Alternative questions in Urdu: from the speech signal to semantics

Miriam Butt
University of Konstanz

Tina Bögel
University of Konstanz

Mark-Matthias Zymla
University of Konstanz

Benazir Mumtaz
University of Konstanz

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Abstract

This paper extends LFG's abilities to include information coming directly from the speech signal (Bögel 2015, 2022; Butt & Biezma 2022). We do this by developing an analysis and concomitant computational implementation for alternative vs. polar questions in Urdu. The implementation allows for a seamless integration of data from the speech signal into a semantic analysis of questions. We build on, but also go beyond, Butt & Biezma (2022), who included a semantic and pragmatic analysis, but did not demonstrate how exactly this could be arrived at on the basis of their c- and f-structural analyses. As far as we are aware, LFG is to date the only theoretical linguistic approach that is able to connect syntactic, semantic and pragmatic representations holistically with information coming directly from the speech signal.

1 Introduction

This paper extends LFG's abilities to include information coming directly from the speech signal (Bögel 2015, 2022; Butt & Biezma 2022). We do this by developing an analysis and concomitant computational implementation for alternative vs. polar questions in Urdu. The implementation allows for a seamless integration of data from the speech signal into a semantic analysis of questions and builds on an understanding of the complex interplay between prosody, morphosyntax, and semantics/pragmatics via LFG's projection architecture.[†] To showcase the effects of prosody on interpretation, we focus on ambiguous structures that can either be interpreted as alternative questions (AltQ) or as polar questions (PolQ). By means of a case study we show how these questions can be distinguished based on prosodic cues and how they can be theoretically modelled and computationally implemented in LFG's modular architecture. In doing so, we present a holistic integration of information from the speech signal into a semantic analysis, thus going all the way from *form* to *meaning*.

We crucially build on previous work by Bögel (2015), which extends the analytical abilities of LFG to include information coming directly from the speech signal in a modular manner. This model of the prosody-syntax interface has been successfully used to analyze a number of different phenomena, including pronominal placement, case disambiguation and question interpretation (e.g., Bögel et al. 2018; Bögel 2020; Butt & Biezma 2022). Building on these theoretical insights, we have been able to implement our approach to the prosody-syntax interface computationally. In recent work, for example, we demonstrated the system's ability to operate at the prosody-syntax interface in order to utilize prosodic cues for the disambiguation of syntactically ambiguous structures in German (Bögel & Zhao 2024). Similarly, Butt & Biezma (2022) integrated prosodic information via Bögel's prosody-syntax interface to disambiguate between a string/utterance that could either be interpreted as a *wh*-question or as a PolQ containing *kya* 'what' as a marker of uncertainty (see Biezma et al. 2024 for a full analysis). Butt & Biezma (2022) include a semantic and pragmatic analysis of the question types, but

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do not demonstrate how exactly this semantic and pragmatic analysis is arrived at on the basis of the prosodically disambiguated c- and f-structural analyses.

In this paper we extend the architecture and implementation to include the dimension of meaning, working with the Glue Semantics Workbench (Meßmer & Zymla 2018) and a co-descriptive approach (though description by analysis is a viable alternative). We focus on the prosodic disambiguation and syntactic and semantic analysis of AltQs and PolQs as a sample phenomenon. We show how our implementation allows for the automatic processing of the speech signal to extract grammatically relevant information that can then be accessed by other modules of grammar (not just the syntax). To the best of our knowledge, we are the only theoretical framework that can provide a formal model and concomitant computational implementation of the integration of prosody with morphosyntax and semantics/pragmatics.

The paper is structured as follows. Section 2 describes the basic data, section 3 introduces Bögel's architecture for the prosody-syntax interface in LFG and shows which prosodic information can be leveraged to disambiguate between AltQ and PolQ (and declarative) interpretations for those strings/utterances in Urdu that are structurally ambiguous. Section 4 then provides semantic analyses for the AltQs and the PolQ versions, working with the Glue Semantics Workbench. Section 5 concludes.

2 Background: Urdu questions

Urdu/Hindi[1] has basic SOV word order and shows a general LH intonational pattern on phrases (Harnsberger 1994; Patil et al. 2008; Puri 2013; Féry 2010; Urooj et al. 2019), as appears to be typical for South Asian languages. The difference between PolQs and declaratives is signaled via intonation: Declaratives as in (1-a) are signaled via a low final intonational phrase boundary tone L%, while PolQs as in (1-b) have a high boundary tone H%. Figure 1 shows the pitch contours and their difference in the final intonational phrase boundary tone for the examples in (1).

(1) a. ʃahina=ne norina=ko $\text{mara}_{\text{L-}\mathbf{L\%}}$
Shahina.F=Erg Norina.F=Acc hit-Perf.M.Sg
'Shahina hit Norina.' (Declarative)

b. ʃahina=ne norina=ko $\text{mara}_{\text{L/H-}\mathbf{H\%}}$
Shahina.F=Erg Norina.F=Acc hit-Perf.M.Sg
'Did Shahina hit Norina?' (Polar Question)

The most robust indication of focus in Urdu/Hindi seems to be a larger pitch excursion of the basic LH contour (Patil et al. 2008; Féry 2010; Jabeen & Braun 2018). Unsurprisingly then, constituent question words carry LH contours in which the H tone corresponds to the highest f_0 peak in the utterance. In (2), this is the constituent question word *kɪs=ko* 'whom'. Constituent questions are unlike PolQs and like declaratives in that they end on a low boundary tone.

[1] Urdu and Hindi are structurally almost identical, with Urdu being the national language of Pakistan and Hindi one of the official languages of India. Differences are mainly located in the lexicon. We use Urdu/Hindi when the discussion pertains to generalizations established for both languages and only Urdu when so far we have information only for Urdu.

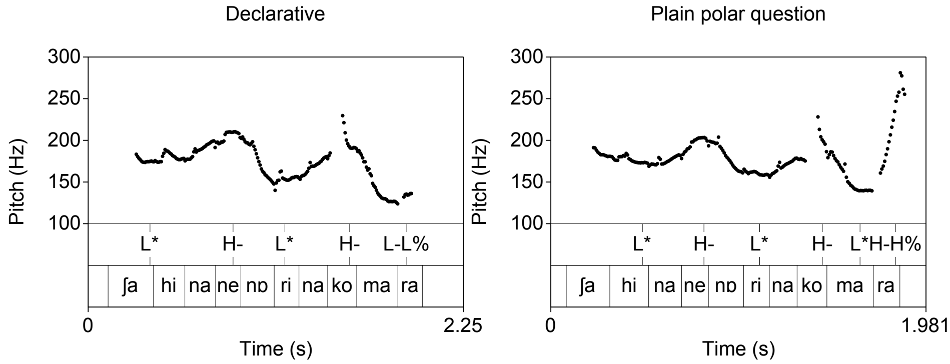


Figure 1: F$_0$ contour of a string identical declarative and polar question

(2) ʃahina=ne kɪs=ko mara$_{\text{L-L\%}}$
Shahina.F=Erg who=Acc hit-Perf.M.Sg
'Who did Shahina hit?' (Constituent Question)

This is crosslinguistically unremarkable and we leave aside further discussion of Urdu constituent questions as they are not the focus of this paper (interested readers are directed to Mahajan 1990, 1997; Dayal 2017; Bhatt & Dayal 2007; Manetta 2010, 2012; Butt 2014; Butt et al. 2016; Gribanova & Manetta 2016, a.o.).

