QNP Textual Entailment with Polynomial Event Semantics

Oleg Kiselyov[0000−0002−2570−2186] and Haruki Watanabe

Tohoku University, Japan
oleg@okmij.org

Abstract. FraCaS textual entailment corpus has become the standard benchmark for semantics theories, in particular, theories of quantification (Sec. 1 of FraCaS). Here we apply it to polynomial event semantics: the latest approach to combining quantification and Neo-Davidsonian event semantics, maintaining compositionality and the in situ analysis of quantifiers. Although several FraCaS problems look custom-made for the polynomial events semantics, there are challenges: the variety of generalized quantifiers (including 'many', 'most' and 'few'); copula, existence, and relative clauses. We address them in this paper.

1 Introduction

The strong point of (Neo-)Davidsonian event semantics [9] (see [8] for a survey) is explaining entailments among sentences without ad hoc meaning postulates. It seems just the right tool to apply to the FraCaS textual inference problem set [2, 7]. However, FraCaS starts with quantifier entailment problems – the weakest point of event semantics. The latest approach to address this weakness (viz., the event quantification problem: see [1] for extensive discussion) is polynomial event semantics [5, 6]. FraCaS however features not only the familiar 'some', 'all' and 'no' quantifiers, but also 'many', 'most', 'at most 10' and 'few' – rarely dealt with in the event quantification problem literature. In this paper we show that the polynomial event semantics surprisingly easily handles the full spectrum of generalized quantifiers – in situ and compositionally. We extend and systematically apply the algebraic approach started in [6]. Sec.1 of FraCaS also contains a number of copula and existential clauses, which, to the authors knowledge, are rarely if at all being dealt with in the event semantics literature. Although they are emphatically not 'action sentences', they can still be analyzed in the event semantics framework and used in entailments, we argue.

Applying event semantics to (mechanically) solve text entailment problems in FraCaS was the primary motivation for developing the polynomial event semantics [5]. That first paper laid the foundation and introduced the model of variable-free event semantics, which not only gets around the event quantification problem but also accounts for quantifier ambiguity. [6] extended the framework to negative quantification – and also introduced the algebraic approach.

The present paper extends the algebraic approach and casts it to what amounts to a deductive system for deciding entailments. The next section, after a brief introduction to the polynomial event semantics, extends the earlier work to all sorts of generalized quantifiers appearing in Sec.1 of FraCaS. In particular, §2.1 discusses negative and downward-monotone quantifiers such as 'at most ten'; §2.2 deals with proportional quantifiers such as 'most' and 'few'. Formally the polynomial event semantics, with its algebra and deduction system, is presented in §3. As an example, §3.1 describes in detail the treatment of negation. We then deal with further challenges of event semantics: copular clauses in §4, and subject relative clauses, often appearing in existential sentences, in §5. Related work is discussed in §6.

2 Generalized Quantifiers

This section introduces both the polynomial event semantics and FraCaS, using the examples from FraCaS to bring up denotations and entailments. Unlike the earlier work, we discuss here truly generalized quantifiers, and in a simpler way.

The poster problem for event semantics is FraCaS problem 023:

(1) Some delegates finished the survey on time.

(2) Some delegates finished the survey.

As with all other problems in the FraCaS corpus, the goal is to check if the last sentence (in our case, (2)) is entailed from the others (that is, (1)).

In polynomial event semantics, these sentences have the following denotations (whose form closely matches the structure of the original sentences):[1]

(3) $$(\mathsf{subj}'/\ (\mathcal{G}_{\mathsf{N}>1}\ \mathsf{Delegate})) \sqcap \mathsf{finished} \sqcap (\mathsf{ob1}'/\ \mathsf{theSurvey}) \sqcap \mathsf{onTime}$$

(4) $$\mathsf{subj}'/\ \mathcal{G}_{\mathsf{N}>1}\ \mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theSurvey}$$

[1] (3) shows how the denotations are supposed to be parenthesized. We drop the parentheses from now on.

Polynomial event semantics deals with individuals and event sets, which are collectively called atoms and denoted by uncapitalized san-serif identifiers: $\mathsf{theSurvey}$ is the particular salient survey,[2] $\mathsf{finished}$ is a set of finished events, onTime is the set of events on time.[3] Capitalized san-serif identifiers stand for sets of individuals, called concepts: $\mathsf{Delegate}$.

The characteristic of the polynomial event semantics is polyconcepts, which are atoms, and also groups.[4] The latter are formed by the operator $\mathcal{G}_n$: whereas $\mathsf{Delegate}$ is a set of delegates, $\mathcal{G}_5\,\mathsf{Delegate}$ is a group of 5 delegates (if there are that many delegates; otherwise, $\mathcal{G}_5\,\mathsf{Delegate}$ is $\perp$: the empty polyconcept). $\mathcal{G}_{N>1}$ in (3) and (4) means a group of N delegates where N is a positive number that should be clear from the context. The vagueness is inherent in the meaning of 'several' and plural 'some'.

