all its relation symbols have finite rank. A formula is restricted if every one of its atomic subformulas has the form $\mathbf{R}(v_0, \ldots, v_{\kappa-1})$, where $\mathbf{R}$ has rank κ.

If $\mathfrak{M}$ is a possible model for an ordinary language, then the relations definable in $\mathfrak{M}$ by means of restricted formulas forms a cylindric set algebra (4.3.3). This algebra has dimension equal to the number of variables in Λ, it is both regular and locally finite-dimensional (4.3.5), and it has a distinguished set of generators, corresponding to the relation symbols of Λ. An especially important observation is that since Λ is ordinary, the same algebra is obtained by using all formulas (4.3.7). This justifies the focus on restricted formulas, and for algebraic purposes, this limitation is extremely convenient. Conversely, every locally finite-dimensional regular cylindric set algebra with generators comes from a unique possible model for Λ (4.3.10). The logical concept of possible model for a language is thus provided with an algebraic translation.

For any set Σ of formulas, two kinds of equivalence relative to Σ are considered—semantical and proof-theoretical. Semantical equivalence is defined as usual from the notion of satisfaction for formulas, and proof-theoretical equivalence comes from an especially simple axiomatization of first-order logic. For ordinary languages these two equivalence relations are the same, by the completeness theorem. But they may be different for non-ordinary languages, as shown by the existence of non-representable cylindric algebras.

For any set of formulas Σ and either type of equivalence, a cylindric algebra can be constructed by defining operations on the equivalence classes of formulas. The main logical representation result (4.3.28) states that every cylindric algebra can be obtained in this way, by using proof-theoretical equivalence, and every representable cylindric algebra can be so obtained, by using semantical equivalence. It also says that the algebras of formulas naturally associated with first-order theories are exactly the locally finite-dimensional cylindric algebras. This result can be used to establish equivalences between representation theorems and completeness theorems.

A representable cylindric algebra of dimension 3 or more that is free on 4 generators is not atomic (4.3.32). This is an application of the connection established by 4.3.28, and uses a result from logic, due to Ehrenfeucht and Fuhrken. Németi has improved this result by replacing "4" with "1" and eliminating "representable." This confirms a result of Tarski, mentioned in Part I, p. 339. Tarski's proof could not be reconstructed after his death.

Several other ways of translating logical notions into algebraic ones are discussed. Usually there is more than one translation. Here is a sample of some pairs of corresponding logical and algebraic concepts: theories and filters (4.3.30), interpretations and homomorphisms (4.3.37), definitional equivalence and isomorphisms (4.3.43), and formulas and terms (4.3.56). The correspondence between terms and formulas allows characterizations of proof-theoretical and semantical equivalence in terms of identities true in all cylindric algebras and all representable cylindric algebras, respectively (4.3.57 and 4.3.49). The section closes with algebraic translations of a few standard logical results on categoricity, elementary extensions, omitting types, Beth's theorem, and prime models.

Chapter 5 is devoted to other algebraic versions of logic, with emphasis on their connections with cylindric algebras. Five versions are considered in detail: diagonal-free cylindric algebras, projective algebras, relation algebras, polyadic algebras, and relativized cylindric algebras. Diagonal-free cylindric algebras differ from cylindric algebras by not having diagonal elements, while Halmos's polyadic algebras have, in a sense, more operations than cylindric algebras. In Part II their algebraic theory is developed to some extent, and many results for cylindric algebras have analogues for these two types of algebras. The projective algebras of Everett and Ulam correspond to certain types of 2-dimensional diagonal-free cylindric algebras (5.2.4), while relation algebras correspond to a special class of 3-dimensional cylindric algebras (5.3.17). Relativized cylindric algebras may not be cylindric algebras. The main results are that two natural classes of relativized cylindric algebras form varieties that are not finitely axiomatizable (5.5.8, 5.5.10, 5.5.12). The chapter closes with a survey of the abstract algebraic logic of Andréka and Németi, and twenty-one other kinds of algebraic logics, such as W. Craig's algebras of sets of finite sequences, B. Schein's general relation algebras, and dynamic algebras from computer science.

Each chapter has its own list of problems (some now solved). There are two bibliographies and three indexes of symbols (all continuations of the ones in Part I), and an index of names and subjects.

ROGER D. MADDUX

HARRY C. BUNT. ***Mass terms and model-theoretic semantics.*** Cambridge studies in linguistics, no. 42. Cambridge University Press, Cambridge etc. 1985, xiii + 325 pp.