2.1 Interaction between PolQs and AltQs

Polar questions can be optionally expressed with *kya* 'what', as in (3). The precise semantic and pragmatic import of this "polar *kya*" has been the subject of debate, with the most recent work by Biezma et al. (2024) concluding that it expresses that the speaker has no preconceived idea of the answer (yes or no) and thus in effect functions as a marker of uncertainty (see Biezma et al. 2024 for details). Bhatt & Dayal (2020) propose a different analysis of polar *kya* in terms of the precise pragmatics and syntax-semantics/pragmatics interface, but both Biezma et al. and Bhatt & Dayal agree that polar *kya* is a focus sensitive operator whose job is to provide more precise information about the underlying question.

(3) (**kya**) ʃahina=ne norina=ko mara?
what Shahina.F=Erg Norina.F=Acc hit-Perf.M.Sg
'Did Shahina hit Norina?'

Of interest to this paper is that polar *kya* can also optionally occur in questions containing alternatives, as illustrated in (4) (Han & Romero 2004; Bhatt & Dayal 2020).

(4) (kya) tʃand̪ra=ne kofi p-i ya tʃae?
what Chandra.F=Erg coffee.F.Nom drink-Perf.F.Sg or tea.F.Nom
'Did Chandra drink tea or coffee?'

Bhatt & Dayal (2020) show that there is an interesting interaction between AltQs and polar *kya* in that when polar *kya* appears initially, as in (5), where the disjunction is between two NPs, both PolQ and AltQ readings are available. However, if the polar *kya* appears in clause final position, the AltQ reading is not available, as shown in (6).

(5) **kya** tʃan̪dra=ne kofi ya tʃae p-i?
what Chandra.F=Erg coffee.F.Nom or tea.F.Nom drink-Perf.F.Sg
'Did Chandra drink tea or coffee?'
Alternative Question reading: 'Did Chandra drink tea or did she drink coffee?'
Polar Question reading: 'Is it the case that Chandra drank either tea or coffee?'

(6) tʃan̪dra=ne kofi ya tʃae p-i **kya**?
Chandra.F=Erg coffee.F.Nom or tea.F.Nom drink-Perf.F.Sg what
'Did Chandra drink tea or coffee?'
*Alternative Question reading: 'Did Chandra drink tea or did she drink coffee?'
Polar Question reading: 'Is it the case that Chandra drank either tea or coffee?'

There is no ready syntactic explanation for the patterns in (5) and (6). Bhatt & Dayal (2020) therefore speculated that this interaction might be due to a prosody-syntax interaction by which clause-final polar *kya* becomes difficult to pronounce. Biezma et al. (2024) instead propose a different explanation, which involves the scope of polar *kya*. Biezma et al. show that when polar *kya* is clause initial it is ambiguous between targeting either the verb (as the default focus of the clause) or just the item immediately to its right (if that item is marked prosodically as being in focus). In either case, both a PolQ and an AltQ interpretation are possible. On the other hand, if polar *kya* is in clause final position, then its scope is over the whole clause and, under these circumstances, an AltQ reading becomes impossible. The disjunction is not accessible for questioning since the alternative answers are only calculated at the clause level. Thus the only two available options to be questioned are: 1) Did Chandra drink tea or coffee; 2) Did Chandra not drink tea or coffee? This results in only a yes-no (polar) question, not a question targeting the alternatives of tea vs. coffee.

At the time of the writing and research conducted by both Bhatt & Dayal and Biezma et al. there was next to no information available on the prosody of Urdu/Hindi AltQs. In parallel, we therefore set out to gather information as to the prosody of Urdu AltQs via a series of experiments. We used both ambiguous PolQ vs. AltQ structures as in (5) and unambiguous AltQ vs. PolQ structures to gather data. We used the opposition to PolQs to have a benchmark to compare against, since the prosody of PolQs was comparatively better understood. These experiments and their results are detailed in Mumtaz & Butt (2024a,b). Overall, the results showed that string-identical AltQs vs. PolQs as in (5) could indeed be disambiguated via prosodic cues. In the next subsection we briefly present the results relevant for this paper.

2.2 Experimental evidence: Prosody of PolQs vs. AltQs

The discussion in this section is based on Mumtaz & Butt (2024a,b). In order to accumulate data on the prosody of AltQs, we conducted a series of production and perception experiments that contrasted AltQs with PolQs. We worked with both ambiguous and unambiguous strings, providing contexts for the ambiguous strings that prompted speakers to produce either AltQs or PolQs. The experiments were conducted in Lahore at the Center for Language Engineering (CLE) at the University of Engineering and Technology (UET). All participants were born and raised in Lahore, Pakistan, were fluent in Urdu and Punjabi, and knew some English.

2.2.1 Materials

For the experiments that are relevant for this paper, we worked with string-identical examples that are potentially ambiguous between AltQs and PolQs, as in (7).[2]

(7) t̪ʊm muli ja gobʰi kʰɑo-gi?
you radish.F.Nom or cauliflower.F.Nom eat-Fut.F.Sg
AltQ: ‘Will you eat radish or$_{\text{ALT}}$ (will you eat) cauliflower?’
PolQ: ‘Will you eat either radish or cauliflower (yes or no)?’

All examples were presented alongside disambiguating contexts as in (8).

(8) **AltQ Context**: *You are planning to cook dinner. There are only two vegetables in the house, radish and cauliflower, and you can only cook one vegetable. Ask your sister what she will eat.*

PolQ Context: *You get up to cook dinner. There are some vegetables available in the house. But you don’t know whether your sister will eat those vegetables or not. Ask her:*

Following this approach, we constructed a total of seven sentence pairs with the same structure to minimize acoustic variation; see Table 1. Each target sentence began with the pronoun [t̪ʊm] ‘you’ and only contained bisyllabic CVCV nouns with stress on the first syllable and ending in [i]. The verb always ended with the future morpheme *gi*. The stimuli were presented in written form together with the context and participants were asked to produce the corresponding utterance in consideration of the context.

AltQ	Translation
t̪ʊm məri jɑ bɑli dʒɑo-gi?	Will you go Murree or Bali?
t̪ʊm pɑni jɑ kofi pɪjo-gi?	Will you drink water or coffee?
t̪ʊm muli jɑ gobʰi kʰɑo-gi?	Will you eat radish or cauliflower?
t̪ʊm lɑri jɑ gɑɽi beʧo-gi?	Will you sell a lorry or a car?
t̪ʊm gʰɔri jɑ kʰot̪i mɑ̃go-gi?	Will you ask for a mare or a donkey?
t̪ʊm roʈi jɑ boʈi kʰɑo-gi?	Will you eat bread or meat?
t̪ʊm bɑli jɑ ʧuɽi d̪ekʰo-gi?	Will you see an earring or a bangle?