If x is a polyconcept of individuals and subj' is a relation between events and individuals (viz., between events and their agents), $\mathsf{subj}'/\,x$ is the polyconcept of events whose agents are x. Likewise, $\mathsf{ob1}'/\,x$ for themes. The symmetric and commutative polyconcept intersection $\sqcap$ is akin to set intersection. We will see in §3 that this overloaded operator is indeed set intersection when applied to event sets.

Unlike Montagovian or the ordinary (Neo-) Davidsonian semantics, the denotations (3) and (4) are not (first- or higher-order) logic formulas. In particular, they have no variables, even the event variable, and no quantifiers. Rather, our denotations are queries, of a database of events. The result of a query is the set of events which witness the corresponding sentence. If we imagine a record of delegates, surveys and their status of completion, then (4) is the query for events, i.e., records of survey completion by at least N delegates.

One query entails another just in case whenever the result of the former is non-empty, so is the result of the latter – for any event database. The entailment may be decided algebraically, keeping in mind that $\sqcap$, like the ordinary set intersection, is upward-monotone in both arguments, as we discuss in more detail in §3:

(5) $$x \sqcap y \Longrightarrow x$$

[2] More generally, definite descriptions can analyzed as $\mathcal{I}\mathsf{Survey}$, see §3. Our example works either way, so we proceed with the simpler analysis.

[3] We suppose there are thematic functions $\mathsf{occursAt}'$ and $\mathsf{deadline}'$ that tell the time of occurrence and the deadline, resp., for an event. Then $\mathsf{onTime} = \{e \mid \mathsf{occursAt}'(e) \leq \mathsf{deadline}'(e)\}$. One may analyze 'on time' differently (e.g., with the deadline being taken from the context). However, that does not matter for entailment, which is decided for our example solely from the property of $\sqcap$, see (5).

[4] By group, here and in the following, we mean any unorderded collection: something like a roster.

The entailment of (4) from (3) (that is, (2) from (1)) is hence decided by the application of (5), without needing to know what exactly $\mathcal{G}_N\ c$ means. (It is still instructive to know: see §3.)

Many other FraCaS generalized quantifier problems are solved analogously: for example,

017 An Irishman won the Nobel prize for literature.
An Irishman won a Nobel prize.

024 Many delegates obtained interesting results from the survey.
Many delegates obtained results from the survey.

025 Several delegates got the results published in major national newspapers.
Several delegates got the results published.

031 At least three commissioners spend a lot of time at home.
At least three commissioners spend time at home.

We do not even need to know how exactly these quantifiers are defined beyond them grouping witnesses somehow. (We describe the analysis of 'many' later.)

2.1 Negative Quantification and Downward Monotonicity

Negation of all kinds – negative quantification, sentential and clausal (VP) negation – is, on our account, about counter-examples. Whereas an affirmative sentence affirms certain events, a sentence with any sort of negation denies certain events – and whose appearance would thus cause contradiction. Therefore, negative sentences mean is what they deny.

As an example, consider problem 022:

(6) No delegate finished the report on time.

(7) No delegate finished the report.

whose denotations are

$$\begin{aligned}(8)\qquad & \mathsf{subj}'/\ \neg\mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport} \sqcap \mathsf{onTime}\\ &= \neg\left(\mathsf{subj}'/\ \mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport} \sqcap \mathsf{onTime}\right)\\ (9)\qquad & \mathsf{subj}'/\ \neg\mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}\\ &= \neg\left(\mathsf{subj}'/\ \mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}\right)\end{aligned}$$

(shown after the equal sign are the results of applying algebraic laws in §3.) (8) and (9) are also queries – searching, however, not for witnesses for the original sentences but for their refutations: counter-evidence, whose polyconcept is denoted $\neg x$. According to (5), (8) entails (9), like with problem 023 before. However, this is the entailment of counter-evidence: The refutation of (6) entailing the refutation of (7) does lead to the emptiness of (8) (i.e., non-refutation of (6)) entailing the emptiness of (9). Thus (7) cannot be concluded from (6). (In fact, the opposite is true.)

Similar is problem 032:

(10) At most ten commissioners spend a lot of time at home.

(11) At most ten commissioners spend time at home.

A refutation for (11) is the existence of at least 11 commissioners who spend time at home. Therefore, the denotation for 'at most ten commissioners' is $\neg\, \mathcal{G}_{11}\, \mathsf{Commissioner}$ and we proceed similarly to problem 022 just above. There are many more similar FraCaS problems:

038 No delegate finished the report.
Some delegate finished the report on time.

070 No delegate finished the report on time.
Some Scandinavian delegate finished the report on time.

2.2 Many, Most, Few

More interesting, and controversial, is problem 056:

(12) Many British delegates obtained interesting results from the survey.

