From Montague Semantics to Modern Type Theories: A Meaningful Comparison

(Proposal for Advanced Course in Language & Logic)

S. Chatzikyriakidis* and Z. Luo†

*CLASP, University of Gothenburg
†Royal Holloway, University of London

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Abstract

Modern type theories (MTTs) have been employed in the last 30 years as foundational languages for formal semantics (MTT-semantics for short), as alternatives to set theory as used in Montague's semantics. However, so far, no direct and meaningful comparison between Montague's semantics and MTT-semantics has been attempted in order to elucidate their similarities/differences and advantages/disadvantages, both on foundational issues in understanding and reasoning and on semantic treatments of linguistic phenomena. In this course, we take up this task and discuss MTT-semantics in direct comparison to Montague semantics. After introducing these two semantic frameworks and discussing their foundational differences, we shall move on to several core linguistic phenomena and compare their treatments in both traditions: modification, copredication, intensionality and event semantics. We discuss the results and propose ways of moving forward.

1 Motivation and Description

Montagovian formal semantics as currently practised in linguistics is based on the set-theoretic model theory, with Church's simple type theory [20] as the intermediate language (cf., Montague Grammar and related approaches within this tradition). Throughout the years, many researchers have realised the benefits of using richer typing systems in formal semantics and proposed various approaches as alternatives or enrichments to the Montagovian approach including [44, 2, 21, 45, 28] and a recent collection of papers in [15]. A typical approach is to consider formal semantics in Modern Type Theories (MTT-semantics for short)[1]. This work already spans more than 30 years: it starts to take shape with Ranta's seminal work [44] but can even be traced back to earlier work by researchers like Sundholm [46, 47]. Many interesting developments in the use of MTTs for linguistic semantics have been made throughout the

*Dr Stergios Chatzikyriakidis; email: stergios.chatzikyriakidis@gu.se

†Prof Zhaohui Luo; email: zhaohui.luo@hotmail.co.uk; home page: http://www.cs.rhul.ac.uk/home/zhaohui/.

[1]By MTTs, we refer to the family of formal systems such as Martin-Löf's intensional type theory [41, 43], pCIC in Coq [23, 22] and the Unifying Theory of dependent Types [30]. MTTs were initially developed for the foundations of constructive mathematics and later implemented by computer scientists in proof assistants [1, 22, 8] for formalisation of mathematics and verification of programs.

years [7, 24, 32, 35, 5, 19] and MTTs have now become a viable alternative for the foundational semantic language [16].

Despite the fruitful developments, communication between the two communities, i.e. the MG and the MTT communities, has been in general poor and there are very limited discussions on the advantages and disadvantages of the two approaches. Put in another way, there have been no meaningful comparisons on the ways that these different formal systems treat core linguistic phenomena. In this course, we will attempt such a meaningful comparison of these two different approaches to semantics, highlighting similarities/differences and advantages/disadvantages of MG on the one hand, and MTT-semantics on the other.

We shall start by introducing the formal systems behind the two approaches. MTTs have a rich type structure which is not available in simple type theory (or IL, the intermediate language in Montague Grammar [42, 25]); these include:

- Dependent Σ-types. Besides modelling intersective adjective modification [44, 34], Σ-types are also useful in describing subsets as types and organisations in formal semantics.

- Dependent Π-types and type universes. Π-types are useful especially when used together with universes to provide the mechanism of Π-polymorphism. These can be exemplified by the proposals of modelling co-ordinations [10] and those for modelling verb-modifying adverbs, subsective adjective modification and generalised quantifiers [33, 14, 29].

- Many other inductive types, which have proved useful in semantic modelling and organisation of formal semantics. For example, disjoint union types have been usefully employed to model privative adjective modification [11, 14].

Furthermore, some of the mechanisms in MTTs, developed in formalisation of mathematics, have proved to be very useful in formal semantics; these include (1) setoids, whose usefulness has been demonstrated by means of modeling the identity criteria of CNs [17], and (2) subtyping mechanisms [31, 40], which has proved to be crucial for MTT-semantics to become viable.

After introducing both formal settings, we shall then focus on three case studies involving well-known linguistic phenomena and discuss how they have been treated in both semantic frameworks, partly based on published results and partly based on new analyses. (1) *Modification* [11, 14]; (2) *Copredication* [32, 17]; (3) *Event Semantics* [39] and *Intensionality*. The third case study involves more advanced (and some new and unpublished) studies.

