Entailment Particles and Content Anaphora in Natural Language

The goal of the paper is to describe a new dynamic system in which we can represent both the *static contents* (i.e. propositions) and the *dynamic meanings* (i.e. context-change potentials) of sentences in discourse. The system is motivated by a range of discourse-level phenomena that are sensitive to contents and not meanings: a paradigm case is the discourse-internal entailment relation that particles like *therefore* or *hence* encode; other phenomena involving discourse-internal entailment relations are answerhood conditions and presupposition resolution (e.g. clefts and factives).

The paper concentrates on the paradigmatic case of entailment and argues that natural language discourse and dialogue treats contents on a par with individuals – hence, we should represent and manage discourse reference to contents (propositions) just as we represent discourse reference to individuals.

The central observation is that modal subordination (e.g. *A wolf might come in. It would eat John*) provides a paradigm for 'extracting' static contents from dynamic meanings and determining relations between contents in a context-sensitive way.

This new perspective makes possible an integrated analysis of several phenomena:

(**i**) entailment relations established *within discourse* by particles like *hence* or *therefore*;

(**ii**) modal subordination, including more complex discourses like (1) below (from **[9]**):

(**1**) **a.** You should buy a lottery ticket and put it in a safe place. **b.** You're a person with good luck.
c. It might be worth millions.

The modal quantification in (1c) is restricted by the content of the first conjunct 'below' the modal *should* in (1a), i.e. given that you're a generally lucky person, **if you buy a lottery ticket, it might be worth millions (**so, you should buy one and put it in a safe place).

(**iii**) the parallel behavior of plural anaphora in the individual and modal domains.

1. The phenomenon: entailment as a relation between context-dependent contents.

Entailment is a phenomenon sensitive to the *content* (i.e. truth-conditions) and not the meaning of expressions, as the Partee marble examples in (2) and (3) below show.

(**2**) **a.** I dropped ten marbles and found all of them, except for one. **b.** It is probably under the sofa.
(**3**) **a.** I dropped ten marbles and found only nine of them. **b.** #It is probably under the sofa.

Sentences (2a) and (3a) have different meanings (they have different anaphora licensing potential), but they entail each other, i.e. they have the same content (see **[2]** and **[3]** for more discussion of the distinction and relation between meaning and content).

However, the content of natural language expressions, although distinct from their meaning, is dependent on it and on the utterance and discourse context: we need to access discourse referents set up in a particular context to determine the content of pronouns and other anaphors, e.g. (4) below entails (5) when uttered on a Thursday in a discussion about John, but not otherwise.

(**4**) **He** came back **three days ago**. (**5**) (Therefore) **John** came back **on a Monday**.

Moreover, we need to take into account the anaphoric dependencies between premises and conclusion to be able to determine their contents, as the pairs (6)-(7), (8)-(9) and (10)-(11) below show. The pair (10)-(11) is particularly interesting because we need an account of *modal anaphora* (which, I argue, is in fact *content* anaphora) between (11) (i.e. *would*) and (10) (i.e. *might* and *would*) to ascertain that entailment between them obtains.

(**6**) **A man** came in. (**7**) (Therefore) **He** entered.
(**8**) **Every man** saw **a woman**. (**9**) (Therefore) **They** noticed **them**.
(**10**) **a.** A wolf **might** come in. **b.** It **would** see John. (**11**) (Therefore) It **would** notice him.

Such examples, involving explicit reference to contents within discourse and requiring a way to store them online for later retrieval by entailment particles, are beyond the capability of both dynamic systems like those in [**1**] and [**8**] and systems that model discourse dynamics using some version of intersective Context Set / Common Ground update.

In sum, to be able to determine entailment relations (or answer questions, resolve presuppositions etc.), we need to *access the contents* of natural language expressions *within* discourse / dialogue, while at the same time account for the fact that: (**i**) determining content is context sensitive and (**ii**) premises crucially contribute to the context of the conclusion.

2. The proposal: Dynamic Plural Logic with Contents (DPLC).

The central observation is that *modal subordination provides a paradigm for accessing contents in discourse and determining relations between them*. Building on previous work on modal and plural individual-level anaphora (see **[10]** and **[11]**), the paper describes a new dynamic system in which we can represent both the *static contents* and the *dynamic meanings* of sentences in discourse.