Table 1: Stimuli for prosodic experiments

[2]Note that we have an inconsistency in our transcriptions. In the previous sections we transcribed the sound [j] as ‘y’, in keeping with the existing literature on Urdu/Hindi, which has traditionally used an orthography based transcription. For the experimental work, we used the IPA transcriptions since we were analyzing the speech signals. This inconsistency mostly pertains to the items *ya/ja* ‘or’ and *kya/kja* ‘what’ in this paper.

2.2.2 Results

We here present a summary of the results from the production experiments, focusing on the properties of AltQs vs. PolQs. For one, we found that the first noun and the following conjunction [jɑ] 'or' have a wider range in f_0 for AltQs compared to PolQs. For the verb we found a wider range of f_0 in PolQs, but the absence of an accent on V in AltQs. These differences are illustrated in in Figure 2, where the f_0 contours of string identical AltQs vs. PolQs are compared (*Qtype* stands for Question Type and *F-marker* for future marker in the legend).

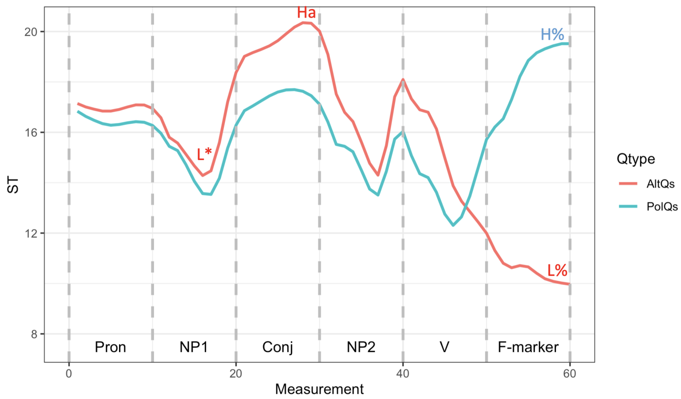


Figure 2: F_0 contour of string identical AltQs vs. PolQs

The statistical analysis also showed that AltQs predominantly have an L% boundary tone, while PolQs predominantly have an H% boundary tone (contra Jabeen 2022, but consistent with Urooj et al. 2019 and Harnsberger 1994); see Table 2.

Tones	PolQs	AltQs
L%	1	135
H%	209	39
HL%	12	50

Table 2: Distribution of boundary tones in AltQs vs. PolQs

A possible semantic analysis of AltQs is as disjunctions of PolQs (cf. Bhatt & Dayal 2020). Our results establish that from a prosodic perspective, AltQs can definitely not be treated as disjunctions of PolQs (i.e., [(PolQ_H%) OR (PolQ_H%)]). We also zeroed in on several prosodic cues that distinguish AltQs from PolQs. While both types of questions follow the general L*H pattern on prosodic phrases found in Urdu (Harnsberger 1994; Urooj et al. 2019), there are differences in terms of the pitch excursion. Recall that the highest pitch excursion in a sentence tends to signal focus. The wider range of f_0 on the verb in PolQs is consistent with the verb being the default focus in PolQs (will the eating event take place?). In contrast, the larger f_0 range on the first noun plus the conjunction [jɑ] 'or' in AltQs suggests a focus on N1+Conj in AltQs. This is consistent with focus placement on one of the proferred alternatives (e.g., radish vs. cauliflower).

Having established that string identical PolQs and AltQs can be differentiated via prosodic cues, we move on to showing how this prosodic information can be used by the syntactic component for disambiguation and how the disambiguated analysis can then be passed onto a semantic component. Thus, we show how one can go from the speech signal to the semantic analysis via the (morpho)syntax and the lexicon.

3 Prosody and disambiguation

3.1 The prosody-syntax interface

We use the approach proposed in Bögel (2015) for our analysis. This approach assumes a two-way exchange of information at the prosody-syntax interface: a) The transfer of vocabulary, which exchanges phonological and morphosyntactic information of lexical elements via the multidimensional lexicon, and b) The transfer of structure, where information on syntactic and prosodic phrasing, and on intonation, is exchanged. The model assumes a general distinction between comprehension (from form to meaning) and production (from meaning to form). Figure 3 illustrates the architecture that is assumed; see Bögel (2023) for a recent detailed discussion.

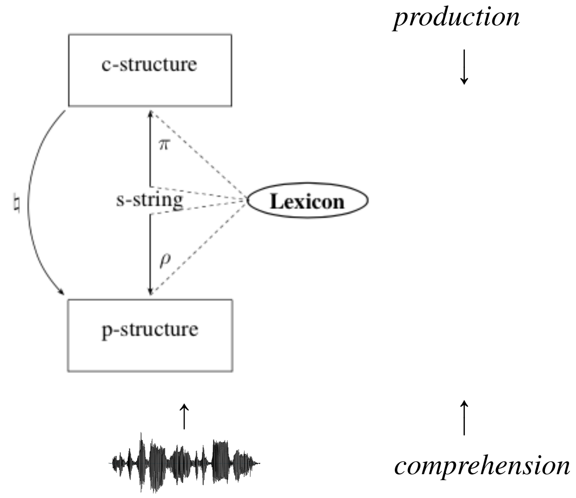


Figure 3: The prosody-syntax interface as proposed in Bögel (2015)

During comprehension, information from the speech signal feeds into p-structure which is represented by the p-diagram, a syllabic representation of the speech signal over time.[3] Figure 4 illustrates how each input syllable is associated with a vector, which records and stores the values associated with different phonetic attributes that are part of the speech signal, for example the duration of the syllable or its mean fundamental frequency (f_0). The lower part of the vector records the raw values from the speech signal. Symbolic information for phonological analyses is determined algorithmically on the basis of these raw values, for example, the occurrence of high and low tones and their individual shapes (see Bögel & Zhao 2024 for details on the tones used below) and prosodic phrasing. In Figure 4, for example, we can see that the highest f_0 value is on the [jɑ] 'or', which can thus be interpreted to have a distinct high tone. A high tone

[3]For the purposes of this paper we assume this syllabic segmentation and do not go into further details as to the algorithms or technology needed for automatic syllabification.

is also found on the final syllable of the second NP. Following the NP, the fundamental frequency values fall towards the end of the utterance, so the final boundary tone is low.

PROS.PHRASE	σ	(σ	σ	σ)	(σ	σ)	(σ	σ	σ)
TONES	–	–	L2	+H4	L2	+H4	–	–	L%
DURATION	0.123	0.212	0.143	0.138	0.194	0.133	0.190	0.079	0.173
FUND. FREQ.	320	266	247	419	240	301	204	194	191
SEGMENTS	[t̪ʊm]	[mu]	[li]	[jɑ]	[go]	[b^{h}i]	[k^{h}ɑ]	[o]	[gi]
VECTORINDEX	$\mathbf{S_1}$	$\mathbf{S_2}$	$\mathbf{S_3}$	$\mathbf{S_4}$	$\mathbf{S_5}$	$\mathbf{S_6}$	$\mathbf{S_7}$	$\mathbf{S_8}$	$\mathbf{S_9}$

Figure 4: The p-diagram for the AltQ version of (7)

We can see from the prosodic analysis contained in the vectors of the p-diagram in Figure 4 that the utterance carries the prosodic characteristics of an AltQ: a strong high tone (H4) on the conjunction [jɑ] and a clear fall towards the end (L%).

