, \varphi_n \boxed{\mathbf{K}})), ?F_{\mathbf{I}})$$

where ?Scope is a new QLF meta-variable, P a new variable and $\alpha_i \in ATR$

We illustrate the mapping in terms of a simple example:

$$\tau_q(\text{SIGMA}, \left[\begin{array}{c} \text{SUBJ} \quad \left[\begin{array}{c} \text{PRED 'representative'} \\ \text{NUM PL} \\ \text{SPEC MOST} \end{array} \right] \boxed{\mathbf{g}} \\ \text{PRED 'support } (\uparrow \text{SUBJ}, \uparrow \text{OBJ})' \\ \text{TENSE PAST} \\ \text{OBJ} \quad \left[\begin{array}{c} \text{PRED 'candidate'} \\ \text{NUM PL} \\ \text{SPEC TWO} \end{array} \right] \boxed{\mathbf{h}} \end{array} \right] \boxed{\mathbf{f}}) =$$

?Scope:form(+f, <gf=sigma, pred=support(subj, obj), tense=past>,

$$P \wedge P(\tau_q(\text{SUBJ}, \left[\begin{array}{c} \text{PRED 'representative'} \\ \text{NUM PL} \\ \text{SPEC MOST} \end{array} \right] \boxed{\mathbf{g}}), \tau_q(\text{OBJ}, \left[\begin{array}{c} \text{PRED 'candidate'} \\ \text{NUM PL} \\ \text{SPEC TWO} \end{array} \right] \boxed{\mathbf{h}})), ?F_{\mathbf{f}}) =$$

?Scope:form(+f, <gf=sigma, tense=past, pred=support(subj, obj)>,

$$P \wedge P(\text{term}(+g, \langle \text{gf}=subj, \text{num}=pl, \text{spec}=most \rangle, \text{representative}, ?Q_{\mathbf{g}}, ?R_{\mathbf{g}}), \\ \text{term}(+h, \langle \text{gf}=obj, \text{num}=pl, \text{spec}=two \rangle, \text{candidate}, ?Q_{\mathbf{h}}, ?R_{\mathbf{h}}), ?F_{\mathbf{f}}).$$

Note that the target QLF is underspecified not only with respect to the scope of the quantificational NPs involved but also (amongst other things) with respect to the main predicate P of the proposition¹² and with respect to the precise nature of the logical quantifiers $?Q_{\mathbf{g}}, ?Q_{\mathbf{h}}$ associated with the surface linguistic determiners.¹³ The main predicate and the logical quantifiers are determined in terms of resolution processes against a context model. Often resolution is guided by syntactic category information in $\langle \dots \rangle$ [Alshawi, 1990]. A possible resolution might yield

?Scope:form(+f, <gf=sigma, tense=past, pred=support(subj, obj)>,

$$P \wedge P(\text{term}(+g, \langle \text{gf}=subj, \text{num}=pl, \text{spec}=most \rangle, \text{representative}, \text{most}, ?R_{\mathbf{g}}), \\ \text{term}(+h, \langle \text{gf}=obj, \text{num}=pl, \text{spec}=two \rangle, \text{candidate}, \text{two}, ?R_{\mathbf{h}}), \text{support}).$$

which can be further reduced (or rather: is equivalent) to:

$$?Scope:\text{support}(\text{term}(+g, \langle \text{gf}=subj, \text{num}=pl, \text{spec}=most \rangle, \text{representative}, \text{most}, ?R_{\mathbf{g}}), \\ \text{term}(+h, \langle \text{gf}=obj, \text{num}=pl, \text{spec}=two \rangle, \text{candidate}, \text{two}, ?R_{\mathbf{h}}))$$

¹²This is a useful feature e.g. in support verb constructions.

¹³An indefinite e.g. can have an existential or a generic interpretation etc.

τ_q as defined above maximizes exploitation of the QLF resolution component. Later we define a mapping which minimizes the effects of QLF contextual resolution by “resolving” predicates and logical quantifiers etc. directly to surface form. Such simpler mappings are used to show preservation of truth of the QLF interpretations of f-structures with respect to independent semantics such as e.g. [Dalrymple *et al.*, 1995b].¹⁴ Note that f-structure reentrancies are handled without further stipulation: reentrancies resurface in terms of identical QLF metavariables and indices, as required. As it stands τ_q covers the first, second and the fourth clause in the definition of *wff-s*. Elsewhere [Cooper *et al.*, 1996] we outlined how it can be extended to non-subcategorizable grammatical functions and how QLF - LFG semantic form argument mismatches can be accommodated.

