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GUEST EDITORIAL

Guest Editors' Introduction

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1 Revision Theory: from Truth to Circular Definitions

As it was originally conceived in the early 1980's by Anil Gupta and, independently, by Hans Herzberger, *revision theory* appears as a proposal to deal with a type-free concept of formal truth that preserves the classical scheme [7, 20, 28, 29]. Though the story is well-known, we think it would be useful to recapitulate here, in a brief and obviously incomplete summary, some of the main events by means of which the original proposals developed into the current, broader field of investigation, to give the uninitiated reader a rough idea of the context for the contributions in this volume.[1]

In his seminal work from the 1930's, Alfred Tarski proved the existence of a fundamental inconsistency emerging in a situation where: (i) there is a formal language $\mathcal{L}$ respecting some modest assumptions on its strength in expressive capabilities; (ii) the language contains a unary, unrestricted predicate T for (codes of) formulas working as a truth predicate, verifying natural principles that require that the formula $T(\ulcorner\varphi\urcorner)$ be equivalent to φ, for every sentence φ of $\mathcal{L}$; (iii) a classical relation of satisfaction for formulas of $\mathcal{L}$ in any interpretation, or model $\mathbf{M}$, is retained, therefore each sentence φ of $\mathcal{L}$ is assumed to take either semantic value 1 or 0. Tarski's contradiction took the form of a theorem about the (arithmetical) undefinability of such predicate T for any $\mathcal{L}$, granted (i)–(iii). Tarski's theorem shows that no sufficiently expressive, classical formal language can consistently contain its own truth predicate. As a solution, he proposed a *typed* theory of formal truth, asserting that every language $\mathcal{L}$ for

[1] The interested reader should consult [38] for a more detailed introduction to revision theory.

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which (i) holds can be extended to a language $\mathcal{L}^+ = \mathcal{L} \cup \{T\}$ containing a truth predicate T for $\mathcal{L}$ for which condition (iii) holds for every sentence φ of $\mathcal{L}$.

The Tarskian theory of the truth was challenged later on, as Saul Kripke (and, independently, Robert Martin and Peter Woodruff), came up with a different approach based on fixed-point models [39, 46]. A central feature of the fixed-point theories is a proof that it is possible to consistently equip a formal language for which (i) holds with a truth predicate such that (ii) is verified. The proofs require moving to a non-classical scheme, which is often viewed as a cost of fixed-point theories. A notable feature of fixed-point models is their inductive structure: one starts from a language $\mathcal{L}^+ := \mathcal{L} \cup \{T\}$ and a ground interpretation $\mathbf{M}_0^T = (\mathbf{M}, X_0^+, X_0^-)$ of it where $\mathbf{M}$ is a model of $\mathcal{L}$, and (X_0^+, X_0^-) offers an interpretation of T in the form of an *extension* X_0^+, and an *anti-extension* X_0^- of T that satisfy certain constraints (where both X_0^+ and X_0^- are sets of sentences of $\mathcal{L}$); then, the interpretation is refined by means of a new one, say $\mathbf{M}_1^T$, that contains a new interpretation (X_1^+, X_0^-) of T which is built by collecting sentences that gets semantic value 1 in $\mathbf{M}_0^T$, respectively semantic value 0 in $\mathbf{M}_0^T$. By iterating this refinement construction, one eventually reaches a fixed-point $\mathbf{M}^T$ after which no further iteration produces new results and candidates itself to be the "ultimate" interpretation of T.[2] Since a three-valued schema of evaluation is used along the way, some sentences can fail to get either value 1 or value 0, and the truth predicate interpreted in this way has "gaps". Yet, the core of (ii) is achieved, as the semantic value of $T(\ulcorner\varphi\urcorner)$ in $\mathbf{M}^T$ is the same as the semantic value of φ, for all sentences φ of $\mathcal{L}$.

Revision theory was used to develop a theory of untyped truth that maintains the classical scheme. The theory bears some similarities to Kripke's, as it is based on building a (transfinite) sequence of interpretations $(H_\alpha[\mathbf{M}])_{\alpha \in On}$ of $\mathcal{L}^+$ (over a given model $\mathbf{M}$ of $\mathcal{L}$ alone), where each successor model is the revision of the predecessor model.

