

VILNIUS UNIVERSITY

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PABIJUTAITĖ

Classical and Contemporary Models
of Indeterministic Temporal Logic:
the Approach of Semantical
Compatibilism

DOCTORAL DISSERTATION

Humanities,
Philosophy (H 001)

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VILNIAUS UNIVERSITETAS

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Klasikiniai ir šiuolaikiniai
nedeterministinės temporalinės
logikos modeliai: semantinio
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SUMMARY

Introduction

The main object of the dissertation is the problem of future contingents – that is the question, if and how we can ascribe a definite truth value to future tense propositions that are neither necessary nor impossible. In the early seventies of the previous century this problem was approached using the tools of temporal logic – a branch of non-classical logic which enables us to properly express temporal information. In the dissertation we analyse eight theories of formal semantics that provide different criteria for the evaluation of future contingent statements: the non-bivalent (multivalent or with truth value gaps) group of theories which consists of 1) *L3* by J. Łukasiewicz, 2) *K3* by S. C. Kleene, 3) *ockhamism* by A. N. Prior, 4) *supervaluationism* by R. Thomason, 5) *relativism* by J. MacFarlane and the bivalent group of solutions consisting of 6) Peircean semantics, 7) *counterpart* theory by D. Lewis and 8) the *Thin Red Line* semantics by P. Øhrstrøm. In the dissertation we provide a detailed analysis of those eight semantical theories and present our own original method of the evaluation of future contingent propositions that lacks the drawbacks characteristic to the eight mentioned solutions. We defend the claim that the most adequate method of evaluation of future contingent statements is the *Thin Red Line* theory based on the branching-time structure and evaluating all future tense propositions as true or false, since it does not require us to reject any of the intuitively acceptable logical principles related to time. Here this theory is defended by providing inovative arguments and modifications of its original version formally developed in the early eighties of the previous century. The most significant modifications offered in the dissertation are a non-traditional interpretation of the existential quantifier without the existential import and also an introduction of the present tense operator that is added to the standart Priorean syntax of temporal logic. In the dissertation tensed

propositions are formalized using the traditional Priorian temporal operators and their truth conditions are described using the means of classical predicate logic (where the moments of time are treated as an object of quantification).

Aim and Objectives of the Dissertation

The dissertation has three aims:

1. to perform a detailed analysis of the most important non-deterministic systems (both classical and contemporary) of temporal logic;
2. after having defined the solution that each of those systems offers to the problem of future contingents, to create a detailed typology of all the solutions based on these criteria:
 - 2.1. their relation to the classical argument for logical determinism which was first formulated in Aristotle's *De interpretatione*, chapter 9;
 - 2.2. the truth values that in each case must be ascribed to the more complex temporal expressions;
 - 2.3. the number of parameters that is required in each of the systems when describing the truth conditions of future contingent statements;
3. to give a detailed explanation how the characteristics of classical and contemporary solutions of the problem of future contingents were determined by the more general metaphysical and methodological views, that is:
 - 3.1. differing views about the ontological status of the basic temporal categories of *past*, *present* and *future*, known as the controversy between A and B series of time. The evaluation of future tense statements and their relation to the past and present tense propositions highly depend on the ontological status that is given to the future. The controversy between A and B series of time rests on an opposition between two possible ways of ordering the events in time. In one case, the

position of any object or event in time is described using the categories of past, present and future and is understood as constantly changing in respect of those categories. In the second case, this position is defined by referring to the temporal relation that object or event has with other objects or events and using the concepts *earlier than .../ later than*; here this position in time is understood as static. The theories of time that belong to the A group (for instance, presentism, where only the present moment of time exists in the strict sense) admit of the objective, metaphysical distinction between past, present and future, whereas in the theories belonging to the B group (for instance, eternalism, where past, present and future have the same ontological status) this distinction is deemed to be merely epistemological and subjective;