We shall also discuss another important respect in this comparison: Montague semantics is model-theoretic (based on set-theoretical model theory), while the MTT-semantics is both set-theoretic and proof-theoretic [36]. We shall illustrate why MTT-semantics can be seen as model-theoretic (and hence proving powerful tools in semantic studies) as well as proof-theoretic, in the sense studied by logicians such as Gentzen and Prawitz (and hence allows meaning-theoretic understanding and practical reasoning for NLs by using the existing proof assistants [13]).

2 Tentative Outline

Tentatively, the course will consist of the following lectures:

- *Monday: Introducing MTTs on a par with Montague Semantics.* In this lecture, we look at the formal systems behind MTTs and MS, concentrating on their similarities and most importantly their differences. The participants will have the opportunity to

familiarize themselves with MTTs, concentrating on dependent typing, typing universes, coercive subtyping and their potential uses in conjunction with a discussion on what new these structures bring to the study of semantics compared to the Montagovian semantic framework.

- *Tuesday: Case study on modification.* In this lecture, we concentrate on modification, both adjectival and adverbial. We compare approaches cast within MTTs and MS respectively and compare predictions. We start with the classic tripartite adjectival distinction of intersective, subsective and non-subsective adjectives, we continue by discussing gradable adjectives, multidimensional adjectives, veridical adverbs, manner and speaker oriented adverbs. Some of the issues that will arise during the discussion are: inference via typing v.s. inference via meaning postulates, regular v.s. polymorphic typing, coarse grained domain of individuals v.s. a fine-grained one.

- *Wednesday: Case study on copredication.* Copredication is the phenomenon in which more than one predicate (verb or adjective) requiring different types of arguments, are used in coordination and applied to the "same" CN argument, e.g. in *John picked up and mastered the book.*. In order to deal with these structures, pustejovsky (1994) introduced the notion of a dot-object, basically an object with two senses. We discuss alternative formalizations of dot-types and discuss why are these constructions problematic. We then look at the introduction of dot-types in MTTs [32, 35] to illustrate how a formal treatment of dot-types can be done in MTT-semantics. We then study the individuation criteria for dot-types, comparing two accounts – one in [17] on the one hand and the other by Gotham in [26, 27] on the other.

- *Thursday: Case study on event semantics and intensionality.* Two more advanced topics in semantics will be studied in this lecture. We shall first (neo-)Davidsonian event semantics both in both the Montagovian setting and the MTT-setting and show that the dependent typing gives a better treatment about events [39] and explain how MTT-based event semantics can be considered. The other topic we shall consider is how to deal with hyperintensionality in MTTs and illustrate this be means of a treatment of belief operator in MTTs (more precisely, in an impredicative MTT).

- *Friday: model-theoretic and proof-theoretic semantics.* In this lecture, we study model-theoretic semantics (in Tarski's tradition) and proof-theoretic semantics (as studied by Gentzen, Prawitz, Martin-Löf, among others). As well-known, Montague semantics is model-theoretic and, as we shall illustrate, MTT-semantics is both model-theoretic and proof-theoretic (cf., [36] and further developments). It is argued that this gives MTT-semantics a valuable advantage: being model-theoretic, it provides powerful mechanisms to capture semantics of a wide range of linguistic features (as illustrated by the above case studies), and being proof-theoretic, it has a solid meaning-theoretic foundation and can be directly implemented by means of the current proof technology to support computer-assisted reasoning in natural language [13]. These give MTT-semantics, as we will claim, unprecedented advantages as compared with the Montague setting.

Course material, including lecture notes, lecture slides and related papers will be made available to the students.

3 Expected Level and Prerequisites

The proposed is an advanced course in the area of Language and Logic. A good background in logic and basic knowledge of Montague Grammar are useful and recommended.

4 Other Information

4.1 Proposed Lecturers

Both of the proposed lecturers have worked extensively on MTT-based formal semantics. Their collaboration started at Royal Holloway, University of London, as part of a grant funded by the Leverhulme Trust in U.K.

- *Prof Zhaohui Luo* is full professor in Department of Computer Science, Royal Holloway, University of London. He is an expert in modern type theories [30] and the associated proof assistants [38, 8]. For a long time, Luo was a member of the steering committee of the TYPES consortium which has a successful conference series on modern type theories and their applications. In the last decade or so, Luo has worked and published on MTT-semantics including, for example, [35, 32, 33, 34, 3, 14, 15] and others.