(13) Many delegates obtained interesting results from the survey.

for which the original FraCaS report gives the answer "Don't know". Bill MacCartney [7] comments that apparently FraCaS editors interpret 'many' as a large proportion. He, among others, however, take 'many' to mean a large absolute number. Polynomial event semantics supports both alternatives. The polyconcept *Many* c (where c is a concept) can be defined in two ways:

(14) $$Many\ c = \mathcal{G}_N\, c \qquad\qquad Many\ c = \mathcal{G}_{\alpha|c|}\, c$$

where N is a large absolute number and $0 < \alpha \leq 1$. Upon the first reading, we apply (5) to obtain the entailment of (13) from (12). On the 'large proportion' reading of 'many', the entailment fails because (13) has generally different, and larger, group cardinality than (12). $Most\ c$

is analyzed then as $\mathcal{G}_{\alpha|c|}\, c$, where α is at least 0.5. Few is handled as the negation of ‘many’:

060 Few female committee members are from southern Europe.
Few committee members are from southern Europe.

3 Algebra of Polynomial Event Semantics

This section presents the polynomial event semantics formally, emphasizing its algebra and deductive system.

At its basis, the polynomial event semantics deals with individuals (notated by metavariable i), events (notated by e) and relations among them, written as rel'. Often-used relations are

$$\mathsf{subj}' = \{(e,i) \mid \mathsf{ag}(e) = i\} \qquad \mathsf{action}' = \{(e,i) \mid \mathsf{action}(e) = i\}$$
$$\mathsf{ob1}' = \{(e,i) \mid \mathsf{th}(e) = i\} \qquad \mathsf{mode}' = \{(e,i) \mid \mathsf{mode}(e) = i\}$$

where ag, th, action and mode are thematic functions. If rel' is a relation of events to individuals, $\mathsf{rel}'/\,i = \{e \mid (e,i) \in \mathsf{rel}'\}$ is the set of events related to i. We call individuals and nonempty event sets atoms, denoted by metavariable j.

The subject of polynomial event semantics is polyconcepts, denoted by metavariables x, y and z, which are atoms and applications of operations described below. Technically, the collection of operations acting on polyconcepts is an algebra. Strictly speaking, polynomial event semantics deals with two algebras: the algebra of individuals and the algebra of event sets. They are very similar and have the same operations. The unary operation is negation (or, marking as counter-evidence) $\neg$. Binary operations, which are commutative and associative, and the correspondent zero-arity operations (units) are as follows.

$\otimes$	unit: $\mathbf{1}$	grouping/conjunction
$\sqcup$	unit: $\bot$	internal choice, union
$\sqcap$	unit: $\top$	intersection
$\oplus$	unit: $\mathbf{0}$	external choice

The often-occurring $\bot$ is the empty polyconcept; it being the unit of $\sqcup$ means $x \sqcup \bot = x$. In the algebra of individuals, $\sqcap$ is defined as

$$i_1 \sqcap i_2 = \begin{cases} i_1 & \text{if } i_1 = i_2 \\ \bot & \text{otherwise} \end{cases}$$

In the algebra of event sets, $\bot$ is identical to the empty set. When applied to atoms (i.e., event sets), $\sqcap$ is set intersection.

The operations satisfy the following additional identities:

$$x \oplus x = x \qquad x \sqcap x = x \qquad x \sqcup x = x$$
$$x \sqcap \bot = \bot \qquad x \otimes \bot = \bot$$

$$\neg x \sqcap \neg y = \neg(x \sqcap y)$$
$$(x \oplus y) \sqcup z = (x \sqcup z) \oplus (y \sqcup z) \qquad (x \oplus y) \sqcap z = (x \sqcap z) \oplus (y \sqcap z)$$
$$(x \oplus y) \otimes z = (x \otimes z) \oplus (y \otimes z)$$

Thus the external choice $\oplus$ distributes over all other binary operations, and can be 'pulled out', so to speak. The negation of $\bot$, notated as $\neg\bot$ or $\bar{\bot}$, is different from $\bot$. In particular, $x \otimes \bar{\bot} \neq \bar{\bot}$. There are further, more specific identities (distribution laws) which holds only for atoms or negated polyconcepts:

$$j \sqcap (x \otimes y) = (j \sqcap x) \otimes (j \sqcap y) \qquad j \sqcap (x \sqcup y) = (j \sqcap x) \sqcup (j \sqcap y)$$
$$j \sqcap \neg y = \neg(j \sqcap y) \qquad \neg z \sqcap (x \sqcup y) = (\neg z \sqcap x) \sqcup (\neg z \sqcap y)$$

Relations rel' bridge the algebras of individuals and of event sets. Technically, rel' act as algebra homomorphisms from the former to the latter:

$$\mathsf{rel}'/\,(\neg x) = \neg\, \mathsf{rel}'/\, x \qquad \mathsf{rel}'/\,(x \sqcap y) = \mathsf{rel}'/\, x \sqcap \mathsf{rel}'/\, y$$

and similarly for other binary operations.