3.2 Prosodic disambiguation

The information contained in the p-diagram thus contains exactly the right information needed to disambiguate examples like (7), repeated below as (9).

(9) t̪ʊm muli jɑ gob^{h}i k^{h}ɑo-gi
you radish.F.Nom or cauliflower.F.Nom eat-Fut.F.Sg
AltQ: 'Will you eat radish or$_{\text{ALT}}$ (will you eat) cauliflower?'
PolQ: 'Will you eat either radish or cauliflower (yes or no)?'
Declarative: 'You will eat radish or cauliflower.'

In fact the string in (9) has three readings as it could also be a simple declarative. These three readings correspond to three different f-structures, whereby the crucial difference lies in the features CLAUSE-TYPE and QUESTION-TYPE; see (10).

(10) a. Alternative question:
[CLAUSE-TYPE interrogative, QUESTION-TYPE alternative]
b. Polar question:
[CLAUSE-TYPE interrogative, QUESTION-TYPE polar]
c. Declarative:
[CLAUSE-TYPE declarative]

The full c- and f-structural analysis for the AltQ analysis is given in Figures 5 and 6. These analyses have been produced by an Urdu grammar fragment that has been implemented via the grammar development platform XLE (Crouch et al. 2017). The fragment follows the analyses and design decisions made by the ParGram project in general (Butt et al. 1999) and the Urdu ParGram grammar in particular (e.g., Butt & King 2007; Sulger et al. 2013). This includes positing an exocentric S category to model the fact that all major constituents can scramble in Urdu. There is furthermore no evidence for a VP constituent (cf. Butt 1995); the verbal complex instead follows a relatively templatic structure.[4] The transcription in the structures is according to the convention established within the Urdu ParGram grammar (Malik et al. 2010).

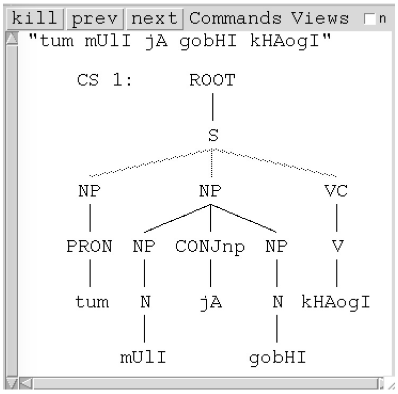


Figure 5: C-structure analysis of AltQ version for (9)

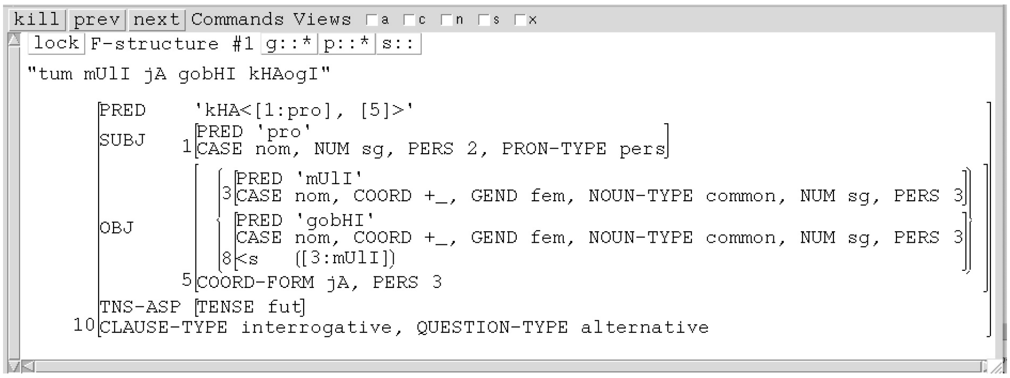


Figure 6: F-structure analysis of AltQ version for (9)

The f-structure in Figure 6 is quite standard, showing a coordinated object whose coordinator is [jɑ] (COORD-FORM). The underscore (_) after a feature's value indicates that this is an instantiated feature that cannot be unified with; see Crouch et al. (2017). The <s feature records the linear precedence of the two NPs in the coordination, indicating on the f-structure for *gobHI* 'cauliflower' that it was preceded by *mUlI* 'radish'. The details of the analysis are not of central relevance here; the main question is how we can leverage the prosodic features and have them interact with the syntactic analysis in order to effect the necessary disambiguation.

Figure 7 shows the p-diagram for the polar question interpreation of (9), which features a strong accent (H4) on [jɑ] and a strong rising final boundary tone (H%).[5]

[4]For sample analyses by the Urdu ParGram grammar, see the ParGram treebank on INESS at http://clarino.uib.no/iness/landing-page?collection=ParGram.

[5]We have left out the first syllable *tʊm* 'you' in Figures 7 and 8 for reasons of space as it is irrelevant for the disambiguation.

PROS.PHRASE	(σ	σ	σ)	(σ	σ)	(σ	σ	σ)
TONES	–	L2	+H4	L2	+H4	–	–	H%
DURATION	0.153	0.119	0.102	0.161	0.128	0.200	0.098	0.261
FUND. FREQ.	263	255	370	252	332	242	212	352
SEGMENTS	[mu]	[li]	[jɑ]	[go]	[b^{h}i]	[k^{h}ɑ]	[o]	[gi]
VECTORINDEX	$\mathbf{S_2}$	$\mathbf{S_3}$	$\mathbf{S_4}$	$\mathbf{S_5}$	$\mathbf{S_6}$	$\mathbf{S_7}$	$\mathbf{S_8}$	$\mathbf{S_9}$

Figure 7: The p-diagram for the PolQ version of (9)

Figure 8 shows the declarative interpretation of (9), with a weak accent (H1) on [jɑ] and a falling final boundary tone (L%).

PROS.PHRASE	(σ	σ	σ)	(σ	σ)	(σ	σ	σ)
TONES	L1	–	H1	–	H1	–	–	L%
DURATION	0.225	0.118	0.142	0.148	0.108	0.250	0.140	0.164
FUND. FREQ.	228	217	231	196	200	178	162	152
SEGMENTS	[mu]	[li]	[jɑ]	[go]	[b^{h}i]	[k^{h}ɑ]	[o]	[gi]
VECTORINDEX	$\mathbf{S_2}$	$\mathbf{S_3}$	$\mathbf{S_4}$	$\mathbf{S_5}$	$\mathbf{S_6}$	$\mathbf{S_7}$	$\mathbf{S_8}$	$\mathbf{S_9}$

Figure 8: The p-diagram for the declarative version of (9)

These differences in prosody, which are captured by the p-diagrams above and are summarised in Table 3, can be used for the disambiguation. The next section shows how we go about this exactly.

type	*coord-tone*	*boundary tone*		*clause-type*	*question-type*
alternative	H4	L%	→	interrogative	alternative
polar	H4	H%	→	interrogative	polar
declarative	H1/2	L%	→	declarative	–

Table 3: Pitch accents and boundary tones of the different semantic interpretations

3.3 Computational implementation

The computational implementation is based on that of Bögel & Zhao (2024) for German and has been adjusted to accomodate specific characteristics of Urdu. It is an extension of the system built for Butt & Biezma (2022), which aimed to disambiguate between Urdu polar *kya* and the corresponding constituent question word *kya* 'what'.