7 A Direct and Underspecified Interpretation of f-Structures

τ_q defines a simple homomorphic embedding from *wff-s* into the language of QLFs so it does not exactly come as a surprise that it can be eliminated. Below we give a direct underspecified QLF style interpretation for *wff-s* in terms of adapting QLF interpretation rules to operate directly on f-structure representations. Models, variable assignment functions, generalized quantifier interpretations etc. carry over unchanged. The “core” of the direct interpretation is an adaptation of the quantification rule Q14 (see above). Q14 retrieves a quantified NP, scopes it over the remaining QLF and recurses on it. The new quantification rule Q14’ distinguishes between quantified NPs and proper names. It non-deterministically retrieves subcategorizable grammatical functions with a SPEC feature and employs the value of the feature in a generalized quantifier interpretation:

Q14’: if $\varphi, \psi[\bar{a}] \in \text{wff-s}$, and $\psi[\bar{a}]$ is a sub-f-structure of φ then

- if $\psi[\bar{a}] \equiv \begin{bmatrix} \text{SPEC} & Q \\ \dots & \\ \text{PRED} & \Pi(\langle \rangle) \\ \dots & \end{bmatrix} [\bar{a}]$ then $\mathcal{V}_g(\varphi, v)$ if $\mathcal{V}_g(Q(\Pi, \lambda x.\varphi[\psi[\bar{a}] \leftarrow x]), v)$, where x is a new variable
- if $\psi[\bar{a}] \equiv \begin{bmatrix} \dots \\ \text{PRED} & \Pi(\langle \rangle) \\ \dots \end{bmatrix} [\bar{a}]$ (i.e. $\text{SPEC} \notin \text{domain}(\psi)$) then $\mathcal{V}_g(\varphi, v)$ if $\mathcal{V}_g(\varphi[\psi[\bar{a}] \leftarrow \Pi]), v)$

The new predication rule Q10’ is defined in terms of a notion of *nuclear scope* f-structure. A *nuclear scope* f-structure is an f-structure resulting from exhaustive application of Q14’. It can be defined inductively as follows:

¹⁴Note that equivalence is with respect to sets of readings obtainable from the QLF in terms of the QLF interpretation rules. The supervaluation semantics associated with the underspecified QLF has no correlate in [Dalrymple *et al.*, 1995b], unless, of course, you decide to associate such a semantics with a set of Premises in a linear logic deduction.

- if γ_i a variable or a constant symbol then
$$\left[\begin{array}{cc} \Gamma_1 & \gamma_1 \\ \dots & \\ \text{PRED} & \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \\ \dots & \\ \Gamma_n & \gamma_n \end{array} \right]$$
 is a nuclear scope f-structure
- if γ_i a variable, a constant symbol or a nuclear scope f-structure then
$$\left[\begin{array}{cc} \Gamma_1 & \gamma_1 \\ \dots & \\ \text{PRED} & \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \\ \dots & \\ \Gamma_n & \gamma_n \end{array} \right]$$
 is a nuclear scope f-structure

D10': if φ is a nuclear scope f-structure and $\varphi \equiv \left[\begin{array}{cc} \Gamma_1 & \gamma_1 \\ \dots & \\ \text{PRED} & \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \\ \dots & \\ \Gamma_n & \gamma_n \end{array} \right]$ then $\mathcal{V}_g(\varphi, v)$
if $\mathcal{V}_g(\Pi(\gamma_1, \dots, \gamma_n), v)$

The reader may check that the f-structure associated with “*Every representative supported a candidate.*” is indeed interpreted in terms of the supervaluation over:

$$\begin{array}{l} \text{all}(\text{representative}, \lambda x. \text{some}(\text{candidate}, \lambda y. \text{support}(x, y))) \\ \text{some}(\text{candidate}, \lambda y. \text{all}(\text{representative}, \lambda x. \text{support}(x, y))) \end{array}$$

The direct interpretation scheme can be extended to cover non-subcategorizable grammatical functions as outlined in [Cooper *et al.*, 1996].

