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Where is Logic Going?

On October 14 – 16, 2013, a large group of Chinese and foreign logicians gathered at Tsinghua University to present a broad and lively picture of the field of logic in its various ramifications today. As can be seen in the scientific program at the webpage www.tsinghualogic.net, topics at the international conference "Logic across the University: Foundations and Applications" ranged from mathematics, philosophy, and linguistics to computer science and the cognitive and social sciences. In addition, two evening lectures highlighted major outside interfaces of logic with society and industry. The interested reader can find the material of this conference in the *Proceedings*, prepared by the editors of the current piece, that appeared with College Publications London. Moreover, reports for a more general audience on various aspects of the conference have appeared in *China Science Daily* and *Chinese Social Sciences Today*.

While participants came from a wide range of disciplinary backgrounds, many logical themes ran across the various subfields, tying the conference together, such as language, information, knowledge, proof, games, or probability, providing a common language and common concerns. What also held the event together were the lively exchanges between participants who did not hesitate to express their views on where logic as they see it is heading, when asked to do so. The resulting discussions were sometimes, as diplomats say, 'frank and lively', but also always interesting and entertaining.

We have tried to collect a fair sample of such perspectives for the reader. We asked all participants to express their views on their own research and its wider outreach, keeping a more general audience in mind. To help trigger responses, we suggested a few questions, not as a compulsory format, but as an aid which people could use as they saw it :

1. What is logic about, and what role does it play in your research?
2. What are major developments in your research area?
3. What are the uses of logic, inside the university, but also outside in society?
4. What major outreach activities are you yourself involved in?
5. What do you see as the exciting future developments in the field?

We asked participants to be brief, concrete, and personal in their responses. The resulting statements, mostly in the form of responses to some of our questions, but some of them freestanding, are printed here in alphabetical order, and they range from general philosophical views of logic to concrete social outreach activities that people

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are engaged in. Many authors also dare to cross from the descriptive to the normative, and suggest where they think the discipline of logic should be heading in the future.

We have edited these texts only very lightly for length and intelligibility, while taking care to preserve the difference in communication atmosphere between the academic disciplines and the world cultures represented here. That is the best guarantee of giving the readers of *Studies in Logic* a fair view of what working logicians and congenial colleagues from other fields from all around the world have to say about logic today, and the wide range of opinions and trends one may encounter in this setting. To us, the resulting music, including both harmonies and dissonants, is what real logic conferences are about.

Samson Abramsky, Department of Computer Science, Oxford University

(1) *What is logic about and what role does it play in your research?*

'Logic' can be interpreted in many different ways. It mostly has not been established as a subject in its own right, but as an auxiliary to other disciplines: philosophy, mathematics, nowadays computer science. For me, it represents the study of the formal structure of the most general and basic concepts, as they appear throughout the sciences. Thus its nature is essentially mathematical, since it must be rigorous; at the same time, it has a very wide range of applications. In fact, it arises in any developed field of thought. This kind of applied logic is central to my own research.

In my current work, I am studying quantum information and foundations using tools, essentially logical tools, which have been developed within Computer Science. The logical analysis of deep features of quantum mechanics such as non-locality and contextually leads in turn to identifying abstract structures which can be found also in classical computation, and in the modelling of human cognition and language. I call this broad program 'Contextual Semantics'.

(2) *What are the uses of logic, inside the university, but also outside in society?*

Some training in formal logic should be a basic part of training in Computer Science and related fields. More broadly, being able to analyse the logical structure of arguments is important in several different ways, in everyday life as well as in technical occupations. On the one hand, we can learn to detect fallacious reasoning. Equally importantly, we can appreciate the limitations of logical reasoning, and the incredible subtleties and nuances of natural language in the expression of our thoughts and emotions. Our fate as human beings lies somewhere in the balance between logic and feeling, and we must learn to appreciate both sides of this equation!

(3) *What are the most exciting future developments in the field?*

I will mention just a couple:

(i) Many particular logical systems have been studied. Understanding the struc-

ture of the 'space of logics', the 'logic of logic', will be an important future development.

(ii) Traditionally, logic has abhorred the circular argument, the infinite regress. Yet it seems that key features of our thinking and social interactions are inherently reflexive: an agent tries to understand and predict a system which contains it and which it can influence. Computer Science has developed tools for understanding such reflexivity. These need to be absorbed more centrally into logic.