The input to the system consists of a speech signal, annotated with syllables in Praat (Boersma & Weenink 2021), as shown in Figure 9. Our system extracts all the information from this speech signal automatically via Praat (for example, calculating

f_0-values and duration). Based on these calculations, pitch accents, boundary tones, and prosodic constituents are determined automatically and recorded in the p-diagram.

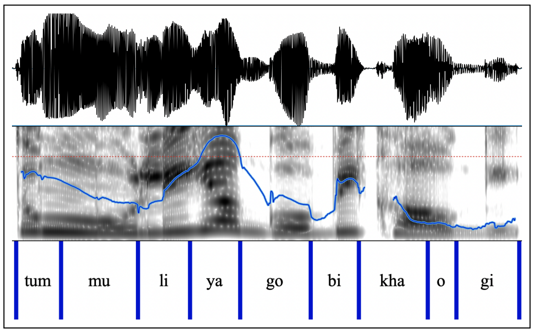


Figure 9: Input to the system: a speech signal annotated with syllables

Within the prosody-syntax interface, the transfer of vocabulary is activated in order to determine which lexical items are involved. This is done by matching the syllables against the multi-dimensional lexicon defined as part of the grammar. An example is provided in the middle of Figure 11, where the lexicon includes the usual functional information (PRED, etc.), but also phonological information as to the phonological segments involved: stress and the metrical frame of the item, for example. The matching is done greedily so that longer matches are preferred to shorter ones. Concretely, the input syllables are matched against a lexicon that is implemented using powerful finite-state methods (xfst; Beesley & Karttunen 2003). The lexicon transforms the prosodic-syllabic string into the syntactic string, thus modelling the transfer of vocabulary. This syntactic string serves as the input to an Urdu grammar, which parses the string of words and provides c- and f-structural analyses.

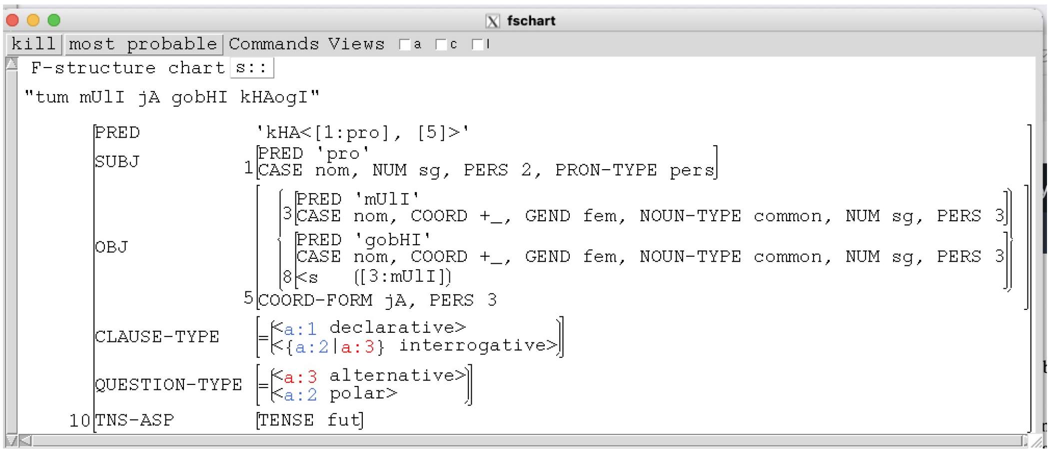


Figure 10: Fschart for the example in (9), showing three different parsing possibilities in a packed representation

The syntactic analysis results in three different possibilities for our sample input in Figure 9: 1) an AltQ; 2) a PolQ; 3) a declarative. These three possibilities are displayed together via the packed representation afforded by XLE in the fschart, as shown in Figure 10. The goal of the system now is to disambiguate the possibilities in this fschart. In order to do this, the system checks back with p-structure and the information in the p-diagram in order to identify high and low tones at crucial positions, i.e., with the coordination [jɑ] and on the final position of the clause as specified in Table 3.

Figure 11 illustrates the analysis of the AltQ in (9) at the prosody-syntax interface from the comprehension (parsing) direction.[6] The analysis in Figure 11 shows some of the raw signal information (mean f_0 values and segments) and the calculation of high and low tones and accent phrases (ap) based on the signal information in the p-diagram. This information is matched against LFG's multi-dimensional lexicon, for which we provide the examples for *mUlI* 'radish' and *gobHI* 'cauliflower'.

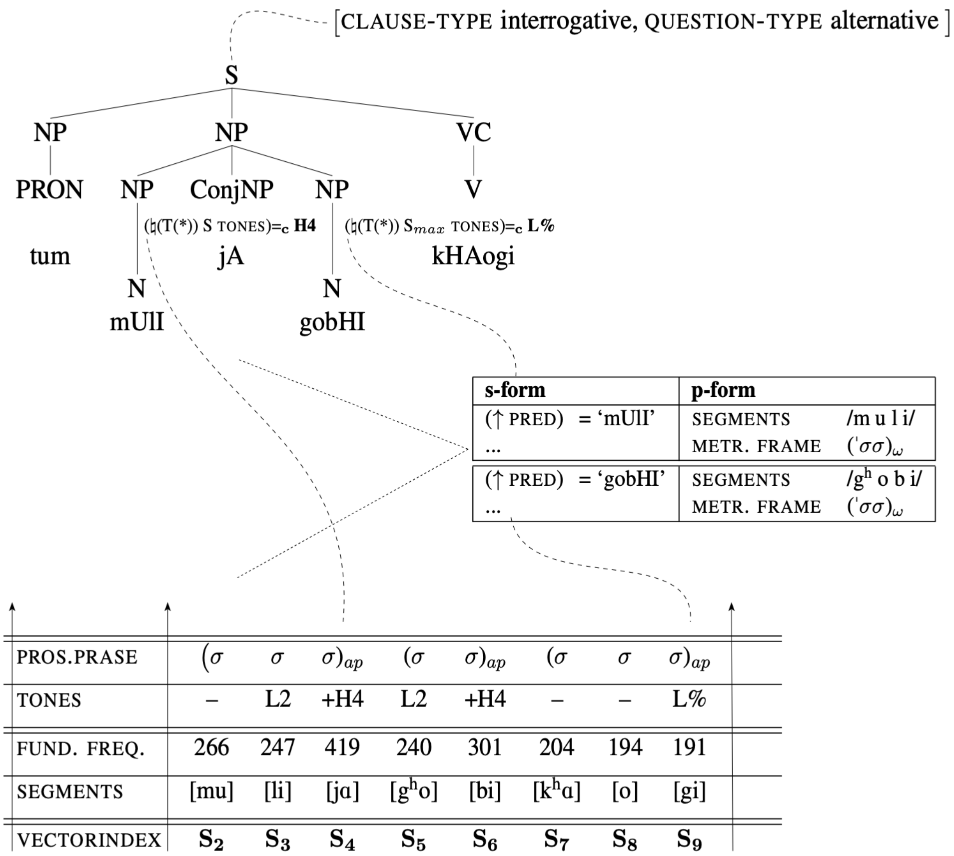


Figure 11: An AltQ at the prosody-syntax interface during comprehension

The figure also includes parts of the constraints responsible for the prosodic disambiguation of an AltQ. For example, as shown in (11), the constraints associated with the conjunction [jɑ] state that the corresponding syllable (S) in the p-diagram has to have an H4 tone as the value of the attribute TONES. If this is the case, then CLAUSE-TYPE is interrogative, but the QUESTION-TYPE can be alternative or polar.

