# Picturing Questions and Answers – a formal approach to SLAM

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**Abstract.** In this paper, we present a formal approach to compositional processing of questions and answers in the Schizophrenia and Language, Analysis and Modeling corpus [1]. We address dialogue lexicality issues starting from the formal definitions of so-called Düsseldorf Frame Semantics given in [2]. We introduce a view of dialogues as compositions of *negotiation phases* that can be studied separately one from another while linked by a common *dialogue context* (accessible to all participants of a dialogue).

**Keywords:** dialogue, questions, answers, compositionality, dynamicity, discourse, dialogue structure, wh-questions

## 1 Introduction

The Schizophrenia and Language, Analysis and Modeling (SLAM) project aims to systematise the study of pathological conversations as part of an interdisciplinary approach combining psychology, linguistics, computer science and philosophy. The SLAM corpus is composed of 80 semi-structured interviews in French performed by psychologists with either patients with schizophrenia under medication, patients with schizophrenia without medication or control patients (without any known diagnosis) [1]. First observations on the corpus have shown several significant differences, both linguistic and semantic, between interviews with patients with schizophrenia and interviews with other participants. See Section 2 and [3] for further insight into the subject.

As SLAM is composed of medical (sensitive) data, it is not publicly available. Anonymised parts of the corpus can be found throughout publications and can be used to conduct further studies. See in particular Section 5 for examples. We aim at a systematical study of the corpus from a formal computational linguistics point of view. This attempt is not the first one, as [3] present an analysis of the SLAM corpus using the DRT framework. See Section 6 for a presentation and discussion about DRT. Our idea is to focus on the conversational aspect of SLAM's data, particularly in terms of cooperation and question and answer mechanisms, through formal semantics.

Formal semantics of dialogue is a fundamental subject that has been extensively studied from numerous points of view [4]. As written by Jonathan Ginzburg in [5], the main idea that has to be investigated is the (dialogue) context. At once, it governs the conversation, allowing or forbidding possible dialogue moves, and it stores seeds of future dialogue opportunities.

It appears that dialogue studies so far have tried to focus on one core dialogue phenomenon at once. Among the most frequently studied one can find Non Sentential Utterances, described by Ludwig Wittgenstein in [6] and Why-Because Systems with Questions, introduced by Charles Leonard Hamblin in [7]. The latter presents a first model which attempts to describe a dialogical setting in terms of propositional logic predicates, each having the possibility to affect a set of commitments. This idea can be found nowadays in models such as those introduced in [8]. We put our model in perspective by comparing it with existing approaches in Section 6.

We consider three types of dialogue act: *questions*, *answers*, and *assertions*[1] and we give a view of conversations as concatenations of *negotiation phases* (see Section 3). We focus on a study of question and answer phenomena only – see Section 4.2. We base our framework on the Düsseldorf version of Frame Semantics [9,10] in order to test and explore the limitations of this approach. See Section 4.1 for a presentation of Frame Semantics and of how we modified it.

[1] Note that an assertion is an utterance that is not part of a question/answer relationship.

## 2 Approaching SLAM

Studying further the data assembled within SLAM is a matter of interdisciplinary interest. Research based on data produced by patients with schizophrenia is difficult to conduct because the corpora are laborious to obtain and have limited life span (3 years) as they contain sensitive medical data. Several projects are conducted at the moment in relation with dialogue and schizophrenia; see in particular DRiPS [11] (further presentation in Section 6). We think that we can help making progress in these studies in two aspects: first, by opening the path to computational approches in order to help provide quantitative results and observations; second, by leading the way to formalisations of this corpus, towards mathematical logic-driven accounts of the encountered semantic phenomena. See Section 5 for our corpus-related dialogue phenomena discussion.

The SLAM corpus is composed of semi-structured interviews. Knowing this, one could imagine that each conversation presents a well observable asymmetry, the psychologist being the interviewer and the patient the interviewee. However, first observations of the corpus rebut this claim.

Some of the conversations are explicitly guided by the patient, who asks most of the questions; in some other conversations, the patient is totally passive, compelling the psychologist to structure the interview with closed (*yes/no-*)questions only, as the patient answers solely by “yes” or “no” or by repeating the content of the question in an assertive way, and does not elaborate any further-going sentences. This brings us to the next observation: dialogues from SLAM cannot be thought of as fully cooperative in the sense of Gricean maxims of cooperativity [12].

Yet, non-cooperativity that can be found in SLAM differs in nature from deliberate non-cooperativity such as the one that can be encountered in political interviews [13] or in bargaining games [14]. All the participants are willing to talk to the psychologist. The apparent non-cooperation in SLAM interviews is found on the psycho-linguistic level – conversation failures are inherent to the behaviour of the person being interviewed, but not designed by that person. Hence, a modeling of SLAM should be particularly strong with respect to this phenomenon, as it should not depend on the (non-?)-cooperation of the dialogue participants. Therefore, SLAM presents a particular interest for computational linguists, as it contains cooperative dialogues showing non-cooperation phenomena. The studies conducted on SLAM for now have focused on the semantic content of the utterances [3]. In this article, we introduce a framework based on frame semantics that allows us to stay closer to the exact linguistic formulations.

The most encountered speech acts in SLAM are questions and answers. We build our formal approach of SLAM on this observation, studying question and answer mechanisms and related phenomena. See Sections 4.2 and 5.1 for a presentation of our treatment of questions and answers in French dialogues. This paper presents an approach to compositional dialogue modeling in a dynamic framework applied to SLAM. We want to build representations of utterances in a way that would stay close to the linguistic expressions used by the participants of the dialogues. In order to produce these representations we need to access both the semantic content of the utterances and their linguistic expression. In addition, we want to follow the principle of compositionality: the meaning of a complex expression is determined by the meanings of its constitutive expressions and the rules used to combine them.

Our long-term aim is to build representations of utterances in a compositional way. To do so, we need to access the content of the utterances as much as their linguistic formulations. Among the formal models that have emerged lately, Düsseldorf frame semantics present a compositional way of representing sentences. Our goal in this paper is to investigate whether this framework can be easily enough adapted to dialogue interactions. In the following, we first introduce our main architecture ideas and concepts for dialogue interaction. Then, starting from the definition of frames presented in [2], we give our own formalisation of frame semantics. Finally, we apply the resulting framework to examples from SLAM and we make an account of the results in Section 5.2.

## 3 Architecture

Consider a dialogue involving two participants **A** and **B**. If **A** utters something, we should add that utterance's truth value representation to what we will call the *dialogue context*. Yet, if **B** disagrees with **A**'s proposition, **B** will argue against it, and might convince **A**, changing **A**'s point of view. After that, **A** might utter a proposition which will be in contradiction with her previous one, introducing an internal incoherence in the dialogue context. Thus, it is necessary to introduce an intermediary representation mean which will handle the *negotiation phases* of the dialogues and only store propositions in the common dialogue context after an agreement has been reached. We compute these intermediary representations using frame semantics.