8 (Unresolved) QLFs \rightsquigarrow F-Structures: τ_q^{-1}

An inverse mapping τ_q^{-1} from (a subset of) unresolved QLFs into *wff*-s can be defined as follows:

- $\tau_q^{-1}(\text{term}(\mathbb{I}, \langle \text{gf}=\Gamma, \alpha_1 = v_1, \dots, \alpha_n = v_n \rangle, \Pi, _ , _)) := \Gamma \left[\begin{array}{cc} \alpha_1 & v_1 \\ \dots & \\ \text{PRED} & \Pi \\ \dots & \\ \alpha_n & v_n \end{array} \right] \mathbb{I}$
- $\tau_q^{-1}(_ : \text{form}(\mathbb{I}, \langle \text{gf}=\Gamma, \text{pred}=\Pi(\Gamma_1, \dots, \Gamma_m), \alpha_1 = v_1, \dots, \alpha_j = v_j \rangle, \text{P} \hat{\wedge} \text{P}(\varrho_1, \dots, \varrho_m), _)) := \Gamma \left[\begin{array}{cc} \alpha_1 & v_1 \\ \dots & \\ \alpha_j & v_j \\ \text{PRED} & \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_m) \\ \tau^{-1}(\varrho_1) & \\ \dots & \\ \tau^{-1}(\varrho_m) & \end{array} \right] \mathbb{I}$

As expected, QLF **terms** are translated into non-recursive, QLF **forms** into recursive f-structures. The reader may want to check that the QLF associated with “*A representative persuaded every candidate to support ITEL.*” translates as follows

9 Preservation of Truth

τ_q assigns a meaning to an f-structure that depends both on the f-structure and QLF contextual resolution. We define a restricted version τ'_q of τ_q which “switches off” the QLF contextual resolution component. τ'_q maps logical quantifiers to their surface form and semantic forms to QLF formulas (or resolved QLF forms):

$$\begin{aligned}
 & \bullet \tau'_q(\Gamma, \left[\begin{array}{cc} \alpha_1 & v_1 \\ \text{SPEC} & Q \\ \dots & \\ \text{PRED} & \Pi \langle \rangle \\ \dots & \\ \alpha_n & v_n \end{array} \right] \boxed{\mathbb{I}}) := \text{term}(\mathbb{I}, \langle \text{gf}=\Gamma, \alpha_1 = v_1, \dots, \alpha_n = v_n \rangle, \Pi, Q, \mathbb{I}) \\
 & \bullet \tau'_q(\Gamma, \left[\begin{array}{cc} \Gamma_1 & \varphi_1 \boxed{\mathbb{J}} \\ \alpha_1 & v_1 \\ \dots & \\ \text{PRED} & \Pi \langle \uparrow \Gamma_1, \dots, \uparrow \Gamma_n \rangle \\ \dots & \\ \Gamma_n & \varphi_n \boxed{\mathbb{K}} \\ \alpha_m & v_m \end{array} \right] \boxed{\mathbb{I}}) := \\
 & \quad ?\text{Scope:form}(\mathbb{I}, \langle \text{gf}=\Gamma, \text{pred}=\Pi(\Gamma_1, \dots, \Gamma_n), \alpha_1=v_1, \dots, \alpha_m=v_m \rangle, \\
 & \quad \Pi(\tau'_q(\Gamma_1, \varphi_1 \boxed{\mathbb{J}}), \dots, \tau'_q(\Gamma_n, \varphi_n \boxed{\mathbb{K}})), \Pi)
 \end{aligned}$$

