Relating Theories of Formal Semantics: established methods and surprising results

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Aims and Scope

Aim Survey my recent work on ontological relations between intensional theories of formal semantics.

Intensional theories of formal semantics Formal semantics which (attempt to) model intensional expressions like propositional attitude verbs (1) and verbs of change (2):

(1) a. Bill knows that everything is self-identical.
b. everything is self-identical ⇔ 7 is a prime number
c. Bill knows that 7 is a prime number.

(2) a. The temperature is ninety.
b. The temperature is rising.
c. Ninety is rising.

Intensional Semantic Theories & their Ontology

Intensional theories of formal semantics Formal semantics which model intensional expressions (e.g. (1), (2)):

(1) a. Bill believes that everything is self-identical.
b. everything is self-identical ⇔ 7 is a prime number
c. Bill believes that 7 is a prime number.

(2) a. The temperature is ninety.
b. The temperature is rising.
c. Ninety is rising.

Ontology of intensional semantic theories The different (kinds of) objects which intensional theories assume as the semantic values of NL expressions:

Ontology of Intensional Semantic Theories

Extensional objects (same objects in most theories)

Basic objects:	individuals	(type e)
	(generalized) truth-values	(type t)
Derived objects:	extensional properties	(type $e \to t$), ...

Intensional objects (different objects in different theories)

Basic objects:	possible worlds (s)	(Montague, Kripke, Lewis)
or	imposs. worlds (s')	(Hintikka, Rantala, Zalta)
or	poss. situations (s')	(B&P, Kratzer, Muskens)
or	propositions (p)	(Thomason, C&T, Pollard)
Derived objects:	worlds/situations	(type $p \to t$)
model (1)	propositions	(type $s^{(\prime)} \to t$)
model (2)	individual concepts	($s^{(\prime)} \to e$ or $(p \to t) \to e$)

Ontological Relations b/w Intensional Semantic Theories

Ontological relations between intensional semantic theories
Embedding and reduction relations between (models assuming) these theories' objects:

Models \\ **Primitive types**	e	s	t	$\langle s,t\rangle$	i	p	s'	t'
(Montague 1973)	×	(×)	×					
(Gallin 1975)	×	×	×					
(Montague 1970a; Turner 1997)	×			×				
(Zalta 1997; cf. Wansing 1990)	$\times^{+}$						×	×
(Muskens 1995)	×						×	×
(Liefke forthcoming b)	×	[$\times_M$]	[$\times_M$]					
(Muskens 2005)	×	×	×			×		
(Chierchia and Turner 1988)	$\times^{+}$		[$\times_M$]			$\times^{+}$		
(Thomason 1980)	×		×			×		
(Pollard 2008)	×		×		×	×		
(Fox *et al.* 2002)			[$\times_M$]		×	×		

Aims and Scope

Usual rationale for establishing ontol. relations:

- Transfer the modeling success of one theory to another th'y.
- Effect a flow of confirmation betw. the theories.
- Elucidate the requirements on minimal models of a given linguistic phenomenon.

We show: Some reductions have desirable side-effects:

1. They improve on the th's modeling **adequacy**.
2. They widen the theory's modeling **scope**.

Example 1: the partial reduction of Montague-style semantics to extensional semantics (Liefke and Sanders 2016)

Example 2: the reduction of Montague-style semantics to situated single-type semantics (L. and Werning, in revision)

Reduction 1: Montague Semantics → Extens. Semantics

Restriction: Reduce individual concepts ('the temperature' in (2b)) and properties of individual concepts ('is rising') to extensional objects.

➡ We only reduce the (proper) part of Montague-style semantics which models verbs of continuous change:

(2) a. The temperature is ninety.
b. The temperature is rising.
c. ~~Ninety is rising.~~

Strategy:

1. Represent individual concepts as (codes for) finite sequences of natural numbers (type 0^*);
2. Approximate the continuous functional-interpretation of verbs of continuous change (e.g. 'rise') by an associate (type $1 \equiv (0^* \to 0)$).