Typically we deal not with individuals but with sets of individuals, called concepts – and with sets of non-empty event sets, called e-concepts. Since the operations apply uniformly to concepts and e-concepts, we often call them just concepts and use metavariable c.[5] Relations extend to concepts straightforwardly: If c is a set of individuals then $\mathsf{rel}'/\, c = \{\text{nonempty } \mathsf{rel}'/\, i \mid i \in c\}$ is the set of non-empty event sets related to each individual in c. Often we build polyconcepts by applying a binary operation $\sqcup$, $\oplus$ or $\otimes$ to all elements of a concept. We introduce a special notation for such cases:

$$\mathcal{E}c = \sqcup_{j \in c}\, j \qquad \mathcal{I}c = \oplus_{j \in c}\, j \qquad \mathcal{A}c = \otimes_{j \in c}\, j$$

[5] One may hence say that a concept is a set of atoms – however, we never mix individuals and event sets in the same set.

One immediately notices that for singleton concepts:

$$\mathcal{E}\{j\} = \mathcal{I}\{j\} = \mathcal{A}\{j\} = j$$

Specifically for the $\mathcal{E}$ operation, we notice that $\mathcal{E}c = \bot$ iff $c = \varnothing$.

The operation $\sqcap$ extends to concepts as

$$c_1 \sqcap c_2 = \{j_1 \sqcap j_2 \mid j_1 \in c_1, j_2 \in c_2, j_1 \sqcap j_2 \neq \bot\}$$

That is, on sets of individuals, $\sqcap$ is set intersection. The distributivity of $\oplus$ over $\sqcap$ gives $\mathcal{I}c_1 \sqcap \mathcal{I}c_2 = \mathcal{I}(c_1 \sqcap c_2)$.

The grouping $\mathcal{G}_N\, c$ mentioned earlier – the collection of all N-element groups out of c – is defined as

$$\mathcal{G}_N\, c = \sqcup\, \mathcal{A}c' \text{ for all } c' \subset c \text{ such that } |c'| = N$$

Clearly,

$$\mathcal{G}_1 = \mathcal{E} \qquad\qquad \mathcal{G}_N\, c = \bot \quad \text{iff } |c| < N$$

where $|c|$ is the cardinality of c. From the distributivity laws above, we obtain useful identities:

$$(\mathcal{G}_N\, c) \sqcap j = \mathcal{G}_N(c \sqcap j) \qquad\qquad (\mathcal{G}_N\, c_1) \sqcap \mathcal{E}c_2 = \mathcal{G}_N(c_1 \sqcap \{\cup c_2\})$$

Since a relation rel' is the algebra homomorphism,

$$\mathsf{rel}'/\, \mathcal{E}c = \mathcal{E}\, \mathsf{rel}'/\, c \qquad \mathsf{rel}'/\, \mathcal{I}c = \mathcal{I}\, \mathsf{rel}'/\, c \qquad \mathsf{rel}'/\, \mathcal{A}c = \mathcal{A}\, \mathsf{rel}'/\, c$$
$$\mathsf{rel}'/\, \mathcal{G}_{\mathsf{N}}\, c = \mathcal{G}_N\, \mathsf{rel}'/\, c$$

The reader has no doubt noticed the similarity of the presented algebra with linear logic (and that our $\sqcup$ behaves like & and $\sqcap$ as par). We are currently trying to understand this connection.

As an example of using the algebras and its identities, consider (15) below

(15) The delegate finished the report.

(16) $\mathsf{subj}'/\, \mathsf{theDelegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\, \mathsf{theReport}$

whose denotation (16) is the intersection of three event sets: events whose agent is theDelegate, finished events, and events whose theme is theReport. The denotation is hence the set of events that witness (15).

The second example is (2) from the problem 023 analyzed in §2, and its denotation (4), repeated below with an insignificant modification:

Some delegates finished the report.

$$\mathsf{subj}'/\ \mathcal{G}_{\mathsf{N}>1}\ \mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}$$

Applying the algebraic identities to the denotation, we derive

$$\begin{aligned} &\mathcal{G}_{N>1}(\mathsf{subj}'/\ \mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}) \\ &= \mathcal{G}_{N>1}\{\text{nonempty}\ \ \mathsf{subj}'/\ i \cap \mathsf{finished} \cap \mathsf{ob1}'/\ \mathsf{theReport} \mid i \in \mathsf{Delegate}\} \end{aligned}$$

which is non-$\perp$ just in case there are records in the event database of at least $N{>}1$ delegates having finished the report.