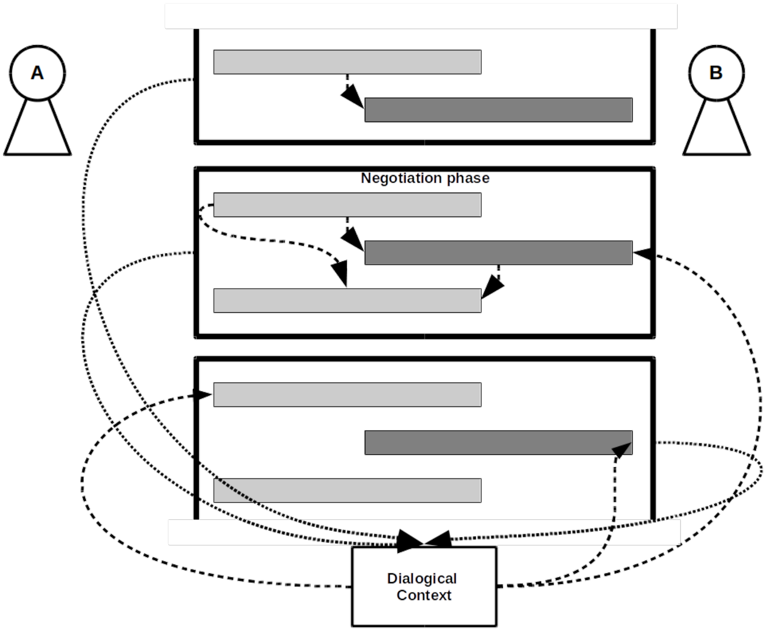


**Fig. 1.** *Articulation of the model.* **A** speaks in light grey, **B** in dark grey. Dashed arrows show how information is used: both information introduced by a previous utterance in the same negotiation phase and information coming from the dialogue context. When a negotiation phase (bold black box) is ended, its representation is computed and stored (following the dotted arrows) in the dialogue context.

In dynamic discourse modeling, meaning representations are directly stored in the context, which contains all entities and information introduced since the beginning of the discourse. The main idea behind our model of dialogue is therefore to introduce an intermediary phase between the computation of meaning representations of utterances and the storage of information in the (dialogue) context, in order for that information to be reused in further elaboration of the dialogue (see dashed arrows, Figure 1).

We focus on a view of the context of a conversation as a common (storage) ground, where information accessible to *both* participants of the dialogue appears. To this end, we consider dialogue as a linear aggregation of *negotiation phases*, each of which results either in an agreement or a disagreement between the participants. Then, if an agreement is reached, we store the final logical representation obtained at the end of each negotiation phase (see Figure 1). This paper presents our model and introduces the processes that allow us to decide whether to store representations (see in particular Section 4.3).

## 4 Formal Set-Up

In the following, we present the formal theoretical framework we use to model examples from the SLAM corpus. Then, after giving a typology of questions in English, we discuss composition in dialogue.

### 4.1 Frame Semantics

The idea lying at the origin of Frame Semantics is the following – a *frame* should be a representation of a situation, its participants, the semantic roles of the participants of this situation, and the roles of each participant within the situation. A frame as intended in [9] is a cognitive semantic unit of information. As 'Frame Semantics' can be associated with several approaches, please be aware that in the following, we will only consider Düsseldorf Frame Semantics. Discussing Löbner and Peterson's ideas is beyond the scope of this paper.

Giving a formal definition of frames presents technical difficulties and can be done in many different ways. Here, we chose to introduce a formal definition of semantic frames as typed base-labelled feature structures built on top of signatures, following the construction exposed in [2]. On top of this construction, we specifically introduce and define the *negation function* $\delta_{neg}$ in order to allow negative information representation. We denote $A^+$ the set of non-empty strings of elements of $A$ and $\mathscr{P}(T)$ the powerset of $T$.

**Frame** A typed base-labelled feature structure over the signature $\langle A, T, B\rangle$, where $A, T, B$ are finite sets of respectively *attributes* (or *features*), *types*, and *base labels*, defined as a 5-tuple $\langle V, \delta, \delta_{neg}, \tau, \beta\rangle$ such that:

- $V$ is a finite set of *nodes*
- $\delta$ is a partial function from $V \times A$ to $V$: the *transition function*
- $\delta_{neg}$ is a partial function from $V \times A$ to $V$: the *negation function*, such that, for all $v \in V, a \in A$, if $\delta(v, a)$ is defined, then $\delta_{neg}(v, a)$ is not. We define $\hat{\delta}$ as an extension of $\delta$ and $\delta_{neg}$. $\hat{\delta}$ is a partial function from $V \times A^+$ to $V$ such that, if $v \in V$ and $p \in A^+$, $p = (a_1, \ldots, a_n)$:

$$\hat{\delta}(v, a_1) = \begin{cases} \delta(v, a_1) \text{ if } \delta(v, p) \text{ is defined;} \\ \delta_{neg}(v, a_1) \text{ if } \delta_{neg}(v, p) \text{ is defined;} \end{cases}$$
$$\hat{\delta}(v, p) = \hat{\delta}(\hat{\delta}(v, a_1), (a_2, \ldots, a_n))$$

- $\tau$ is a function from $V$ to $\mathscr{P}(T)$: *typing function*
- $\beta$ is a partial function from $B$ to $V$: the *base-labelling function*, such that:

$$\forall v \in V, \exists v' \in \beta(B) \text{ and an attribute path}$$
$$p \in A^+ \text{such that } v = \hat{\delta}(v', p)$$

$\beta$ is defined in such a way that every node is reachable from some base node, *i.e* from some element of $\beta(B) \subseteq V$, via attribute path transitions.

Now that the frame data structure is defined, let us propose a frame representation for the following utterance:

**$A_1$** *You turn left here, not there.*

We consider the signature $\langle A, T, B\rangle$ over which we build the frame $\langle V, \delta, \delta_{neg}, \tau, \beta\rangle$, where:

- $A$ is the set of semantic roles labels {`Agent`, `Location`, `Direction`}
- $T$ is the ontologically organized set of types (here, containing the type `TURN`)[2]
- $B$ is the bag of words corresponding to the utterance: {[you], [turn], [left], [here], [there]}[3]
- $V$ contains five nodes (one per word in $B$)
- $\delta$ is pictured in continuous lines, see Figure 2
- $\delta_{neg}$ is pictured in dashed lines, see in Figure 2
- $\tau$ assigns the type `{TURN}` to the node whose base label is *turn* and $\emptyset$ to the other nodes
- $\beta$ is represented by the rectangle boxed nodes-round vertices pairs

This mathematical structure allows us to prove properties in order to compute a dialogue negotiation phase. The formal proofs will not be presented here. We begin by introducing an order on frames.