[6]Again, we have left out the pronoun from the p-diagram for reasons of space.

(11) Constraints associated with the conjunction *ja* ‘or’:

a. $(\natural(T(*))$ S TONES$) =_c$ H4
(↑ CLAUSE-TYPE) = interrogative

b. { (↑ QUESTION-TYPE) = alternative | (↑ QUESTION-TYPE) = polar }

The decision as to whether the question is a PolQ or an AltQ is made based on the information about the final boundary tone. This set of constraints is shown in (12). The first part of the disjunction states that of all the syllables corresponding to this terminal node, if the syllable with the maximum index (S_{max}) has an L% tone, then CLAUSE-TYPE can be either interrogative (with QUESTION-TYPE alternative) or declarative. In contrast, the second part of the disjunction states that if the final boundary tone is H%, then the CLAUSE-TYPE must be interrogative and the QUESTION-TYPE polar.

(12) Constraints associated with the clause final position:

{ $(\natural(T(*))$ S_{max} TONES$) =_c$ L%
  { (↑ CLAUSE-TYPE) = interrogative
    (↑ QUESTION-TYPE) = alternative
  | (↑ CLAUSE-TYPE) = declarative }
| $(\natural(T(*))$ S_{max} TONES$) =_c$ H%
  (↑ CLAUSE-TYPE) = interrogative
  (↑ QUESTION-TYPE) = polar}

Taken together, (11) and (12) thus disambiguate the syntactic structures based on the information from the p-diagram. Computationally, this is achieved by selecting the corresponding option in the fschart. Once the syntactic analysis has been determined, the system is ready to tackle the semantic and pragmatic analysis.

4 A resource-sensitive semantics for questions

The meaning of questions is determined by both semantic and pragmatic factors. In this paper, we focus mainly on the compositional process of assembling the meaning of questions. Our approach uses LFG’s Glue Semantics (Dalrymple 1999), which we extend to be able to deal with alternative semantics. The fundamental property that is attributed to questions is that they partition the Common Ground (Stalnaker 2002) into alternatives corresponding to the answers to a question (Groenendijk & Stokhof 1984). This is fairly intuitive for constituent questions, as shown in (13), where the alternatives are represented as a set of semantic representations. This approach to questions essentially follows Hamblin (1973) and forms the basis for much of the formal semantic literature on questions.

(13) Who ate the radish?
$\{\lambda w_s.eat(jordan, radish, w), \lambda w_s.eat(alex, radish, w), ...\}$

AltQs can be presented as sets of alternatives in a similarly intuitive manner, as shown in (14), since it is generally assumed that AltQs spell out the corresponding possible answers (however, see Meertens 2021 for some special cases). In contrast, PolQs present somewhat more of a challenge as answers to basic PolQs in principle correspond simply to *yes* and *no*, but this correspondence is not necessarily straightforward. The classic analysis due to Hamblin (1973) suggests that for some PolQ $Q(p)$, the denotation in alternative semantics is $\{p, \neg p\}$. However, it has been shown that such a semantics does not capture certain nuances of PolQs, e.g., Van Rooy & Safarova (2003). In our work, we follow Biezma & Rawlins (2012) concerning the semantics for PolQs. Biezma & Rawlins analyze the semantics of a PolQ in terms of a singleton-set corresponding to the/a true answer of the question. This is illustrated in (14-b), which states that there exists some proposition *p* which corresponds to the true answer of the PolQ.

(14) Will you eat radish or cabbage?

a. $\{\lambda w_s.eat(you, radish, w), \lambda w_s.eat(you, cabbage, w)\}$ AltQ

b. $\{\lambda w_s.\exists p[p \in \{\lambda w_s.eat(you, radish, w), \lambda w_s.eat(you, cabbage, w)\} \wedge p(w) = 1]\}$ PolQ

Comparing the semantics of the AltQ and PolQ in (14), it becomes clear that they have a common core: the alternative set $\{\lambda w_s.eat(you, radish, w), \lambda w_s.eat(you, cabbage, w)\}$. This alternative set is not, in fact, introduced by virtue of the expressions being questions (as is the case for constituent questions), but rather by the disjunction (cf. Alonso-Ovalle 2006, who suggests that disjunction is better modeled in terms of alternatives rather than as a Boolean connective).

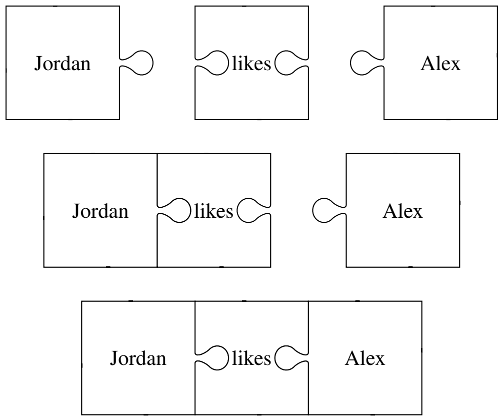
If we adopt the approach to questions sketched in this section, we need to introduce two interacting components to Glue Semantics as a consequence: a semantics of alternatives and a semantics of questions. We show how this is done in the next section.

4.1 Glue Semantics and alternatives

Essentially Glue Semantics can be understood as a puzzle where the grammar provides the individual pieces (see Asudeh 2022, 2023 for some recent compact introductions). For any semantic derivation, all and only the available pieces provided by the grammar need to be used. This is achieved by dividing semantic representations into two components: a representation of meaning (here, λ-First-Order Logic) and assembly instructions (formalized in linear logic). Roughly, the meaning representation corresponds to what is on a puzzle piece and the assembly instructions correspond to the shape of the puzzle piece. This is exemplified in Figure 12, which is accompanied by a (possible) corresponding formal representation, a proof tree. As shown in the figure, linear implication ($\multimap$) is used to indicate that a piece has notches that need to be filled. Atomic premises such as '$g : Jordan$' can fill these notches.[7]

To deal with alternatives, we need to extend our meaning language correspondingly. Concretely, this means that we not only allow simple λ-terms, but also sets of λ-terms. These sets must be restricted to elements of the same type. Thus, (15-a) and (15-b) are valid meaning representations, but (15-c) is not.

[7]Glue semantics also allows for higher-order linear logic terms (Lev 2007), e.g., $(e \multimap t) \multimap t$. These are trickier (i.e., more unwieldy) to represent as puzzle pieces. They are not required for the examples discussed in this paper.



$$\cfrac{\cfrac{Jordan : g \qquad \lambda x.\lambda y.like(x,y) : g \multimap h \multimap f}{\lambda y.like(jordan,y) : h \multimap f} \qquad Alex : h}{like(jordan, alex) : f}$$

Figure 12: Two proof-diagrams for *Jordan likes Alex*

(15) a. $\{jordan, sam\}$
b. $\{\lambda x.\lambda y.visit(x,y), \lambda x.\lambda y.hug(x,y)\}$
c. $\{\lambda x.\lambda y.visit(x,y), \lambda x.\lambda y.hug(x,y), jordan\}$

Through this move, the combinatory instructions can be kept simple, while the heavy lifting in terms of semantics is carried by the meaning side. This allows us to work with the usual computational tools for Glue Semantics (see section 4.3).