3.1 Negation

A more extensive example of applying algebraic identities and semantic calculations is negation. In addition to negative quantification we also consider VP negation, although it is hardly present in FraCaS (certainly not in Sec. 1). We hence expand the account of [6], which, although touched upon the clausal (VP) negation, did not describe it in detail for the lack of space.

Recall that negation of all kinds is, on our account, about counterexamples. Whereas an affirmative sentence affirms certain events, a sentence with any sort of negation denies certain events – and whose appearance would thus cause contradiction.

The following sample illustrates the variety of negation.

(17) The delegate didn't finish the report.

(18) No delegate finished the report.

(19) The delegate finished no report.

(20) A delegate didn't finish the report.

Sentence (17) looks like the negation of (15). Its compositional denotation

$$\begin{aligned} &\mathsf{subj}'/\ \mathsf{theDelegate} \sqcap \neg\ \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport} \\ &= \neg\ \big(\mathsf{subj}'/\ \mathsf{theDelegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}\big) \end{aligned}$$

(where we applied the algebraic identities to pull $\neg$ out) is indeed the negation of the denotation (16). What is a witness for (15) is a counterexample for (17): the two sentences are contradictory, as expected.

The compositional denotation for (18) is

$$\begin{aligned}
&\mathsf{subj}'/\ \neg\mathcal{E}\mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}\\
&= \neg\mathcal{E}(\mathsf{subj}'/\ \mathsf{Delegate}) \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}\\
&= \neg(\mathcal{E}\ \mathsf{subj}'/\ \mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport})
\end{aligned}$$

Once again we are able to pull $\neg$ out, relying on the fact that $\mathsf{finished}$ and $\mathsf{ob1}'/\ \mathsf{theReport}$ are atomic. The denotation is the negation of the denotation for

A delegate finished the report.

which is hence the contradictory with (18). Furthermore, since $\mathsf{theDelegate}$ is included in the set $\mathsf{Delegate}$, we obtain the entailment of (17) from (18). Sentence (19) is analyzed similarly to (18).

However, (20) is different. Its denotation

$$\begin{aligned}
&\mathsf{subj}'/\ \mathcal{E}\mathsf{Delegate} \sqcap \neg\ \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}\\
&= \mathcal{E}(\mathsf{subj}'/\ \mathsf{Delegate}) \sqcap \neg(\mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport})
\end{aligned}$$

but then we cannot pull $\neg$ further up, because $\mathcal{E}(\mathsf{subj}'/\ \mathsf{Delegate})$ is neither atomic nor negated. The key point is that

$$x \sqcap \neg y = \neg(x \sqcap y)$$

(the negation marker propagating up) holds only when x is atomic or negated. We may apply the distributive law however:

$$(x \sqcup y) \sqcap z = (x \sqcap z) \sqcup (y \sqcap z)$$

where z is atomic or negated, obtaining

$$\begin{aligned}
&= \mathcal{E}(\mathsf{subj}'/\ \mathsf{Delegate} \sqcap \neg(\mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport}))\\
&= \sqcup_{i\in\mathsf{Delegate}}\neg(\mathsf{subj}'/\ i \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\ \mathsf{theReport})
\end{aligned}$$

Whereas any delegate finishing the report would be a counter-example for (18), the counter-example for (20) is every delegate finishing the report.

Here are more examples of negation and quantification:

(21) A delegate finished no report.

(22) A delegate didn't finish a report.

(23) A delegate didn't finish any report.

(24) A delegate didn't FINISH a report.

(25) Some delegate finished a report not on time.

Sentence (21) with the negative quantifier has as its denotation

(26) $\mathsf{subj}'/\,\mathcal{E}\mathsf{Delegate} \sqcap \mathsf{finished} \sqcap \mathsf{ob1}'/\,\neg\mathcal{E}\mathsf{Report}$

(27) $= \bigsqcup_{i\in\mathsf{Delegate}} \neg \bigsqcup_{j\in\mathsf{Report}} \mathsf{subj}'/\,i \cap \mathsf{finished} \cap \mathsf{ob1}'/\,j$

with (27) derived using the laws of §3. The sentence is non-contradicted if there is a delegate for which the set of counter-examples (events of this delegate finishing any report) is empty.

The sentence (22) with VP negation has, on the other hand

(28) $\mathsf{subj}'/\,\mathcal{E}\mathsf{Delegate} \sqcap \neg\,\mathsf{finished} \sqcap \mathsf{ob1}'/\,\mathcal{E}\mathsf{Report}$

$$= \bigsqcup_{i\in\mathsf{Delegate}} \bigsqcup_{j\in\mathsf{Report}} \neg(\mathsf{subj}'/\,i \cap \mathsf{finished} \cap \mathsf{ob1}'/\,j)$$

The sentence is non-contradicted if there is a delegate-report pair such that the set of counter-examples (having finished events for that agent, theme pair) is empty. If for every delegate-report pair, either there is a finished event, or failed to finish event, then "A delegate failed to finish a report" (the existence of of the failed-to-finish event) implies an empty counter-example to (22).