**Subsumption** Let $F_1 = \langle V_1, \delta_1, \delta^1_{neg}, \tau_1, \beta_1\rangle$ and $F_2 = \langle V_2, \delta_2, \delta^2_{neg}, \tau_2, \beta_2\rangle$ be two frames over the signature $\langle A, T, B\rangle$. We say that $F_1$ subsumes $F_2$ (denoted $F_1 \sqsubseteq F_2$) if there exists a morphism $h$ from $V_1$ to $V_2$ such that:

[2] $T$ is not represented on Figure 2 but is crucial for the simplified representation used in Section 4.3.
[3] $B$ does not contain "not", as it is interpreted as a logical operation.

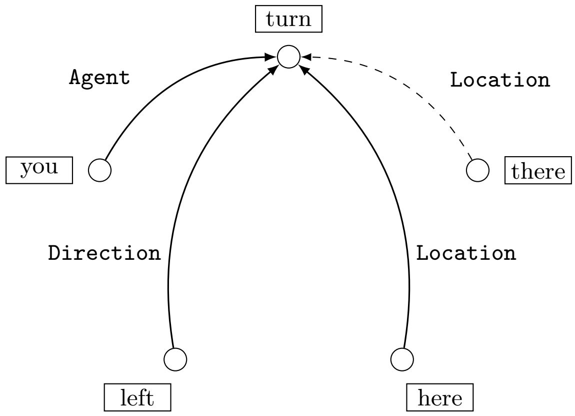


**Fig. 2.** Graphical representation of a frame.

- If $\delta_1(v, f)$ is defined for $v \in V_1$ and $f \in A$, then $\delta_2(h(v), f)$ is defined and equal to $h(\delta_1(v, f))$
- If $\delta^1_{neg}(v, f)$ is defined for $v \in V_1$ and $f \in A$, then $\delta^2_{neg}(h(v), f)$ is defined and equal to $h(\delta^1_{neg}(v, f))$
- $\forall v \in V_1$, $\tau_1(v) \subseteq \tau_2(h(v))$
- If $\beta_1(b)$ is defined for $b \in B$, then $h(\beta_1(b)) = \beta_2(b)$

It follows in particular that the domain of $\beta_1$ is contained in the domain of $\beta_2$.

We can now define an equivalence relation, on top of which we define minimal frames with respect to a set.

**Equivalent frames, minimal frames** Let $F_1$ and $F_2$ be two frames over the same signature. $F_1$ is *equivalent* to $F_2$ (denoted $F_1 \cong F_2$) if and only if $F_1 \sqsubseteq F_2$ and $F_2 \sqsubseteq F_1$.
Let $\mathscr{F}$ be a set of frames and let $F$ be a frame, $F \in \mathscr{F}$. $F$ is a *minimal* frame of $\mathscr{F}$ if for all $G \in \mathscr{F}, G \sqsubseteq F$ implies $G \cong F$.[4]

**Union of two frames** Let $F_1$ and $F_2$ be two frames over the same signature, $\mathscr{F}_1 = \{F|F_1 \sqsubseteq F\}$ and $\mathscr{F}_2 = \{F|F_2 \sqsubseteq F\}$ be the sets of frames subsuming $F_1$ and $F_2$ respectively. Let $\mathscr{I} = \mathscr{F}_1 \cap \mathscr{F}_2 = \{F|(F_1 \sqsubseteq F) \wedge (F_2 \sqsubseteq F)\}$. Then, two cases are possible:[5]

1. $\mathscr{I}$ contains at least two non-equivalent minimal frames
2. $\mathscr{I}$ contains at least one minimal frame, and all its minimal frames are equivalent

In the first case, the union is not defined. In the second case, let $I \in \mathscr{I}$ be a minimal frame. We denote the union of $F_1$ and $F_2$ as $F_1 \sqcup F_2$ and we have $F_1 \sqcup F_2 \cong I$.

For our linguistic application, we want to be able to combine the frames. For now, the most frequent linguistic usage case of application which we will consider concerns two frames, one of which is empty. It corresponds, linguistically, to a situation where no previous context is available – for example, at the beginning of a conversation. First, we give a formal definition of the empty frame.

**Empty frame** A frame is said to be *empty* and is denoted by [ ] if it is defined as a typed base-labelled feature structure $\langle V, \delta, \delta_{neg}, \tau, \beta \rangle$ over any signature $\langle A, T, B \rangle$ such that $V = \emptyset$.

We will use the following result: let $F$ be a frame and [ ] be the empty frame. Then:

$$F \sqcup [\,] \cong F$$

*Proof.* Let $\mathscr{I}$ be the set $\{A|F \sqsubseteq A \wedge [\,] \sqsubseteq A\}$. Then, by the definition of the empty frame, $[\,] \sqsubseteq A$ for every frame $A$, which gives $\mathscr{I} = \{A|F \sqsubseteq A\}$. Let $G \in \mathscr{I}$ be a frame such that $G \sqsubseteq F$. Then, by the definition of $\mathscr{I}$, $F \sqsubseteq G$. Therefore, $F \cong G$. By the definition of a minimal frame, $F$ is thus minimal, which means that $\mathscr{I}$ contains at least one minimal frame.

[4] It is possible to build a set of frames without a minimal frame.
[5] It is possible to show that $\mathscr{I}$ necessarily contains at least one minimal frame.

Let $B$ be a minimal frame of $\mathscr{I}$. As $B \in \mathscr{I}$, $A \sqsubseteq B$ by the definition of $\mathscr{I}$. As $B$ is a minimal frame of $\mathscr{I}$ and $A \in \mathscr{I}$, we have $B \sqsubseteq A$. Therefore, $A \cong B$ and hence all minimal frames of $\mathscr{I}$ are equivalent. By the definition of the union, we have $F \sqcup [\,] \cong F$.

We now focus on question and answer relations.

### 4.2 Questions

We start our model outline by a close-up of different types of questions and corresponding answers. We take [15] as a starting point for our study of interrogative constructions, and present closed and open (*wh*-)questions separately.

A closed question (also called *yes/no*-question) is used to ask a question with yes or no as an answer [16]. According to [15], in a real-life dialogue setting, it is important to distinguish two parts in an answer to a closed question. Consider the following example:

$\mathbf{A_1}$ Do you live in Paris?
$\mathbf{B_2}$ Yes, near the Louvre.

The answer begins, as expected, with "Yes", called hereafter the *short answer* (following the terminology of [15]). Yet, the answer does not stop there and continues; this part corresponds to what is called *aboutness* [15] – it appends additional details to $\mathbf{A_1}$.

Despite what could be expected given their name, *yes/no*-questions can be answered by three types of short answers: "yes", "no", but also "maybe" (as well as "probably", "perhaps", etc.). When the short answer is "yes", it triggers the action of the *storage* operator for the approved frame. If the short answer "yes" is followed by an aboutness part, then the stored frame is the one containing the information added in the aboutness.

When the short answer is "no", one could think that, as no agreement has been reached, the frame under negotiation should be dismissed. Yet, this would actually lead to a loss of information. Indeed, consider the following example:

$\mathbf{A_1}$ Do you live in Paris?
$\mathbf{B_2}$ No.

