NEW FORMS OF DIAGRAMMATIC LOGIC

Research Proposal (short version)

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General Description and Motivation

Logic is the 'immune system of the mind'. It is the intellectual backbone of reasoning and decision-making of both the human mind and of the general intelligence assumed of computational machines. Theories of logic and reasoning developed since Aristotle have attempted to instruct us how to value arguments, how to weed out inferences that are ill, and how to improve our conduct and creative engagement when faced with problematic life situations. A good theory of logic could thus in this wide sense result in an improvement in intellectual abilities and in rational and ethically conscious decisions in life. As both a theory and an art, logic is expected to have a positive impact on the healthy operation of the mind, human and artificial.

Yet despite centuries of research, the function of logical thinking is not understood well, much like the precise response of immune system in human biology is not understood well. The problem is that current theories of logic are ill-suited to carry out such a wider job of instruction and conduct involved in matters of practical reasoning. The tradition has almost singularly taken the requisite theories to come in the form of a language – in the sense resembling those of natural languages – that we could read and write using certain external, largely *symbolic* and *formal* representations, rather than as forms that could directly be intuited in cognition. But just as for our immune system to function

well a complex balance between harmony and speed is essential, logical judgments that prove beneficial should occur in the mind without need of translating underlying descriptions into formal codes. To achieve this, a new *notation* that represents the basic concepts of logic and critical reasoning *as a cognitive technique* is needed.

The Purpose of the Project

The project ***New Forms of Diagrammatic Logic*** proposes such a new approach: it develops and works with certain *graphical notation* to represent the theory of logic and processes of inference. This method differs from all other approaches in that instead of using the language familiar from ordinary symbolic and formal notations, the subject matter indeed is a *graphical*, or in other words a *diagrammatic language*. We cannot speak or communicate Diagram *in voce*, but we can imagine the forms and relationships present in it, and develop its theory.

The main hypothesis of the present proposal is that diagrammatic languages open up a novel panorama to the nature of logic, inference and thought by which one could address the central questions that have bothered contemporary research in logic and its philosophy. Such questions concern the true nature of *logical reasoning representation*, *logical consequence relation*, *logical constancy*, as well as certain specific concepts such as *quantification*, *identity* (equality) and *modality*. The leading idea is that the proposed developments on graphs now provide a *diagrammatic syntax* which, unlike most other and ordinary approaches, is neither linear nor one-dimensional. Among the consequences of this proposal is that the notion of *proof* in such many-dimensional, diagrammatic syntax becomes of the nature of *deep inference*.

Which most of this should certainly be regarded as new, the history of the topic continues to surprise. The background of such diagrammatic modes of thinking and reasoning dates back to the theory of *Existential Graphs* of American polymath Charles S. **Peirce** (1839-1914). His massive and to date still largely unexplored logical material

that we find in his manuscripts deposited at Houghton Library will in this project be investigated by contemporary tools of philosophical logic, and his writings indeed play the conceptual and historical counterpoint for the proposed project.

Scientific Novelty and Significance

New Forms of Diagrammatic Logic seeks to advance this so far under-explored field in the intersections of logic, language, information and cognition by presenting a range of new graphical logical languages for the perusal of the community of logicians, philosophers, linguists and mathematicians. The array of publications that result from this project introduce various *non-standard and non-classical diagrammatic logics* that have not been developed or discovered before. The more precise nature of these scientific contributions are detailed in the section on methods.

The Impact of the Results

This project is calculated to open up a new direction in the fields of logic and its philosophical, cognitive and knowledge-representation related applications. Those applications include methods and theories of computation that work better with visual and continuous representations rather than formal-symbolic-discrete languages. Evidence for this is that new discoveries in science and mathematics have invariably been preceded by the development of entirely new notations and a modification of existing ones, thus contributing to conceptual change. Among such future possibilities are multi-dimensional diagrammatic representations that could encode massive data received from fMRI scans representable in a propositional yet non-conceptual form.

A review of previous research conducted in the world related to the topic and their relationship with the project

The first proper presentations of Peirce's diagrammatic logic of existential graphs were by Jay Zeman (1964) and Don Roberts (1973). After that they were taken up by John

Sowa (1983, 2006) and used in the fields such as conceptual graphs and formal concept analysis. Sun-Joo Shin (2002) provides a book-length description of a part of Peirce's theory. The modest amount of literature that exists on this topic leaves lots of room for development. For example, Roberts (1973) is mainly a historical and exegetic exposition concerning the development of Peirce's logic and its basic features in his manuscript sources. It does not provide the necessary logical and theoretical details what is expected to be characteristic of contemporary treatises, papers and monographs. Shin (2002) is an exploration of the topic of Peirce graphical logic but contains almost nothing of the content of the present proposal, and what is there is presented in an inferior form. The PI, together with his co-authors (Ma, Bellucci, Chiffi, Moktefi, Liu, full references in CV and bibliography below) have thus far published several papers in the leading journals of the field that have aimed at improving upon both the formal logical aspects as well as the philosophical, notational, pragmatic and historical interpretations of these earlier works.

