A Single-Type Semantics for Natural Language

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Partee's Conjecture

Barbara H. Partee, "Do We Need Two Basic Types?" (2006)

Single-Type Hypothesis

- The distinction between entities and propositions is inessential for the construction of a rich linguistic ontology.
- All object-types can be bootstrapped from a single basic type.

Montague Semantics

- Basic types: e (for entities) and $\langle s, t\rangle$ (for propositions);
- Derived types: $\langle e, \langle s, t\rangle\rangle$ (for properties), $\langle e, \langle e, \langle s, t\rangle\rangle\rangle$ (relations).

Single-Type Semantics

- Basic type: q (for entities and propositions);
- Derived types: $\langle q, q\rangle$ (for properties), $\langle q, \langle q, q\rangle\rangle$ (for relations).

Partee's Motivation

Andrew Carstairs-McCarthy, *The Origins of Complex Language* (1999)

Single-Category Hypothesis

- The distinction between NPs and sentences is inessential for the generation of complex modern languages.
- All categories can be constructed from a single basic category.

Categorial Syntax

- Basic categories: NP (for noun phrases) and S (for sentences);
- Derived categories: $NP\backslash S$, $(NP\backslash S)/NP$ (for (in-)transitive verbs).

Monocategoric Syntax

- Basic category: X (for noun phrases and sentences);
- Derived categories: $X\backslash X$, $(X\backslash X)/X$ (for (in-)transitive verbs).

Arguments for the Single-Category Hypothesis

1. Evolutionary linguistics The NP/S-distinction is a contingent property of modern grammar.
2. Nominalization Many sentences can be converted into NPs (cf. Carstairs-McCarthy's 'Nominalized English').
3. Language acquisition The function of NPs is often ambiguous bw reference and assertion (Snedeker et al., 2007).

- Arguments 2, 3 have direct counterparts in semantics.
- Especially, the construction of a single-base syntax for NL can be paralleled on the level of semantics.

Objective Define such a semantics!

The Plan

1. Single-Type Semantics
   - Survey the objects in our domains.
   - Describe their interrelations.
2. Linguistic Application
   - Show that single-type semantics models the PTQ-fragment.
3. Wrap-Up

Single-Type Objects

Basic and Derived Objects

Let $\mathcal{A} := D_e$ be the domain of entities.

$$\left.\begin{array}{rl} \text{Individuals} & \text{Filters (or ideals) in } \mathcal{P}(\mathcal{A}) \\ \text{Propositions} & \text{Filters (or ideals) in } \mathcal{P}(\mathcal{A}) \\ \text{Worlds} & \text{Filters (or ideals) in } \mathcal{P}(\mathcal{A}) \end{array}\right\} \text{basic}$$

$$\left.\begin{array}{rl} \text{Individual Concepts} & \text{Fct's from worlds to individuals} \\ \text{Proposit'l Concepts} & \text{Fct's from worlds to proposit's} \\ \text{Properties} & \text{All fct's in the domain hierarchy} \end{array}\right\} \text{derived}$$

Single-Type Objects: Individuals

- Entities and propositions are unsuitable single-type domains:
  - Entities (type e) lack an algebraic structure;
  - Propositions (type $\langle s, t\rangle$) cannot represent entities.
- We adopt basic sets of sets of entities in $D_{\langle\langle e,t\rangle,t\rangle} := \mathcal{P}^2(\mathcal{A})$:

$$\begin{aligned} \text{John} &:= \{\text{is self-identical}, \text{is a man}\} \\ \text{Mary} &:= \{\text{is self-identical}, \text{is a woman}\} \end{aligned}$$

- We interpret connectives via set-theoretic operations:

$$\begin{aligned} [\![\textit{John and Mary}]\!] &:= \text{John} \cap \text{Mary} = \{\text{is self-identical}\} \\ [\![\textit{John or Mary}]\!] &:= \text{John} \cup \text{Mary} = \{\text{is self-identical}, \ldots\} \\ [\![\textit{not John}]\!] &:= \text{John}' = \{\text{is a woman}\} \end{aligned}$$

Single-Type Objects: Propositions

- We identify individuals with filters in $\mathcal{P}(\mathcal{A})$:
  - Individuals are closed under finite intersection:

$$\begin{aligned} \text{John} &:= \{\text{is self-identical, is a man}\} \\ \Longrightarrow \text{John} &:= \{\text{is self-identical} \cap \text{is a man}\} \end{aligned}$$