This negotiation phase gave us the information that the content of the feature `Location` is **not** "Paris". If we dismiss the frame, we will lose this information. The *negation function* in frames, $\delta_{neg}$ (defined in Section 4.1) operates in this type of cases. We draw a dashed transition labelled `Location` and linking the node base-labelled "Paris" to the one base-labelled "live" to represent the negative information. We then can store this frame.

Finally, as mentioned above, *yes/no*-questions can also be answered by short answers such as "maybe" or any semantic equivalent. In this case, no information about the content of the frame is given; therefore, we use a *dismiss* operator.

If a party takes a position and the other one remains undecided then the matter cannot be added to the left context. **A** can reuse the subject later but will have to reintroduce it; and as **B** did not agree nor disagree, **B** will not be able to make a direct reference to what has been said by **A**.

Reaching agreement or disagreement at the end of a negotiation phase is explicit when we consider closed questions. When *wh*-questions (also called open, by opposition to *yes/no*-questions) are involved, the focus of the negotiation phase shifts. Instead of trying to reach a validation of a previously constructed frame, the aim of *wh*-negotiation phases consists in the construction of the frames under discussion.

*Wh*-questions are defined as questions, in English, that give rise to answers whose semantics matches the semantics of the *wh*-phrase contained in the interrogative [15]. A *wh*-phrase is introduced by a *wh*-word; *what, when, where, who, whom, which, whose, why, how* [16] (see Table 1).

Studying *wh*-questions allows us to make observations on the scope of their answers in view of an encoding of questions and answers in terms of frames. When we introduced frames, we did not discuss the way the set of attributes (features) $A$ should be constructed. In fact, it seems that virtually any set of features could be defined. It is difficult to come up with a set of features which would both be exhaustive, allowing to represent any possible sentence, and computationally realistic – without overlapping and/or redundant scopes of features (one sentence constituent should ideally correspond to one and only one

| *WH*-WORD | QUERY |
|---|---|
| What | Entity, object |
| When | Time, moment |
| Where | Position, place |
| Who | Person |
| Whom | Person |
| Which | Choice, alternative |
| Whose | Person, entity |
| Why | Reason |
| How | Way, manner, characteristic |

**Table 1.** *Wh*-words and corresponding queries.

feature). There is a great diversity in feature sets one can define. An example of commonly used thematic roles (corresponding to what we call features) can be found in [17]: `Agent`, `Experiencer`, `Force`, `Theme`, `Result`, `Content`, `Instrument`, `Beneficiary`, `Source`, `Goal`.

The main problem of this list is that it is non-exhaustive. Back to the example pictured in Figure 2, we see that none of the roles from [17] correspond to the features `Direction` and `Location`. `Location` can eventually be viewed as a combination of `Source` and `Goal`, but the same can (with some effort) be said about `Direction`. In our treatment of "You turn left here, not there.", "left" and "here" bear two distinct types of information content, whereas if we directly adopt Jurafsky and Martin's set of features, this distinction will be lost. However, simply adding `Direction` and `Location` to the previous set would still not solve the issue, as `Source`, `Goal`, `Direction` and `Location` would then be redundant.

We chose to build our own set starting from the previous one by pairing, when possible, one *wh*-word to one feature, in order to ease the definition of algorithms.

**Who** Two roles correspond to "Who" – `Agent` and `Experiencer`. We unite these roles under the feature `Agent`.

**Whom** Two roles correspond to "Whom" – `Theme` and `Beneficiary`. We unite these roles: `Theme`.

**Whose** No role can clearly be identified as corresponding to "Whose". We create the role `Owner`.

**Where** "Where" can correspond to `Source` or `Goal`. As our main aim is to ease computability and reduce redundancy, we combine those two roles in one: `Location`.

**Why** We chose here to create a new thematic role, identified by the fact that the corresponding sentence constituent should be introduced by "because". We call this role `Reason`. See [18] for an extensive discussion on 'Why?' questions.

**When** Jurafsky and Martin's list does not contain roles intended for temporal data representation. We create a feature called `Temporality`, though some difficulties in usage might appear: first, durations can be relative (ex: *since 2015*) or absolute (ex: *for 5 years*). Then, one has to distinguish punctual durations (ex: *on October the 5th, 2015*) from time intervals (ex: *in November 2015*). On top of that, a set of punctual durations is not equivalent to a time interval: "every Thursday" cannot be considered as a time interval. Yet, it is possible to find punctual durations inside all time intervals (ex: *every Thursday of November 2015*).

**What** Problem: non-specificity of usage. An answer to a question starting by "What" could be a `Force`, a `Result`, a `Content` or an `Instrument`. These features are so different that we cannot unite them without breaking our model. Therefore, it is necessary to look at the whole *wh*-phrase contained in the interrogative. Then, the feature corresponding to the answer will be the one semantically corresponding to the focus phrase of the interrogative (ex: *"What* time *is it?"* corresponds to the feature `Temporality`).

**Which** As above, "Which + focus phrase" corresponds to the feature of the focus phrase. Ex: *"Which city do you prefer, Paris or London?"* calls for an answer of semantic type `Location`.

**How** The answers expected for a question starting by "How" vary greatly depending on the phrase that follows the interrogative word (ex: "How much" VS "How good"). Yet, unlike for the answers to questions starting by "What" and "Which", it is possible to come up with a unique designation for all the answers to questions starting by "How": `Characteristic`. The remaining exception is "How long", calling for an answer corresponding to `Temporality`.

We obtain Table 2. This table allows us to systematically construct semantic representations of lexical terms.

| WORD | FEATURES |
|---|---|
| What | `Feature`(focus phrase) |
| When | `Temporality` (`Tmp.`) |
| Where | `Location` (`Loc.`) |
| Who | `Agent` (`Ag.`) |
| Whom | `Theme` (`Th.`) |
| Which | `Feature`(focus phrase) |
| Whose | `Owner` (`Ow.`) |
| Why | `Reason` (`Re.`) |
| How | `Characteristic` (`Ch.`) |
| How long | `Temporality` (`Tmp.`) |

**Table 2.** *wh*-words and features pairing.

Though we changed the original list of thematic roles presented, these changes are not significant enough for us not to be able to use the computability results given in [17]. Despite the fact that our model is yet far from being handy in a computational sense, it is still satisfying to check that our theoretical considerations do not drive us too far away from reality.

### 4.3 Compositional Modeling

This section presents our compositional treatment of question and answer combination. The approach presented bellow focuses on modeling assertions, questions and answers to set the common ground between dialogue participants. To this end, we use frame semantics enriched with type theory. We model combinatorics of dialogue acts with types and operators for utterances while representing the content with frames. Adding types to the objects we work with gives us access to a deeper control on combinatorics of dialogue acts. In this way, we work towards compositionality. We keep the frame as a representation of the semantics content of the utterance. The features of the frame as well as the frame itself are now typed. Therefore the frame is now, from the type theory point of view, an operator. In the following, we present the formalization.