An important difference between the two proposals lies in the interpretation of the T-biconditionals, the equivalence, for each sentence φ of $\mathcal{L}^+$, between $T(\ulcorner\varphi\urcorner)$ and φ: whereas they work as logical principles in Kripke's case, dictating that $T(\ulcorner\varphi\urcorner)$ should be semantically equivalent to φ, in revision theory they are seen as providing a *rule for revision* that determines the passage from each interpretation $H_\alpha[\mathbf{M}]$ for T to the subsequent $H_{\alpha+1}[\mathbf{M}]$. According to this rule, any sentence of the form $T(\ulcorner\varphi\urcorner)$ receives semantic value 1 at $\alpha + 1$, provided φ has semantic value 1 at α. In later work, Gupta [21] argued that the T-biconditionals provide a partial *definition* of truth.

A revision sequence of interpretations for T is, in general, non-monotonic (i.e., it can happen that $H_\alpha[\mathbf{M}] \not\subseteq H_{\alpha+1}[\mathbf{M}]$), hence the sequence may fail to reach a fixed-point. Moreover, this property of the revision sequence leaves open what to do at limit stages. Several proposals for limit rules have been made, the easiest of which to present is the "liminf" rule that collects at stages $H_\lambda[\mathbf{M}]$, where λ is a limit ordinal, all those sentences that are "stably true" below λ, i.e. receive semantic value 1 from some stage $H_\beta[\mathbf{M}]$ onwards, where $\beta < \lambda$. If the sequence $(H_\alpha[\mathbf{M}])_{\alpha \in On}$ is constructed

[2] It is known that, in general, there is no unique fixed-point for such a construction, and there are results exploring the algebraic structure of the collection of fixed-points (see [11, 19], [26, ch. 2] and [58, 59]).

in this way, then one can prove by cofinality arguments that there are many *closure ordinals* ζ such that $H_\zeta[\mathbf{M}]$ contains all and only those sentences which are stably true with respect to the sequence of interpretations. In particular, it turns out that the whole construction has a cyclic structure: as the iteration goes on transfinitely, more and more sentences lacking the stability property are filtered out until only the stable ones are retained; then, owing to the sequence being non-monotonic, unstable sentences start to come back in again and the process repeats itself with a constant period.

Most of the work done on revision theory in the early years, featuring the study of the basic properties of revision sequences hinted at above, is accounted for in the book by Anil Gupta and Nuel Belnap [26], which this year (2018) celebrates its 25th anniversary. This source is crucial in the history of revision theory because it contains the presentation of the approach in *full generality*, namely as a theory of interdependent definitions rather than just a theory of formal truth. Therefore, results are made general to accommodate both situations in which a formal language $\mathcal{L}$ is extended by means of a (possibly infinite) *set* of predicates $(G_i)_{i\in I}$ whose defining conditions A_i are formulas of $\mathcal{L}_i = \mathcal{L} \cup \{G_i : i \in I\}$ (hence, are formulas such that any defined predicate G_j may occur in any of the defining conditions A_i) and the use of a non-classical scheme. Revision theory has attracted the attention of scholars both in its original form as a theory of truth, as well as in its latter, more general form as a theory of definitions. In the remaining part of this section, we would like to offer a brief, non-comprehensive overview of some of the main contributions made since the publication of [26], letting their variety serve as an additional motivation for this special issue.

First of all, we should mention papers which, in addition to the papers mentioned above, essentially contributed to consolidating the understanding of revision theory for the sake of future developments. This is the case of Burgess [10], which contains basic results on complexity issues of the theory in comparison to other approaches that proved to be quite illuminating. As a matter of fact, the issue of the high complexity connected with revision theory turned out to play an important role in the early developments of it. On the one hand, Kremer [35] proved that the two main semantic theories proposed by Gupta and Belnap in [26] are not axiomatizable (which has prevented revision theory being used for the sake of defining *axiomatic* theories of truth, as other theories have been). On the other hand, however, it can be argued that the mathematical complexity of the theory is among the reason for the variety of possibilities in the application of it. This was supported by the early work of Aldo Antonelli [1, 2, 4, 5], as well as by his application of revision to the theory of non-well founded sets [3].