Following **[6]** and **[7]**, the dynamic system is formulated in many-sorted type logic; the basic types are t (truth-values), e (individuals), s (modeling variable assignments) and $\mathbf{w}$ (possible worlds). For simplicity, I ignore the temporal and eventuality domains. Just as in **[11]**, information states I, J etc. are sets of assignments (i.e. type st). An individual discourse referent (dref) u (type se) stores a plurality with respect to an info state I, abbreviated $uI{:=}\{x_e{:}\ \exists i_s{\in}I_{st}\ (x{=}ui)\}$. The subscripts on terms indicate their types. A modal dref p (type $s\mathbf{w}$) stores a proposition (a set of worlds), $pI := \{w_{\mathbf{w}}{:}\ \exists i_s{\in}I_{st}\ (w{=}pi)\}$.

Encoding pluralities and propositions in this way and not via drefs for sets (their type would be $s(et)$ and $s(\mathbf{w}t)$ respectively) allows us to capture *structured* inter-sentential plural anaphora: e.g. (8) above entails (9) only if, for each man m that saw a woman n, we assert that m noticed n. Entailment does not obtain if man m_1 saw woman n_1 and m_2 saw n_2, while we interpret (9) as asserting that m_1 noticed n_2 and m_2 noticed n_1. The plural info states (type st) allow us to store and pass on this *distributive* structure: for each $i_s{\in}I_{st}$, we require that the man in i saw (hence noticed) the woman in i.

Sentence *contents* (propositions) are represented as modal drefs. Sentence *meanings* are Discourse Representation Structures (DRSs), i.e. relations between info states (type $(st)((st)t)$). DRSs have the form in (12) below. The 'linearized box' notation in (12) is just a convenient abbreviation of the type-logical term in (13), which requires the output state J to differ from the input state I at most with respect to the **new drefs** and each **condition** to be satisfied by the output state J.

(12) **[new drefs**, e.g. u, p **| conditions**, e.g. $come\_back_p\{u\}$**]**
(13) $\lambda I_{st}J_{st}.\ I[$**new drefs**$]J$ & **conditions**J

Consider again the sentence *He came back three days ago* in (4) above; ignoring temporal issues, the content of (4) is the proposition $\{w{:}\ come\_back_w(john)\}$, i.e. the *maximal* set of worlds w in which John comes back. We need a maximizing operator ***max*** over modal drefs to be able to extract and store this proposition – just as we need maximization in the individual domain (see **[11]**) to correctly represent Evans-style examples like *Harry bought* ***some sheep***. *Bill vaccinated* ***them***, where Bill vaccinates *all* the sheep that Harry bought.

Thus, the *meaning* of (4) is represented by the DRS in (14) below and the *content* of (4) is encoded by the dref p. The $\mathbf{max}^p$ operator, defined in (15), can be thought of as dynamic λ-abstraction over possible worlds: it introduces a new modal dref p (symbolized as $I[p]H$) and makes sure that each and every world in pJ satisfies the DRS D (by DHJ); the set pJ is maximal because any other set of worlds satisfying D, stored as pK, has to be included in pJ.

(14) $\mathbf{max}^p$ ([| $come\_back_p\{John\}$]),
where $come\_back_p\{John\} := \lambda I_{st}.\ \forall i{\in}I\ (come\_back_{pi}(Johni))$ and $John{:=}\lambda i.john_e$.

(15) $\mathbf{max}^p\ (\mathrm{D}){:=}\lambda IJ.\ \exists H\ (\ I[p]H\ \&\ \mathrm{D}HJ\ )\ \&\ \forall K\ (\ \exists H(I[p]H\ \&\ \mathrm{D}HK) \rightarrow pK{\subseteq}pJ\ )$

The proper name in (14) is interpreted as the constant dref *John* mapping any 'assignment' i to the individual *john* (see **[7]**). The lexical relation in (14) (of type $(st)t$) is interpreted pointwise: for each 'assignment' i, the world pi is such that the individual *john* comes back.