Finite Types

Our partial reduction of Montague semantics to extensional semantics uses finite types over the natural numbers:

Definition (Finite types)
The set $\mathbb{T}$ of all **finite types** is the smallest set of strings s.t.,
(i) $0 \in \mathbb{T}$;
(ii) if $\rho, \tau \in \mathbb{T}$, then $(\rho \to \tau) \in \mathbb{T}$.

- We abbreviate $0 \to 0$ as 1, $((0 \to 0) \to 0)$ $(\equiv\ 1 \to 0)$ as 2, and $(n \to 0)$ as $n+1$.
- We denote natural numbers which code finite sequences of natural numbers by 0^*.

Strategy Part 1: representation

- The individ'l concept 'the temperature' from (1) (type $s \to e$) can be represented as the sequence over natural numbers from (2) (type $1 \equiv (0 \to 0) \equiv (\mathbb{N} \to \mathbb{N})$):

$$\langle w, t_0\rangle \mapsto 89, \langle w, t_1\rangle \mapsto 90, \ldots, \langle w, t_n\rangle \mapsto 89 + n \qquad (1)$$

$$89, 90, \ldots, 89 + n \qquad (2)$$

NB: Finite sequences can be coded by a single natural number (type 0^*). But not all numbers code a finite sequence.

- The property of individual concepts 'is rising' can be represented as a set of such sequences: i.e. as the functional φ_{rise} (type $2 \equiv (1 \to 0) \equiv (\mathbb{N}^{\mathbb{N}} \to \mathbb{N})$)

➥ The temperature as given by $\gamma = (T_0, T_1, \ldots)$ is rising iff $\varphi_{\text{rise}}(\gamma) = 1$ and is not rising iff $\varphi_{\text{rise}}(\gamma) = 0$.

Strategy Part 2: countable approximation

- The functional φ_{rise} is continuous:
  - Input sequences are only 'finitely relevant': We assert that $\varphi_{\text{rise}}(\gamma) = 1$ after having observed γ **up to some (finite) point in time n**, i.e. after considering $\overline{\gamma}n = (T_0, \ldots, T_n)$.
  - Identical sequences up to some point n are 'equivalent': If $\beta = (T'_0, T'_1, \ldots)$ has **the same initial segment-up-to-n** as γ, i.e. if $\overline{\beta}n = \overline{\gamma}n$, we also assert that $\varphi_{\text{rise}}(\beta) = 1$.

Definition (Continuity of type-2 functionals)

A type-2 functional φ is **continuous** if

$$\forall \gamma^1 \exists n^0 \forall \beta^1 (\overline{\gamma}n = \overline{\beta}n \to \varphi(\gamma) = \varphi(\beta)),$$

where $\overline{\gamma}n = (T_0, T_1, \ldots, T_n)$ and $\overline{\beta}n = (T'_0, T'_1, \ldots, T'_n)$ (both type 0^*) are the initial segments up to n of γ resp. β.

Strategy Part 2: countable approximation (cont'd)

Definition (Continuity of type-2 functionals)

A type-2 functional φ is **continuous** if

$$\forall \gamma^1 \exists n^0 \forall \beta^1 (\overline{\gamma}n = \overline{\beta}n \to \varphi(\gamma) = \varphi(\beta)),$$

where $\overline{\gamma}n = (T_0, T_1, \ldots, T_n)$ and $\overline{\beta}n = (T'_0, T'_1, \ldots, T'_n)$ (both type 0^*) are the initial segments up to n of γ resp. β.

!! The point of continuity n may be different for different sequences (e.g. 'the temperature', 'the oil price').

'Continuous functionals'-interpretation of (2)

$$\exists \gamma^1 (\forall \beta^1 [temp^2(\beta) \leftrightarrow \gamma = \beta] \land now^2(\gamma) = ninety^0)$$

$$\exists \gamma^1 (\forall \beta^1 [temp^2(\beta) \leftrightarrow \gamma = \beta] \land \varphi^2_{\text{rise}}(\gamma) = 1)$$

$$\varphi^2_{\text{rise}}(\boldsymbol{ninety}^1) = 1$$

Strategy Part 2: associates

- Continuous functionals φ can be countably approximated via their **associates** α_φ (type $1 \equiv (0^* \to 0)$). Associates α_φ enumerate the values of φ at all $\overline{\gamma}n$:

Definition (Associates (Kleene/Kreisel 1959))

An **associate**, α_φ, of a continuous type-2 functional φ is a sequence of numbers (i.e. type $1 \equiv (0^* \to 0)$) such that

$$\forall \gamma^1 \exists n^0 \; \forall N^0 \geq n [\alpha_\varphi(\overline{\gamma}N) = \varphi(\gamma) + 1 \land (\forall i < n)\, \alpha_\varphi(\overline{\gamma}i) = 0].$$

$$\alpha_{\text{rise}}(\overline{\gamma}m) = \begin{cases} 2 & \text{if } \varphi_{\text{rise}}(\gamma) = 1\text{, i.e. the temperature is rising;} \\ 1 & \text{if } \varphi_{\text{rise}}(\gamma) = 0\text{, i.e. the temperature is not rising;} \\ 0 & \text{if } \overline{\gamma}m \text{ is too short to judge if the temp. is rising.} \end{cases}$$

Montague's vs. our 'Associates'-Interpretation of (2)

(2) a. The temperature is ninety.
b. The temperature is rising.
c. Ninety is rising.

Montague's interpretation of (2)

(3) $\exists c^{se}(\forall c_1^{se}[\mathrm{TEMP}^{(se)t}(c_1) \leftrightarrow c = c_1] \wedge c\,(@^s) = \mathrm{NINETY}^e)$
$\exists c^{se}(\forall c_1^{se}[\mathrm{TEMP}^{(se)t}(c_1) \leftrightarrow c = c_1] \wedge \mathrm{RISE}^{(se)t}(c))$
$\mathrm{RISE}^{(se)t}(\mathbf{ninety}^{se})$

Our 'associates'-interpretation of (2)

(4) $\exists \gamma^1(\forall \beta^1[temp^2(\beta) \leftrightarrow \beta = \gamma] \wedge now^2(\gamma) = ninety^0)$
$\exists \gamma^1(\forall \beta^1[temp^2(\beta) \leftrightarrow \beta = \gamma] \wedge \exists n^0[\alpha^1_{\mathrm{rise}}(\overline{\gamma} n) = 2])$
$\exists m^0(\alpha^1_{\mathrm{rise}}(\overline{\mathbf{\mathit{ninety}}}\, m) = 2)$

Advantages of the 'Associates'-Interpretation

Our 'associates'-interpretation of (2)

(4) $\exists \gamma^1(\forall \beta^1[temp^2(\beta) \leftrightarrow \beta = \gamma] \wedge now^2(\gamma) = ninety^0)$
$\exists \gamma^1(\forall \beta^1[temp^2(\beta) \leftrightarrow \beta = \gamma] \wedge \exists n^0[\alpha^1_{\mathrm{rise}}(\overline{\gamma} n) = 2])$
$\exists m^0(\alpha^1_{\mathrm{rise}}(\overline{\mathbf{\mathit{ninety}}}\, m) = 2)$

1. Lower-type interpretations: Concept DPs and intensional VPs are interpreted in type 0 (i.e. 0^*) resp. 1, not in type 1 resp. 2!
2. Computability of NL interpretations: For all relevant cases, associates can be computed from continuous type-2 functionals.
   ➡ Our interpretation of (2) is 'computable'!
3. Context-sensitivity: Associates are introduced through the use of a context-dependent variable. ➡ The domain of application of 'rise' is restricted to a specific, contextually salient, interval.

Advantages of 'Associates': 1. lower types

The 'associates'-interpretation of verbs of continuous change lowers the type-complexity of NL interpretations:

	Montague semantics		Extens. sem.		K&K
Names	se	(rk 1)	e	(rk 0)	**0**
CNs	$(se)t$	(rk 2)	et	(rk 1)	$\mathbf{2} \equiv (1 \to 0)$
IVs	$(se)t$	(rk 2)	et	(rk 1)	$\mathbf{1} \equiv (0^* \to 0)$
TVs	$(((se)t)t)((se)t)$	(rk 4)	$((et)t)(et)$	(rk 3)	...

NB This is in line with the natural sciences and most parts of mathematics, in which very-high-rank objects are extremely uncommon.