- 3.2. commitment to the different conceptions of truth, or the tension between semantic realism and antirealism. According to semantic realism, we understand the meaning of all the declarative statements by finding out what the truth conditions of those statements are. Semantic realism is based on the bivalent and potentially recognition-transcendent conception of truth – this means that every meaningful statement here has the value *true* or *false* irrespectively of our ability to find out what this value is. In opposition to realists, who are willing to ascribe a definite truth value to every proposition, the proponents of semantic antirealism think that a proposition might have a truth value only if there exists a definite and epistemically accessible way to confirm or deny that truth value. This means that when such method is lacking (in this case – in a non-deterministic setting) semantic antirealists refuse to apply the principle of bivalence;
- 3.3. accepting different conceptions of truthmakers (events/objects/states of affairs that make a proposition true). Our willingness to ascribe a definite truth value to a future

tense statement highly depends on the existence of a requirement for each true proposition to have a truthmaker that makes it true. A theory based on such a requirement is called *truthmaker maximalism* – if the future does not exist in the strict sense or is not yet determined, truthmaker maximalists tend not to ascribe a truth value to the future tense proposition leaving it with a truth value gap or with some other non-standard truth value. The proponents of a position called *truthmaker optimalism* (those who usually do not apply the principle of bivalence in cases of universal or negative statements, but may also include future contingent statements in this group) and *truthmaker nihilists* (those who do not admit of a requirement of a truthmaker at all) may claim that the truth of future contingent statements is a brute fact, but at the same time should be able to explain how, having two identical states of affairs, the propositions about those states of affairs could have different truth values;

4. to create and present in detail an original method of evaluating future contingent statements that would lack the drawbacks characteristic to the already existing methods, and also to demonstrate its applicability in temporal propositional and temporal predicate logic.

General Thesis and Claims

The author of this dissertation defends the position called *semantical compatibilism*, the proponents of which claim that the principle of bivalence and the open future intuition are compatible. The commitment to this thesis is made by defending these claims:

1. in the dissertation it is claimed that the most adequate criteria of evaluation of future contingent statements are provided by the theory called the *Thin Red Line* which ascribes the truth values *true* and *false* to all future tense statements while keeping a relatively low number of

- parameters and saving all of the logical principles expressing our basic intuitions about time;
2. in opposition to the default position in the contemporary metaphysics of time, here it is argued that the *Thin Red Line* theory is compatible with an indeterministic worldview and is in fact maximally neutral in respect of methodological and metaphysical commitments discussed in the dissertation;
 3. it is argued that the *Thin Red Line* theory can be also applied to first-order temporal logic where next to the temporal axioms classical rules of quantification are added. It is shown that the Barcan scheme provable in some of the weakest systems of first-order temporal logic is compatible with the dynamic worldview in which objects start and cease to exist. This is done by introducing a non-traditional interpretation of the existential quantifier – here it is claimed that this quantifier should be treated as having no existential import and be left only with the purpose of expressing the quantity of objects;
 4. in the very last sections of the dissertation it is argued that, having removed existential import from the sphere of the quantifiers, existence should be understood as an ordinary property equal to the properties of another kind. Defining existence as temporal location, it is shown that there is no need to introduce a separate predicate for expressing existence in temporal expressions as the work of indicating the position in time is done by a temporal operator. Having proved that, it is argued in favor of expanding the classical Priorian four-operator syntax with a new present tense operator N .

Methodology of the Research

The research is based on a method dominant in the current analytic metaphysics: here the problem is approached both from an analytical and a historical perspective, showing a close interrelation between the classical (ancient and medieval) and contemporary logical investigations. In the beginning of the previous century, logical and metaphysical conceptions formulated in the ancient times (especially those by Aristotle) started to be treated as an integral part of modern philosophical controversies; later on, in the early eighties, this approach was also applied to medieval philosophy and logic. In this work the analysis of contemporary philosophical and logical systems is accompanied by the translations of some of the relevant primary sources of the classical period from Latin language (see *Priedas nr. 1*).

In contemporary temporal logic it is common to formalize tensed expressions using one of the two prominent systems of notation: extensional notation of N. Rescher which is based on the quantification of time moments, or intensional notation of A. Prior, which uses the aforementioned temporal operators that function in the same way all modal operators do. In order to remain as metaphysically neutral as possible, in this dissertation we choose the middle way by invoking temporal operators when formalizing temporal expressions and using the means of classical predicate logic when describing the truth conditions of temporal expressions. The objects of quantification here are the moments of time (alternative and more expressive logical systems which choose periods of time as an object of quantification are not taken into consideration). Polish notation (also known as Warsaw or Łukasiewicz's notation) which was widely used in the earliest works on temporal logic and the users of which write the usual logical connectives such as *and*, *or*, *if* and *iff* before the whole proposition, is not invoked here due its complexity – instead of it, we make a more common choice today and use Peano-Russell notation writing the connectives between their arguments.