- *Dr Stergios Chatzikyriakidis* did his PhD in KCL and is currently a permanent researcher at the University of Gothenburg and Research Coordinator of the Centre for Linguistic Theory and Studies in Probability. He has worked on various aspects of MTT-based semantics [11, 9, 19] and he has used Coq for NL semantics, implementing MTT semantics to reason about them and also deal with various Natural Language Inference phenomena [18, 6].

The proposers are coauthoring a book on Formal Semantics in Modern Type Theories to be published by Wiley/ISTE. More information MTT-semantics and related publications can be found at the following web page: `http://www.cs.rhul.ac.uk/home/zhaohui/lexsem.html`.

4.2 Previous ESSLLI Courses

- At ESSLLI 2011 in Ljubljana, one of the proposers (Z. Luo) gave a joint advanced course with Prof N. Asher on Lexical Semantics [4].

- At ESSLLI 2014 Tubingen, the proposers gave an advanced course titled *Formal Semantics Using Modern Type Theories: Theory and Implementation* [12].

- At ESSLLI 2017 in Toulouse, one of the proposers (Z. Luo) gave an introductory course titled *Modern Type Theories for Natural Language Semantics* [37].

References

[1] Agda proof assistant. `http://appserv.cs.chalmers.se/users/ulfn/wiki/agda.php`, 2008.

[2] N. Asher. *Lexical Meaning in Context: a Web of Words*. Cambridge University Press, 2012.

[3] N. Asher and Z. Luo. Formalisation of coercions in lexical semantics. *Sinn und Bedeutung 17, Paris*, 2012.

[4] N. Asher and Z. Luo. Type-theoretical lexical semantics. *Advanced course at ESSLLI 2014, Tubingen, Germany*, 2014.

[5] D. Bekki. Representing anaphora with dependent types. *LACL 2014, LNCS 8535*, 2014.

[6] Jean-Philippe Bernardy and Stergios Chatzikyriakidis. A type-theoretical system for the fracas test suite: Grammatical framework meets coq. In *IWCS 2017-12th International Conference on Computational Semantics-Long papers*, 2017.

[7] P. Boldini. Formalizing context in intuitionistic type theory. *Fundamenta Informaticae*, 42(2):1–23, 2000.

[8] P. Callaghan and Z. Luo. An implementation of LF with coercive subtyping and universes. *Journal of Automated Reasoning*, 27(1):3–27, 2001.

[9] S. Chatzikyriakidis. Adverbs in a modern type theory. In N. Asher and S. Soloviev, editors, *Proceedings of LACL2014. LNCS 8535*, pages 44–56, 2014.

[10] S. Chatzikyriakidis and Z. Luo. An account of natural language coordination in type theory with coercive subtyping. In Y. Parmentier and D. Duchier, editors, *Proc. of Constraint Solving and Language Processing (CSLP12). LNCS 8114*, pages 31–51, Orleans, 2012.

[11] S. Chatzikyriakidis and Z. Luo. Adjectives in a modern type-theoretical setting. In G. Morrill and J.M Nederhof, editors, *Proceedings of Formal Grammar 2013. LNCS 8036*, pages 159–174, 2013.

[12] S. Chatzikyriakidis and Z. Luo. Formal semantics in modern type theories: Theory and implementation. *Advanced course at ESSLLI 2014, Tubingen, Germany*, 2014.

[13] S. Chatzikyriakidis and Z. Luo. Proof assistants for natural language semantics. *Logical Aspects of Computational Linguistics 2016 (LACL 2016)*, 2016.

[14] S. Chatzikyriakidis and Z. Luo. Adjectival and adverbial modification: The view from modern type theories. *J. of Logic, Language and Information*, 26, 2017.

[15] S. Chatzikyriakidis and Z. Luo, editors. *Modern Perspectives in Type-Theoretical Semantics*. Springer, 2017.

[16] S. Chatzikyriakidis and Z. Luo. *Formal Semantics in Modern Type Theories*. Wiley & ISTE, 2018. (to appear).

[17] S. Chatzikyriakidis and Z. Luo. Identity criteria of common nouns and dot-types for copredication. *Oslo Studies in Language*, 2018. Submitted manuscript.

[18] Stergios Chatzikyriakidis and Zhaohui Luo. Proof assistants for natural language semantics. In *International Conference on Logical Aspects of Computational Linguistics*, pages 85–98. Springer, 2016.

[19] Stergios Chatzikyriakidis and Zhaohui Luo. Adjectival and adverbial modification: The view from modern type theories. *Journal of Logic, Language and Information*, 26(1):45–88, 2017.