Proposition: τ' is truth preserving with respect to an independent semantics, e.g. the glue language semantics of [Dalrymple *et al.*, 1995b]. Preservation of truth, hence correctness of the translation, is with respect to sets of disambiguations. The proof is by induction on the complexity of φ . Proof sketch: refer to the set of disambiguated QLFs resulting from $\tau'(\varphi)$ through application of the QLF interpretation clauses as $\mathcal{V}(\tau'(\varphi))$ and to the set of conclusions obtained through linear logic deduction from the premises of the σ projections of φ as $(\sigma(\varphi))_{\vdash}$. Consider the fragment without modification. Base case: for φ with nonrecursive values of grammatical functions show $\mathcal{V}(\tau'(\varphi)) = (\sigma(\varphi))_{\vdash}$.¹⁷ Induction I: for recursive φ with immediate non-recursive sub-f-structures φ_i on the assumption that for each i : $\mathcal{V}(\tau'(\varphi_i)) = (\sigma(\varphi_i))_{\vdash}$ (IH) show $\mathcal{V}(\tau'(\varphi)) = (\sigma(\varphi))_{\vdash}$. Induction II: for recursive φ with immediate recursive and/or non-recursive sub-f-structures φ_i on the assumption that for each i : $\mathcal{V}(\tau'(\varphi_i)) = (\sigma(\varphi_i))_{\vdash}$ (IH) show $\mathcal{V}(\tau'(\varphi)) = (\sigma(\varphi))_{\vdash}$. The correctness result carries over to the direct interpretation since what is eliminated is τ' .¹⁸

10 F-Structures \rightsquigarrow UDRSs: τ_u

In this section we will interpret f-structures as UDRSs. The ease with which f-structures can be translated into QLF representations has led to the formulation of direct underspecified semantic interpretation rules for f-structure representations. By contrast we will illustrate the UDRT mapping by exploiting

¹⁷Strictly speaking, of course, \mathcal{V} doesn't interpret terms in isolation.

¹⁸If the results of linear logic deductions are interpreted in terms of the supervaluation construction we have preservation of truth directly with respect to underspecified representations, QLFs and sets of linear logic premises.

the UDRS proof system to f-structure images under τ_u . (U)DRT distinguishes between genuinely quantificational NPs, indefinite NPs and proper names. Accordingly we have

$$\begin{aligned}
& \bullet \tau_u^{\boxed{J}} \left(\begin{array}{c} \Gamma_1 \quad \varphi_1 \quad \boxed{I_1} \\ \dots \\ \text{PRED} \quad \Pi(\uparrow \Gamma_1, \dots, \uparrow \Gamma_n) \\ \dots \\ \Gamma_n \quad \varphi_n \quad \boxed{I_n} \\ \Pi(\delta_{\boxed{I_1}}, \dots, \delta_{\boxed{I_n}}) \end{array} \right) \boxed{I} := \tau_u^{\boxed{I}}(\varphi_1 \quad \boxed{I_1}) \cup \dots \cup \tau_u^{\boxed{I}}(\varphi_n \quad \boxed{I_n}) \cup \{l_{\boxed{I}_0} : \\
& \text{where } \delta_{\boxed{I}_i} := \begin{cases} x_{\boxed{I}_i} & \text{iff } \Gamma_i \in \{\text{SUBJ, OBJ, OBJ}_2, \text{OBL}_{\text{OBJ}}\} \\ l_{\boxed{I}_i} & \text{iff } \Gamma_i \in \{\text{COMP, XCOMP}\} \end{cases} \\
& \bullet \tau_u^{\boxed{J}} \left(\begin{array}{c} \alpha_1 \quad v_1 \\ \text{SPEC} \quad \text{EVERY} \\ \dots \\ \text{PRED} \quad \Pi\langle \rangle \\ \dots \\ \alpha_n \quad v_n \\ l_{\boxed{J}}, l_{\boxed{J}_0} \leq l_{\boxed{J}_2} \end{array} \right) \boxed{I} := \{l_{\boxed{I}} : l_{\boxed{I}_1} \forall x_{\boxed{I}} l_{\boxed{I}_2}, l_{\boxed{I}_1} : x_{\boxed{I}}, l_{\boxed{I}_1} : \Pi(x_{\boxed{I}}), l_{\boxed{I}} \leq \\
& \bullet \tau_u^{\boxed{J}} \left(\begin{array}{c} \alpha_1 \quad v_1 \\ \text{SPEC} \quad \text{A} \\ \dots \\ \text{PRED} \quad \Pi\langle \rangle \\ \dots \\ \alpha_n \quad v_n \end{array} \right) \boxed{I} := \{l_{\boxed{I}} : x_{\boxed{I}}, l_{\boxed{I}} : \Pi(x_{\boxed{I}}), l_{\boxed{I}} \leq l_{\tau}, l_{\boxed{J}_0} \leq l_{\boxed{I}}\} \\
& \bullet \tau_u^{\boxed{J}} \left(\begin{array}{c} \alpha_1 \quad v_1 \\ \dots \\ \text{PRED} \quad \Pi\langle \rangle \\ \dots \\ \alpha_n \quad v_n \end{array} \right) \boxed{I} := \{l_{\tau} : x_{\boxed{I}}, l_{\tau} : \Pi(x_{\boxed{I}}), l_{\boxed{J}_0} \leq l_{\tau}\}
\end{aligned}$$