  - Individuals are closed under entailment:

$$\begin{aligned} &(\text{is self-identical} \cap \text{is a man}) \subseteq \text{is self-identical} \\ \Longrightarrow \text{John} &:= \{X \mid \text{is self-identical} \cap \text{is a man} \subseteq X\} \end{aligned}$$

- Trivially true propositions assert a property's membership in a filter:

$$\{X \mid \text{is self-identical} \cap \text{is a man} \subseteq X\} \cap \{\text{is a man}\}$$

- Informative propositions constitute proper filter extensions:

$$\text{John}_{\text{new}} := \{X \mid \text{is self-identical} \cap \text{is a man} \cap \text{runs} \subseteq X\}$$

Single-Type Objects: Properties

Property attribution := Filter extension

- We interpret predicates as functions from filters to filters.
- A filter in the function's domain may not be more informative than the filter from its range:

$$[\![\textit{runs}]\!] : \text{John} \rightarrow \text{John}_{\text{new}}$$

s.t. $\text{John} \subseteq \text{John}_{\text{new}}$.

- Relations have a similar representation:

$$[\![\textit{loves}]\!] : \langle \text{John}, \text{Mary} \rangle \rightarrow \langle \text{John}_{\text{new}}, \text{Mary}_{\text{new}} \rangle$$

where $\text{John}_{\text{new}} := \text{John} \cap \{\text{loves Mary}\}$,
$\text{Mary}_{\text{new}} := \text{Mary} \cap \{\text{is loved by John}\}$.

Single-Type Objects: Individual Concepts

To enable proper filter extensions, we associate individual constants with families of filters in $\mathcal{P}(\mathcal{A})$:

1. Interpret individual constants as individual concepts, i.e. functions $f : \mathcal{P}^2(\mathcal{A}) \to \mathcal{P}^2(\mathcal{A})$;
2. Apply individual concepts to different worlds in $\mathcal{P}^2(\mathcal{A})$;
3. Obtain different world-specific individuals.

$\Longrightarrow$ We have two sorts of basic-type objects: individuals, worlds

Worlds will always be at least as informative as their individuals:

Single-Type Objects: Example

- Let $w := \{X \mid \text{is self-identical} \cap \text{is a man} \subseteq X\}$, where

$$\begin{aligned} \text{is self-identical} &:= \{\text{John}, \text{Mary}, \text{the Moon}\}, \\ \text{is a man} &:= \{\text{John}\}, \\ \text{is not a man} &:= \{\text{Mary}\}. \end{aligned}$$

- Then, since

$$\begin{aligned} \{\text{is self-identical}\} &\subseteq \text{John}(w), \\ \{\text{is a man}\} &\subseteq \text{John}(w), \\ \Longrightarrow \text{John}(w) = w &= \{X \mid \text{is self-identical} \cap \text{is a man} \subseteq X\} \end{aligned}$$

- But, since

$$\begin{aligned} \{\text{is a man}\} &\not\subseteq \text{the Moon}(w), \\ \{\text{is not a man}\} &\not\subseteq \text{the Moon}(w), \\ \Longrightarrow \quad \text{the Moon}(w) &\neq w \end{aligned}$$

Single-Type Objects: Partiality

We need to separate a constant's denotation and complement:

1. Only thus can we account for truth-value gaps.
2. Only thus can we enable proper filter extensions.

Implementation Remove LEM from the axioms of our algebra:

- Weaken the structure on single-type domains;
- Split the interpretation and assignment functions;
- Partialize the algebraic operations.

Partial Truth

- Single-type objects are def'd by their properties & privations:

$$\text{John} \;:=\; \langle \text{John}^+, \text{John}^- \rangle, \text{ with}$$

John^+ The set of properties John is known to have;

John^- The set of properties John is known to lack.

- We split worlds into a denotation- and a complement-world.
- Truth at a world is defined as an object's inclusion in a world.
- Compatibility with a world is defined as an object's inclusion of a world.
- Both notions are double-barrelled.

Worlds

In single-type semantics, possible worlds serve a triple-duty:

1. Worlds obtain families of individuals (propositions);
2. Worlds enable the evaluation of their truth value;
3. Worlds define the modal operators.

Worlds are well-defined:

- Worlds are partial and consistent;
- Worlds are partially ordered;
- Worlds are extensional.

Worlds and Accessibility

The accessibility relation $R_{\langle\langle q,q\rangle,q\rangle}$ inherits its properties from the partial order on D_q:

Definition (Accessibility)

Let $\lambda j \lambda i.\, R\, ij$ formalize *j includes the information of i*. Then,

i.	$\forall i. R\, ii$	(Reflexivity);
ii.	$\forall i \forall j \forall k.(R\, ij \wedge R\, jk) \rightarrow R\, ik$	(Transitivity).

