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An inquisitive account of *wh*-questions through event semantics

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Abstract. Question processing is a frequently discussed topic in Natural Language Processing, in particular for chatbots or question and answer systems. However, it is difficult to have a logical representation of questions that can be used in these tasks, let alone automatically produced. We present a compositional method for logically computing the semantic representations of *wh*-questions. We use compositional Neo-Davidsonian Event Semantics as presented in [10] with thematic roles, joined with Inquisitive Semantics [14]. We implement our encoding using the Abstract Categorical Grammars framework [23]. Our model results in an operationalized view of *wh*-questions and inquisitive existentials which we illustrate on several examples of *wh*-questions including *who*, *which* and *where*.

Keywords: Questions · Logic · Semantics · Inquisitive Semantics · Events

1 Introduction

Modeling the meaning of sentences in natural languages is a task that can be approached from different perspectives, starting from distributional semantics [27] and up to formal semantics [6]. The study presented in this paper is conducted from the point of view of and in the scope of formal semantics.

There are multiple formal accounts of declarative sentences, starting from Richard Montague’s [33]. Montagovian approaches are compositional and truth-conditional. They assign a truth value to each declarative sentence by computing it using the sentence’s constituents. In this work, our object of study is interrogative sentences, and for this type of sentence, truth-conditional approaches do not hold, as it is not clear what assigning a truth value to a question would mean [21]. Is a yes/no-question true or false? What is a negative answer to a yes/no-question? What does it mean for a *wh*-question to be true or false?

To keep the compositional approach but be able to account for interrogative sentences, a possible method is to use a logic that treats interrogative and declarative sentences without differentiation. It is the case of Inquisitive semantics [14]. Inquisitive semantics is not directly compositional, but studies such as [15] show that the two approaches are compatible.

Following classic literature on formal semantics of interrogative sentences such as [26], [29], [21], we investigate questions through the semantic type of queries they raise. This leads us to envision a compositional approach that makes extensive use of thematic roles [18, 25]: Neo-Davidsonian Event Semantics [35].

The main idea behind our construction is that it is possible to see a *wh*-extraction as an existential quantification on a variable inhabiting the thematic role corresponding to the *wh*-word used in the *wh*-question. To do so, we define a procedural calculus that produces such a logical formula. Our idea is that of a parallel between *wh*-extractions and quantification, as in both cases, the scope is central to the interpretation. We achieve a technical solution that presents a similar approach for *wh*-extractions and quantification through the use of Inquisitive semantics, which translates the *wh*-extractions by existential quantifiers.

In this article, we present a compositional method for logically computing the semantic representations of *wh*-questions. We use compositional Neo-Davidsonian Event Semantics as presented in [10] joined with Inquisitive semantics [14]. We implement our encoding using the Abstract Categorical Grammars framework [23]. This paper unravels as following: first, we present the preliminary notions (in Section 2) needed to introduce our model in Section 3. Then, we make a focus on a crucial part of our method that is responsible for the control of the derivations in Section 4 and we discuss our proposition in Section 5. Finally we compare our work with other approaches in Section 6 and conclude in Section 7.

2 Linguistic & mathematical preliminaries

Our approach is rooted in classic formal accounts of interrogative sentences such as [26], [29], [21], [19]. We base our method on several existing and well-studied frameworks, presented in the following sections, which we combine in a systematic and operational way. We start with semantic considerations, through the presentation of thematic roles and Neo-Davidsonian Event Semantics, and turn to more technical aspects with Inquisitive semantics and Abstract Categorical Grammars. [38] and [39] have shown how these different theories can be used in a shared perspective.

2.1 *Wh*-questions and thematic roles

As defined in [20], *wh*-questions, in English, are questions that give rise to answers whose semantic types match those of the *wh*-phrase contained in the interrogative. A *wh*-phrase is introduced by a *wh*-word: **what**, **when**, **where**, **who**, **whom**, **which**, **whose**, **why**, **how** [1].

For this definition to be operational, it is necessary to systematically define the semantic types. A way to do so is by using *thematic roles*, as inspired by [17, 31]. This raises many discussions related to the interpretation and definition of thematic roles. To tighten up, we use a list of thematic roles inspired by Fillmore’s and Gruber’s works [18, 25], adapted from [4] and [7]: **participant**, **actor**,

cause, agent, undergoer, instrument, theme, pivot, patient, attribute, location, see the definitions in Table 1.