Mass nouns such as 'water,' 'sand,' and 'furniture' and mass *terms* such as 'cold water' and 'sand in the box' differ from count nouns and count terms such as 'frog,' 'table,' and 'red apple' on both syntactic and semantic grounds. Syntactically, mass terms do not have a singular and a plural form, they do not take number words or the indefinite article, and they take the determiners 'much' and 'little' rather than 'many' and 'few.' Semantically, mass terms differ from count terms in that they typically refer without individuating, without "dividing" their extension into discrete objects. The book under review, which is an extension and revision of Bunt's doctoral dissertation, attempts to provide a formal, model-theoretic semantics that can account for these syntactic and semantic differences. Such a semantics should, according to Bunt, (1) "offer a precise specification of the truth conditions of sentences" containing mass terms, "expressed in terms of the denotations of their constituents" (p. 4), (2) account for the logical properties of sentences containing mass terms, such as the validity of inferences (p. 25), and (3) assign entities to serve as denotations of mass terms that are in accord with semantic intuitions as to how mass terms refer (p. 43). Although I do not think that Bunt is entirely successful in attaining these goals, the book contains much valuable and original material that should be of interest to both linguists and philosophers. Many chapters contain introductory sections that help make the book accessible to the non-expert. In general, I think anyone with an interest in the semantics of mass terms will profit from reading this book.

Chapters 1–4 contain a thorough, if somewhat disjointed, account of the problems that must be faced in adapting standard model-theoretic semantics, whose set-theoretic apparatus was developed with the case of count terms in mind, to the case of mass terms. It includes an extensive critical review of proposals by Quine, Moravcsik, Parsons, Burge, and others. Chapters 5–7 present Bunt's own semantic framework for mass terms, including developments of his "ensemble theory" and "two-level model-theoretic semantics" (discussed below), and a formal analysis of amount terms (such as 'two tons of snow'). Chapters 8 and 9 contain detailed accounts of mass term quantification and modification that are sensitive to subtle and often ignored distinctions. The accounts are illustrated by providing formal semantic representations for sample English sentences containing mass terms, and a grammar capable of generating these representations.

Bunt begins by discussing attempts to characterize the mass-count distinction in syntactic terms. Although Bunt's discussion of syntactic criteria is illuminating, this section coheres rather badly with the rest of the book. Bunt argues that syntactic criteria must be applied to noun occurrences, not nouns, because most nouns have both a count and a mass use. He therefore *defines* 'mass noun' as short for 'mass occurrence of noun,' where the latter is defined by a short list of syntactic criteria (p. 15). But on this definition most of the examples throughout the book do not contain mass nouns at all; for example, noun occurrences preceded by 'the' will not be classified one way or the other. Moreover, the lexicon of the grammar presented in Chapters 8 and 9 assigns nouns the attribute mass or count without regard to how they occur. The practice of the book is to take semantic criteria as primary: a noun occurrence can be labeled count or mass on semantic grounds whether or not the distinction is reflected in surface grammar.

Bunt turns next to semantic criteria. To capture the semantic difference between mass terms and count terms, Bunt uses the part-whole relation of mereology. Mass terms, unlike count terms, refer *cumulatively*, i.e., any sum of things which are *m* is *m*; and, according to Bunt, *distributively*, i.e., any part of something which is *m* is *m*. On Bunt's semantics, both of these conditions are formally valid for any mass term '*m*' (p. 98), a point I will return to below. These two conditions, however, do not fully capture the semantic difference between mass and count terms. The fundamental semantic distinction, according to Bunt, is captured by his *homogeneous reference hypothesis*: "Mass nouns refer to entities as having a part-whole structure without singling out any particular parts and without making any commitments concerning the existence of minimal parts" (p. 46). Although Bunt claims that "all the linguistic evidence" supports this hypothesis (p. 45), he never explains what sort of evidence he has in mind. Nor is it ever made clear how this hypothesis is supposed to relate to the conditions of cumulative and distributive reference, joint satisfaction of which is also called, confusingly, *homogeneous reference* (p. 203).

How does the homogeneous reference hypothesis constrain a semantics for mass terms? Bunt seems to hold that it rules out an approach that uniformly takes the denotations of mass terms to be sets. But that seems wrong. Why should the set of all parts of a mereological whole be any more committed to minimal parts than the whole itself? Moreover, if one is willing to make use of idealized (or fictional) point objects, then mereological wholes can be represented by sets of point objects, and an appropriate part-whole relation can be defined set-theoretically. (For example, "is a subset with measure greater than zero" has the right formal structure.) Bunt's rejection of a set-theoretic approach to mass terms seems to be based more upon a semantic intuition that sets are inappropriate, rather than any general argument that such an approach is unworkable (although his criticisms of particular set-based proposals are sound, pp. 33–43).