For (23), we have

$$\mathsf{subj}'/\,\mathcal{E}\mathsf{Delegate} \sqcap \neg\,\mathsf{finished} \sqcap \mathsf{ob1}'/\,\neg\mathcal{E}\mathsf{Report}$$
$$= \bigsqcup_{i\in\mathsf{Delegate}} \neg \bigsqcup_{j\in\mathsf{Report}} \mathsf{subj}'/\,i \cap \mathsf{finished} \cap \mathsf{ob1}'/\,j$$

which turns out identical to (21).

In the sentence with the stressed negation (24), the negated VP has the mixed denotation $\mathsf{action}'/\,\mathcal{E}\mathsf{Action} \otimes \neg\,\mathsf{action}'/\,\mathsf{finished}$. The sentence is true if there is a delegate who did something with a report, but that action was not the finishing action. (25) is similar.

4 Copula Clauses

Having introduced the polynomial event semantic in full in §3, we are set to tackle further challenges. This section deals with copular clauses; existence and subject relative clauses are considered in §5.

Copular clauses are frequent in FraCaS (in Sec.1 and others); for example, problem 049:

(29) A Swede won a Nobel prize.

(30) Every Swede is a Scandinavian.

(31) A Scandinavian won a Nobel prize.

Copular clauses are not 'action sentences'; one may wonder if the event semantics even applies. We argue it does: Just as 'it', on Davidson's analysis, in "John died. I did not know it until yesterday" refers to the event of John's death, so should 'it' in "John is tall. I did not know it until I saw him" refer to an event: an event of being tall whose 'agent' is John.

Formally, for each individual i we introduce the event of being that individual, to be denoted as $\mathsf{be}(i)$, of which i is an agent. The function be may also be regarded as the relation be', so that $\mathsf{be}'/\ i$ is the singleton event set, of the event of i existence. The e-concept of all existence events (in the current 'world') is then

$$\mathsf{Be} = \mathsf{be}'/\ \mathsf{AllIndividuals} \tag{32}$$

If Tall is a set of all tall (by some standard) things and people, the corresponding BeingTall e-concept is $\mathsf{be}'/\ \mathsf{Tall} \subset \mathsf{Be}$. Since i is an agent of its being, $\mathsf{ag}(\mathsf{be}(i)) = i$, which can be written as

$$\mathsf{be}'/\ c = \mathsf{subj}'/\ c \sqcap \mathsf{Be} \tag{33}$$

for any concept c, from which it immediately follows that

$$\mathsf{subj}'/\ c_1 \sqcap \mathsf{be}'/\ c_2 = \mathsf{be}'/\ c_1 \sqcap \mathsf{be}'/\ c_2 = \mathsf{be}'/\ (c_1 \cap c_2) \tag{34}$$

This is *not* a meaning postulate, but a logical consequence of (33) and the algebraic identities.

Returning to problem 049, the denotation of (30) then takes the form:

$$\begin{aligned}
&\mathsf{subj}'/\ \mathcal{G}_{|\mathsf{Swede}|}\ \mathsf{Swede}\ \sqcap\ \mathsf{be}'/\ \mathcal{E}\mathsf{Scandinavian}. && (35)\\
&= \mathcal{G}_{|\mathsf{Swede}|}\ \mathsf{subj}'/\ \mathsf{Swede}\ \sqcap\ \mathcal{E}\ \mathsf{be}'/\ \mathsf{Scandinavian} &&\\
&= \mathcal{G}_{|\mathsf{Swede}|}(\mathsf{subj}'/\ \mathsf{Swede} \sqcap \{\cup\, \mathsf{be}'/\ \mathsf{Scandinavian}\}) &&\\
&= \mathsf{be}'/\ \mathcal{G}_{|\mathsf{Swede}|}(\mathsf{Swede} \cap \mathsf{Scandinavian}) && (36)
\end{aligned}$$

by applying identities of §3 and (34). Thus the denotation (36) is non-$\perp$ just in case $|\,\mathsf{Swede} \cap \mathsf{Scandinavian}\,| \geq |\,\mathsf{Swede}\,|$, that is, $\mathsf{Swede} \subseteq \mathsf{Scandinavian}$. With this premise, the entailment of (31) from (29) follows by monotonicity of $\mathcal{E}$. We must stress that we have used only the ordinary set theory (and the properties of polyconcept operators justified from set theory [6]), without any extra-logical meaning postulates.

5 Existence and Subject Relative Clauses

FraCaS also contains a number of existential sentences many of which include subject relative clauses, such as (38) of problem 001:

(37) An Italian became the world's greatest tenor.