Table 1: Adapted from [4], without thematic roles specific to events with symmetrical participants, events of perception, or events of communication, and with the addition of the **Location** role from [7].

Thematic role	Definition
Participant	Entity involved in a state or event
Actor	Participant that is the instigator of an event
Cause	Actor (animate or inanimate) in an event, that initiates the event, without intentionality or consciousness, existing independently of the event
Agent	Actor in an event who initiates and carries out the event intentionally or consciously, existing independently of the event
Undergoer	Participant in a state or event that is not an instigator of the event or state
Instrument	Undergoer that is central to an event or state that is not an instigator of the event or state
Theme	Undergoer that is central to an event or state that does not have control over the way the event occurs, is not structurally changed by the event, and/or is characterized as being in a certain position or condition throughout the state
Pivot	Theme that participates in an event with another theme unequally but is central to the event
Patient	Undergoer in an event that experiences a change of state, location, or condition, that is causally involved or directly affected by other participants, and exists independently of the event
Attribute	Undergoer that is a property of an entity or entities, as opposed to the entity itself
Location	Place where an event occurs or a state is true

We note that a more detailed list of thematic roles is presented in the DIT++ schema [7], a semantically based framework for the analysis and annotation of dialogue. Following [3]’s statement that no fixed list of thematic roles can be established (nor crosslinguistic, nor for English only), we choose to showcase our method on a shorter list for the sake of readability. Our model can be easily tailored to a different list of thematic roles.

Once the thematic roles are set, asking a *wh*-question corresponds to interrogating the content of a thematic role. Therefore, for a compositional computation of a formal representation of an interrogative sentence, we need a formalism that gives access to variables corresponding to the content of the thematic roles. Neo-Davidsonian Event Semantics [35] is such a formalism.

2.2 Neo-Davidsonian Event Semantics

Neo-Davidsonian Event Semantics (NDES) is a formalism in which every sentence is considered in terms of occurring events and ways the sentence’s semantic

constituents relate to this event. Recent updates such as [10] present a compositional version of NDES, called *quantificational event semantics*. Representations of declarative sentences can then be built in a way that flattens down the sentence’s syntactic structure and makes thematic roles accessible for further work [2]. NDES follows the Montagovian truth-conditional tradition presented in the introduction, so in order to use it for both declarative and interrogative sentences, we need a different type of logical approach.

More formally, quantificational event semantics is based on three atomic types:

\mathbf{e} : individual/entity
 \mathbf{t} : truth value
 \mathbf{v} : event

e and t are inherited from Montague Semantics [33]; v is specific for event semantics. [8] presents a simple example for a declarative sentence:

$$(1) \quad [\text{John kissed Mary}] = \exists e.kiss(e) \wedge agent(e, john) \wedge patient(e, mary)$$

In (1), the type of the predicate of the verb is restricted to $\mathbf{v} \rightarrow \mathbf{t}$. The link with the variables of the other elements used in the sentence is made with the event variable e of type \mathbf{v} in thematic roles predicates. One of the main arguments in support of NDES is its flexibility for the representation with regard to the optional arguments.

The semantic representation of a declarative sentence S (of type t) is then built through a process that assumes an existing definition of a syntax-semantic interface:

1. get the syntactic parsing of S ;
2. building of the deep syntactic tree of S (also called *logical form* of S) ;
3. translate the elements of the tree to their semantic representations through the syntax-semantics interface (e.g. λ -terms);
4. composition of the elements of the tree following the types constraints of the semantic representations and syntactic tree structure.

2.3 Inquisitive Semantics

Most frameworks for semantic representation do not focus on question processing. An exception is Inquisitive semantics which introduces different levels of interpretation. In Inquisitive semantics, all propositions are considered to have both an informative and an inquisitive content, which allows for a uniform treatment of declarative and interrogative sentences, and also to manage interactions with quantifiers, modals, or discourse structures. In the view of dynamic semantics, [28], in Inquisitive semantics, an utterance is considered to be a context update function. While declaratives introduce only one possibility of update, questions open up alternatives.

The logic features two projection operators, $!$ and $?$. The first one transforms any proposition into a purely informative one by canceling its inquisitive content, which corresponds to a declarative sentence. Conversely, the second one transforms any proposition into a purely inquisitive one by canceling its informative content. Figure 1 shows the decomposition of a proposition in its non-informative and non-inquisitive projections.