[20] A. Church. A formulation of the simple theory of types. *J. Symbolic Logic*, 5(1), 1940.

[21] R. Cooper. Records and record types in semantic theory. *J. Logic and Compututation*, 15(2), 2005.

[22] The Coq Development Team. *The Coq Proof Assistant Reference Manual (Version 8.3), INRIA*, 2010.

[23] Th. Coquand and G. Huet. The calculus of constructions. *Information and Computation*, 76(2/3), 1988.

[24] R. Dapoigny and P. Barlatier. Modeling contexts with dependent types. *Fundamenta Informaticae*, 21, 2009.

[25] Daniel Gallin. Intensional and higher-order modal logic: with applications to montague semantics. 1975.

[26] M. Gotham. *Copredication, quantification and individuationy.* PhD thesis, University College London, 2014.

[27] Matthew Gotham. Composing criteria of individuation in copredication. *Journal of Semantics*, 34(2):333–371, 2016.

[28] Justyna Grudzinska and Marek W. Zawadowski. Generalized quantifiers on dependent types: A system for anaphora. *CoRR*, abs/1402.0033, 2014.

[29] G. Lungu and Z. Luo. Monotonicity reasoning in formal semantics based on modern type theories. *Logical Aspects of Computational Linguistics 2014 (LACL 2014), Toulouse. LNCS 8535*, 2014.

[30] Z. Luo. *Computation and Reasoning: A Type Theory for Computer Science.* Oxford University Press, 1994.

[31] Z. Luo. Coercive subtyping. *Journal of Logic and Computation*, 9(1):105–130, 1999.

[32] Z. Luo. Type-theoretical semantics with coercive subtyping. *Semantics and Linguistic Theory 20 (SALT20), Vancouver*, 2010.

[33] Z. Luo. Contextual analysis of word meanings in type-theoretical semantics. *Logical Aspects of Computational Linguistics (LACL'2011). LNAI 6736*, 2011.

[34] Z. Luo. Common nouns as types. In D. Bechet and A. Dikovsky, editors, *Logical Aspects of Computational Linguistics (LACL'2012). LNCS 7351*, 2012.

[35] Z. Luo. Formal semantics in modern type theories with coercive subtyping. *Linguistics and Philosophy*, 35(6):491–513, 2012.

[36] Z. Luo. Formal Semantics in Modern Type Theories: Is It Model-theoretic, Proof-theoretic, or Both? *Invited talk at Logical Aspects of Computational Linguistics 2014 (LACL 2014), Toulouse. LNCS 8535*, pages 177–188, 2014.

[37] Z. Luo. Modern type theories for natural language semantics. *Introductory course at ESSLLI 2017, Toulouse, France*, 2017.

[38] Z. Luo and R. Pollack. LEGO Proof Development System: User's Manual. LFCS Report ECS-LFCS-92-211, Dept of Computer Science, Univ of Edinburgh, 1992.

[39] Z. Luo and S. Soloviev. Dependent event types. In de Queiroz R. Kennedy J., editor, *Logic, Language, Information, and Computation. WoLLIC 2017, LNCS*, volume 10388. Springer, Berlin, Heidelberg, 2017.

[40] Z. Luo, S. Soloviev, and T. Xue. Coercive subtyping: theory and implementation. *Information and Computation*, 223:18–42, 2012.

[41] P. Martin-Löf. An intuitionistic theory of types: predicative part. In H.Rose and J.C.Shepherdson, editors, *Logic Colloquium'73*, 1975.

[42] R. Montague. *Formal Philosophy*. Yale University Press, 1974. Collected papers edited by R. Thomason.

[43] B. Nordström, K. Petersson, and J. Smith. *Programming in Martin-Löf's Type Theory: An Introduction*. Oxford University Press, 1990.

[44] A. Ranta. *Type-Theoretical Grammar*. Oxford University Press, 1994.

[45] C. Retoré. The montagovian generative lexicon Tyn: a type theoretical framework for natural language semantics. In R. Matthes and A. Schubert, editors, *Proc of TYPES2013*, 2013.

[46] G. Sundholm. Proof theory and meaning. In D. Gabbay and F. Guenthner, editors, *Handbook of Philosophical Logic III: Alternatives to Classical Logic*, pages 471–506. Reidel, 1986.

[47] G. Sundholm. Constructive generalized quantifiers. *Synthese*, 79(1):1–12, 1989.