Research Objectives, Methods and their Justification

The methods of the proposed research are from the fields of logic, mathematics, philosophical analysis, and the history of these ideas. As to the last method, the historical one, the development of this unique graphical approach dates back to Peirce and his theory and method of existential graphs and their historical precedents. PI has researched thoroughly the unpublished manuscripts and archives of Peirce's and is completing a large edition on them (under review, Indiana University Press). The ideas can also be seen to underpin Wittgenstein's philosophy of logic and notation. Through these contributions, the project puts the developments that took place in early analytic philosophy into a new perspective. The contemporary exploration of that theory, on the other hand, has previously been confined to the development of the theories of conceptual graphs, only relatively loosely connected to real advances in the fields of logic.

The methods and their justification in terms of the objectives of the research and its scientific contributions are delineated in more detail as follows: In three main objectives and their justification and feasibility which is broken down into three sub-objectives each.

1. First, we develop the logic and philosophy of **the Alpha part** of the system of graphical logics which in the first instance concerns how to represent propositional information and inference. The resulting systems can be either classical or non-classical (deviant, fragments, extensions, etc.). The classical approach is largely co-extensive with Peirce's original proposal on the existential graphs of the alpha part. Three main parts of research are involved here.

    a. The current project extends this historical baseline into a range of non-classical and deviant cases of propositional logic. Among them can be listed *graphical intuitionistic logic* (the theory of this has been already been achieved in the applicant's publication Ma & Pietarinen 2017a.

    b. What remains to be done is that this intuitionistic system is to be further explored and implications sorted out), and that its dual, which has never been attempted before, namely *graphical co-intuitionistic/Brouwer/Brouwer-Heyting logic* (publication of this work is in progress), is also to be produced.

    c. Among other and highly interesting propositional and sub-propositional graphical logics to be developed include *De Morgan (distributive) logic* (publication of this work is in progress); *graphical logic of assertions (assertive graphs), illocutionary force and pragmatic logic* (ongoing research); *connexive logic* (ongoing research); *implicational logic*; *relevance logic*; and *paraconsistent logics*. These are in their main the areas to be explored and the results concerning them published during the period of validity of the applied grant.

2. Second, the project explores **the Beta part** of these systems which concern graphical methods for first-order logic of quantifiers. This part of the project splits into the following three chapters:

   a. *Graphical quantified propositional logic*, a fragment of a first-order logic currently much used in various fields, especially in computer science and in natural logic related to formal and theoretical linguistics. We will investigate this logic together with significant variations and interesting special fragments. Now Peirce's own original proposal was to have a first-order logic, and he indeed succeeded to have some of its fragments. This question needs to be addressed in two parts.

   b. First comes *graphical quantificational logic without equality*. This possibility amounts to significant consequences, since it goes back to Wittgenstein's proposal to be able to eliminate equality (the sign of identity) from logical notations. Wittgenstein did not succeed to present any convincing proposal of how to achieve that, and the recent attempts likewise have left the issue wanting. Since the graphical approach, which the current proposal advanced to be developed in its full in this department of Beta, shows how the notions of quantification and identity in fact belong together (that they are just one and the same sign), it is here in this approach that lies the clue to the resolution of Wittgenstein's problem. The challenge is to separate identity from quantification, but it looks like this can be done by manipulating the continuity of the representation of that sign with a broken line of identity.

   c. The project then also aims at developing a *full graphical first-order logic with equality*, which takes into account the full expressive resources of elementary logic and presents, for the first time, a full such graphical logic.

3. Third, *New Forms of Diagrammatic Logic* explores **the Gamma part** which is on graphical modal logics and their various systems, with extensions to epistemic and multiple modalities. This gamma compartment needs to be developed in three parts.

    a. First, we know that there are reasonable *graphical propositional modal logics*. This was initially explored in Zeman (1964) after which it fell into oblivion. Ma & Pietarinen (2017) launched a new exploration and mapped the complete systems of modal logics.

    b. This paper is to be continued in a follow-up exploration, especially in terms of *graphical epistemic and other modal logics such as beliefs for propositional attitudes*, which are increasingly important both philosophically and in recent areas in cognitive and computing sciences.

    c. This second section leads naturally to *graphical multi-modal logics*, which is kept here as a topic to be addressed only if time permits.