Advantages of 'Associates': 2. computable interpretations

- Possible worlds are not effectively/tractably representable (➡ the intractability problem; cf. Lappin 2013, 2015).

➡ Possible world semantics fail to be computationally plausible.

vs. Our proposed semantics does not use possible worlds.

- Our semantics is inspired by the Kleene-Kreisel model, which represents continuous functionals via computable associates.

➡ Our semantics provides **computable** NL interpretations.

Computational properties of associates

The computability of associates:

- In general, there is **no** computable functional which returns an associate on input a continuous type-2 functional.
- Yet, every primitive recursive fct'l has a canonical associate which can be computed via the proc. from (Troelstra 1973).

The computability of the point of continuity *n*:

- In general, there is **no** computable functional which returns *n* on input a continuous type-2 functional and a sequence.
- Yet, the fan functional returns a point of (uniform) continuity on the above input in a fixed compact space (FF is in KK).

➥ Since temp. measurements have bounds dictated by physics, we can compute a point of continuity of φ_{rise} for α_{rise} and γ.

A Note on the Compositional Implementation

- Remember: there is, in general, **no** computable functional that returns an associate on input a continuous type-2 functional.

➥ We can**not** introduce a constant, α, for such a functional in the compositional translation of (2).

- Instead, we introduce a type-1 constant, α_φ, for each type-2 constant φ (e.g. *rise*) that is interpreted as a continuous fctl.
  - Constraints for the **continuity** of *rise*:
    $$\forall\gamma^1 \exists n^0 \forall\beta^1 (\overline{\gamma}n = \overline{\beta}n \rightarrow rise(\gamma) = rise(\beta))$$
  - Constraints for α_{rise} being an **associate** of *rise*:
    $$\forall\gamma^1 \exists n^0 \forall N^0 \geq n[\alpha_{\text{rise}}(\overline{\gamma}N) = rise(\gamma){+}1 \wedge (\forall i < n)\, \alpha_{\text{rise}}(\overline{\gamma}i) = 0]$$

Advantages of 'Associates': 3. context-sensitivity

Intuition 1 (Linguistic context-sensit'y) **For diff. DPs**, 'rise' asserts the DP-referent's rising over different-length intervals:

(5) a. The temperature is rising. (in a few minutes/hours)
b. The oil price is rising. (over several weeks/months)

↩ The point *n* varies with different input sequences.

Intuition 2 (Communicative context-sensit'y) Even **for the same DP**, 'rise' is interpreted w.r.t. diff.-length intervals:

(6) a. Local weather forecast: The temperature is rising. (observe its behavior for a few days)
b. Global climate development: The temp. is rising. (observe its behavior for several decades)

↩ The same sequence has multiple points of continuity.

Integrating the Different Side-Effects

- Associates are computable, lower-type representations of continuous functionals that approximate these functionals w.r.t. a contextually determined parameter.

➥ The advantages of the 'associates'-interpretation are all sides of the same coin!

⬅ vs. other interpretations, which still assume more complex types, are not computable, or rely on the use of other methods to render the interpretation of the sentences from (2) context-sensitive.

Domain and Scope of the 'Associates'-Approach

The 'associates'-approach generalizes to all (continuous) degree achievement verbs and change-of-state verbs:

1. verbs of continuous calibratable change of state:
   drop, grow, increase, plummet, plunge, rocket, rise, surge, ...
2. verbs of entity-specific continuous change of state:
   blush, blossom, burn, ferment, molt, rust, sprout, swell, ...
3. other verbs of continuous state-change, e.g.
   - adjective-related verbs: blunt, clear, cool, dry, empty, quiet, ...
   - change-of-color verbs: blacken, brown, gray, redden, tan, ...
   - '-en' verbs: darken, harden, ripen, sharpen, strengthen, ...
4. (continuous) directed motion verbs:
   arrive, ascend, descend, drop, enter, fall, pass, rise, ...
5. accomplishment verbs: run a mile, build a house, grow up, ...

Domain and Scope of the 'Associates'-Approach (cont's)

Note: The interpretations of the verbs from classes 2 to 5 ...