It is important to note that the notion of a proposition which is the most common in contemporary temporal logic and which is also accepted in this dissertation, is very different from the one which is seen as default in the other contexts of modern logic. Today it is usual to ascribe the status of a proposition to such expressions whose truth and falsity do not depend on the time of their utterance (for instance, *The fur of a cow is shorter than that of a sheep* or *The first day of the year 1992 is Wednesday*), whereas such expressions as *I belong to more than one association* or *Something interesting is happening there* are deemed to be incomplete and in need of specification due to the inclusion of indexical words such as *I* or *there*. This means that such expressions as *Something interesting is happening there* and *Something interesting is happening here* are usually seen as different statements expressing the same proposition. Although in a similar manner statements such as *Tomorrow there will be a sea-battle* could also be seen as incomplete (as long as it is not changed in a way that would remove every instance of temporal indexicality from it), the classical tradition of A. N. Prior is based on a different conception of a proposition that has its roots in the ancient and medieval logical systems. In ancient and medieval logic it was a common thing to use the statements which, although being tensed, either did not give any direct temporal references, or those references were indexical (dependent on the circumstances of the utterance of that statement), and such statements were not taken as incomplete or requiring specification. This means that the example of a standard proposition in the classical period was not *A sea battle is happening at the moment T* with a stable truth value, but rather *There is a sea battle happening [now]* with a changing truth value. Committing to the classical tradition, in this dissertation we choose the latter conception of a proposition.

The Relevance of the Dissertation

Due to the wide expressive abilities of temporal logic and its versatile applicability the development of this branch of logic is relevant not only to philosophers and logicians that are interested in the topic of indeterminism, but also to some other scientific communities which are not associated by any common ontological commitments. Using the slightly modified Kripke semantics for modal statements (Kripke 1963a, 1963b) in the temporal context and interpreting possible worlds as moments of time, we have the ability to precisely construct different models of time – here, using only formal means, we can describe the differences between linear, circular, branching and other structures of time much more precisely. Besides, temporal logic is widely used in the development of artificial intelligence and computer science – the disciplines that rely heavily on the formalization of natural language and the possibility to give a precise form to all kinds of temporal information. The close association between computer science and temporal logic, anticipated already by Prior, was put into practice in the late seventies of the previous century (Pnueli 1977), when it was noticed that it is convenient to express some of the properties of program systems using the formalisms of temporal logic; the latter discovery is being developed until this very day.

Although the logical analysis of future contingent statements has a huge practical relevance, a significant part of contemporary investigations is motivated by a mere theoretical interest – speculative approach to the problem has the oldest roots and is common to both classical and contemporary period. The necessity to deal with the propositions that express an objectively undetermined state of affairs in terms of logic arises due to the principle of a unified knowledge of the world and the interrelation of philosophy, logic and physical sciences prevalent in the contemporary analytic philosophy. In the Middle Ages the creation of various systems of temporal logic was motivated by the position of logic in the *trivium* (having language as

a common subject with grammar and rhetorics, logic had to provide the tools to analyse the statements having temporal aspects) and also by the need to solve some theological problems (such as the problem of divine omniscience and free will), whereas in the 20th century one more significant motive for this development was the rise of quantum mechanics and the formulation of Heisenberg uncertainty principle.

Literature review

The problem of future contingents has gained its popularity in the early thirties of the previous century when the Polish school of logicians started to investigate the works of Aristotle using the tools of modern logic (Łukasiewicz, 1970 [1920]). Later, in the late sixties, the problem of future contingents started to be analysed not only from the historical, but also from the conceptual perspective – having established temporal logic as an independent branch of logic, philosophers and logicians started to offer their own original methods of evaluation of future tense statements. Although temporal information has been treated a valid object of logical investigation since the late fifties (after A. N. Prior's seminal work *Time and Modality* (1957)), the active search of an adequate solution to the problem of future contingents has started a decade later, when in 1967 Prior published his study *Past, Present and Future*: after the development of the branching time structure, different models of evaluation of future contingent statements based on that structure were offered by P. Øhrstrøm (1981), H. R. Thomason (1970), J. MacFarlane (2003) and N. Belnap (1994 (together with M. Green), 2001) – their interpretations are known by the names of the *Thin Red Line* theory, supervaluationism, relativism and ockhamism, respectively. The very recent investigations that have appeared in this century usually have a more modest aim to combine the aforementioned theories or to provide a different interpretation of them lacking the drawbacks of the original version (for instance, Malpass & Wawer (2012)). The majority of the current investigations are based on the branching time

structure, however, recently there have been some attempts to revive the linear structure of time by showing the incompatibility of indeterministic worldview and the idea of branching future (for instance, Rosenkranz (2013) and Benovsky (2013)).