Though Montague semantics offers numerous expressivity advantages due to its compositionality, it lacks dynamical notions. Dynamicity can be reached by using simply-typed $\lambda$-calculus to represent meaning and $\beta$-reduction, following [19]. We consider three atomic types:

- $\iota$ : individual/entity
- $o$ : proposition
- $\gamma$ : left context

Then, an utterance is interpreted according to its left and right contexts. As a sentence is considered to be equivalent to a proposition, it should be of type $o$. Therefore, the type of the right context is $\gamma \to o$. In the following frames are considered to be of type $\gamma$.

Let us consider the following dialogue example:

**$\mathbf{A_1}$** I live in Paris.
**$\mathbf{B_2}$** How long have you been living there?
**$\mathbf{A_3}$** For five years.

In what follows, we use a simplified representation of frames. As an illustration, the frame semantic representation of $\mathbf{A_1}$ "I live in Paris." is given by:

$$[\![A_1]\!] = \begin{bmatrix} \quad LIVE \\ \texttt{Ag:}\ A \\ \texttt{Loc:}\ Paris \end{bmatrix}$$

In order to represent the focus of the questions and the answers, we $\lambda$-abstract the feature under consideration. The result is called a *query-frame* on a feature. For example, the question "*Where do you live?*" is now represented by the following query-frame:

$$\lambda l. \begin{bmatrix} LIVE \\ \texttt{Ag:}\ A \\ \texttt{Loc:}\ l \end{bmatrix}$$

To solve the questions, it is necessary to define an operator that is able to retrieve the base label corresponding to the interrogated feature as well as the $\lambda$-abstraction representing the modification path inside the frame. We call $find_v$ such an operator, for $v$ a feature. When given a frame, $find_v$ returns a pair where the first component is the content of the feature $v$ and the second component is the query-frame on $v$. $find_v$ operator is typed as follows:

$$find_v : \gamma \to v \times (v \to \gamma)$$

Applying the operator $find_{Loc}$ to the frame representation of $A_1$, we obtain:

$$(Paris, \lambda l. \begin{bmatrix} LIVE \\ \texttt{Ag:}\ A \\ \texttt{Loc:}\ l \end{bmatrix})$$

As mentioned above, this model focuses on dialogue settings that involve only three types of dialogue acts: assertions, questions and answers. Moreover, we restrict our setting to questions which produce query-frames (concerning one feature only), and corresponding answers (on that feature).

We present a constructive way to combine the utterances in order to compute the representation of the dialogue's meaning. We define three linear aggregation operators $\overset{u}{\circ}$, $\overset{q}{\circ}$ and $\overset{a}{\circ}$. In the following we assume that the semantic interpretation can only be computed within a context. Thus these operators embed the contextual information. We will not go in further details here.

$$\overset{u}{\circ} = \lambda U_1 U_2 c. U_2(U_1 c)$$
$$\overset{q}{\circ} = \lambda U Q c. Q(U c)$$
$$\overset{a}{\circ} = \lambda Q A c. A(Q c)$$

The operator $\overset{u}{\circ}$ takes two assertions and the context, and produces a third assertion, a combination of the first two with the context. The operator $\overset{q}{\circ}$ takes an assertion and a question, along with the context. It produces a feature $v$ and a query-frame on $v$.[6] The operator $\overset{a}{\circ}$ takes a feature $v$ and a query-frame on $v$ to produce an utterance which solves the query-frame.

Note that a question can follow a proposition, an answer can follow a question, but an answer cannot follow a proposition. Theses constrains are easily verified in our treatment of questions and answers through type-checking. We will see an example of these dialogue act combinations bellow.

In our example, $\mathbf{A_1}$ is an assertion and $\mathbf{B_2}$ a question about the feature `Temporality` of the frame representation of $\mathbf{A_1}$. $\mathbf{A_3}$ is an answer to $\mathbf{B_2}$. The semantic representation is computed by combining $\mathbf{A_1}$ with $\mathbf{B_2}$ using the operator $\overset{q}{\circ}$. The result is combined with $\mathbf{A_3}$ using $\overset{a}{\circ}$.

$$\begin{aligned} [\![A_1 \overset{q}{\circ} B_2]\!] &= \Big(\lambda U Q\ c. Q(U\ c)\Big)[\![A_1]\!][\![B_2]\!] \\ &\to_\beta \Big(\lambda Q\ c. Q([\![A_1]\!]\ c)\Big)[\![B_2]\!] \\ &\to_\beta \lambda c. [\![B_2]\!]\Big([\![A_1]\!]\ c\Big) \end{aligned}$$

Then, we can aggregate $\mathbf{A_3}$ to the result, using the operator $\overset{a}{\circ}$, as $\mathbf{A_3}$ is an answer.

[6] Technically, this exactly corresponds to the use of $find_v$.

$$
\begin{aligned}
[\![A_1 {}^q_\circ B_2]\!]^a_\circ [\![A_3]\!] &= [\![A_1 {}^q_\circ B_2 {}^a_\circ A_3]\!] \\
&= \Big(\lambda Q A\ c.A(Q\ c)\Big)[\![A_1 {}^q_\circ B_2]\!][\![A_3]\!] \\
&\to^*_\beta \lambda c.[\![A_3]\!]\Big([\![A_1 {}^q_\circ B_2]\!]\ c\Big) \\
&= \lambda c.[\![A_3]\!]\Big(\big(\lambda c.[\![B_2]\!]([\![A_1]\!]\ c)\big)\ c\Big) \\
&\to_\beta \lambda c.[\![A_3]\!]\Big([\![B_2]\!]([\![A_1]\!]\ c)\Big)
\end{aligned}
$$

First, we want to incorporate $\mathbf{A_1}$ in its context (the surrounding conversation). We use $\sqcup$ with a frame $c$ representing the *substantive* conversational context. The *substantive* semantic representation of $\mathbf{A_1}$ in context is now:

$$
\langle\!\langle A_1 \rangle\!\rangle = \begin{bmatrix} \quad LIVE \\ \texttt{Ag:}\ A \\ \texttt{Loc:}\ Paris \end{bmatrix} \sqcup c
$$

Here we consider this dialogue for itself, so $c$ becomes the empty frame. As presented in section 4.1, the empty frame is the identity element for $\sqcup$. Thus here $\langle\!\langle A_1 \rangle\!\rangle = [\![A_1]\!]$. Then, we compute $[\![B_2]\!]$.

$$
[\![B_2]\!] = \lambda t. \begin{bmatrix} LIVE \\ \texttt{Ag:}\ A \\ \texttt{Tmp:}\ t \end{bmatrix}
$$

Embedding $[\![B_2]\!]$ in its context, *i.e.* $[\![A_1]\!]^q_\circ[\![B_2]\!]$ produces:

$$
\langle\!\langle B_2 \rangle\!\rangle = \lambda t. \begin{bmatrix} \quad LIVE \\ \texttt{Ag:}\ A \\ \texttt{Loc:}\ Paris \\ \texttt{Tmp:}\ t \end{bmatrix}
$$

Finally, we combine $[\![A_3]\!]$ with the above:

$$
\langle\!\langle A_3 \rangle\!\rangle = \begin{bmatrix} \quad LIVE \\ \texttt{Ag:}\ A \\ \texttt{Loc:}\ Paris \\ \texttt{Tmp:}\ Five\ years \end{bmatrix}
$$

This result ends the computation of a dialogue's negotiation phase. It can now be stored on the common dialogue context. This construction concludes the section presenting the formal description of our work. In the following, we show how our framework can be applied to SLAM and we discuss the first results.