Be that as it may, Bunt chooses to extend the formal semantic apparatus in a way that will allow mass terms to denote (something like) mereological wholes. The use of mereology in providing a semantics for mass terms presents two problems, and it is the ways in which Bunt tries to resolve these problems that make his approach unique. First, there is the familiar problem of minimal parts. For many mass terms, there is a minimal size beneath which the term no longer applies: 'furniture' applies to tables, but not legs of tables; 'water' applies to puddles, but not atomic parts of puddles. This suggests that to analyze, for example, 'x is water' as '$x \subseteq$ WATER,' where 'WATER' denotes a mereological whole and '$\subseteq$' denotes the part-whole relation, cannot get the truth conditions right, as can be seen by taking 'x' to denote an oxygen atom that is part of some water molecule in a puddle of water. I return to this problem below.

The second problem, according to Bunt, is this: "mereology has to be 'interfaced' with the logical framework of the general semantic theory, which is based on modern set theory" (p. 51). To solve the interface problem, Bunt introduces his *ensemble theory*, a theory that unifies set theory and mereology by taking the subset relation to be a special case of the part-whole relation. Ensemble theory has two primitives. There is a part-whole relation, $\subseteq$, in terms of which such operations as merge (summation) and overlap (intersection) can be defined. Whereas all ensembles have a part-whole structure, some have a further, internal structure that can be expressed using the second primitive, the unicle relation, which corresponds to the relation between an element and its singleton ('unicle' for 'unique element of'). From these two primitives, a membership relation can be defined: x is a *member* of y iff x is the unicle of some part of y. An *atomic* (or minimal) ensemble is a non-empty ensemble that has only itself and the empty ensemble as parts. (There is a unique empty ensemble). An ensemble is *continuous* if it is non-empty and has no minimal parts; *discrete* if it is the merge of its atomic parts (in which case every part contains an atomic part); otherwise it is *mixed*. Given the postulate that all atomic ensembles have unicles, the discrete ensembles can be identified with sets. Part II of the book, Chapters 10–13, includes an axiomatization of ensemble theory, proofs of basic theorems, the construction of a model, and a proof that ensemble theory includes, in an appropriate sense, set theory and mereology.

Why base semantics upon ensemble theory rather than simply adding to set theory a part-whole relation and appropriate postulates? Bunt's argument that ensemble theory is needed to solve the "interface" problem is not convincing. His first example involves the case of a "count" adjective modifying a mass noun, such as 'small furniture,' which might suggest the need for intersections between sets and mereological wholes. But in ensemble theory, such intersections are trivialized: the intersection between a discrete and a continuous ensemble is always empty. Indeed, on Bunt's semantics, these examples are treated by taking the mass noun in question to denote a set (discrete ensemble), thus bypassing the interface problem altogether. Bunt's second example involves conjunctive phrases, such as 'rice and beans,' that seem to require the sum of a set and a mereological whole for their denotation. Such sums, indeed, are not trivialized in ensemble theory: the merge of a continuous and a (non-empty) discrete ensemble results in a mixed ensemble. But ensemble theory is not needed here: a mixed sum could just as well be represented by an ordered pair consisting of a set and a mereological whole. Indeed, the fact that such ordered pairs can be used to provide a model for ensemble theory (pp. 270–271) suggests that they can everywhere replace ensembles as denotations of mass terms.

I think there are reasons to favor ensemble theory, but they are philosophical, not linguistic. They have to do with whether one takes the part-whole relation of mereology to apply literally only to concrete objects, or to apply universally to all entities including sets. Ensemble theory embodies the latter view: sets have a natural part-whole structure that is given by the subset relation. As Bunt notes (p. 51), if mereology is simply added to set theory, the part-whole structure of sets will be introduced twice, once by way of the mereological primitive, and once by way of the membership relation. Ensemble theory avoids this unnecessary duplication of structure. Whoever shares the universal conception of mereology should find ensemble theory of interest; that includes metaphysicians and philosophers of science in addition to semanticists.