... are **not** restricted to input sequences of natural numbers;
... may **not** describe temporal change (cf. 'The trail *narrowed* at the end'; 'His skin *darkens* near the artery' (Deo *et al.* 2013));
... do **not** presuppose an established scale or unit of measurement;

e.g. Blushing is a property of sequences of temporal states of an individual, rather than of sequences of natural numbers;

e.g. There is no established unit of measurement of a person's facial redness (or of a window cracking, a storm arriving, etc.).

This does not compromise the applicability of our approach:

Strategy:
- Label temporal/spatial stages of objects by natural numbers;
- Identify a contextually salient unit and scale for the measurement of the relevant property (e.g. visible change in hue).

A Very Partial Reduction?

Restriction: The 'associates'-approach excludes verbs of discontinuous change, that are interpreted as discontinuous functionals (e.g. 'is mostly above 90').

Answers:

1. In natural language, discontinuous expressions are rather rare (5 out of 369 in (Levin 1993)).
2. Verbs of discontinuous change can be accommodated in Bezem's model of strongly majorizable functionals:

Bezem's model	::	Kleene-Kreisel model
weak continuity functional	::	the fan functional
partial representation	::	total/accurate representation

Wrap-Up

We have seen that ...

1. a proper part of Montague-style semantics (which models concept DPs and verbs of change) can be reduced to an extensional semantics inspired by the Kleene-Kreisel model.
2. this reduction improves upon the modeling **adequacy** of Montague-style semantics by ...
   - lowering the types of NL interpretations;
   - ensuring the computability of these interpretations;
   - respecting the role of context in these interpretations.

End of

Reduction 1: Montague Sem's $\rightarrow$ extens. semantics

... on to ...

Reduction 2: Montague Sem's $\rightarrow$ situated single-type semantics

Preview

We will see that ...

1. Montague-style semantics can be completely reduced to an intensional single-type semantics that neutralizes the distinction between individuals and propositions.
2. This reduction widens the modeling **scope** of Montague-style semantics by ...
   - giving a uniform account of the distributional similarities between DP and CP;
   - explaining the truth-evaluability of DP-fragments;
   - explaining semantic relations between DPs and CPs.

Red. 2: Montague Sem. $\rightarrow$ (Situated) Single-Type Sem.

Idea (Partee 2006) NL can be modeled in a semantics that neutralizes the distinction b/w individuals and propositions.

➡ Reduce individuals and propositions to a single basic type, o $(:= s(st))$.

Dual-Type Semantics (DTS; cf. Montague 1970)

- Basic types: e (for ind's) and p (for propositions/sets of worlds);
- Derived types: $\alpha_1(\ldots(\alpha_n\, \boldsymbol{e}))$ and $\alpha_1(\ldots(\alpha_n\, \boldsymbol{p}))$ for all types $\alpha_1, \ldots, \alpha_n$.

Single-Type Semantics (STS)

- Basic type: o (for individuals **and** propositions);
- Derived types: $\alpha_1(\ldots(\alpha_n\, \boldsymbol{o}))$ for all types $\alpha_1, \ldots, \alpha_n$.

!! STS still assumes a hierarchy over the basic type:
➡ single-**base**-type semantics, or **hierarchical** STS

STS vs. DTS Typing

Syntactic Category	DTS type	STS type
Referential DP	e	o }
CP	p	o }
CN, IV	ep	oo }
Complementizer	pp	oo }
⋮	⋮	⋮
Other categories	Replace e and p by o	

NB STS analyzes o as a **complex** type (viz. $s(st)$).

➡ STS identifies individuals and propositions only indirectly (via the introduction of a common reduction base whose members code objects of both types).

STS: the basics

STS interprets CPs and ref'l DPs as functions from contextually specified situations (type s) to situative propositions (type st).

- Contextually specified situations (CSSs) are informationally incomplete parts of possible worlds,
  i.e. are "partial specifications of some of the entities in the universe with [their] properties" (Moltmann 2005).
- CSSs are obtained from worlds in two steps:
  1. Identify spatio-temporal world-parts (specified via the communicative context);
  2. Extract the contextually salient/shared information about the targeted world-part.

