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Harrie de Swart

Philosophical and Mathematical Logic

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Harrie de Swart
Faculty of Philosophy
Erasmus University Rotterdam
Rotterdam, The Netherlands

Department of Philosophy
Tilburg University
Tilburg, The Netherlands

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Logic is to improve human thinking in order to improve human existence.
[Andrzej Grzegorzcyk]

However, this same [mathematical] form of thinking, this same kind of concept analysis, is also applicable to many other areas that are directly related to the immediate reality of our daily lives. And such a broader application of the mathematical form of thought seems to me to be of the highest importance. After all, the unparalleled development of the technique in a narrow sense, of the technical technique, one could say, is followed by a hardly less important development of the psychological technique, of the advertising technique, propaganda technique, in short, of means to influence people. However, we have failed to strengthen our defense equipment against belief and suggestion attempts by others by improving our *thinking technology*. [...] In this tangle of questions and sham questions we can find a guide in the conceptual analysis, demonstrated in the mathematical way of thinking. Against all these known and unknown psychic influences we can forge a weapon by *improving our thinking technique*. And that such a reinforcement of our spirit is required, urgently needed, is my deepest conviction. [David van Dantzig, 1938, inaugural lecture, Delft, the Netherlands; translated from Dutch]

*This book is dedicated to Johan J. de Iongh
(1915 - 1999)*

My friend and teacher

It is the main task of a philosopher to show people that things do not have to be the way they are, that they might be different and that in some cases they should be different. [Johan de Iongh]

Johan de Iongh (1915 - 1999) was a student of L.E.J. Brouwer (1881 - 1966), the founding father of intuitionism. He was convinced of the soundness of the intuitionistic view of mathematics. He also had a great affinity with the significant position, represented by Gerrit Mannoury (1867 - 1956).

He became professor in Nijmegen in 1961, where he was teaching the course on analysis for first-year students. Later de Iongh devoted most of his teaching to courses on logic, the foundations and the philosophy of mathematics, and in particular intuitionistic mathematics. He was very careful in giving an accurate presentation of Brouwer's views. He took a great interest in the well-being of his students and found it important to know them personally.

Johan de Iongh was as much a philosopher as a mathematician. He shared Plato's view that the study of mathematics is the correct introduction to philosophy. He has published very little. His Platonic distrust towards the written word was great; his tendency to share his thoughts and ideas with friends, rather than to write them down, much greater. Yet some texts from him have been preserved, and many of his ideas have been worked out in Ph.D. theses and papers by his students.

His broad scholarship was impressive. He read Greek and Latin authors in the original. His interest in science reached far beyond mathematics and he was widely read in world literature.

He was a convinced Catholic and his thinking on mathematics and philosophy has developed in continuing discussion with St Augustine, St. Thomas Aquinas, St. Thomas More and Nicholas of Cusa. He always started his lectures with a short prayer in Latin: *Spiritus sancti gratia illuminet sensus et corda nostra* [May the grace of the Holy Spirit illuminate our senses and our hearts]. And he always finished his lectures with the following prayer: *Gratias tibi agimus, Domine, pro omnibus beneficiis tuis* [We thank you, my Lord, for all your blessings].

It was a privilege to be his student, his PhD student, his assistant and his friend.

Foreword

The following quotation is from Lewis Carroll, *Symbolic Logic and The Game of Logic*; Introduction.

The learner, who wishes to try the question *fairly*, whether this little book does, or does not, supply the materials for a most interesting recreation, is *earnestly* advised to adopt the following Rules:

(1) Begin at the *beginning*, and do not allow yourself to gratify a mere idle curiosity by dipping into the book, here and there. This would very likely lead to your throwing it aside, with the remark ‘This is *much* too hard for me!’, and thus losing the chance of adding a very *large* item to your stock of mental delights. . . . You will find the latter part *hopelessly* unintelligible, if you read it before reaching it in regular course.

(2) Don’t begin any fresh Chapter, or Section, until you are certain that you *thoroughly* understand the whole book *up to that point*, and that you have worked, correctly, most if not all of the examples which have been set. So long as you are conscious that all the land you have passed through is absolutely *conquered*, and that you are leaving no unsolved difficulties *behind* you, which will be sure to turn up again later on, your triumphal progress will be easy and delightful. Otherwise, you will find your state of puzzlement get worse and worse as you proceed, till you give up the whole thing in utter disgust.