Sergei Artemov, The Graduate Center, City University of New York

(1) *What is logic about and what role does it play in your research?*

The basic laws of logic were discovered in ancient Greece by observing how human beings reason, just as the laws of gravity were presumably formulated in the 16th century after observing how heavy objects move and fall down. Whereas physics describes the universe around us, logic teaches correct ways to think and come to reliable conclusions by the power of intellect, both human and computer-aided. In my research, logic is the primary tool that helps to uncover structure beneath surface complexity in philosophy and mathematics, law and business, computer science and information security, and other fields.

(2) *What are the uses of logic, inside the university, but also outside in society?*

Ever since Euclid's "Elements", which was intrinsically a logic-based theory, logic has maintained a prominent presence in foundational studies of the sciences, philosophy, and law. At the dawn of the computer age, logic became a ubiquitous element of technology. From high-performance computing and critical software to smart phones and car navigation—intelligent systems are everywhere.

(3) *What do you see as the most exciting future developments in the field?*

Mathematics and the exact sciences have long utilized logic in their foundations. The social sciences have proved to be more difficult to formalize and make the subject of logical studies. During the last couple of decades, there have been promising developments in the area of logical methods in the studies of knowledge, belief, and evidence, as well as in game theory and decision making. For example, when the game is played, the state of knowledge or the beliefs of the players about the game and each other comprise the crucial input of the game analysis, and this is where logic inevitably comes into play. There is now a strong possibility of making logic a key foundational ingredient in these areas.

Noah Goodman, Department of Psychology, Stanford University

(1) *What is logic about, and what role does it play in your research?*

Logic is the way humanity has developed to precisely specify knowledge. One of the major goals of cognitive science is to understand human knowledge and the

role it plays in our everyday reasoning. In my research I borrow tools from logic, and from statistics, to make precise theories of human knowledge and reasoning. I then take the psychological theories and use them to design more intelligent machines.

(2) *What are the uses of logic, inside the university, but also outside in society?*

Logic is useful as set a set of tools for precise specification and reasoning. Within academia these tools help us build theories, and help us communicate across the sciences. In society logic can help us to make sure our reasoning is sound and that we understand our assumptions.

(3) *What do you see as the most exciting future developments in the field?*

To me the most exciting developments on the horizon are the unification of logic with statistics, enabling powerful machine intelligence, and the application of these new tools to understand the human mind.

Davide Grossi, Department of Computer Science, Liverpool University

(1) *What role does logic play in your research area, and what are major developments?*

I am a researcher based at a Computer Science department within an Artificial Intelligence group. I see logic as a privileged tool for doing research on topics that very naturally span across different disciplines. One of these is decision-making: how do individuals acquire information, evaluate options and take decisions? While several aspects of decision-making have found or are now finding solid foundations—from the dynamics of information in groups (Epistemic Logic), to strategic interaction (Game Theory)—one in particular still awaits conclusive analysis, namely the collective aspect of decision making: how do groups of individual take decisions? Voting is a well understood process (Social Choice Theory), but it is a 'niche' process when it comes to taking decisions in group, practiced only in special circles like committees, assemblies and parliaments. More widespread and 'fluid' processes, such as argumentation and deliberation, are far from being comprehensively modeled and understood: can we build accurate models of the processes underlying a political debate, or a scientific dispute? That is, I believe, one of the major open research challenges in the study of rationality and decision-making and where logic could play a pivotal role.

(2) *What broader logic outreach efforts are you involved in?*

These are exciting times for the future of logic in the UK. September 2014 will see the start of a major overhaul of the school curricula and, in particular, the introduction of a new Computing Curriculum. This will bring Computer Science and its foundations (including elementary logic!) to pupils from young ages. I am personally involved, together with other colleagues in my department, in promoting the implementation of the new curriculum. In particular, we have set up many activities to

support school teachers in the Liverpool area in gaining confidence with the new materials they will be asked to teach. Because of my involvement with these activities, I have been invited to participate as a panelist at a meeting of the Westminster Education Forum (a forum for policymakers in the British Parliament and government) to be held next February, concerning the implementation of the new computing curriculum. Logic is one of the pillars upon which Computer Science rests, and this new curriculum can be an unprece-dented chance to promote the discipline beyond its merely academic stronghold. [1]