STS: the basics (cont'd)

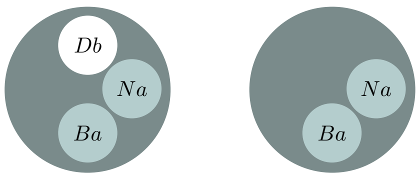
STS interprets CPs and ref'l DPs as functions from contextually specified situations (type s) to situative propositions (type st).

- Situative propositions (SPs) are (characteristic functions of) partial sets of situations.
- ↩ Such sets are familiar from the representation of CP-meanings in situational generalizations of possible world semantics (cf. Muskens 1995).
- But: SPs include information beyond the CPs' lexical info'n.
  ➡ A CP's SP is smaller than the set of situations as which the CP is traditionally interpreted.
- !! To increase granularity, we could instead analyze SPs as primitive propositions.

STS: the basics (cont'd)

Observation The STS-interpretation of CPs and ref'l DPs will use extensions of situations.

- σ_1 is an extension of σ_2, i.e. $\sigma_2 \sqsubseteq \sigma_1$, iff σ_1 contains the information of σ_2.



σ_1 σ_2

!! Every situation σ is an extension of the 'empty' situation, †, s.t. $\dagger \sqsubseteq \sigma \sqsubseteq w$.

STS: interpretations of CPs and referential DPs

- STS interprets a CP p as the type-$s(st)$ function

$$\sigma' \mapsto \{\sigma \mid \sigma' \sqsubseteq \sigma \ \&\ p \text{ in } \sigma\} \quad \text{or} \quad \lambda j^s \lambda i^s [p(i) \wedge \forall q^{st}(q(j) \twoheadrightarrow q(i))],$$

where $\forall q^{st}(q(\sigma_2) \twoheadrightarrow q(\sigma_1))$
$:=$ 'σ_1 contains the info of σ_2' (cf. Muskens 1995, p. 50)

$$\begin{aligned} [\![\text{Bill walks}]\!](\sigma_0) &= \{\sigma \mid \sigma_0 \sqsubseteq \sigma \ \&\ \text{Bill walks in } \sigma\} \\ &= \{\sigma \mid \sigma_0 \sqsubseteq \sigma \ \&\ \text{Bill inhabits } \sigma \ \&\ \text{walks in } \sigma\} \end{aligned}$$

- STS interprets a referential DP a as the type-$s(st)$ function

$$\sigma' \mapsto \{\sigma \mid \sigma' \sqsubseteq \sigma \ \&\ a \text{ inhabits } \sigma\}$$

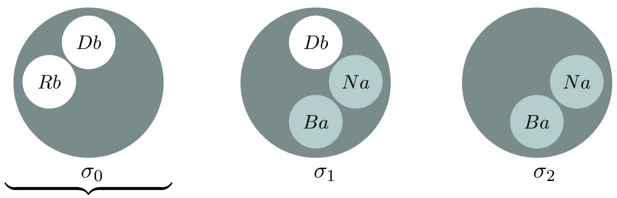
$$[\![\text{Bill}]\!](\sigma_0) = \{\sigma \mid \sigma_0 \sqsubseteq \sigma \ \&\ \text{Bill inhabits } \sigma\}$$

Example: interpretations of CPs and referential DPs

Assume a universe consisting of

- three situations: σ_0, σ_1, σ_2
- two individuals: Barbara (b) and Angelika (a)

Below, *Db* abbreviates Barbara is in the door
Rb abbreviates Barbara is wearing a red sweater
Na abbreviates Angelika is next to the door
Ba abbreviates Angelika is wearing a blue t-shirt



members of the set $[\![$Barbara is (the person) in the door$]\!](\sigma_0)$
$= [\![$Barbara$]\!](\sigma_0) = \{\sigma \mid \sigma_0 \sqsubseteq \sigma$ & Barbara is in the door in $\sigma\}$

Consequences of STS

Observation 1

At each contextually specified situation, the STS-interpretation of a referential DP is a **superset** of the STS-interpretation of each upward-entailing CP containing the DP.

Observation 2

At a contextually specified situation at which the upward-entailing CP containing a referential DP is true, the STS-interpretation of the DP is **identical** to the STS-interpretation of the CP.