- Other properties (e.g. symmetry, euclideanness) can be stipulated via non-logical axioms.
- From R, the modal operators are standardly defined.

An Acid Test

Objective Define a single-type semantics for NL!

- To compare our semantics' modeling power with that of multi-type systems, we model the PTQ-fragment.
- Measure for success Our semantics' ability to interpret all expressions of the fragment.
- We associate complex expressions with sets of syntactic structures.
- We render syntactic structures into single-type terms via type-driven translation.

Conventions

We employ the following typographical conventions:

Variable	TY_0^3 type	TY_2 type	Objects
i, j	q	$\langle\langle e, t\rangle, t\rangle := s$	worlds
z	q	$\langle\langle e, t\rangle, t\rangle := e$	individuals
x, y	$\langle q, q\rangle$	$\langle s, e\rangle$	ind. concepts
P_1, P_2	$\langle\langle q, q\rangle, \langle q, q\rangle\rangle$	$\langle s, \langle e, \langle s, t\rangle\rangle\rangle$	FO properties
Q	$\langle\langle\langle q, q\rangle, \langle q, q\rangle\rangle, \langle q, q\rangle\rangle$	$\langle s, \langle\langle s, \langle e, \langle s, t\rangle\rangle\rangle, t\rangle\rangle$	SO properties

Basic PTQ-Translations

Words	Translation
John, Mary, Bill, ...	$\lambda i.john\ i, \ldots$
runs, walks, talks, ...	$\lambda i.run\ i, \ldots$
man, woman, unicorn	$\lambda i.man\ i, \ldots$
finds, loves, ...	$\lambda Q \lambda y \lambda i.Q(\lambda x.find\ yxi), \ldots$
seeks	$\lambda i.\forall P \forall x(seek\ xPi \leftrightarrow try\ x\ \ find\ Pi)$
rapidly, allegedly, ...	$\lambda i.rapidly\ i, \ldots$
necessarily	$\lambda z.\forall i\,((\Omega i \wedge Ri) \to (z \to i))$
in	$\lambda Q \lambda P \lambda y \lambda i.Q(\lambda x.in\ xPyi)$
believes that	$\lambda y \lambda x \lambda i.believe\ xyi, \ldots$
tries to, wishes to	$\lambda P \lambda x \lambda i.try\ xPi, \ldots$
is	$\lambda Q \lambda y.Q(\lambda x \lambda i.x = yi)$
some, a	$\lambda P_2 \lambda P_1 \lambda i.\exists x(P_2 xi \wedge P_1 xi)$
every	$\lambda P_2 \lambda P_1 \lambda i.\forall x(P_2 xi \to P_1 xi)$
the	$\lambda P_2 \lambda P_1 \lambda i.\exists x(\forall y(P_2 yi \leftrightarrow y = x) \wedge P_1 xi)$
t_n	v_{α_n} with $\alpha \in$ Monotype

More PTQ-Translations

(1)	[Bill walks]	$walk\,(bill)$
(2)	[[a man] walks]	$\lambda i \exists x. man\ xi \wedge walk\ xi$
(3)	[John finds a unicorn]	$\lambda i \exists x. unicorn\ xi \wedge find\ john\ xi$
(4)	[John [seeks [a unicorn]]]	$\lambda i. try\ john\ \exists x (unicorn\ xi \wedge find\ john\ xi)$
	[[a unicorn]^1[John [seeks t_1]]]	$\lambda i. \exists x (unicorn\ xi \wedge try\ john\ find\ john\ xi)$
(5)	[Bill [is Mary]]	$\lambda i. bill = mary\ i$
(6)	[Bill [is a man]]	$\lambda i. \exists x (man\ xi \wedge x = bill\ \ i)$
(7)	[Necessarily [Bill [is Bill]]]	$\forall i\,((\Omega i \wedge Ri) \rightarrow (bill = bill\ i \rightarrow i))$
(8)	[Possibly [Bill [is Mary]]]	$\neg \forall i\,((\Omega i \wedge Ri) \rightarrow (\neg bill = mary\ i \rightarrow i))$

Wrap-Up

We have developed a single-type semantics for NL:

- The domain D_q unifies individuals, propositions, and worlds.
- From D_q, we can construct individual/propositional concepts, properties, and relations.
- Single-type models assign every PTQ-rendering a denotation and complement in the partial algebra.

We have developed a single-type semantics for 'Montague'-English:

- To model larger fragments, we must define more operations (nominalization, collectivization, grinding, . . .).

Thank you!

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