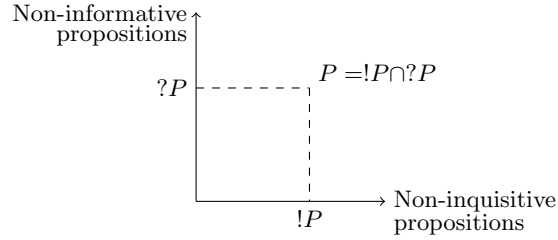


Fig. 1: Propositions with informative and inquisitive content, projection operators, [14].

More formally, inquisitive semantics interprets a proposition as a set of sets of possible worlds. Intuitively, an inquisitive proposition may therefore be seen as a set of classical (modal) propositions. Then, if \mathbf{s} is the type of possible worlds and \mathbf{t} the type of truth values, the type of inquisitive propositions \mathbf{p} is defined as follows:

$$\mathbf{p} = (\mathbf{s} \rightarrow \mathbf{t}) \rightarrow \mathbf{t}$$

Which gives the following definition of first-order inquisitive logic, with φ and ψ of type \mathbf{p} and \mathbf{e} the type of individuals/entities:

$$\begin{aligned} \mathbf{R}_i t_1 \dots t_n &:= \mathcal{P}(\mathbf{R} t_1 \dots t_n) \\ &\text{where } \mathcal{P} a = \lambda b^{\mathbf{s} \rightarrow \mathbf{t}}. \forall w^{\mathbf{s}}. (b w) \rightarrow (a w) \\ \varphi \wedge_i \psi &:= \lambda a^{\mathbf{s} \rightarrow \mathbf{t}}. (\varphi a) \wedge (\psi a) \\ \varphi \vee_i \psi &:= \lambda a^{\mathbf{s} \rightarrow \mathbf{t}}. (\varphi a) \vee (\psi a) \\ \varphi \rightarrow_i \psi &:= \lambda a^{\mathbf{s} \rightarrow \mathbf{t}}. \forall b^{\mathbf{s} \rightarrow \mathbf{t}}. (\forall w^{\mathbf{s}}. (b w) \rightarrow (a w)) \rightarrow ((\varphi b) \rightarrow (\psi b)) \\ \neg_i \varphi &:= \lambda a^{\mathbf{s} \rightarrow \mathbf{t}}. \forall w^{\mathbf{s}}. (a w) \rightarrow \neg(\exists b^{\mathbf{s} \rightarrow \mathbf{t}}. (\varphi b) \wedge (b w)) \\ \forall_i x^{\mathbf{e}}. \varphi x &:= \lambda a^{\mathbf{s} \rightarrow \mathbf{t}}. \forall x^{\mathbf{e}}. \varphi x a \\ \exists_i x^{\mathbf{e}}. \varphi x &:= \lambda a^{\mathbf{s} \rightarrow \mathbf{t}}. \exists x^{\mathbf{e}}. \varphi x a \\ !\varphi &:= \neg_i \neg_i \varphi \\ ?\varphi &:= \varphi \vee_i \neg_i \varphi \end{aligned}$$

In Hintikka's tradition of possible worlds, Inquisitive semantic includes connectives (e.g., and, or, not), quantifiers, and modal operators (e.g., may, should).

The aim is to bring together propositional, predicate, and modal logics while allowing a more detailed study of the relations between the elements involved. This sheds new light on various technical and linguistic aspects, but also brings to light new questions, thanks to a more refined analysis methodology.

One important remark for our purpose is that the interpretation of quantifiers is not the usual one. A universal quantifier cannot be the one of a question because the properties will hold for all the instantiation of the variable. An existential quantifier binds a variable that can be both inquisitive and informative. Then, using an existential also corresponds to a missing piece of information (which is not the variable). The use of ! projects the content of the formula into a purely informative content, thus without any missing element.

2.4 Abstract Categorical Grammars

The Abstract Categorical Grammars (ACGs) are a type-theoretic grammatical formalism for natural languages, based on the implicative fragment of multiplicative linear logic. It was introduced in [23], based on the Lambek calculus [32] and semantic recipes expressed as type λ -calculus. The core principle of ACGs is to use the same type theory for both syntax and semantics. By doing so, ACGs define concrete and abstract signatures, linked by a lexicon.