Within the confines of the proposed project, we envisage also **the Delta part.** The possibility of the Delta was mentioned in Peirce's manuscripts twice, but nothing on it has ever been developed, neither back then by him nor by anyone ever since. This delta part could provisionally taken to be on the graphical approach to *quantified modal logics*, of which we do have many examples by Peirce but no systematic exploration to date exists.

This project thus not only develops new, diagrammatic logics and respective calculi, but is strongly geared towards tracking the philosophical implications of the approach and the ramifications of those implications to prominent contemporary questions in philosophy of logic on the notions of identity, logical constancy, pluralism, logical consequence, and the nature of deep inference.

Statement of Academic Ethics

The project does not involve human or animal subjects, or any experimentation on those subjects. It does not involve datasets or digital data to be archived. The highest academic standards and professional conduct is observed in the execution and implementation of the proposed project, including those related to research, archival work, preparation of papers, books, presentations and other material for publication, working with co-authors, submission and publication of those papers, and the dissemination of the research and outreach.

Division of intellectual property rights

It is not expected that patents, trademarks or similar copyrights arise directly from this project, which is of the nature of basic and foundational scientific research. The copyrights concerning the publications that fall from the project are regulated by the publication policies of the respective journals and publishers. The exclusive rights for the creative aspects of the research that is conducted within the duration of the project remain with their respective authors.

Feasibility Plan

This is a high-risk research project in that none of these proposed novel forms of logic have been attempted before except as already preliminarily carried out by the PI and his team of collaborators. The novelties at present lie especially in the sub-objectives of Alpha-(c), Beta-(b) and Gamma-(c). For example, it is possible that no feasible graphical paraconsistent logic actually exists, or that multi-modal variant of modal logic is not well-amenable to a diagrammatic methodology. In addition, the proposed systematic exploration of the Delta part is entirely new.

We prepare for these risks as follows. In case one or more of these high-risk sub-objectives appears not to be satisfactorily in progress, there will still be plenty of food

for thought in the objectives Alpha-(a) and (b), Beta-(a) and (c), and Gamma-(a) and (b). Alternatively, then, we can turn out attention to them. Alpha-(a) is a low-risk objective while Alpha (b) is a moderate risk one but is known to work. Beta-(a) is also known to work, while Beta-(b) may be tedious but doable. Gamma-(a) has been preliminarily and successfully done and that line just needs to be continued and pursued further. Gamma-(b) is another medium-risk sub-objective that is promising in its applications to different modalities and their application, in turn, in various fields in science, including formal semantics and pragmatics. The Delta objective involves a systematizing a theory of quantified modal logic in a new way that has remained unsolved but even if it cannot be done it is hoped to result in some new philosophical and conceptual insights concerning the various modes of identification of possibilities and actualities.

Expected results

New Forms of Graphical Logic develops this so far under-explored field in the intersections of logic, language, information and cognition and presents a range of new graphical logical languages for the perusal of the community of logicians, philosophers, linguists and mathematicians. The results of the project advance state-of-the-art in non-standard and non-classical diagrammatic logics and they have not been developed or discovered before.

In short, the scientific impact of the project is calculated to be three-fold, and can be expressed in the following three theses:

- Any algebraizable logic becomes graphicalizable, with its own simple and elegant rules. Hence these graphs provide a new tool for the study of various algebraic structures.

- Only a simplest and iconic notation suffices for such graphicalizability: we use only closed curves and open lines (both continuous and broken). This has impact on various and contemporary topics in philosophy of logic, language and cognition.

- The sequent-calculi types of proofs of the graphical logic are the real deep inference.

The applicability of research results

New forms of graphical logics are calculated to open up a new and a major direction in the fields of logic and its philosophical, cognitive and knowledge representation applications. Those applications include methods and theories of computation that work better with visual and continuous representations rather than formal-symbolic-discrete languages. New discoveries in science and mathematics have invariably been preceded by the development of entirely new notations. Among such future possibilities are multi-dimensional diagrammatic representations that could encode massive data received from fMRI scans representable in a propositional yet non-conceptual form. It is to be noted that future and emerging applications in numerous scientific fields have increasing needs for iconic, visual and multi-modal modes of expression beyond language and symbols.

Target consumers of the results

Academics, graduate students of logic, mathematics, linguistics, cognitive science and related disciplines. The book that is to be written is the first one to present graphical logic in a unifying and contemporary form. Moreover, its graphical approach offers unique pedagogical advantages in teaching logic and reasoning. A textbook on this topic has not been written and that would be one of the important components of the follow-up grant application.

Publications

The project results in 6-8 high-quality journal articles to be submitted to top journals within the period of 12 months (mostly in Q3-4 of 2018 as detailed in the above work programme). The project would also result in a book proposal and in the first version of that book draft which is to be submitted to a major international university publishing house in late 2018.

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