(3) When you come to any passage you don’t understand, *read it again*: if you *still* don’t understand it, *read it again*: if you fail, even after *three* readings, very likely your brain is getting a little tired. In that case, put the book away, and take to other occupations, and next day, when you come to it fresh, you will very likely find that it is *quite* easy.

(4) If possible, find some genial friend, who will read the book along with you, and will talk over the difficulties with you. *Talking* is a wonderful smoother-over of difficulties. When *I* come upon anything - in Logic or in any other hard subject - that entirely puzzles me, I find it a capital plan to talk it over, *aloud*, even when I am all alone. One can explain things so *clearly* to one’s self! And then, you know, one is so *patient* with one’s self: one *never* gets irritated at one’s own stupidity!

If, dear Reader, you will faithfully observe these Rules, and so give my little book a really *fair* trial, I promise you, most confidently, that you will find Symbolic Logic to be one of the most, if not *the* most, fascinating of mental recreations!

...

Mental recreation is a thing that we all of us need for our mental health; and you may get much healthy enjoyment, no doubt, from Games, such as Back-gammon, Chess, and the new Game ‘Halma’. But after all, when you have made yourself a first-rate player at any

one of these Games, you have nothing real to *show* for it, as a *result*! You enjoyed the Game, and the victory, no doubt, *at the time*; but you have no *result* that you can treasure up and get real *good* out of. And, all the while, you have been leaving unexplored a perfect *mine* of wealth. Once master the machinery of Symbolic Logic, and you have a mental occupation always at hand, of absorbing interest, and one that will be of real *use* to you in *any* subject you may take up. It will give you clearness of thought - the ability to *see your way* through a puzzle - the habit of arranging your ideas in an orderly and get-at-able form - and, more valuable than all, the power to detect *fallacies*, and to tear to pieces the flimsy illogical arguments, which you will so continually encounter in books, in newspapers, in speeches, and even in sermons, and which so easily delude those who have never taken the trouble to master this fascinating Art. *Try it*. That is all I ask of you!

[From Lewis Carroll, *Symbolic Logic and The Game of Logic*. Introduction; Dover Publications, Mineola, NY, 1958.]

Preface

Having studied mathematics, in particular foundations and philosophy of mathematics, it happened that I was asked to teach logic to the students in the Faculty of Philosophy of the Radboud University Nijmegen. It was there that I discovered that logic is much more than just a mathematical discipline consisting of definitions, theorems and proofs, and that logic can and should be embedded in a philosophical context. After ten years of teaching logic at the Faculty of Philosophy at the Radboud University Nijmegen, thirty years at the Faculty of Philosophy of Tilburg University and nine years at the Faculty of Philosophy of the Erasmus University Rotterdam, I got many ideas how to improve my LOGIC book which was published twenty five years ago in 1993 by Verlag Peter Lang. Although the amount of work was enormous, I felt I should do it. It is like working on a large painting where you put some extra color in one corner, add a little detail at another place, shed some more light on a particular face, etc.

This book was written to serve as an introduction to *logic*, with special emphasis on the interplay between logic and *mathematics, philosophy, language and computer science*. The reader will not only be provided with an introduction to *classical propositional and predicate logic*, but to *philosophical* (modal, deontic, epistemic) and *intuitionistic logic* as well. *Arithmetic and Gödel's incompleteness theorems* are presented, there is a chapter on the *philosophy of language* and a chapter with applications: *logic programming, relational databases and SQL*, and *social choice theory*. The last chapter is on *fallacies and unfair discussion methods*.

Chapter 1 is intended to give the reader a first impression and a kind of overview of the field, hopefully giving him or her the motivation to go on.

Chapter 2 is on (classical) *propositional logic* and Chapter 4 on *predicate logic*. The notion of *valid consequence* is defined, as well as three notions of (formal) *deducibility* (in terms of logical axioms and rules, in terms of tableaux and in terms of rules of natural deduction). A procedure of searching for a formal deduction of a formula B from given premisses A_1, \dots, A_n is given in order to show the equivalence of the notions of valid consequence and (formal) deducibility: *soundness and completeness*. This procedure will either yield a (formal) deduction of B from A_1, \dots, A_n

– in which case B is deducible from A_1, \dots, A_n and hence also a valid consequence of these premisses – or (in the weak, not necessarily decidable sense) if not, one can immediately read off a counterexample – in which case B is not a valid consequence of A_1, \dots, A_n and hence not deducible from these premisses.