An ACG is defined on a set of atomic types (A). The set $\mathcal{T}(A)$ of linear implicative types built upon A is inductively defined as follows: if $a \in A$, then $a \in \mathcal{T}$; if $\alpha, \beta \in \mathcal{T}$, then $(\alpha \rightarrow \beta) \in \mathcal{T}(A)$.

Then a higher-order linear signature is defined as a triple $\Sigma = \langle A, C, \tau \rangle$ where A is a finite set of atomic types, C a finite set of constants and $\tau : C \rightarrow \mathcal{T}(A)$ a function that assigns to each constant in C a linear implicative type in $\mathcal{T}(A)$. It is then possible to use a set of linear λ -terms build upon these signatures.

Given two higher order linear signatures, named *vocabularies*, $\Sigma_1 = \langle A_1, C_1, \tau_1 \rangle$ and $\Sigma_2 = \langle A_2, C_2, \tau_2 \rangle$, a *lexicon* \mathcal{L} from Σ_1 to Σ_2 is defined as a pair $\mathcal{L} = \langle F, G \rangle$ such that:

1. $F : A_1 \rightarrow \mathcal{A}$ is a function that interprets the atomic types of Σ_1 as linear implicative types built upon A_2 ;
2. $G : C_1 \rightarrow \Lambda(\Sigma_2)$ is a function that interprets the constants of Σ_1 as linear λ -terms built upon Σ_2 ;
3. the interpretation functions are compatible with the typing relation.

The structure of these relations is summarized in Figure 2.

$$\begin{array}{c} \Sigma_1 \\ \mathcal{L} \downarrow \\ \Sigma_2 \end{array}$$

Fig. 2: Schematic view of an ACG.

In the following, we define signatures and lexicons in such a way that we produce question representations that integrate thematic roles, NDES, and Inquisitive Semantics.

3 A categorial formalisation of the syntax and semantics of *wh*-interrogatives

It is usual in the categorial grammar tradition to distinguish between the quantified noun phrases and the mere noun phrases, at the syntactic level. While the latter are assigned a simple atomic type *np*, the former are assigned the functional type $(np \rightarrow s) \rightarrow s$, which reflects the fact that a quantified expression takes a scope. This allows for a smooth treatment of scope ambiguities.

Let us illustrate this approach by considering the following sentence:

(2) *every farmer fed a donkey*

the two possible readings of which are captured by the two syntactic structures of Figure 3.

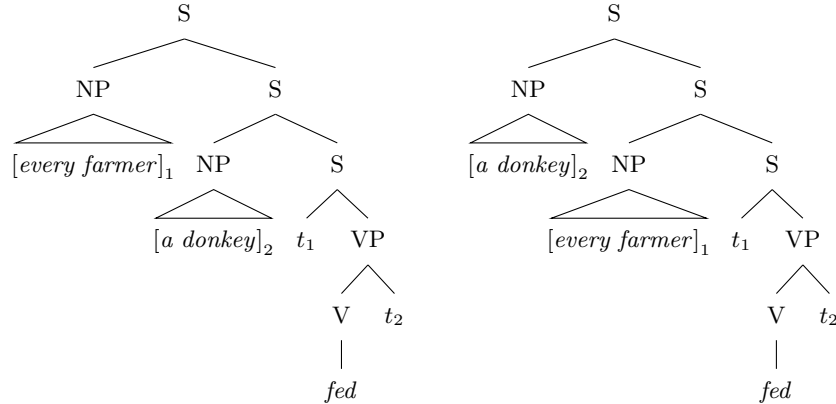
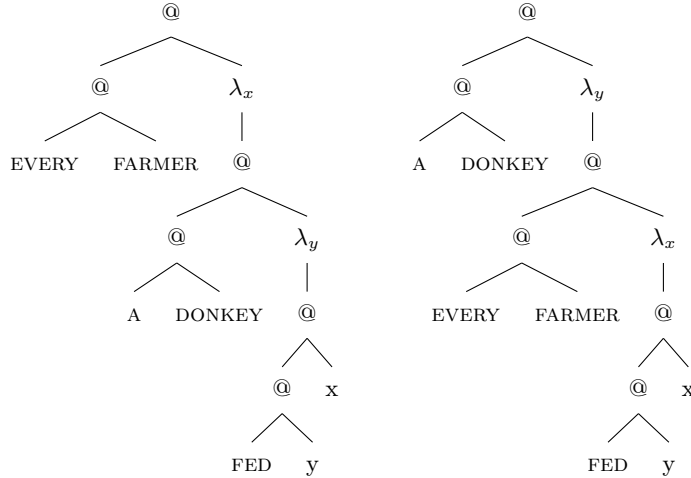


Fig. 3: Syntactic structures of two possible readings for sentence (2).

