The 2015 MoL S.-Y. Kuroda Prize

The Association for Mathematics of Language (SIGMOL) awards the second S.-Y. Kuroda Prize for Lasting Contributions to the Mathematics of Language to

Professor Edward L. Keenan

of the UCLA Linguistics Department. The prize recognizes Ed for his work on boolean semantics of natural language, and in particular on the study of determiners.

Formal natural language semantics began in earnest with the papers of Richard Montague (see Montague [1974]). Published in the early 1970's, Montague's work built on ideas from mathematical logic and type theory, and showed linguists that the field of formal semantics was possible in the first place. Ed's work on *boolean semantics* developed model-theoretic semantics in two related ways.

First, Ed went beyond unstructured sets in thinking about meaning. *Boolean algebras* are algebraic structures where one takes as basic operations that correspond to the conjunctions *and* and *or*, the negation operator *not*, and also a notion of abstract truth value objects "true" and "false". Typical boolean algebras are the powerset algebras consisting of the set of all subsets of a set A, with intersection, union, and complement as the operations, the empty set as "false", and A itself as "true". Ed is responsible for the suggestion that the 'meaning spaces' of most linguistic categories should be taken as boolean algebras. Ed's book with L. Faltz, *Boolean Semantics for Natural Language* [Keenan and Faltz, 1985] persuasively argues that the semantic spaces of nearly all syntactic categories should be seen as boolean algebras rather than as unstructured sets. This allows one to use ideas from the mathematical study of boolean algebras to natural language semantics. Indeed, it is a hallmark of Ed's work to find algebraic structure in language and to use that structure to make interesting findings about language.

Second, Ed applied this boolean viewpoint in particular to the semantics of determiners (Dets). Dets combine with nouns to form noun phrases (or determiner phrases) and thus denote functions from subsets of the universe to noun phrase denotations. The idea of letting noun phrases denote sets of subsets (of the universe of a model) goes back to Montague. So Det denotations would be functions from subsets to sets of subsets. These are known as *generalized quantifiers* from mathematical logic [Lindström, 1966, Mostowski, 1957]. Ed was one of the pioneers of using the theory of generalized quantifiers in the

semantics of noun phrases and determiners, together with Barwise and Cooper [1981] and Higginbotham and May [1981]. A crucial property of determiner denotations is that, for a sentence of the form [Det N] VP, only the objects in the restriction (the N denotation) matter for its truth value; objects in the VP denotation outside the restriction play no role. Thus, for example, *Most philosophers smoke* is logically equivalent to *Most philosophers are philosophers who smoke*; smokers that are not philosophers have no bearing on the truth or falsity of this sentence. This property was observed independently by the authors mentioned above; Keenan named it *conservativity* and that name has stuck.

Important early papers by Keenan on the semantics of determiners and noun phrases are Keenan and Stavi [1986] (written and circulated around 1980), Keenan and Moss [1985], and Keenan [1987]. The approach is distinctly algebraic, emphasizing the boolean structure of all the categories involved. A main interest of Ed was the *expressivity* of natural language in these categories, which he took to be the following question: Given a finite universe E, which of the mathematically possible noun, noun phrase, and determiner denotations over E are actually denotable by English phrases of the corresponding category? His well-known Effability Theorem states that *all* conservative functions from noun denotations to NP denotations are thus denotable. The method of proof is to start from a small class of basic determiner denotations, and then show that all conservative ones can be obtained from these by boolean operations. The result is remarkable since the number of such conservative functions grows exponentially with the size of E; as Ed showed, it is 2^{3^n} when E has n elements.

Someone might object that although it is well attested that boolean structure can be found in almost all syntactic categories, can we really assume that, say, the class of Det denotations is closed under *arbitrary* (finite) boolean operations? Ed had several responses. One is that although it might be syntactically illicit to prefix a Det with"not", or insert "and" between two Dets, there are often other Dets with just that denotation. For example, *not at least five* is not an English Det, but *at most four* is. A more sophisticated answer used algebraic facts about possessive Dets. In fact, the analysis of a rich class of possessive English constructions in Keenan and Stavi [1986] was unprecedented both in terms of empirical coverage and systematic semantics. Keenan and Stavi gave a mathematical argument concerning the functions denoted by expressions like the possessive marker *'s* and the more complex *'s five or more* (as in *John's five or more cats are a nuisance to his neighbors*) that the class of Det denotations must indeed be closed under boolean operations.

Ed studied other important subclasses of Dets and their algebraic properties, such as *cardinal* Dets, *exceptive* Dets, and *intersective* Dets. The latter are those for which only the intersection of the N denotation and the VP denotation matters, and these figure in the careful analysis in Keenan [1987] of the time-worn problem of 'existential there' sentences: Why is it that *There are exactly five guests in the garden* is fine, but *There are most guests in the garden* is not? Ed convincingly argued that, essentially, exactly the intersective Dets can appear in these constructions, thus giving a semantic solution to this problem.

Ed has many further papers on the mathematical properties of Det denotations, for example, his study of quantifier prefixes and of sortal reducibility in Keenan [1993]. Let us end by mentioning his work on polyadic quantifiers, in particular those arising from sentences with quantified subjects and objects, as in *Most critics reviewed at least two films.* This sentence can be taken to involve a quantifier relating two sets (*critic* and *film*) and one binary relation (*reviewed*), that is, a polyadic quantifier, but in this particular case a compositional analysis reveals that the quantifier is *reducible* to the two monadic NP denotations *most critics* and *at least two films.* It is thus inside what Johan van Benthem called the "Frege boundary", but many similar-looking constructions are not reducible; for example, *Different people like different things*, or *Every student answered the same questions on the exam.* Keenan [1992, 1996] presents an enormous variety of non-reducible constructions in English, and gives a mathematical characterization of the class of reducible quantifiers.

As we have seen, Ed's work used ideas and tools from abstract algebra in connection with serious problems in semantics. As a result, his legacy in formal semantics and in the mathematics of language is indisputable. (Indeed, Ed is famous for his work in several other areas of linguistics, but here we have focused only on boolean semantics and determiners.) The study of boolean structure in meaning spaces that he initiated is now commonplace. And his work on the semantics of determiners, both the theoretical results and the many detailed analyses of important classes of determiners, are obvious points of reference for today's formal semanticists.

Larry Moss
Dag Westerståhl

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Shorter version, tailored for the presentation itself

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Second, Ed applied this boolean viewpoint in particular to the semantics of determiners (Dets). This includes work on the expressive power of natural language, on the semantics of possessive determiners, existential "there" sentences, polyadic quantifiers, and sortal reducibility. Again, Ed's work used ideas and tools from abstract algebra in connection with serious problems in semantics.

Due to this large body of work, his legacy in formal semantics and in the mathematics of language is indisputable. (Indeed, Ed is famous for his work in several other areas of linguistics, but here we have focused only on boolean semantics and determiners.) The study of boolean structure in meaning spaces that he initiated is now commonplace. And his work on the semantics of determiners, both the theoretical results and the many detailed analyses of important classes of determiners, are obvious points of reference for today's formal semanticists.