Side-Effects of STS

STS has two different kinds of side-effects:

1. Side-effects of the **same-type interpret'n** of DPs and CPs:
   - STS gives a uniform account of the distributional similarities between DP and CP. ➥ the uniformity argument for STS
2. Side effects of the **type-*s*(*st*) interpretat'n** of DPs and CPs:
   - STS straightforwardly explains the truth-evaluability of DP-fragments. ➥ the assertoricity argument for STS
   - STS straightforwardly explains semantic DP/CP-relations. ➥ the entailment argument for STS

The Uniformity Argument

Observation 1 CPs and DPs serve as complements of (some of) the same verbs, and are aligned in some construct's:

(7) a. Pat remembered/saw/imagined/feared/respects [$_{\text{DP}}$Bill].
b. Pat remembered/saw/imagined/feared/respects [$_{\text{CP}}$that Bill was waiting for her].

(8) a. [$_{\text{DP}}$Bill] sucks/is weird/frightens Pat/destroyed his friendship with John.
b. [$_{\text{CP}}$That Bill is obsessed with Pat] sucks/is weird/frightens Pat/destroyed his friendship with John.

(9) a. Pat hat Angst [$_{\text{PP}}$vor [$_{\text{DP}}$Bill]].
b. Pat hat Angst [$_{\text{PP}}$<u>da</u>vor, [$_{\text{CP}}$dass Bill sie küssen könnte]].

The Uniformity Argument (cont'd)

Observation 1 CPs and DPs serve as complements of (some of) the same verbs, and are aligned in some construct's:

⋮ ⋮

(10) Pat remembered/saw/imagined/feared/respects [[$_{DP}$Bill] and [$_{CP}$that he was waiting for her]].

(11) [[$_{DP}$Today's weather] and [$_{CP}$that it does not seem to improve]] sucks.

(12) [$_{DP}$The problem] was [$_{CP}$that Pat did not like Bill].

(13) Mary noticed [$_{DP}$the problem], viz. [$_{CP}$Pat's dislike of Bill].

(14) Mary believes [$_{CP}$that Bill has feelings for Pat]. John is certain of [$_{PRO}$it]$_i$.

The Uniformity Argument (cont'd)

Observation 1 CPs and DPs serve as complements of (some of) the same verbs, and are aligned in some construc's.

Observation 2 To explain Observation 1, DTS needs to combine different special tools/mechanisms:

- polysemy (cf. Sag *et al.* 2005)
- type-shifting (cf. Chierchia and Turner 1988; Potts 2002)
- covert syntactic operators (cf. Kastner 2015)

Observation 3 STS explains Observation 1 without the above tools/mechanisms!

The Assertoricity Argument

Observation 1 DP-fragments express a contextually salient proposition about the DPs' type-*e* referent (cf. Stainton 2006):

(15) A woman is entering the room. A linguist turns to her friend, gestures towards the door, and says (a).
a. [$_{DP}$Barbara Partee].
b. [$_{DP}$Barbara Partee] is the person in the door.

- In the context from (15), the utterance of (15a) is intuitively true iff (15b) is true.

Observation 2 To explain Observation 1, DTS – but not STS – needs to resort to ellipsis (cf. Merchant 2005) or flexible DP-typing (cf. Progovac 2013).

The Entailment Argument

Observation 1 In linguistic contexts that allow the embedding of DPs and CPs, the embedded DP enters into semantic inclusion relations with the associated embedded CP:

(16) Pat remembered [$_{DP}$Bill] and [$_{CP}$that he was waiting for her].

- DP/CP-**entailment** The CP from (16) semantically includes the DP 'Bill' in any utterance context.

Support i: The DP conj. from (16) is intuitively redundant.

Support ii: We cannot only negate the **DP** conj. from (16):

(17) #Pat did not remember [$_{DP}$Bill], but remembered [$_{CP}$that he was waiting for her].

The Entailment Argument (cont'd)

Observation 1 In linguistic contexts that allow the embedding of DPs and CPs, the embedded DP enters into semantic inclusion relations with the associated embedded CP:

- DP/CP-**equivalence** In contexts in which Bill is waiting for Pat, the DP 'Bill' also semantically includes the CP.