In order to give an abstract categorial account of sentence (2), one may declare abstract constants of the following types:

$$\begin{aligned} \text{FARMER, DONKEY} &: n \\ \text{A, EVERY} &: n \rightarrow (np \rightarrow s) \rightarrow s \\ \text{FED} &: np \rightarrow np \rightarrow s \end{aligned}$$

Then, the above syntactic structures are encoded in an almost straightforward way by the following λ -terms of the Figure 4.

Fig. 4: λ -terms corresponding to the syntactic structures presented in Figure 3.

This categorial treatment of scope ambiguities, which directly derives from Montague [34], might be problematic when the targeted semantic formalism is Davidson’s event semantics. It has indeed been argued that Montague’s treatment of quantification does not combine smoothly with event semantics. The problem is that, in event semantics, a declarative sentence that is ultimately interpreted as a truth value (\mathbf{t}) is first interpreted as a set of events ($\mathbf{v} \rightarrow \mathbf{t}$). Then, switching from the latter interpretation of a sentence to the former necessitates an existential-closure operator, which may badly interact with the quantifiers that occur in the interpretation of the sentence. Fortunately, the literature provides at least two solutions to this problem. A first one is due to Champollion [9], and a second one to Winter and Zwarts [40]. We follow this second solution since it is in line with the categorial tradition that we are advocating.

Winter and Zwarts’ solution consists in assigning two different syntactic types to the sentences. On the one hand, a first type (s_0) is used for the “open” sentences, i.e., the sentences that are semantically interpreted as sets of events, and, on the other hand, a second syntactic type (s) is used for the sentences that are interpreted as truth values. Then, the existential closure operator allows values of type s_0 to be coerced into values of type s . Accordingly, the abstract signature we have sketched above is transformed as follows:

$$\begin{aligned}
 \text{FARMER, DONKEY} &: n \\
 \text{A, EVERY} &: n \rightarrow (np \rightarrow s) \rightarrow s \\
 \text{FED} &: np \rightarrow np \rightarrow s_0 \\
 \text{E-CLOS} &: s_0 \rightarrow s
 \end{aligned}$$

This ensures that the existential closure operator will always take a narrower scope with respect to the other quantifiers.

Now, it is well known that there is a strong analogy between quantifier raising and *wh*-extraction. Following this analogy suggests that we should assign to a *wh*-noun phrase the type that we assign to quantified noun phrases. Typically:

$$\text{WHO} : (np \rightarrow s) \rightarrow s$$

Similarly, a *wh*-determiner must be assigned the same type as a quantificational determiner:

$$\text{WHICH} : n \rightarrow (np \rightarrow s) \rightarrow s$$

Finally, *wh*-adverbs must be assigned the same type as the quantified adverbial modifiers, which are assigned $((s_0 \rightarrow s_0) \rightarrow s) \rightarrow s$ [22]. Accordingly, we have:

$$\text{WHERE} : (s_0 \rightarrow s_0) \rightarrow s \rightarrow s$$

Putting everything together, we end up with an abstract syntax specified by the signature given in Table 2, where Q is a syntactically silent operator that will allow a declarative proposition to be turned into a polar question.

Table 2: Abstract Syntax Signature

<i>Abstract Syntax</i>	
FARMER, DONKEY, MEADOW	$: n$
THE	$: n \rightarrow np$
A, SOME, EVERY, WHICH	$: n \rightarrow (np \rightarrow s) \rightarrow s$
IN	$: np \rightarrow s_0 \rightarrow s_0$
FED, DID-FEED	$: np \rightarrow np \rightarrow s_0$
WHO	$: (np \rightarrow s) \rightarrow s$
WHERE	$: (s_0 \rightarrow s_0) \rightarrow s \rightarrow s$
E-CLOS	$: s_0 \rightarrow s$
Q	$: s \rightarrow s$

In abstract categorial grammars, the language generated by an abstract signature (such as the one given in Table 2) acts as a pivot language between surface forms and semantic interpretations. Figure 5 is typically the way an abstract categorial grammar models the syntax-semantics interface:

Consequently, in order to complete the picture, it remains to give the syntactic and the semantic translations of the abstract syntax specified by the signature of Table 2. These are given in Table 3 and Table 4, respectively.