For the meaning side, we assume that λ-terms can be coerced into singleton sets at no cost. With this assumption in place, we only have to define function application (the process by which we compositionally combine meanings) for sets. Figure 13 specifies a rule for pointwise function application in the spirit of Hamblin (1973).[8,9] Function application with sets thus boils down to forming the Cartesian set of functors and arguments combining the elements via function application. Thus, intuitively, each element of the functor set is applied to each element of the argument set.

$$\frac{\alpha : A \multimap_{\times} B \qquad \beta : A}{\{\alpha_i(\beta_j) \mid \alpha_i \in \alpha, \beta_j \in \beta\} : B} \multimap_{\times}\text{-E}$$

Figure 13: Implication elimination with alternatives

[8]We assume that pointwise function application is the default when sets are involved. Regular function application is required only in special cases (see section 4.2). Thus, the glue fragment presented here remains fully type logical, as there are no ambiguities as to which application rule to choose.

[9]A corresponding rule for λ-abstraction or implication introduction is not required for present purposes. There are two possibilities for dealing with sets of alternatives: introducing a separate λ-binder for each element in the meaning set or having a global λ-binder scoping over the set. Here, the choice is irrelevant (i.e., equivalent), but probing deeper into the semantics of alternatives, e.g., for modeling focus, might force us to make a choice. We leave this for future work.

Set formation can be induced by various semantic devices. Relevant for us is the disjunction *or*, which, intuitively, creates alternatives from its disjuncts. In our puzzle analogy, *or* allows us to create pieces corresponding to multiple elements while maintaining the same combinatory properties, as illustrated in Figure 14. As shown there, we combine two consumable resources to produce a new consumable resource of the same semantic type e. Example (16) presents the corresponding formal notation, where the set operation $\cup$ coerces simple λ-terms into singleton sets. Example (16) roughly corresponds to the semantics of *or* following Alonso-Ovalle (2006).[10]

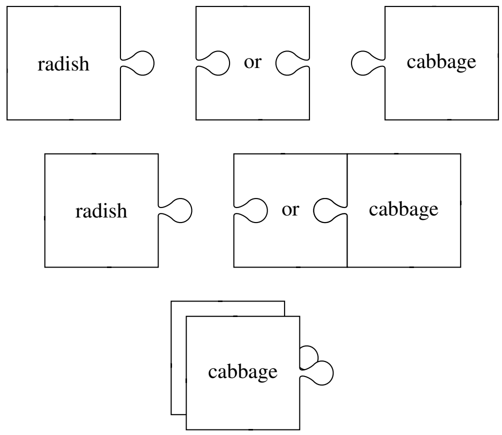


Figure 14: Creating alternatives

(16) a. $\lambda x_e.\lambda y_e.x \cup y : r_e \multimap c_e \multimap o_e$
b. $\{\textit{radish}, \textit{cabbage}\} : o_e$

This semantic machinery allows us to capture the basic facts of alternative semantics and allows us to formalize the semantics of disjunctive PolQs and AltQs.

4.2 From alternatives to questions

Recall that the semantics of questions have the sets of their answers as denotations. Thus, for AltQs, the question form does not contribute any additional semantic content. Rather, it has a pragmatic effect. Biezma & Rawlins (2012) model this in terms of presuppositions targeting the question under discussion (QUD; Roberts 2012), following Alonso-Ovalle (2006) in treating the alternative set introduced by *or* as underspecified. In this paper, we focus on the semantics since a computationally viable formalization for the pragmatics remains to be developed in future work (but see Zymla et al. 2015 for some initial work). We have therefore also set the system up in such a way that it can be extended easily in the future to account for pragmatic factors.

[10]Alternative sets need to be closed off corresponding to the meaning of the disjunctive element. Thus, both *or* and and denote sets of alternatives, but *or* requires only one of the alternatives to be true, whereas *and*, following standard assumptions about conjunction meaning, requires all elements in its alternative set to be true. This is achieved by closing off the alternative sets later in the derivation. We formalize this idea for questions below.

With respect to the semantics, we posit a semantically vacuous closure operator for AltQs, see (17). This provides us with an anchor for the relevant presuppositions in the derivation. Informally, Biezma & Rawlins (2012) suggest that AltQs have two requirements: the possible answers must be either salient alternatives or neutral in the context, and there is more than one such alternative.

(17) $[\![\, Q(\alpha) \,]\!] = [\![\, \alpha \,]\!]$

Thus, the AltQ operator takes a set of propositions and returns the same set with the appropriate pragmatic properties, here simply specified as *Q*. This can be combined with the underspecified semantics for alternatives presented in (18). As the meaning constructors there and the corresponding derivation in Figure 15 show, we can derive the meaning $\{\lambda w_s.eat(you, radish, w), \lambda w_s.eat(you, cabbage, w)\}$ for the disjunctive proposition set: first we combine *or* with *radish* and *cabbage*. Our semantics for *or* form a set of alternatives from its disjuncts. Given this alternative set, $\{radish, cabbage\}$, we can derive the semantics of a disjunctive proposition (i.e., *you eat radish or cabbage*) represented as a set of alternatives. This is the result at the bottom of Figure 15.

(18) a. Will you eat [radish or cabbage]$_o$?

	or	$\lambda x.\lambda y.x \cup y : r_e \multimap c_e \multimap o_e$
	eat	$\lambda x.\lambda y.\lambda w.eat(x, y) : u_e \multimap o_e \multimap w_s \multimap f_t$
b.	**cabbage**	$cabbage : c_e$
	radish	$radish : r_e$
	you	$you : u_e$

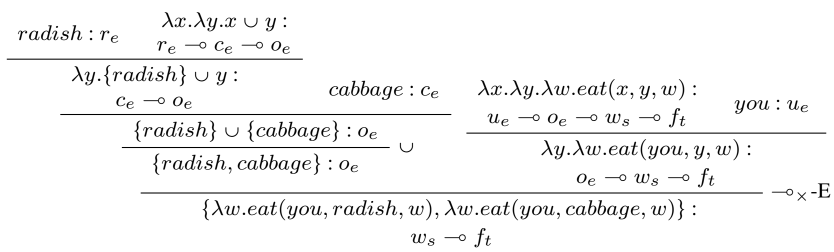


Figure 15: Underspecified disjunctive question

As discussed above, the difference between PolQs and AltQs lies in how we close off the alternatives (of which there are two in our running example). For AltQs, we simply apply the identity function (ignoring pragmatic constraints, as they do not affect the compositional process). However, to properly close off the derivation, we give it a special type. As shown in (19), we close off the derivation with a compound type for propositions *st* following a proposal made in Asudeh (2005).[11] Thus, as we expect, questions are denoted by sets of propositions.