## 5 Real-Life Settings

As the examples and theories presented above seemingly treat only the English language, the following explains the way our theories adapt to French. Then, we discuss examples coming from the SLAM corpus. Finally, we come back to the notion of dialogue context.

### 5.1 French Interrogatives

One can distinguish two types of French interrogatives: total ones, corresponding to English polar questions, and partial ones, corresponding to English *wh*-ones [20]. Unlike in English, in French, partial questions can be driven by multiple morphological variations of interrogative pronouns and adverbs, which are not linguistically identified as easily as *wh*-words. Table 3 presents correspondences that can be drawn. It was constructed according to the following process:

1. Retrieval of a list of English *wh*-words from [16].
2. Retrieval of a list of French interrogative pronouns and adverbs from [20].
3. Translation of the English set of words into French, using `Reverso`.
4. Translation of the English set of words into French, using `Linguee`.
5. Translation of the French set of words into English, using `Reverso`.
6. Translation of the French set of words into English, using `Linguee`.
7. Compilation of the previously obtained information.
8. Verification, using `Systran`.

In addition, Table 3 shows the thematic roles encoding that can be used as starting point for a formal and/or computational approach.

| WH-WORD | FRENCH EQUIVALENTS | THEMATIC ROLE | |
|---|---|---|---|
| What | que, qu'<br>quoi, de quoi<br>quel, quelle, quels, quelles | `Thematic role`(focus phrase) | |
| When | quand | `Temporality` | tmp |
| Where | où | `Location` | loc |
| Who | qui<br>quel, quelle, quels, quelles<br>lequel, laquelle, lesquels, lesquelles | `Agent` | ag |
| Whom | qui<br>lequel, laquelle, lesquels, lesquelles | `Theme` | th |
| Which | qui<br>lequel, laquelle, lesquels, lesquelles<br>auquel, à laquelle, auxquels, auxquelles | `Thematic role`(focus phrase) | |
| Whose | à qui | `Owner` | ow |
| Why | pourquoi | `Reason` | re |
| How<br><br>How (much) | en quoi<br>comment<br>combien | `Characteristic` | ch |

**Table 3.** English to French correspondence.

### 5.2 Corpus Considerations

Here, we discuss few examples to highlight the different question and answer related phenomena that appear in SLAM.

(1) **$A_1$** Qu'est-ce que vous avez vendu ?
"What did you sell?"
**$B_2$** Des pulls.
"Sweaters."

This first small example allows us to illustrate the previous considerations. The psychologist asks a *wh*-question containing the *wh*-word "What", followed by the focus phrase "sell". The thematic role corresponding to "sell" is `Theme`, so the psychologist's question interrogates the thematic role `Theme`. Then, **B** answers, assigning the value "sweaters" to the thematic role `Theme`. The representation corresponding to the *result* (informational content) of this dialogue is:

$$[\![B_2]\!] = \begin{bmatrix} \quad SELL \\ \texttt{Ag:}\ B \\ \texttt{Th:}\ sweaters \end{bmatrix}.$$

The next example is slightly more sophisticated, as it combines several phenomena.

(2) **$A_1$** Vous habitez où ?

“Where do you live?”

**B₂** À T.
“In T.”

**A₃** C’est dans la ville de L.
“It is in the city of L.”

**B₄** Oui.
“Yes.”

First, the psychologist asks a *wh*-question containing the *wh*-word “Where”. That question interrogates the thematic role `Location`. Then, **B** answers, assigning the value “T” to the thematic role `Location`. The corresponding representation is then:

$$[\![B_2]\!] = \begin{bmatrix} \mathit{LIVE} \\ \texttt{Ag: } B \\ \texttt{Loc: } T \end{bmatrix}.$$

The conversation continues as the psychologist asks a new question, a polar question interrogating the result of the previous dialogue, specifically the thematic role `Location`. As the question is about the thematic role `Location` of the thematic role `Location` of the previous representation, we need a two layered representation:

$$[\![B_4]\!] = \begin{bmatrix} & \mathit{LIVE} \\ \texttt{Ag: } B & \\ \texttt{Loc: } & \begin{bmatrix} \mathit{IS\ IN} \\ \texttt{Ag: } T \\ \texttt{Loc: } L \end{bmatrix} \end{bmatrix}.$$

Yet, real-life dialogue settings have even more complicated specificities. See the following example:

(3) **A₁** Et après vous avez eu...
“And then you had...”

**B₂** Ben quand je suis souriante, ça va.
“Well, when I’m smiling, it’s ok.”

Cognitively, this break in the dialogue rules corresponds to the feeling that **B** is sidestepping the question that the psychologist is about to ask.

An example of the complementary phenomenon is the following:

(4) **A₁** Comment ça se passe, votre quotidien ?
“How is your day-to-day life going?”

**B₂** Le quotidien se passe bien.
“Day-to-day life is fine.”

**B₃** Le matin je me lève à six heures, je déjeune, je fais ma toilette.
“In the morning I wake up at six o’clock, I eat breakfast, I wash myself.”

Here, **B** gives an over-extensive answer to the psychologist’s question. This answer is composed of two parts: a short, closed answer, solving the question, and a second, elaborated answer. Two interpretations are possible here – first, one can consider that $\mathbf{B_2}$ and $\mathbf{B_3}$ are each independent answers to $\mathbf{A_1}$ and should be treated as such. In this case, the main problem will be in the choice of the computation that should be done to obtain the final representation of this conversation.

The second idea would be to say that – following the terminology given in [21] – $\mathbf{B_3}$ is an elaboration of $\mathbf{B_2}$. In this case, a model handling SLAM should deal with rhetorical relations.

Some dialogues in SLAM contain explicit linguistic clues that indicate a change of topic. This can come in handy when a subdivision of a long dialogue is needed. Consider the following example:

(5) **A₁** Vous êtes arrivés pour quoi au V. ?
“For what reason did you come to V.?”

**B₂** Pour une TS.

“For a suicide attempt.”

**$\mathbf{A_3}$** D’accord.
“OK.”

After **B**’s answer, the psychologist does not have anything to add on the topic. « D’accord » can here be interpreted as a linguistical expression of the end of a the part of the dialogue concerning this specific topic. As shown above, « D’accord » is directly translatable in English without loss of meaning – according to `Reverso`, accurate translations are either “All right” or “OK” and `Linguee` gives “OK” as the main translation and “All right” as a less used variant.