I return now to the problem of minimal parts. Bunt's solution involves distinguishing two levels of semantic analysis: formal and referential. At the formal level, all mass terms are treated alike without regard to the question of minimal parts. Thus, 'this puddle is water' is translated into the ensemble language EL_f as '$p_0 \subseteq$ WATER,' where the actual denotations of 'p_0' and 'WATER' are not yet assigned. At the referential level, the EL_f sentence is further translated into the ensemble language EL_r as '$p_{ro} \subseteq$ $WATER_r$,' where '$WATER_r$' will denote either a discrete or a continuous ensemble, depending upon "our actual beliefs about the world" (p. 130). If we believe that nothing smaller than a water molecule is itself water, then '$WATER_r$' will denote the discrete ensemble whose members are all the water molecules. This is turn will constrain 'p_{ro}' to denote, not the puddle, but a discrete ensemble containing the water molecules in the puddle, thus introducing an ambiguity into 'this puddle' where none seemed to exist. That might be tolerable if everything else worked; but it does not. As we just saw, taking a mass term to denote a discrete ensemble at the referential level can constrain the denotations of other terms in the sentence. This leads to a serious problem when sentences contain two or more mass terms, for it will not always be possible to satisfy jointly the constraints in a satisfactory way. Consider 'some furniture is wood' (or 'something is both furniture and wood'), which I take it is true. If 'furniture' denotes a discrete ensemble whose members are pieces of furniture and 'wood' denotes a discrete ensemble more finely individuated (or a continuous ensemble), then the sentence will come out false on Bunt's semantics since no subset of the set of furniture is a subset of the set of particles of wood (or a part of the mereological sum of all wood); yet those assignments at the referential level are certainly in accord with our beliefs about furniture and wood.

There are other cases in which Bunt's approach fails to assign correct truth conditions. Bunt requires that translations between EL_f and EL_r preserve logical form (where '$\subseteq$' is taken to be a logical particle). Now consider the distributive reference condition, 'any part of something that is *m* is *m*,' which Bunt (p. 98) formalizes in EL_f as $\forall x(x \subseteq M \rightarrow (\forall y \subseteq x)(y \subseteq M))$. This is formally valid in ensemble theory, which Bunt takes to support his view that mass terms refer to objects *as if* they are continuous. But, of course, the sentence is false at the referential level for some substitutions of '*m*'; for example, it is not the case that any part of something that is furniture is furniture. But no translation of a formally valid sentence of EL_f that preserves logical form will result in a false sentence of EL_r. It follows that Bunt's approach will fail to assign correct truth conditions to some sentences containing mass terms.

The book is attractively produced and contains very few typographical errors. In the last paragraph of page 40, '(3.63)' and '(3.60)' should be '(3.76)' and '(3.73)', respectively. On line 7 of page 168, 'EL_f' should be 'EL_r'. On page 289, the bound variable 'x' in Definition 2.1.2 should be 'z'.

PHILLIP BRICKER

Towards a theory of information, The status of partial objects in semantics, by Fred Landman, Groningen-Amsterdam studies in semantics, no. 6, Foris Publications, Dordrecht and Riverton, N.J., 1986, xiv + 228 pp.—Therein:

FRED LANDMAN. *Data semantics: an epistemic theory of partial objects.* Pp. 1–96.

FRED LANDMAN. *Pegs and alecs.* Pp. 97–155.

FRED LANDMAN. *Data semantics for attitude reports.* Pp. 157–182. (Reprinted from ***Logique et analyse***, n.s. vol. 27 (1984), pp. 165–192; also in ***Varieties of formal semantics, Proceedings of the fourth Amsterdam Colloquium, September 1982***, edited by Fred Landman and Frank Veltman, Groningen-Amsterdam studies in semantics, no. 3, Foris Publications, Dordrecht and Cinnaminson, N.J., 1984, pp. 193–217.)

FRED LANDMAN. *Paradoxes of elimination.* Pp. 183–228.

The book is a collection of four papers written between 1982 and 1985 dealing with natural language semantics and structures for the representation of partial information, discussing in particular how the first relates to the second.

The first paper, *Data semantics: an epistemic theory of partial objects*, gives a self-contained presentation of the theory of data semantics. Conditionals and epistemic modal operators are interpreted in "forcing-like" structures of partial information states, where the latter are ordered by an accessibility relation describing which information states may grow into which others. Neither the information states nor the accessibility relation is taken as primitive; such a choice is considered undesirable by the author. The accessibility relation will typically enforce an array of implicit information patterns, which one would like to analyze in further detail than is possible with a primitive accessibility relation. For this reason, Landman instead chooses as primitive the ordering between propositions in a certain type of De Morgan lattice, where central importance is given to a notion of incompatibility between propositions. Relative to this lattice, information states are then taken to be filters of a certain type, while the accessibility relation is ordinary set-theoretic inclusion between states. The latter part of the paper is