Chapter 3 contains the traditional material on *sets* treated informally in such a way that everything can easily be adapted to an axiomatic treatment. A sketch of the axioms of Zermelo-Fraenkel is given. The notions of *relation* and *function* are presented, since these notions are useful instruments in many fields. From a philosophical point of view *infinite sets* are interesting, because they have many properties not shared by finite sets. The notion of *enumerable* set is needed in the Löwenheim-Skolem theorem in predicate logic, reason why the chapter on sets is presented before the chapter on predicate logic.

At appropriate places *paradoxes* are discussed because they are important for the progress in philosophy and science. Chapter 5 presents a discussion of formal number theory (arithmetic). Peano's axioms for *formal number theory* are presented together with an outline of Gödel's *incompleteness theorems*, which say roughly that arithmetic truth cannot be fully captured by a formal system.

Chapter 6 deals with modal, deontic, epistemic and temporal logic, frequently called *philosophical logic*. It has several applications in the *philosophy of language* whose major topics are discussed in Chapter 7.

It is interesting to note that traditional or classical logic silently is presupposing certain philosophical views, frequently called Platonism. L.E.J. Brouwer (1881 - 1966) challenged these points of view, resulting in a completely different and much more subtle *intuitionistic logic* which we present in Chapter 8.

Interestingly, both logic and set theory have applications in computer science. In Chapter 9 we discuss *logic programming* and the programming language PROLOG (PROgramming in LOGic), which is a version of the first-order language of predicate logic. To illustrate the role of set theory in the field of computer science, we discuss the logical structure of *relational databases* and the *query language SQL*. In this chapter we also discuss *social choice theory* which deals with elections and voting rules. Finally, in Chapter 10 we discuss a number of *fallacies* and *unfair discussion methods*.

I have tried to give the reader some impressions of the *historical development of logic*: Stoic and Aristotelian logic, logic in the Middle Ages, and Frege's Begriffsschrift, together with the works of George Boole (1815 - 1864) and August De Morgan (1806 - 1871), the origin of modern logic.

Since 'if ... , then ... ' can be considered to be the heart of logic, throughout this book much attention is paid to *conditionals*: material, strict and relevant implication, entailment, counterfactuals and conversational implicature are treated and many references for further reading are given.

At the end of most sections are exercises; the solutions can be found at the end of the chapter in question. Starred items are more difficult and can be omitted without loss of continuity. The expression $:=$ is used as an abbreviation for 'is by definition'.

Acknowledgements

It was Johan de Iongh (1915 – 1999) in Nijmegen who introduced me to mathematics, foundations and philosophy of mathematics, logic in particular, history of mathematics, Plato and other philosophers. I had the privilege of studying and working under his guidance from 1962 till 1980. We became friends forever. I also owe much to my colleagues in the group around prof. de Iongh: Wim Veldman and Wim Gielen in particular.

The influence of Kleene's books, *Introduction to Metamathematics* and *Mathematical Logic*, is noticeable throughout.

I spent the academic year 1976 – 1977 at the department of History and Philosophy of Science of the Faculty of Philosophy of Princeton University, with a grant of the Niels Stensen Foundation. It is here that I attended courses by John Burgess (philosophy of language), David Lewis (modal logic, counterfactuals) and had conversations with Saul Kripke. The chapters on the philosophy of language and modal logic are to a high degree influenced by these lectures.

The subsection on relational databases and SQL is the result of taking a course given by Frans Remmen at the Technical University of Eindhoven. I am grateful to Luc Bergmans and Amitabha Das Gupta for their contributions on G. Mannoury and L. Wittgenstein respectively.

I am most grateful to the Faculty of Humanities of Tilburg University and to the Faculty of Philosophy of the Erasmus University Rotterdam for providing me with the facilities of office space, computer, etc. In particular, I like to thank Willy Ophelders, who was instrumental in my appointment in Rotterdam; without this appointment this book would not have appeared.

I am happy that Springer Verlag is willing to publish this work. I thank Ties Nijssen and Christi Lue, who were extremely helpful in the preparation of this book.

Most of all I owe a lot to the many students who attended my courses and even were willing to pay for that. Their critical questions and remarks helped enormously to shape this book. It is a privilege that people are willing to listen to you, even when they have troubles with understanding what you are trying to say. I only realized this when I was a member of the local city council, where almost nobody was willing to listen to anybody.

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