We may now illustrate the overall approach by treating the following example:

- (3) *where did every farmer feed a donkey*

Its two possible readings are captured by the two following λ -terms built upon the signature given in Table 2:

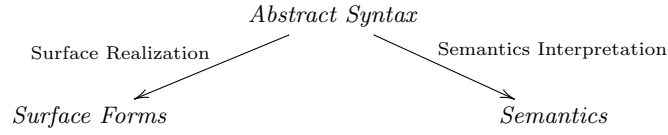


Fig. 5: Syntax-semantics interface in ACGs.

Table 3: Surface Realisation Lexicon

<i>Surface Realization</i>
FARMER := farmer
DONKEY := donkey
MEADOW := meadow
THE := $\lambda x. \mathbf{the} + x$
A := $\lambda xp. p(\mathbf{a} + x)$
SOME := $\lambda xp. p(\mathbf{some} + x)$
EVERY := $\lambda xp. p(\mathbf{every} + x)$
WHICH := $\lambda xy. \mathbf{which} + x + (y \in)$
IN := $\lambda xy. y + \mathbf{in} + x$
FED := $\lambda xy. y + \mathbf{fed} + x$
DID-FEED := $\lambda xy. \mathbf{did} + y + \mathbf{feed} + x$
WHO := $\lambda x. \mathbf{who} + (x \in)$
WHERE := $\lambda q. \mathbf{who} + (q(\lambda x. x))$
E-CLOS := $\lambda x. x$
Q := $\lambda x. x$

(4) $Q(\text{WHERE}(\lambda f. \text{EVERY FARMER}(\lambda x. \text{A DONKEY}(\lambda y. \text{E-CLOS}(f(\text{DID-FEED } y x))))))$

(5) $Q(\text{WHERE}(\lambda f. \text{A DONKEY}(\lambda x. \text{EVERY FARMER}(\lambda y. \text{E-CLOS}(f(\text{DID-FEED } x y))))))$

Indeed, both (4) and (5) yield the same result when they are applied the translation given in Table 3:

(6) **where + did + every + farmer + feed + a + donkey**

By contrast, when applied the translation given in Table 4, (4) and (5) yield the two expected different readings: (1) and (2), respectively.

$$\begin{aligned}
 ?\exists x. \forall y. (\mathbf{farmer } y) \rightarrow & !((\exists z. (\mathbf{donkey } z) \wedge !((\exists e. (\mathbf{fed } e) \wedge (\mathbf{patient } e z) \\
 & (\mathbf{agent } e y) \wedge (\mathbf{location } e x)))))) \quad (1)
 \end{aligned}$$

Table 4: Semantic Interpretation Lexicon

<i>Semantic Interpretation</i>	
FARMER	:= $\lambda x. \mathbf{farmer} x$
DONKEY	:= $\lambda x. \mathbf{donkey} x$
MEADOW	:= $\lambda x. \mathbf{meadow} x$
THE	:= $\lambda p. \mathbf{the} (\lambda x. p x)$
A, SOME	:= $\lambda p q. !(\exists x. (p x) \wedge (q x))$
EVERY	:= $\lambda p q. \forall x. (p x) \rightarrow (q x)$
WHICH	:= $\lambda p q. \exists x. (p x) \wedge (q x)$
IN	:= $\lambda x p. \lambda e. (p e) \wedge (\mathbf{location} e x)$
FED, DID-FEED	:= $\lambda x y. \lambda e. (\mathbf{fed} e) \wedge (\mathbf{patient} e x) \wedge (\mathbf{agent} e y)$
WHO	:= $\lambda p. \exists x. p x$
WHERE	:= $\lambda p. \exists x. p (\lambda q. \lambda e. (q e) \wedge (\mathbf{location} e x))$
E-CLOS	:= $\lambda p. !(\exists e. p e)$
Q	:= $\lambda x. ?x$

$$\begin{aligned}
 ?\exists x.!(\exists y.(\mathbf{donkey} y) \wedge (\forall z.(\mathbf{farmer} z) \rightarrow!(\exists e.(\mathbf{fed} e) \wedge (\mathbf{patient} e y) \\
 \wedge (\mathbf{agent} e z) \wedge (\mathbf{location} e x)))))) \quad (2)
 \end{aligned}$$