The first clause defines the recursive part of the translation function and states that the translation of an f-structure is simply the union of the translations of its component parts. The base cases of the definition are provided by the three remaining clauses. The first one deals with genuinely quantificational NPs, the second one with indefinites and the third one with proper names. The definitions ensure clause boundedness of quantificational NPs $\{l_{\boxed{I}} \leq l_{\boxed{I}}\}$, allow indefinites to take arbitrary wide scope $\{l_{\boxed{I}} \leq l_{\tau}\}$ and assign proper names to the top level of the resulting UDRS $\{l_{\tau} : x_{\boxed{I}}, l_{\tau} : \Pi(x_{\boxed{I}})\}$ as required.¹⁹ Reentrancies are handled without further stipulation. We illustrate the approach in terms of a simple example inference:

f	Every representative supported a candidate.
g	Smith is a representative.
I	Smith supported a candidate.

¹⁹If clause boundedness is dropped it can be shown that τ_u is truth preserving with respect to an independently given semantics like [Dalrymple *et al.*, 1995b] in the sense that each of the complete disambiguations of the resulting UDRSs corresponds to a reading obtainable with the linear logic glue language approach.

Premise \mathbb{f} is ambiguous between an wide scope and a narrow scope reading of the indefinite NP. From \mathbb{f} and \mathbb{g} we can conclude \mathbb{h} which is not ambiguous. Assume that the following (simplified) f-structures $\varphi_{\mathbb{f}}, \psi_{\mathbb{g}}$ and $\xi_{\mathbb{h}}$ are associated with \mathbb{f}, \mathbb{g} and \mathbb{h} , respectively:

$$\frac{\left[\begin{array}{l} \text{SUBJ} \left[\begin{array}{l} \text{PRED 'representative'} \\ \text{SPEC EVERY} \end{array} \right]_{\mathbb{f}} \\ \text{PRED 'support } \langle \uparrow \text{SUBJ}, \uparrow \text{OBJ} \rangle' \\ \text{OBJ} \left[\begin{array}{l} \text{PRED 'candidate'} \\ \text{SPEC A} \end{array} \right]_{\mathbb{f}} \end{array} \right]_{\mathbb{f}} \quad \left[\begin{array}{l} \text{SUBJ} \left[\text{PRED 'smith'} \right]_{\mathbb{g}} \\ \text{PRED 'representative } \langle \uparrow \text{SUBJ} \rangle' \end{array} \right]_{\mathbb{g}}}{\vdash \left[\begin{array}{l} \text{SUBJ} \left[\text{PRED 'smith'} \right]_{\mathbb{h}} \\ \text{PRED 'support } \langle \uparrow \text{SUBJ}, \uparrow \text{OBJ} \rangle' \\ \text{OBJ} \left[\begin{array}{l} \text{PRED 'candidate'} \\ \text{SPEC A} \end{array} \right]_{\mathbb{h}} \end{array} \right]_{\mathbb{h}}}$$

We have that

$$\begin{aligned} \tau_u^\top(\varphi_{\mathbb{f}}) = & \langle \{ l_{\mathbb{h}} : l_{\mathbb{h}_1} \forall x_{\mathbb{h}} l_{\mathbb{h}_2}, l_{\mathbb{h}_1} : x_{\mathbb{h}}, l_{\mathbb{h}_1} : \text{representative}(x_{\mathbb{h}}), \\ & l_{\mathbb{f}} : x_{\mathbb{f}}, l_{\mathbb{f}} : \text{candidate}(x_{\mathbb{f}}), l_{\mathbb{f}_o} : \text{support}(x_{\mathbb{f}}, x_{\mathbb{f}}) \}, \\ & \{ l_{\mathbb{h}} \leq l_{\mathbb{f}}, l_{\mathbb{f}_o} \leq l_{\mathbb{h}_2}, l_{\mathbb{f}} \leq l_\tau, l_{\mathbb{f}_o} \leq l_{\mathbb{f}} \} \rangle \hat{=} \\ & \left. \begin{array}{c} \begin{array}{c} \boxed{x_{\mathbb{h}}} \\ \text{representative}(x_{\mathbb{h}}) \end{array} \quad \begin{array}{c} \forall \\ \boxed{x_{\mathbb{h}}} \end{array} \quad \begin{array}{c} \boxed{y_{\mathbb{f}}} \\ \text{candidate}(y_{\mathbb{f}}) \end{array} \\ \text{support}(x_{\mathbb{f}}, y_{\mathbb{f}}) \end{array} \right\} = \mathcal{K}_{\mathbb{f}} \end{aligned}$$