(38) There was an Italian who became the world's greatest tenor.

We take the existential sentence (38) to be a surface variant of

(39) An Italian who became the world's greatest tenor existed.

Let wgt be the 'world's greatest tenor'. Then $\mathsf{became} \sqcap \mathsf{ob1}'/\ \mathsf{wgt}$ is a polyconcept of events of having become the world's greatest tenor, and "who became the world's greatest tenor" is the agent of those events:

$$\overline{\mathsf{subj}}'/\ (\mathsf{became} \sqcap \mathsf{ob1}'/\ \mathsf{wgt}) \tag{40}$$

where the overline denotes an inverse relation. Recall, subj' relates events with their agents. The inverse relation $\overline{\mathsf{subj}}'$ then relates individuals with the events they are agents of. We thus have

$$(a)\quad \overline{\mathsf{subj}}'/\ \mathsf{subj}'/\ c = c \qquad\qquad (b)\quad d \Longrightarrow \mathsf{subj}'/\ \overline{\mathsf{subj}}'/\ d \tag{41}$$

as the composition of a relation with its inverse includes the identity relation. Since thematic functions are functions, (41)(a) is stronger.

Overall, the denotation of (39) becomes

$$\begin{aligned}
&\mathsf{subj}'/\ (\mathcal{E}\ \mathsf{Italian} \sqcap (\overline{\mathsf{subj}}'/\ (\mathsf{became} \sqcap \mathsf{ob1}'/\ \mathsf{wgt}))) \sqcap \mathcal{E}\ \mathsf{Be} \\
&= \mathsf{subj}'/\ (\overline{\mathsf{subj}}'/\ \mathsf{subj}'/\ \mathcal{E}\mathsf{Italian} \sqcap \\
&\qquad\qquad (\overline{\mathsf{subj}}'/\ (\mathsf{became} \sqcap \mathsf{ob1}'/\ \mathsf{wgt}))) \sqcap \mathcal{E}\ \mathsf{Be} &(42)\\
&= \mathsf{subj}'/\ \overline{\mathsf{subj}}'/\ (\mathsf{subj}'/\ \mathcal{E}\mathsf{Italian} \sqcap \mathsf{became} \sqcap \mathsf{ob1}'/\ \mathsf{wgt}) &(43)\\
&\qquad\qquad \sqcap \mathcal{E}\ \mathsf{Be}
\end{aligned}$$

where (42) is obtained by applying (41)(a), and (43) by distributing relation application over intersection. Be is the set of 'being an individual', i.e., the existence events. The expression in parentheses in (43) is exactly the denotation of (37). Thus entailment is immediate, if we overlook the existence claim. The past tense of 'became' does presuppose the existence of such Italian, so the entailment of (39) from (37) is justified. At present we do not account for tense and related presuppositions however.

Many of subject relative clauses in FraCaS are copular clauses, e.g., (45) of problem 007:

(44) Some great tenors are Swedish.

(45) There are great tenors who are Swedish.

which also exhibits a bare plural. In the context of an existential clause, it seems justified to treat is as existentially quantified; therefore, as explained earlier, we treat the whole (45) as a surface realization of

(46) Several great tenors who are Swedish exist.

Applying the just outlined approach to subject relative clauses, coupled with the analysis of copular clauses in §4 gives as the denotation for (46):

$$\begin{aligned}
&\mathsf{subj}'/\ (\mathcal{G}_{N>1}\ \mathsf{GreatTenor} \sqcap (\overline{\mathsf{subj}}'/\ \mathsf{be}'/\,\mathcal{E}\mathsf{Swedish})) \sqcap \mathcal{E}\ \mathsf{Be}\\
&= \mathsf{subj}'/\ (\mathcal{G}_{N>1}(\overline{\mathsf{subj}}'/\,\mathsf{subj}'/\ \mathsf{GreatTenor}) \sqcap (\overline{\mathsf{subj}}'/\ \mathsf{be}'/\,\mathcal{E}\mathsf{Swedish})) \sqcap \mathcal{E}\ \mathsf{Be}\\
&= \mathsf{subj}'/\ \overline{\mathsf{subj}}'/\ (\mathsf{subj}'/\,\mathcal{G}_{\mathsf{N}>1}\ \mathsf{GreatTenor} \sqcap \mathsf{be}'/\,\mathcal{E}\mathsf{Swedish}) \sqcap \mathcal{E}\ \mathsf{Be}\\
&= \mathsf{subj}'/\,\mathcal{G}_{\mathsf{N}>1}\ \mathsf{GreatTenor} \sqcap \mathsf{be}'/\,\mathcal{E}\mathsf{Swedish}
\end{aligned}$$

(note that $\mathsf{be}'/\,\mathcal{E}\mathsf{Swedish}$ are existence events). The result is exactly the denotation of (44), which is thus equivalent on our analysis to (46).