The field of temporal logic has become even more popular in the recent decades: having been previously treated as a marginal discipline being of interest only to a minority of logicians and philosophers, in *The Handbook of Philosophical Logic* consisting of 18 volumes and published during 2001-2018 (ed. D. M. Gabbay, F. Guentner) temporal logic is presented in a separate chapter where Prior is compared with such major figures as G. Boole, G. Frege and B. Russell.

The Novelty of the Dissertation

In the dissertation there have been reached several original results. First of all, in opposition to the majority of previous studies that have some one particular semantical theory as their object of investigation, here we analyse and compare all now prevalent methods of evaluation of future contingent statements by giving them a unified logical form and rewriting the truth conditions of the statement Fp given in each of the theories using the slightly modified Kripke possible world semantics. Such standardization of the theories that were created in different historical periods using different logical notations and their comparison according to ten criteria (indicated in part 2.2.2) allows us to reach an overall view of all the existing solutions of the problem of future contingents which has not been offered in the previous studies. Secondly, opposing the dominant practice to treat the problems of temporal propositional logic and temporal predicate logic as separate and unrelated, the main ideas defended in this dissertation are applicable to both these branches of logic. Thirdly, although the position of semantical compatibilism defended in this work is by no means novel, we provide the original arguments that strengthen this theory significantly – that is, present an

innovative interpretation of the existential quantifier and offer to introduce the additional temporal operator for the present tense. Although the ideas of the existential quantifier without existential import and the present tense operator have been offered previously (McGinn 2000 and Kamp 1971, respectively), here for the first time these conceptions are applied in the field of temporal logic by showing the interrelation of them.

The Structure of the Dissertation

The dissertation consists of three parts:

1. the first part indicates the main objectives of the investigation by defining the main terminology used in the dissertation, providing with a detailed analysis of the classical argument for logical determinism and outlining the criteria of evaluation of the solutions of the problem of future contingents;
2. the second part of the dissertation is devoted for a detailed analysis of the most important semantical theories that provide the criteria of evaluation of future contingent statements. This analysis is performed in two stages: first, by choosing the most adequate temporal structure that could serve as a basis for the evaluation of future contingent propositions, secondly, by comparing the truth conditions of future tense statements that are given in the semantical theories based on that structure;
3. in the third part of the dissertation we extend the results reached in the second part of the work to temporal predicate logic: here we show that our interpretation of the existential quantifier can be applied when solving the most pressing issue in first-order temporal logic – that is, the question, if and how it is possible to reconcile the Barcan formula provable in some of the weakest systems of temporal predicate logic with the dynamic worldview in which at least some of the objects start and cease to exist.

Conclusions

1. In the dissertation, we have analysed eight theories of formal semantics providing different criteria for the evaluation of future contingent statements: the non-bivalent (multivalent or with truth value gaps) group of theories which consists of 1) *L3* by J. Łukasiewicz, 2) *K3* by S. C. Kleene, 3) *ockhamism* by A. N. Prior, 4) *supervaluationism* by R. Thomason, 5) *relativism* by J. MacFarlane and the bivalent group of solutions to which belongs 6) Peircean semantics, 7) *counterpart* theory by D. Lewis and 8) the *Thin Red Line* semantics by P. Øhrstrøm. Having made the comparative analysis of those theories, the *Thin Red Line* theory was proven to provide the most reliable method of evaluation of future tense propositions: by ascribing the values true and false to all future contingent statements, it allows us to retain all basic logical principles expressing our intuitions about the passage of time:
 - a. the principle of future excluded middle $F(x)p \vee F(x)\sim p$, implication $Fp \rightarrow Fp$ and the principle expressing retrospective evaluation of future contingent statements $p \rightarrow PFp$ here are tautologies, i. e., remain always true, and the formula expressing two incompatible future states of affairs $F(x)p \& F(x)\sim p$ is a contradiction, i. e. is never true;
 - b. in this semantical theory, based on the branching time structure, the formula $\diamond Fp \& \diamond \sim Fp$ expressing different future alternatives is satisfiable and the implication $Fp \rightarrow \square Fp$ indicating the necessity of every future state of affairs is never true.
2. In this work it has been proven that the theory of *Thin Red Line* which belongs to the group of semantical compatibilism is not only superior from the logical perspective, but also has solid metaphysical grounds compatible with the

indeterministic worldview. Having made the analysis of the counterarguments of the Belnap school, we have shown that in order to commit ourselves to the theory of *Thin Red Line* we are not required to posit any objects, events or states of affairs that would determine the one and only possible continuation of the present moment. This result was reached by developing a non-traditional interpretation of the existential quantifier the essence of which is the removal of the existential import from the sphere of the quantifier and leaving to it only the function of expressing quantity.