Huang Huaxin, Center for the Study of Language and Cognition, Zhejiang University

(1) *What is the role of logic in your research area, and what are major developments?*

Given the current development of cognitive science, logic faces both development opportunities and grave challenges that are unprecedented in history. There are two major tendencies for the discipline that we have to meet. The first is concerned with intelligent machines. How to improve the intelligent level of these machines is not only an issue of hardware upgrading but also an issue of software updating. The rapid advances of formal argumentation theory and natural language processing in logic will probably push these machines to a higher intelligent level and facilitate human-machine interaction. The second issue focuses on human beings. In an age of information explosion, a variety of internet mass incidents have made more and more people realize that we are easily lost in the ocean of information and make irrational decisions. Therefore, how to improve the public's logical thinking and awareness and how to develop their ability of critical and creative thinking will constitute a primary task for logic researchers.

(2) *What broader logic outreach efforts are you involved in?*

With the guidance of the above two orientations, logic needs to play a better role in facilitating the connection between the natural sciences and the humanities and social sciences. In the following five years, a series of cooperative programs and society-oriented promotional projects will be launched. For example, we are going to cooperate with experts in the field of computer science to analyze symbolic interaction in the context of multiple robots under the framework of formal argumentation and signaling games; we will also work together with linguistic researchers to examine some key questions related to natural language processing in Chinese from the perspective of syntax, semantics and pragmatics; and we also intend to collaborate with educators in philosophy of science, with the help of cases in the history of science and technology, to impart to college students how to properly utilize inductive

[1] A news item I have written for the University of Liverpool about the above outreach activities can be accessed here: http://news.liv.ac.uk/2013/06/06/the-liverpool-view-empowering-\the-nextgeneration-of-computing-teachers/.

reasoning, deductive reasoning or abductive reasoning when they are solving problems. Additionally, we are interested in the domain of children's education where logic teaching will be applied organically to the design of educational toys as well as to parent-child interaction. In such a new era, logic researchers need a wider vision and greater bravery to seize opportunities and confront challenges.

He Xiangdong, Institute for Logic and Intelligence, South West University

(1) *What is the role of logic in your research area, and what are major developments?*

My research is mainly on inductive logic and its applications. The current trends in this area concern the following three aspects: dynamics of information in inductive reasoning, the cognitive basis of induction, and applications of inductive logic in AI. My finished key project on Contemporary Inductive Logic granted by the Chinese Ministry of Education made some important progress in this area.

(2) *What broader logic outreach efforts are you involved in?*

Inductive logic has great value in applications. For example, data-mining systems based on fuzzy logic (a kind of inductive logic) has been established in China. This kind of system can be used in enrollment of university students in Chongqing. Cognitive psychologists in my research group revealed the cognitive mechanism of inductive reasoning in learning. Moreover, inductive reasoning is also vastly used in areas like machine learning, programming, design, information search etc.

Vincent Hendricks, Department of Philosophy, Copenhagen University

(1) *What is logic about, and what role does it play in your research?*

On the classical conception, logic is the study of valid inferences. On the modern, and interdisciplinary conception, logic is the study of correct information processing for both single agents and groups of such. From this perspective logic has a great deal to say about the structure and nature of reasoning, rationality, deliberation, decision and even action for individuals and collectives. As of late, my research and research group (of whom I would like to mention my brilliant student Rasmus K. Rendsvig in particular) has focused on how information technology—social media, blog universes, discussion forums etc.—may amplify irrational group behavior. By way of example, the term "bubble" is normally reserved for situations in finance. There are stock, real-estate and other bubbles associated with financial markets. However, one may also identify filter bubbles, opinion bubbles, political bubbles, science bubbles, social bubbles, status bubbles, fashion bubbles, art bubbles, all pushing collectives of agents in the same (often unfortunate) direction; not only buying the same stock or real estate but also thinking the same thing, holding the same opinions, appreciating the same art, "liking" the same posts on social media, purchasing the same brand names, subscribing to the same research program in science etc. Bubbles may

thus generally refer to (often) irrational ways of aggregating collective beliefs, behavior or preferences based on what social psychologists refer to as "social proof". "Social proof" means that single agents assume beliefs, norms or actions of other agents in an attempt to reflect the correct view, stance, or behavior for a given situation. Logic is an excellent tool for uncovering the structure and dynamics of various derivatives of social proof like bystander effects, lemming effects, herding behavior, bandwagon effects etc.