6 Related Work

Treating denotations as queries and considering the entailment of queries is rather rare, although one may say it is fully in the spirit of Heim and Kratzer [4]. The (only) closest related work is that of Tian et al. [3, 10] on abstract Dependency-based Compositional Semantics (DCS). It also appeals to the intuition of database queries, uses relational algebra and algebraic entailments, and also Sec.1 of FraCaS. For example, "students read books" gets the abstract denotation

$$\mathbf{read} \cup (\mathbf{student}_{SUBJ} \times \mathbf{book}_{OBJ})$$

"It is not hard to see the abstract denotation denotes the intersection of the 'reading' set (as illustrated by the 'read' table in Table 1) with the product of 'student' set and 'book' set." [10, §2.2] The meaning of the declarative sentence is the statement about the denotation: its non-emptiness [10, §2.4.2].

The above reads quite like the opening sections of [5]. Then the differences emerge: our denotations are not (queries for) simple sets of events: rather, they are more complicated polyconcepts, capable of explaining all sorts of quantifier ambiguities (including those due to negative quantification and negation). Although [10] mentions negation, it is only 'atomic' (that is, antonym) and 'root' (sentential).

Tian et al. do not actually use event semantics, and do not consider denotations to be witnesses of the truth of the sentence. Denotations in the abstract DCS are rather coarse: the meaning of "Mary loves every dog" is a one-point set (trivial database relation). Therefore, "mary loves every dog" and "John likes every cat" (if true) have the identical truth value. In contrast, our semantics is 'hyperfine': true sentences have distinct truth value: their own witnesses of the truth.

Finally, there are also methodological differences. Tian et al. work is in the context of NLP rather than theoretical linguistics, and widely uses approximate paraphrasing, word sense similarity and other NLP techniques.

For critical analysis of other approaches to event quantification problem, see [6].

7 Conclusions

We have presented, on paper for now, the application of the polynomial event semantics to textual entailment problems in Sec.1 of FraCaS. This required extending the prior work to the whole set of generalized quantifiers (including proportional ones), as well as copula and existential clauses and subject relative clauses. The mechanical implementation of this approach is pending.

Also the subject of future work is the treatment of tense and the presuppositions of existence.

Acknowledgments We are very grateful to the reviewers and Daisuke Bekki for their insightful comments and questions. This work was partially supported by a JSPS KAKENHI Grant Number 17K00091.

Bibliography

[1] Champollion, L.: The interaction of compositional semantics and event semantics. Linguistics and Philosophy **38**(1), 31–66 (2015)

[2] Cooper, R., Crouch, D., van Eijck, J., Fox, C., van Genabith, J., Jan, J., Kamp, H., Milward, D., Pinkal, M., Poesio, M., Pulman, S., Briscoe, T., Maier, H., Konrad, K.: Using the framework. Deliverable D16, FraCaS Project (1996)

[3] Dong, Y., Tian, R., Miyao, Y.: Encoding generalized quantifiers in dependency-based compositional semantics. In: Proceedings of the 28th Pacific Asia Conference on Language, Information and Computation, PACLIC 28, Cape Panwa Hotel, Phuket, Thailand, December 12-14, 2014. pp. 585–594 (2014), `http://aclweb.org/anthology/Y/Y14/Y14-1067.pdf`

[4] Heim, I., Kratzer, A.: Semantics in Generative Grammar. Blackwell Publishers, Oxford (1997)

[5] Kiselyov, O.: Polynomial event semantics - Non-Montagovian proper treatment of quantifiers. In: JSAI-isAI Workshops. Lecture Notes in Computer Science, vol. 11717, pp. 313–324. Springer (2019). https://doi.org/10.1007/978-3-030-31605-1_23

[6] Kiselyov, O.: Polynomial event semantics: Negation. In: JSAI-isAI Workshops: New Frontiers in Artificial Intelligence. Lecture Notes in Computer Science, vol. 12758, pp. 82–95. Springer (2021). https://doi.org/10.1007/978-3-030-79942-7_6

[7] MacCartney, B.: The FRACAS textual inference problem set. `https://nlp.stanford.edu/~wcmac/downloads/fracas.xml`

[8] Maienborn, C.: Event semantics, chap. 8, pp. 232–266. Semantics - Theories, De Gruyter Mouton (2019). https://doi.org/10.1515/9783110589245-008

[9] Parsons, T.: Events in the Semantics of English: a Study in Subatomic Semantics. The MIT Press, Cambridge, Massachusetts (1990)

[10] Tian, R., Miyao, Y., Matsuzaki, T.: Logical inference on dependency-based compositional semantics. In: ACL (1). pp. 79–89. The Association for Computer Linguistics (2014), `http://aclweb.org/anthology/P/P14/`