  Support: In these contexts, we cannot only negate the **CP** conjunct from (16):

(18) ?? Pat remembered [$_{\text{DP}}$Bill], but did not remember [$_{\text{CP}}$that he was waiting for her].

Observation 2 To explain Obs. 1, DTS – but not STS – again needs to resort to ellipsis or flexible DP-typing.

Wrap-Up

We have seen that ...

1. Montague-style semantics can be reduced to a single-type semantics that neutralizes the distinction between individuals and propositions.
2. This reduction widens the modeling **scope** of Montague-style semantics by ...
   - giving a uniform account of the distributional similarities between DP and CP;
   - explaining the truth-evaluability of DP-fragments;
   - explaining semantic relations between DPs and CPs.

Conclusion

- Different intensional semantic theories stand in different ontological (reduction) relations.
- Most of these relations are identified through familiar techniques from logic (cf. Pollard 2008; Liefke 2016).
- Some **new** relations are identified through established mathematical techniques (e.g. countable approximation), which are **not widely applied** in formal semantics.
- The thus-performed reductions improve upon the reduced theory's modeling **adequacy** and/or modeling **scope**.

Future work: Investigate the promising use of (other) mathematical techniques in other areas of formal semantics!

Thank you!

Chierchia, G. and R. Turner. 1988. *Semantics and property theory*, L&P **11/3**, 261–302.

Deo, A., I. Francez, and A. Koontz-Garboden. *From change to value difference in degree achievements*, Proceedings of SALT 23, UC Santa Cruz, 2013.

Kastner, I. 2015. *Factivity mirrors interpretation*, Lingua **164**, 156–188.

Kleene, S. *Countable functionals*, Constructivity in Mathematics, North-Holland, 1959.

Kreisel, G. *Interpretation of analysis by means of constructive functionals of finite types*, Constructivity in Mathematics, North-Holland, 1959.

Lappin, S. 2015. *Curry typing, polymorphism, and fine-grained intensionality*, Handbook of Contemporary Semantics: second edition (C. Fox and Shalom Lappin, eds.), Wiley Blackwell.

Levin, B. 1993. *English Verb Classes and Alternations*, U of Chicago Press.

Liefke, K. 2016. *Codability and robustness in formal natural language semantics*, New Frontiers in Artificial Intelligence, LNAI, vol. 9067, Springer.

Liefke, K. and S. Sanders. 2016. *A computable solution to Partee's temperature puzzle*, Logical Aspects of Computational Linguistics 2016, LNCS, vol. 10054, Springer.

Liefke, K. and M. Werning. 2016. *Evidence for single-type semantics – an alternative to e/t-based dual-type semantics*, in revision, 46 p.

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Merchant, J. 2005. *Fragments and ellipsis*, L&P **27/6**, 661–738.

Moltmann, F. 2005. *Part structures in situations*, L&P **28/5**, 599–641.

Montague, R. 1970. *English as a formal language*, Formal Philosophy (R.H. Thomason, ed.), Yale UP, 1976.

______. 1973. *The proper treatment of quantification in ordinary English*, Formal Philosophy (R.H. Thomason, ed.), Yale UP, 1976.

Muskens, R. 1995. *Meaning and Partiality*, CSLI.

Partee, B. 2006. *Do we need two basic types?*, Snippets, Vol. 20, Berlin, 2009.

Pollard, C. 2008. *Hyperintensions*, J. of Logic & Computation **18/2**, 257–282.

Potts, C. 2002. *The lexical semantics of parenthetical -as and appositive -which*, Syntax **5/1**, 55–88.

Progovac, L. 2013. *Non-sentential vs. ellipsis approaches*, Language and Linguistic Compass, Vol. 7/11, John Wiley and Sons.

Sag, I., T. Wasow, and E. Bender. 2003. *Syntactic Theory*, CSLI.

Stainton, R. 2006. *Words and Thoughts*, Oxford UP.

Troelstra, A.S. 1973. *Metamathematical Investigation of Intuitionistic Arithmetic and Analysis*, Lecture Notes in Mathematics, vol. 344, Springer.