Likewise for $\psi_{\mathbb{g}}$ we get

$$\begin{aligned} \tau_u^\top(\psi_{\mathbb{g}}) = & \langle \{ l_\tau : x_{\mathbb{g}}, l_\tau : \text{smith}(x_{\mathbb{g}}), l_{\mathbb{g}_o} : \text{representative}(x_{\mathbb{g}}), \{ l_{\mathbb{g}_o} \leq l_\tau \} \} \rangle \hat{=} \\ & \left. \begin{array}{c} \boxed{x_{\mathbb{g}}} \\ \text{smith}(x_{\mathbb{g}}) \\ \uparrow \\ \boxed{\text{representative}(x_{\mathbb{g}})} \end{array} \right\} = \mathcal{K}_{\mathbb{g}} \end{aligned}$$

In the calculus of [Reyle, 1993; Reyle, 1995] we obtain the UDRS $\mathcal{K}_{\mathbb{h}}$ associated with the conclusion in terms of an application of the rule of detachment (DET):

$$\begin{aligned} & \mathcal{K}_{\mathbb{f}}, \mathcal{K}_{\mathbb{g}} \vdash \\ & \langle \{ l_\tau : x'_{\mathbb{f}}, l_\tau : \text{smith}(x'_{\mathbb{f}}), l'_{\mathbb{f}} : x'_{\mathbb{f}}, l'_{\mathbb{f}} : \text{candidate}(x'_{\mathbb{f}}), l'_{\mathbb{f}_o} : \text{support}(x'_{\mathbb{f}}, x'_{\mathbb{f}}), \\ & \quad \{ l'_{\mathbb{f}_o} \leq l_\tau, l'_{\mathbb{f}_o} \leq l'_{\mathbb{f}}, l'_{\mathbb{f}} \leq l_\tau \} \} \rangle \hat{=} \end{aligned}$$

$$\left. \begin{array}{c}
\boxed{\begin{array}{l} x' \\ smith(x') \end{array}} \\
\uparrow \\
\boxed{\begin{array}{l} x' \\ candidate(x') \end{array}} \\
\uparrow \\
\boxed{\begin{array}{l} support(x', x') \end{array}}
\end{array} \right\} = \mathcal{K}_{\mathbb{I}} = \tau_u^\top \left(\begin{array}{l} \text{SUBJ} \quad \left[\text{PRED 'smith'} \right]_{\mathbb{M}} \\ \text{PRED} \quad \text{'support' } \langle \uparrow \text{SUBJ}, \uparrow \text{OBJ} \rangle \\ \text{OBJ} \quad \left[\begin{array}{l} \text{PRED 'candidate'} \\ \text{SPEC} \quad \text{A} \end{array} \right]_{\mathbb{N}} \end{array} \right)_{\mathbb{I}}$$

which turns out to be the translation image under τ_u of the f-structure $\xi_{\mathbb{I}}$ associated with the conclusion \mathbb{I} .²⁰ Summarizing we have that indeed:

$$\tau_u^\top(\varphi_{\mathbb{I}}), \tau_u^\top(\psi_{\mathbb{G}}) \vdash \tau_u^\top(\xi_{\mathbb{I}})$$

11 Conclusion

We have shown how abstract syntactic representations, f-structures, can be interpreted as underspecified semantic representations, here QLFs or UDRSs. The QLF mappings have inspired a direct underspecified interpretation of f-structures while the UDRS mappings have allowed us to exploit the UDRS calculus which suggests that in principle at least it may be possible to reason directly with f-structure representations. On a more general note both QLF and UDRT - that is recent developments in formal semantics - provide further independent motivation for a level of representation similar to LFG f-structure which antedates both of them by more than a decade.