Another aspect that has been debated at length in the early period that is worth emphasizing here, is the effectiveness of revision theory as a theory of truth. A defense of it in this sense was provided by Yaqūb [70], discussed further by Chapuis [12]. The topic was critically considered further by McGee [48] and D.A. Martin [45], with a response by Gupta [22]. A systematic comparison between fixed-point and revision theories of truth was provided by Kremer [36]. There was a critical evaluation of the motivations for adopting revision rules presented by Shapiro [54], with a response by Gupta [25, 160–161].

As we hinted earlier, several aspects just mentioned have been deepened further in subsequent years, and whole new topics connected with the original revision-theoretic framework were brought to the attention of scholars. On the former side, the comprehensive library of results provided by Philip Welch stands out. His papers can indeed be viewed as extending the previous knowledge on revision theory in a number of different directions. First, there is his work clarifying the complexity of revision-theoretic constructions, with a focus on relations to subsystems of second-order number theory (see [63, 64, 67], as well as [44], which is joint work with B. Löwe, and [40], joint work with K.-U. Kühnberger, B. Löwe and M. Möllerfeld). Next, he has several papers comparing revision theory as a theory of formal truth with other proposals (see [65, 66, 68], the first and the last of this list being about a theory of truth that has been developed and defended by Hartry Field [15–18] and that uses revision-theoretic techniques itself. Finally, he has unveiled connections with the generalized theory of computability, and particularly with infinite time Turing machines (see [61, 62], as well as [43] by B. Löwe for a related viewpoint on the topic).

Apart from Welch, a number of other scholars have contributed to exploring other aspects of revision theory and to fostering new directions in the application of it. Martinez [47] and Gupta [24] study finite definitions, which are definitions that do not require the iteration of the revision-theoretic machinery to the transfinite to reach closure stages. There has been work dealing with (partial) formalization of the theory both in axiomatic form (see [30]) and in sequent form (see [8]). In this direction, it is worth mentioning the recent paper [27] by Gupta and Standefer, who have studied the logic of the rule of revision via conditionals devised to reflect it. The paper also explores an interpretation of the proposed conditionals by means of a modal operator, a connection that had been considered already in [55], and which has been further investigated proof-theoretically in [57]. The behavior of truth in languages with no vicious self-reference, which was investigated in [26, ch. 6], has been further explored by Kremer [37] and Wintein [69]. Rivello [52, 53] has explored periodicity, reflexivity, and cofinality in revision sequences.

As for new applications of revision theory, one can similarly count many of them: the application to meaning by Orilia and Varzi [51] and Orilia [49], to paradoxes of belief by Lee [41], to property theory by Orilia [50], to strategic rationality [9, 13, 14, 25, ch. 4], and to degrees of paradoxicality (pairing with graph theory) by Hsiung [31–34], on the logical and mathematical side; the application to epistemology by Gupta [23] and [25, ch. 7-8], to vagueness by Asmus [6], and to the theory of abstract objects by Wang [60], in a more philosophical direction.

This special issue was conceived to celebrate revision theory in all of its facets, and, in our opinion, the papers we collected accomplish the task. These contributions now add to the already notable list we have sketched, and we hope they pave the way to further investigations of revision theory in the decades to come.

2 On the Content of this Volume

We will now provide a brief overview of the seven papers in this volume. These papers touch on many aspects of revision theory mentioned above. Some papers discuss circular definitions and some truth. Some develop and apply revision theory and others defend competing proposals.

As noted above, there are options as to how to handle limit stages of revision sequences. While it is clear how to treat elements that have stabilized going up to a limit stage, it is less clear what to do with unstable elements. In "Limits in the Revision Theory: More Than Just Definite Verdicts", Catrin Campbell-Moore discusses the limit rule question and proposes a new approach to limit rules, one that combines the usual rule for stable elements with additional constraints based on properties of the hypotheses involved. The usual limit rules fall out as special cases.