3. The non-traditional interpretation of the existential quantifier allowed us to offer an original interpretation of the Barcan formula provable in first-order temporal logic. Usually thought to be in conflict with the intuition that at least some of the objects are temporary, here it is shown to be compatible with the dynamic worldview as long as we do not ascribe any ontological status to the quantifier $\exists x$.

PUBLICATIONS ON THE TOPIC OF THE
DISSERTATION

1. Pabijutaitė Ž. „Kodėl Aristotelis nesvarstė tuščių terminų problemos?“. *Problemos*, nr. 91, 2017, p. 141-155.
2. Pabijutaitė Ž. „On the Difference Between the Two Barbaras“. *Problemos*, nr. 93, p. 90-101.
3. Pabijutaitė Ž. „Capturing Indeterminacy: Non-Linear Temporal Models in the 20th Century Logic and Metaphysics“. *Preeminence of Myth and the Decline of Instrumental Reason*, ed. Pat Arneson, 2020, Ohio University Press, p. 114-126.
4. Pabijutaitė Ž. „Logic and Metaphysics in Vilnius during 16-18th Centuries: the Most Important Sources of Vilnius Libraries“. *Civitas*, nr. 24, p. 117-133.
5. Pabijutaitė Ž. Temporalinės logikos sistemų CL ir K_b semantinės interpretacijos su tradicinių teisingumo reikšmių pertrūkais. *Problemos*, nr. 97, 2020, p. 132-149.
6. Pjeras Abeliaras. *Dialektika* (antroji knyga). Vertimas iš lotynų kalbos. *Problemos*, nr. 91, 2017, p. 156-165.
7. Ričardas Lavenhamas. Apie būsimų įvykių baigtį (vertimas iš lotynų kalbos). Su įvadu: Pabijutaitė Ž., "Kaip galimas neklystamas žinojimas apie atsitiktinę ateitį?". *Problemos*, 2018 supplementary, p. 113-115.
8. Luisas de Molina: Kaip laisvas apsisprendimas dera su malonės dovanomis, dieviškuoju išankstiniu žinojimu bei numatymu, lemtimi ir pasmerkimu (vertimas iš lotynų kalbos). *Problemos*, 2018 supplementary, p. 116-125.
9. Ciceronas: *Apie lemtį*. Translation from Latin language with an introduction and commentary. Vilnius: *Jonas ir Jokūbas*.

PAPERS PRESENTED ON THE TOPIC OF THE
DISSERTATION

1. Pabijutaitė Ž. (speaker): "Does Branching Time Allow Upcoming, but Non-Necessary Future?". International congress *2nd World Congress on Logic and Religion*, Warsaw, 2017-06-18 – 22.
2. Pabijutaitė Ž. (speaker): "Logic and Metaphysics in Vilnius during 16-18th Centuries: an Overview of the Most Important Sources of Vilnius Libraries". International conference *Polonica Philosophia Orientalia: Archiwalia*, Krakow, 2018-07-02 – 04.
3. Pabijutaitė Ž. (speaker): „On the Present Tense Operator in the First-Order Tense Logic“. International conference *Space and Time: an Interdisciplinary Approach*. Vilnius, 2018-09-27 – 29.
4. Pabijutaitė Ž. (speaker): „Capturing Indeterminacy: Non-Linear Temporal Models in the 20th Century Logic and Metaphysics“. International conference *Preeminence of Myth and Decline of Instrumental Reason*. Vilnius, 2018-10-01 – 02.
5. Pabijutaitė Ž. (speaker): „Temporalinės logikos sistemų CL ir K_b semantinės interpretacijos su tradicinių teisingumo reikšmių pertrūkais“. Seminar of The Institute of Philosophy, Vilnius, 2019-04-24.
6. Pabijutaitė Ž. (speaker): „Solutions of the Problem of Future Contingents Based on the Rejection of the Necessity of the Past“. International conference *Space and Time: an Interdisciplinary Approach*. Vilnius, 2019-09-26 – 28.
7. Pabijutaitė Ž. (speaker): „Atsitiktinių teiginių problema Viljamo Okamo Traktate apie lemtį“. National conference *Antikos ir Viduramžių tyrimai 2019*. Vilnius, 2019-10-11 – 12.

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