It is therefore interesting to look at the following example:

(6) **$\mathbf{A_1}$** Avoir mal physiquement on le sait depuis tout petit ce que ça fait
“From a young age, you know what it feels like to be hurt physically”
**$\mathbf{B_2}$** Quand on tombe on se fait un bleu ?
“When you fall, you get a bruise?”
**$\mathbf{A_3}$** Voilà.
“Yes, that’s it.”

The semantic phenomenon in the original excerpt is the same here as in the previous example. However, any direct translation attempt fails – `Reverso` produces the set “here is; well; so; that’s it; now”, while `Linguee` adds “that is” and “there”. The English translation of « Voilà » presented in Example 6 (cross-validated by an American English native-speaker) attempts to translate the utterance by fully taking into account its context. Still, it under-specifies the meaning and transforms the observed phenomenon, shifting it from a linguistical expression of the end of the part of the dialogue concerning a specific topic to an enhanced answer to an implied polar question. Yet, modeling both phenomena can be done in a similar way.

### 5.3 Context and Accessibility

Our idea is to store information in a structure that we call common (dialogue) context, where information accessible to *both* participants of the dialogue appears (as introduced in Section 3). We need an operation that will allow us to store a frame in the context once the participants of the dialogue have reached an agreement at the end of the negotiation phase.

**$\mathbf{A_1}$** Is this chair new?
**$\mathbf{B_2}$** Yes, it is.

We perform this operation through the use of a *storing* operator. Yet, sometimes, the negotiation phase ends with a disagreement. Though a further discussion should be conducted, we will simply use the *dismiss* operator in such cases. It does not store the frame resulting from the negotiation and simply shifts the computation of the context on to the next negotiation phrase of the dialogue.

**$\mathbf{A_1}$** Should we buy a new chair?
**$\mathbf{B_2}$** No, our old ones are still good!
**$\mathbf{A_3}$** Yet, I think we should.

In this case, if the dialogue stops there, no agreement has been reached. Therefore, the resulting frame has been dismissed.

In this article, we use the word “discussion” in a very broad sense. The following dialogue is in our sense a discussion (and even a negotiation phase):

**$\mathbf{A_1}$** Is it sunny outside?
**$\mathbf{B_2}$** Yes.

Yet, it is possible to imagine the following:

**begin negotiation phase**
**$\mathbf{A_1}$** It is sunny outside.

**end negotiation phase**

Either we would include $[\![A_1]\!]$`(says A)` or we include directly $[\![A_1]\!]$ in the left context. In the second case, if $\mathbf{B_n}$ "You said before that it was sunny outside" would appear in the continuation of the dialogue, we would have to analyze the introductory reference words ("You said before that") and we would trigger a *pop*-operator that cuts $[\![A_1]\!]$ from the left context and puts it back in the negotiation phase computation. If the first solution was to be chosen, an epistemic logic modeling of the content of the left context should be considered.

We chose to separate context modeling from negotiation phase computation on purpose – our aim is to proceed step by step in order to have full control over the computation process. As our model needs to be able to catch phenomena relative to mutual incomprehension, we focus on a view of the left context of a conversation as a common (storage) ground, where information accessible to *both* participants of the dialogue appears.

Back to the $\lambda-$abstraction introduced in Section 4.3. Consider:

$\mathbf{A_1}$ Will the race take place tomorrow?
$\mathbf{B_2}$ If the weather is sunny.

Our treatment of closed questions as presented in Section 4.2 is not based on the $\lambda-$abstraction. Until here, we have only considered well-formed answers to *wh*-questions. To deal with this example, we have to consider frames such as:

$$\begin{bmatrix} \multicolumn{1}{c}{\mathit{TAKE\ PLACE}} \\ \texttt{Ag:}\ \mathit{race} \\ \texttt{Tmp:}\ \mathit{tomorrow} \\ \texttt{Ch:}\ \mathit{if} \begin{bmatrix} \mathit{IS} \\ \texttt{Ag:}\ \mathit{weather} \\ \texttt{Ch:}\ \mathit{sunny} \end{bmatrix} \end{bmatrix}$$

$\mathbf{B}_2$ should be decomposed in two parts: "If the weather is sunny." is semantically equivalent to "Yes, if the weather is sunny.", where "Yes" is the short answer and "if the weather is sunny." the aboutness. This suggestion is not really satisfying as it does not allow us to stick with the precise linguistic expression of the utterance. This shows how many aspects there are yet to be processed in SLAM. The following section displays how our model fits in the landscape of dialogue modeling frameworks.

## 6 Related Work

The aim of our current work is to propose a compositional treatment of question and answer mechanisms in dialogue. We want to build representations of utterances in a way that would stay close to the linguistic expressions used by the participants of the dialogues. In that, we would like to follow approaches introduced in dynamic semantics frameworks such as Discourse Representation Theory (DRT), [22].

The main idea of DRT is to consider the meaning of segments composing a discourse as a relation between the meanings of the previous and the future sentences, as objects that can entail modifications in the previously conducted discourse analysis. The core notion underlying DRT's framework is the one of *discourse representation structures* (DRS) – a representation of discourse that is being enriched as new sentences are analysed, as a human hearer would proceed with a mental representation of a discourse [23]. Yet, the construction operators (DRS merge) conceal the information relative to the dialogue structures: in particular, it is difficult to retrieve who said what. Frame representation such as presented here doesn't keep this information as well; yet, careful usage of features (such as creating the feature `Speaker`) can allow keeping track of the conversational structure.

Since the 90's, Nicolas Asher and Alex Lascarides have been developing a theory that extends dynamic semantics by exploiting not only the semantics of each sentence's constituents but also additional information contained in discourse. On top of the sentences order in a discourse, their inherent syntax and the way they can be composed, the idea underlying Segmented Discourse Representation Theory

(SDRT) is to take into consideration rhetorical relations, such as `Explanation`, between segments of discourse [21]. This allows one to handle a wider collection of discourse-related phenomena. In particular, it copes with non-chronological accounts of events (ex: *John fell. Mary pushed him.*). SDRT has been used in previous works on SLAM [3]. It successfully accounts for incoherences in discourse such as ones that break the right-frontier rule, but is doesn't show more fine-grained logical incoherences that occur at the lexical level. We would like to keep the linguistic expressions used by the participants of the dialogues.

Frameworks such as Type Theory with Records (TTR), [24] allow to keep track of the dialogue structure. Using a game board representation, TTR grants a visual way of following the dialogue moves of the participants. However, as TTR is a concept representation [25], it directly comes with a higher level of representation than the one we are able to work at for now. TTR allocates types to situations as abstractions independent from the descriptions' formulations. TTR will be used in reasoning contributions modeling for DRiPS [11].