4 Controlling *wh*-extraction and quantifier raising

The grammar we have sketched in the previous section is quite simple, and has the advantage of highlighting the parallel that exists between declarative and interrogative sentences. In particular, it is based on a uniform treatment of quantification raising and *wh*-extraction. This simplicity, however, is not without its drawbacks. These are threefold. Firstly, our grammar assigns the same syntactic categories to both the declarative and the interrogative forms (for instance, EVERY and WHICH are both assigned $n \rightarrow (np \rightarrow s) \rightarrow s$). This gives rise to a grammar that generates ungrammatical surface forms such as the following one:

$$(7) \quad *every\ farmer\ fed\ which\ donkey\ in\ which\ meadow$$

Secondly, allowing the quantifiers to take any possible scope results in spurious ambiguities. For instance, a sentence such as:

$$(8) \quad a\ farmer\ fed\ a\ donkey\ in\ a\ meadow$$

will give rise to six different abstract syntactic structures the semantic interpretations of which are all logically equivalent. Finally, the interactions between *wh*-extraction and quantifier raising must obey some constraints. For instance, in a *wh*-question, the *wh*-quantifier must always take the wider scope. Consider

again example (3). The signature given in Table 2 allows one to built syntactic structures, such as the following one, that do not respect the *wh*-quantifier wider scope constraint:

(9) EVERY FARMER (λx . WHERE (λf . A DONKEY (λy . E-CLOS (f (DID-FEED $y x$))))))

Consequently, our grammar might allow nonsensical semantic interpretations to be derived.

The three kinds of defects that our grammar presents are all the consequence of a same fact: the signature of Table 2 allows too many abstract syntactic structures to be derived. We should therefore be able to select among the λ -terms that can be built upon the signature of Table 2 the ones that correspond to legitimate abstract syntactic structures. A modular and efficient solution to this problem consists in using another abstract categorial grammar in order to control the *Abstract Syntax* signature, which corresponds to the grammatical architecture shown in Figure 6.

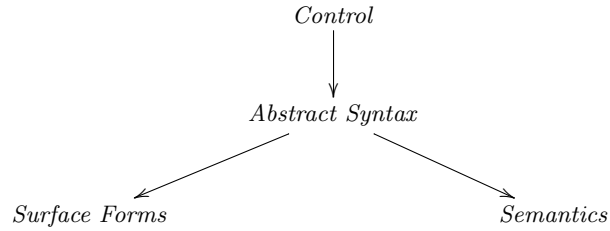


Fig. 6: Grammatical architecture of our model.

We have developed such a control grammar, which is unfortunately too large to be presented here¹. Just to give a flavor of it, by way of illustration, we give the excerpt that allows example (3) to be dealt with.

$$\begin{aligned}
 a &: n \rightarrow npe \\
 \text{every} &: n \rightarrow npu \\
 \text{Inpe} &: npe \rightarrow np \\
 \text{Inpu} &: npu \rightarrow np \\
 \text{farmer, donkey} &: n \\
 \text{did-feed} &: np \rightarrow vpq \\
 \text{where} &: sq_0 \rightarrow s \\
 \text{SQ4} &: np \rightarrow vpq \rightarrow sq_0 \\
 \text{did-feed2} &: vpq_{np} \\
 \text{QRq13} &: npe \rightarrow sq_{0npe} \rightarrow sq_0
 \end{aligned}$$

¹ It is about three times larger than the grammar presented in Section 3.

$$\begin{aligned}
a &:= A \\
\text{every} &:= \text{EVERY} \\
\text{Inpe, Inpu} &:= \lambda x. x \\
\text{farmer} &:= \text{FARMER} \\
\text{donkey} &:= \text{DONKEY} \\
\text{did-feed} &:= \lambda p x f. p (\lambda y. f (\text{DID-FEED } y x)) \\
\text{where} &:= \lambda p. Q (\text{WHERE } (\lambda f. p (\lambda s. \text{E-CLOS } (f s)))) \\
\text{SQ4} &:= \lambda p q f. p (\lambda x. q x f) \\
\text{did-feed2} &:= \lambda x y f. f (\text{DID-FEED } x y) \\
\text{QRq13} &:= \lambda p q f. p (\lambda x. q x f)
\end{aligned}$$

5 Discussion

In the previous sections, we have presented a categorial formalisation of the syntax and semantics of *wh*-interrogatives. In its current state, our model doesn't give a direct solution for the representation of *wh*-questions that contain the *wh*-words “what”, “whose”, “why”, and “how”.