All this machinery is independently needed to properly represent modal subordination: the discourse in (10) is true if there is an epistemic possibility p in which a wolf u comes in and sees John and, *in addition*, any epistemic possibility p in which a wolf u comes in is such that the wolf u sees John (see **[8]**). So, to properly represent (10) – see (16) below – we need *maximality* (we consider *any* epistemically accessible world in which a wolf comes in) and also *distributivity*: just as in (8)-(9) above, we establish a *structured* correspondence between each world w and the wolf x that enters in w (and which can vary from world to world). If wolf x_1 enters in world w_1 and x_2 in w_2, sentence (10b) requires w_1 to be such that x_1 (and not x_2!) sees John.

(16) $\mathbf{max}^p$ ([u| $wolf_p\{u\}$, $come\_in_p\{u\}$, $p{\subseteq}p_0$]); [| $see_p\{u, John\}$],
where ';' is dynamic conjunction, interpreted as relation composition:
D; D' := $\lambda IJ.\ \exists H(\mathrm{D}IH\ \&\ \mathrm{D}'HJ)$.

The modal verb *might* introduces and maximizes p; the dref p_0 encodes the contextually specified set of epistemically accessible worlds. The modal anaphor *would* refers back to and elaborates on p.

These ingredients are sufficient for the definitions of truth and entailment below.

(17) **Truth.** A text T with a meaning of the form $\mathbf{max}^p$ (D), where p is the designated content referent of T, is **true** with respect to a world w and an input info state (i.e. context) I **iff** there is an output state J such that $\mathbf{max}^p$ (D)IJ and $w{\in}pJ$.

i.e. pJ is the content expressed by T in context I and we check that this content (proposition) is true in world w.

(18) **Entailment.** A text T with a meaning of the form $\mathbf{max}^p$ (D) **entails** a text T' with a meaning of the form $\mathbf{max}^{p'}$ (D') with respect to an input info state (i.e. context) I iff there is an intermediate state H and an output state J such that $\mathbf{max}^p$ (D)IH and $\mathbf{max}^{p'}$ (D')HJ and $(p{\sqsubseteq}p')J$, where $p{\sqsubseteq}p'$ is a structured inclusion condition defined in (19) below.

i.e. $pJ(=pH)$ is the content expressed by T in context I, $p'J$ is the content expressed by T' in the intermediate context H (crucial for the anaphoric connections between premises and conclusion) and the content of T is at least as informative as the content of T'.

(19) Structured inclusion: $p \sqsubseteq p' := \lambda I_{st}.\ \forall i \in I\ (\ \exists i' \in I\ (i[p']i'\ \&\ p'i'=pi')\ )$

Structured inclusion is necessary for entailment cases involving anaphoric dependencies between premises and conclusion: since these anaphoric dependencies are captured via structured plural anaphora, the two contents should also be related in a structured way.

The definition of entailment in (18) recaptures, in a dynamic setup, the intuitive appeal of the slogan 'entailment is content / proposition inclusion' as modeled in possible-worlds semantics. Also, it accounts for context-sensitivity (the input state I) and for structured anaphora between premises and conclusion via the intermediate state H.

With the system and the definition of entailment in hand, we can give lexical entries for items like *therefore* and *hence* and open the way for an analysis of other entailment-based phenomena like answerhood conditions and presupposition resolution. The lexical entries for *therefore* / *hence* have two components: (**i**) they are anaphoric to the content of the premises; (**ii**) they test that the content of the premises is included (in a structured way) in the content of the conclusion.

(20) **The interpretation of entailment particles.** A text of the form $Therefore_p\ T$ (or $Hence_p\ T$), where p is the content of the premises and the conclusion T has a meaning of the form $\mathbf{max}^{p'}$(D), is interpreted as $\mathbf{max}^{p'}$(D); $[\ |\ p \sqsubseteq p']$.

The paper ends with a review of the parallels between the individual and the modal domains that are explicitly captured in the DPLC system and with a sketch of how the system should be extended to incorporate the analysis of modal quantification in **[4]** and **[5],** so that we can account for the more complex example of modal subordination in (1) above.

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