References

- [Alshawi and Crouch, 1992] Alshawi, H. and Crouch, R. 1992. Monotonic semantic interpretation. In *Proceedings 30th Annual Meeting of the Association for Computational Linguistics*. 32–38.
- [Alshawi *et al.*, 1992] Alshawi, A.; Carter, D.; Crouch, R.; Pulman, S.; Rayner, M.; and Smith, A. 1992. Clare: A contextual reasoning and cooperative response framework for the core language engine. Technical Report CRC-028, SRI International, Cambridge Research Centre. Also available as cmp-lg/9411002.
- [Alshawi, 1990] Alshawi, H. 1990. Resolving quasi logical form. *Computational Linguistics* 16:133–144.
- [Alshawi, 1992] Alshawi, H., editor 1992. *The Core Language Engine*. MIT Press, Cambridge Mass, Cambridge, Mass., and London, England.
- [Cooper *et al.*, 1996] Cooper, R.; Crouch, R.; Eijck, J.van; Fox, C.; Genabith, J.van; Jaspars, J.; Kamp, H.; Pinkal, M.; Milward, D.; Poesio, M.; and Pulman, S. 1996. Building the framework. Technical Report FraCaS deliverable D16, FraCaS: A Framework

²⁰Note that the conclusion UDRS $\mathcal{K}_{\mathbb{I}}$ can be “collapsed” into the fully specified DRS

$$\boxed{\begin{array}{l} x \ y \\ smith(x) \\ candidate(y) \\ support(x, y) \end{array}}$$

for Computational Semantics. Also available by anonymous ftp from ftp.cogsci.ed.ac.uk, pub/FRACAS/del16.ps.gz.

- [Dalrymple *et al.*, 1993] Dalrymple, M.; Lamping, J.; and Saraswat, V. 1993. Lfg semantics via constraints. In *Proceedings of the 6th Meeting of the European ACL (EACL)*, Utrecht.
- [Dalrymple *et al.*, 1995a] Dalrymple, M.; Kaplan, R.M.; Maxwell, J.T.; and Zaenen, A., editors 1995a. *Formal Issues in Lexical-Functional Grammar*. CSLI lecture notes; no.47. CSLI Publications.
- [Dalrymple *et al.*, 1995b] Dalrymple, M.; Lamping, J.; Pereira, F.C.N; and Saraswat, V. 1995b. Quantifiers, anaphora, and intensionality. cmp-lg/9504029.
- [Fenstad *et al.*, 1987] Fenstad, J.E.; Halvorsen, P.K.; Langholm, T.; and Benthem, J.van 1987. *Situations, Language and Logic*. D.Reidel, Dordrecht.
- [Halvorsen and Kaplan, 1988] Halvorsen, P.K. and Kaplan, R. 1988. Projections and semantic description in lexical-functional grammar. In *Proceedings of the International Conference on Fifth Generation Computer Systems*, Tokyo: Institute for New Generation Computer Technology. 1116–1122.
- [Halvorsen, 1983] Halvorsen, P.K. 1983. Semantics for lfg. *Linguistic Inquiry* 14:567–615.
- [Kamp and Reyle, 1993] Kamp, H. and Reyle, U. 1993. *From Discourse to Logic*. Kluwer, Dordrecht.
- [Kaplan and Bresnan, 1982] Kaplan, R.M. and Bresnan, J. 1982. Lexical functional grammar. In Bresnan, J., editor 1982, *The mental representation of grammatical relations*. MIT Press, Cambridge Mass. 173–281.
- [Reyle, 1993] Reyle, U. 1993. Dealing with ambiguities by underspecification: Construction, representation and deduction. *Journal of Semantics* 10:123–179.
- [Reyle, 1995] Reyle, Uwe 1995. On reasoning with ambiguities. In *Seventh Conference of the European Chapter of the Association for Computational Linguistics — Proceedings of the Conference*, Dublin. ACL. 1–8.
- [Wedekind and Kaplan, 1993] Wedekind, J. and Kaplan, R.M. 1993. Type-driven semantic interpretation of f-structures. In Krauwer, S.; Moortgat, M.; and Tombe, Louisdes, editors 1993, *Sixth Conference of the European Chapter of the Association for Computational Linguistics — Proceedings of the Conference*. ACL. 404–411.