[11]This is done mainly for stylistic reasons, i.e., so that our computations have an atomic result type. Generally speaking, f_{st} is equivalent to $f_s \multimap f_t$. This becomes relevant when embedding questions, e.g., *Do you know whether you want radish or cabbage?*

(19) **AltQ** $\lambda p_{st}.Q(p) : (w_s \multimap f_t) \multimap f_{st}$

The semantics of PolQs then only differs in the applied closure operator, which is given in (20). This operator has a special property as it takes a set as an argument. This means it does not apply in a pointwise fashion to the input set. We mark this with a special type in the meaning language we call α.

(20) **PolQ** $\lambda q_{\alpha}.\{\lambda w_s.\exists p[p \in q \wedge p(w) = 1]\} : (w_s \multimap f_t) \multimap f_{st}$

A functor asking for an argument of type α essentially asks that its argument is a set and that it is treated as a regular argument. This is shown in action in Figure 16. The type α is underspecified on the meaning side; however, due to the Curry-Howard isomorphism, its type is fixed by the linear logic side, thus avoiding unwanted combinations.

$$\frac{\begin{array}{c}\lambda q_{\alpha}.\{\lambda w_s.\exists p[p \in q \wedge p(w) = 1]\} : \\ (w_s \multimap f_t) \multimap f_{st}\end{array} \qquad \begin{array}{c}\{\lambda w_s.eat(you, radish, w), \lambda w_s.eat(you, cabbage, w)\} : \\ w_s \multimap f_t\end{array}}{\begin{array}{c}\{\lambda w_s.\exists p[p \in \{\lambda w_s.eat(you, radish, w), \lambda w_s.eat(you, cabbage, w)\} \wedge p(w) = 1]\} : \\ f_{st}\end{array}}$$

Figure 16: Applying the PolQ operator

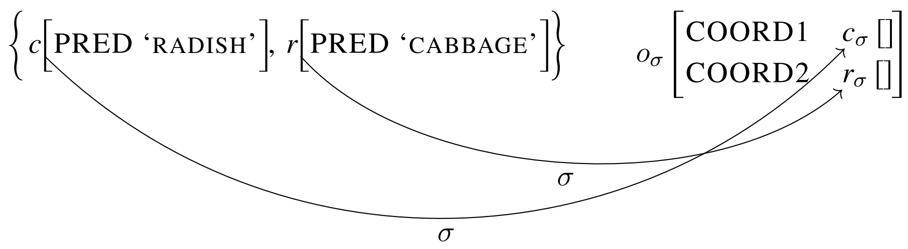
With this, we now have a Glue Semantics approach to AltQs and PolQs in place and can use the Glue Semantics Workbench to implement it computationallly.

4.3 Computational implementation

The semantics are implemented in XLE+Glue (Dalrymple et al. 2020) which interfaces XLE with the Glue Semantics Workbench (GSWB; Meßmer & Zymla 2018). For the purposes of this paper, the GSWB has been updated to include an ability to calculate alternatives, including the special type α.

In addition, we assume a semantic analysis that proceeds via a co-descriptive approach (though description by analysis is also a viable alternative), so we need to adjust the Urdu grammar fragment to include semantic information. It turns out that we need to include semantic information in just two places: 1) the NP coordination rule; 2) where the clause-type of the utterance is determined. For the NP coordination, we simply take over the ParGram approach to coordination (Crouch et al. 2017) and store each conjunct's s-structure index as a conjunct in the s-structure. These references are used to specify the meaning constructor for disjunction. The element o_σ is also the glue index corresponding to the semantics of the conjoined NP and the grammatical function it instantiates. The following example summarizes this:

(21) $\lambda x_e.\lambda y_e.x \cup y : r_\sigma \multimap c_\sigma \multimap o_\sigma$



Meaning constructors:

```
{
cabbage : 5_e
(/q_a.{(/w_s.Ep_<s,t>(in(p,q)&eq(p(w),1)))}) : ((12_s -o 12_t) -o 12_t)
[/x_e.[/y_e.[/w_s.eat(x,y,w)]]] : (10_e -o (3_e -o (12_s -o 12_t)))
you : 10_e
radish : 4_e
(/x_e.(/y_e.{x,y})) : (4_e -o (5_e -o 3_e))
}
{
cabbage : 5_e
[/q_<s,t>.q] : ((12_s -o 12_t) -o 12_t)
[/x_e.[/y_e.[/w_s.eat(x,y,w)]]] : (10_e -o (3_e -o (12_s -o 12_t)))
you : 10_e
radish : 4_e
(/x_e.(/y_e.{x,y})) : (4_e -o (5_e -o 3_e))
}
```

Figure 17: GSWB-representation of meaning constructor sets for underspecified questions

These alternatives percolate through the derivation all the way up to the clausal level. Since questions and declaratives are string-identical in Urdu, the question operators are introduced at the S node at c-structure rather than by concrete lexical items. We therefore also add the question-specific semantic information at this level. Additionally, the disjunctions are dependent on certain features, e.g., AltQs are only available if there is an alternative-inducing operator, i.e., disjunction. This is tested for at the level of f-structure by checking for the existence of the COORD-FORM feature somewhere in the f-structure.[12]

Given these two additions, an XLE+Glue grammar produces the correct meaning constructors for PolQs vs. AltQs for a corresponding string, as shown in Figure 17. Based on these individual meaning pieces, we can derive the correct results shown in (22). Which meaning is to be associated with the string is dependent on the prosodic disambiguation described in section 3. Concretely, the question closure operators are sensitive to the CLAUSE-TYPE feature, as was illustrated in (12). In our current implementation they are attached at the clause level (the S-node) in the c-structure rules in the same disjunct. There are different attachment possibilities, but approaches for ambiguity management, e.g., Findlay & Haug (2022), may profit from attaching question operators high in the tree. We leave an extended exploration of this possibility for future work.

(22) **Resulting solutions:**

a. PolQ:
$\{\lambda w_s.\exists p[p \in \{\lambda z_s.eat(you, radish, z), \lambda z_s.eat(you, cabbage, z)\} \wedge p(w) = 1]\}$

b. AltQ: $\{[\lambda w_s.eat(you, radish, w)], [\lambda w_s.eat(you, cabbage, w)]\}$

[12]These constraints can certainly be refined, but work well for our purposes so far.

5 Conclusion

In this paper we have focused on showing how the projection architecture of LFG allows for an elegant and holistic integration of prosodic information with morphosyntax and semantics. We demonstrated this with respect to Urdu AltQs vs. PolQs, which are string identical, but which can crucially be disambiguated via prosodic cues. We established the prosodic cues involved via a series of experiments described in detail in Mumtaz & Butt (2024a,b). We extracted the identified cues automatically from a speech signal and showed how the prosodic information can be passed to the syntax via the prosody-syntax interface first defined by Bögel (2015). We then showed how Glue Semantics and the GSWB can be extended to provide a semantics for alternatives and how this can be integrated directly into a core LFG grammar. To the best of our knowledge, LFG is the only framework to date whose architecture and concomitant computational implementation allows for a seamless asscociation of a speech signal with a semantic analysis via a morphosyntactic analysis.

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