“what” appears to be close in behavior either to “who” and “whom”, or to “which”. The difference between “what” and “which” seems to come from pragmatic considerations: the interpretation of “what” hugely depends on the context in which this interrogative word is used, while “which” is restrained in its interpretation by the definition of the set from which the choice of the response is made. “what did the farmer do” is an example that we cannot account for in the current state of our model: the issue raised by this question concerns the action, therefore the event, in our Neo-Davidsonian view. In order to be able to model this example, we would need a quantification on the predicates, so a higher-order logic.

Regarding “how”, the difficulty is quite close to the one encountered with “what”: the meaning of the *wh*-word “how” depends on the expression “how” is paired with. Consider the difference between “how old” and “how far”: in the first case, the interrogated thematic role could be something time or age-related; in the second, the thematic role is **location**.

“whose” raises the problem of modeling the possessive relation. The semantics of possessives is a subject on its own, see for example [36] for investigations on the semantics of English possessives. In our case, modeling “whose” would require an extension of our grammar with the addition of the preposition “of” used as a possessive, therefore as a modifier of a noun.

Finally, the difficulty with “why?” comes from its very large scope. Indeed, “why” can take a whole sentence as its argument (ex: “why did a farmer feed every donkey?”). In particular, it means that “why” introduces a quantification on the event predicate, which requires a higher-order logic treatment.

6 Related work

We compare our model to existing works by discussing related approaches, in particular related to the linguistic and mathematical tools that we use.

In [8], Lucas Champollion’s presents *Quantificational event semantics*, an original take on Neo-Davidsonian event semantics. Quantificational event semantics is compositional and natively computational. Our method takes advantage of Champollion’s compositional presentation of event semantics while following a different path in terms of sentence closure, to be able to account for interrogative sentences.

[15] introduces typed Inquisitive Semantics, a compositional take on Inquisitive Semantics, that addresses quantification, negation, some *wh*-questions, notions of entailment and coordination. [11] uses typed Inquisitive Semantics to model questions and presuppositions. Our approach can be viewed as very similar to a combination of typed Inquisitive Semantics and quantification event semantics, which, to our knowledge, had not yet been done.

[24] presents a dynamic approach to discourse modeling. Based on Montague semantics, it is compositional and computational through the usage of simple type theory [12] and λ -calculus. It is operationalized through the ACG toolkit [23, 37].

7 Conclusion & Future work

We present a compositional method for the computation of logical representations of *wh*-questions through the use of thematic roles, based on Neo-Davidsonian Event Semantics and Inquisitive Semantics and implemented through the Abstract Categorical Grammars framework. This paper shows that our approach is operational and computationally sound. We showcase our method on multiple examples and present several thoughts on future extensions.

In particular, the approach presented in this paper aims at staying as general as possible with regard to language specificities. We focused the presentation on English because of the simplicity of *wh*-words-based presentation, but we aim to produce a system that would be easily extendable to other languages such as French and Russian, using for example insights from [41].

The grammar presented in this article is a toy grammar for a fragment of English. It can easily be extended, for example in order to include syntactic tags such as the ones from the Stanford parser² [30], currently available for 6 languages: Arabic, Chinese, English, French, German, and Spanish, or following other exploration on question and answer relations [16].

One of the future development directions for our work would be to add dynamicity to our model. A way to achieve this goal would be by integrating [24]’s framework along with Inquisitive Dynamic Epistemic Logic [13].

The next step for our work will be in addressing the *wh*-questions that are out of the scope of our current model, such as “why”, see Section 5. Then, we would like to integrate this work in the perspective of a dialogue model. In such a model, it is necessary to be able to represent declarative sentences, interrogative sentences, but also non-sentential utterances (for partial answers or clarification

² <https://stanfordnlp.github.io/CoreNLP/>

questions). A dialogue model also needs to have context-related parts. We would like to extend a model such as the one presented in [5] using the method from this article.

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