On the other hand, frameworks such as Questions Under Discussion (QUD), presented by Jonathan Ginzburg in [26] make direct use of linguistic formulations. QUD brings us insight in the linguistic articulation of mechanisms of question and answer. In particular, QUD offers a way to differentiate questions that are currently being discussed, at some point in the dialogue, from those that have been introduced before. We cannot directly use QUD as an algorithmic approach, yet the wider our negotiation phases will get, the more we will need ideas such as QUD's ones in order to keep track of the dialogue moves being discussed. KoS is a framework built on top of TTR integrating QUD ideas, but not making use of linguistic formulations. We will need a version of KoS enhanced with lexical and linguistic considerations.

## 7 Conclusion

Dialogue modeling is a computational semantics task that inherits methods and insights from semantics of discourse. It has challenged us into defining a new framework in the field of semantics of dialogue by combining dynamic discourse modeling ideas, with a formal view of frame semantics. We adapted frame semantics and defined a controlled way of storing information in the dialogue context.

Our view of frames allows a proper use of embedded frames, helping to extend the compositional properties of our model, which happens to be an issue as soon as the dialogues get bigger than toy ones. In particular, the long-term aim of this work is to forge a model of dialogue interaction that would be strong enough to both handle correct conversation and acknowledge conversational failures. In a correct dialogue setting, applying this model should result in a non-contradictory logical proposition, whereas a conversational failure should be acknowledged, notified and handled.

Our formalism in its current state does not keep the origin of each utterance in the dialogue. That is one of the reasons why we need to introduce intermediary computation steps via negotiation phases. In future work, we would like to be able to add a way to handle phenomena of the kind of intensionalisation and presupposition. We are considering using KoS in a second phase of modeling, in particular to represent the internal structure of the dialogue context. Before that, we need to improve our negotiation phase computation.

Our idea would be to integrate our framework somewhere near KoS, following the approaches presented in [5] and [25], with a strong DRT inspiration. We need to be able to deal with complex and structured contexts and treat negotiation phases, while keeping an open access to the semantic content of the utterances. We want to continue working on SLAM starting from the results of [3] obtained with SDRT modeling. For now, when a problem is identified in the corpus, the representation of the excerpt is not built in standard SDRT representation. We want to keep this result and yet to gain a more fine-grained semantical and lexical representation. For this reason, we use frames, sticking to the idea that the incoherences that can be observed come from type inconsistencies and not from structural ones. Dialogues provided by SLAM give us a strong idea of the phenomena that should and shouldn't be accepted by our model.

The core of our future work will be the precise definition of the internal structure of the dialogue context, as well as of the operators needed to solve references to previous dialogue moves. We will strengthen and enrich the model presented in this article, stretching it in order to be able to add epistemic logic considerations in the dialogue context. Dynamic epistemic modal logic provides a way of storing information and reasoning on knowledge [27], and using it in our model would give us the possibility to add new storage operations and limit cognitive information loss. Another task will involve using inquisitive semantics [28] both for dialogue context modeling and for the negotiation phase computations. As mentioned before, we would also like to refine our linguistic analysis of question and answer mechanisms especially to tackle reasoning processes, for example by following [25].

## References


1. Amblard, M., Fort, K., Demily, C., Franck, N., Musiol, M.: Analyse lexicale outillée de la parole transcrite de patients schizophrènes. Traitement Automatique des Langues **55**(3) (August 2015) 91 – 115
2. Kallmeyer, L., Osswald, R.: Syntax-driven semantic frame composition in lexicalized tree adjoining grammars. Journal of Language Modelling **1**(2) (2014) 267–330
3. Rebuschi, M., Amblard, M., Musiol, M.: Using sdrt to analyze pathological conversations: Logicality, rationality, and pragmatic deviances. In: Interdisciplinary Works in Logic, Epistemology, Psychology and Linguistics. Springer (2014) 343–368
4. Lecomte, A., Quatrini, M., Fleury-Donnadieu, M.R.: Une introduction à la ludique et à ses applications à la pragmatique. (2007)
5. Ginzburg, J.: Semantics of dialogue. The Cambridge Handbook of Formal Semantics (2016)
6. Wittgenstein, L.: Philosophical Investigations. Basil Blackwell, Oxford (1953)
7. Hamblin, C.L.: Fallacies. Methuen, London (1970)
8. Schlöder, J.J., Venant, A., Asher, N.: Aligning intentions: Acceptance and rejection in dialogue. In: Sinn und Bedeutung. Volume 21. (2017)
9. Fillmore, C.: Frame semantics. Linguistics in the morning calm (1982) 111–137
10. Kallmeyer, L., Lichte, T., Osswald, R., Pogodalla, S., Wurm, C.: Quantification in frame semantics with hybrid logic. In: Type Theory and Lexical Semantics. (2015)
11. Breitholtz, E., Howes, C.: Dialogical reasoning in patients with schizophrenia - Invited Talk. (2017)
12. Grice, H.P.: Logic and conversation. Syntax and Semantics (1975) 3:41?58
13. Plüss, B.: A Computational Model of Non-Cooperation in Natural Language Dialogue. PhD thesis, The Open University (2014)
14. Guhe, M., Lascarides, A.: Trading in a multiplayer board game: Towards an analysis of non-cooperative dialogue. In: Proceedings of the Cognitive Science Society. Volume 34. (2012)
15. Ginzburg, J., Sag, I.: Interrogative investigations. Stanford: CSLI publications (2000)
16. Aarts, B., Chalker, S., Weiner, E.: The Oxford dictionary of English grammar. Oxford University Press (2014)
17. Jurafsky, D., Martin, J.H.: Speech and Language Processing. (2015)
18. Schlo der, J.J., Breitholtz, E., Ferna ndez, R.: Why? SEMDIAL 2016 JerSem 5
19. de Groote, P.: Towards a montagovian account of dynamics. Proceedings of semantics and linguistic theory XVI (2006)
20. Riegel, M., Pellat, J.C., Rioul, R.: Grammaire méthodique du français. Linguistique nouvelle (1994)
21. Asher, N., Lascarides, A.: Logics of conversation. Cambridge University Press (2003)
22. Kamp, H.: A theory of truth and semantic representation. Formal semantics – the essential readings (1981) 189–222
23. Kamp, H., Reyle, U.: From discourse to logic: Introduction to modeltheoretic semantics of natural language, formal logic and discourse representation theory. Volume 42. Springer Science & Business Media (2013)
24. Cooper, R.: Type theory with records and unification-based grammar. Logics for Linguistic Structures **201**(9) (2008)
25. Cooper, R., Ginzburg, J.: Type theory with records for natural language semantics. Handbook of Contemporary Semantic Theory, The (2015) 375–407
26. Ginzburg, J.: The interactive stance. Oxford University Press (2012)
27. Van Ditmarsch, H., van Der Hoek, W., Kooi, B.: Dynamic epistemic logic. Volume 337. Springer Science & Business Media (2007)
28. Ciardelli, I., Groenendijk, J., Roelofsen, F.: Inquisitive semantics: a new notion of meaning. Language and Linguistics Compass **7**(9) (2013) 459–476