Suppose that a traveller wants to walk from point A to point B but that there is a countably infinite sequence of gods such that the first plans to put up an impenetrable barrier halfway between A and B and each subsequent one plans to throw up a barrier halfway between A and where the previous god intends to put up a barrier. Plausible argumentation results in the conclusion that the traveller will be unable to move even though no barriers are erected. That is the Benardete-Zeno paradox. In "Revising Benardete's Zeno", Roy Cook formalizes the Benardete-Zeno paradox in a way that brings out the interdependent nature of the central concepts of the paradox. The revision sequences for these concepts over the real numbers eventually cycle between four hypotheses. Cook argues that three of these hypotheses correspond to extant responses to the paradox and he goes on to explore the neglected fourth option.

In "Revision without revision sequences: Circular definitions", Edoardo Rivello proposes an alternative theory of circular definitions. Rivello surveys different approaches to definitions and examines objections to revision theory focused on the complexity of transfinite sequences. Rivello proposes one theory of definitions, S^{Δ}, that combines revision-theoretic techniques with supervaluations in a way that yields a natural, monotonic construction that is bound to reach fixed-points. He motivates a variant system, $S^{\prec}$, by incorporating a better-than ordering on hypotheses into the formal apparatus of S^{Δ}. Rivello compares his theory of definitions $S^{\prec}$ with the Gupta-Belnap theory S^{*} and argues that his theory does as well as the Gupta-Belnap theory.

Starting with the work of Leitgeb [42], there has been an interest in combining an untyped truth predicate with attributions of probabilities to sentences that obey a probabilistic analog of Convention T, that the probability of ϕ equals the probability that ϕ is true. Leitgeb shows that there are probability functions that work, and he suggests that one can see the probability that ϕ as the frequency that ϕ is true in the long run, at least for ω-sequences of models. There is, then, a question about how to extend that idea to transfinite revision sequences. In "Probability for the Revision Theory of Truth", Campbell-Moore, Leon Horsten, and Hannes Leitgeb provide a general construction answering the problem raised by Leitgeb.

In "Truth, Predication and a Family of Contingent Paradoxes", Francesco Orilia and Gregory Landini build on the earlier work on revision-theoretic approaches to property theory by Orilia [50]. They argue that contingent paradoxes pose a problem for typed property theories. They suggest that a type-free property theory is the proper response to these and related paradoxes of predication. They propose a theory of properties, $P^{\#}$, that is defined in terms of near stability, whereas the theory P^{*} of

Orilia [50] is defined in terms of stability. They then compare the features of $P^{\#}$ and P^{*}.

In "Rethinking Revision", P. D. Welch motivates and proposes a broadening of Gupta and Belnap's notion of circular definition that incorporates higher type recursion. Welch begins by briefly surveying work on infinite time Turing machines and their connections to revision sequences with the constant Herzberger limit rule, work on arithmetical quasi-inductive definitions by Burgess [10], and the theory of Spector classes. Welch sketches revision sequences augmented with oracles that can initiate sub-revision-sequences that affect the super-revision-sequences. He indicates how Gupta and Belnap's notion of "categorical in $\mathcal{L}$" fits into his proposal and closes with several open questions for future research.

Revision theory provides one response to the semantic paradoxes. Another sort of response, coming from a proof-theoretic orientation, rejects the structural rules of contraction, the rules going from $\Gamma, A, A \vdash \Delta$ to $\Gamma, A \vdash \Delta$ and from $\Gamma \vdash A, A, \Delta$ to $\Gamma \vdash A, \Delta$. Elia Zardini has developed and defended a non-contractive theory of truth in a series of papers, including [71, 72]. Zardini [71] motivates the failure of contraction by appeal to unstable states of affairs, which he connects to revision theory in a footnote, which was explored in one direction by Standefer [56]. In "Instability and Contraction", Zardini develops a formal account of states of affairs to flesh out his earlier comments. Zardini elaborates the connections to revision theory and connects the formal theory of states of affairs to his preferred non-contractive theory of truth.

The Revision Theory of Truth uses coherent, complete partial orders (ccpo's) as a general setting for studying jump operators, fixed-points, and revision. Visser [59] observed that any finite ccpo is obtainable as the fixed-point poset of the Strong Kleene jump of a suitable ground model. In "Fixed-Point Posets in Theories of Truth", Stephen Mackereth extends Visser's result to an arbitrary ccpo. Further, he shows that there are ccpo's that are not obtainable as the fixed-point poset for the Weak Kleene jump, for any ground model.

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