(2) *What are the uses of logic, inside the university, but also outside in society?*

Since logic, on the modern conception again, is about correct information processing, it features prominently, either directly or indirectly, in many university disciplines. Obviously, in philosophy but also in mathematics, computer science, informatics, linguistics, cognitive science … and in disciplines often enough not associated with the application of formal methods ranging from humanity subjects like psychology, anthropology and even history, to social science, political science and economics. Logic is accordingly a thoroughly interdisciplinary field.

If you look at society, democracy and social order as giant exercises of agents coordinating and interacting, and since logic is, qua being the study of correct information processing, a tool for studying the structure and dynamic behavior of agent coordination, interaction and rationality, then logic will have a great deal to say about how we should configure, maintain and develop such cherished societal institutions. At the same time logical analysis of agent deliberation, coordination and interaction may be used to diagnose problems and warn against the pitfalls of collective rationality. This becomes ever more important in this information age where information travels faster and wider than ever and thus may influence deliberation, decision in action in ways we have never actually seen before. Realize that our experience with say, social media and the proliferation of information through such networks only dates back about 10-15 years. Information is not necessarily in and by itself a boon; it must be properly collected, formatted, handled before it becomes useful for decision and action. Thus, information may used to enlighten but may also be used to manipulate people, opinions and markets. I have a new book, Infostorms (see www.infostorms.com), coming out in January 2014, with my former PhD-student, Pelle G. Hansen, which elucidates how logic may be used to study all sorts of irrational group behavior in science and society and in no small measure aided by modern information technology.

(3) *What do you see as the most exciting future developments in the field?*

This conference and its distinguished participants are a witness to both an ambition and a vision of logic as an interdisciplinary toolbox for describing, analyzing and optimizing social interaction, rationality and coordination among the members of collectives, groups or society at large. And those members would be us. Humans. It is hard to point to a more noble and exciting future for logic than that.

Wesley Holliday, Department of Philosophy, UC Berkeley

(1) *What is the role of logic in your research area, and what are major developments?*

My research studies knowledge, information, and other epistemic phenomena, using the mathematical methods of Epistemic Logic and the philosophical approach of Epistemology. Anyone who has tried to apply formal-logical methods to philosophical issues is probably familiar with the challenges of fostering communication between those who feel at home with formal methods and those for whom formal methods feel foreign, at least at first. This challenge may be related to a wider one, discussed by C. P. Snow in his famous 1959 lecture, "The Two Cultures," of fostering communication between mathematics and the sciences, on the one hand, and the arts and humanities, on the other hand. I hope that some of the major future developments in my area will involve "formal philosophers" appreciating the depth of traditional philosophical problems and perspectives, and "traditional philosophers" appreciating the power of formal methods to illuminate some of those problems and perspectives. Formal philosophers can help build bridges by increasing the accessibility and philosophical sensitivity of their work, and traditional philosophers can help build bridges by investing the time it takes to understand new logical tools.

(2) *What broader logic outreach efforts are you involved in?*

At my institution, UC Berkeley, we have a large student body—over 25,000 under-graduates—and a long tradition in logic, supporting our Group in Logic and the Methodology of Science (logic.berkeley.edu) since 1957. As a result, we have the great opportunity to introduce logic to many students at different levels every year. We teach a variety of courses in logic, ranging from the classical mathematical logic sequences offered in Mathematics and Philosophy, to courses in philosophical logic, formal semantics, set theory, and more. I have the pleasure of teaching courses on modal logic and classical logic to a diverse group of students from Philosophy and other fields, ranging from English to Physics. In my view, interdisciplinary appeal should be one of the strongest selling points for logic in the modern university, a view strongly supported by our conference at Tsinghua!

Gerhard Jäger, Department of Linguistics, University of Tübingen

What is the role of logic in your research area, and what are major developments?

From my perspective as a linguist, I see three major new trends in logic - conceived in the broadest sense - with immediate and significant relevance for other cognitive sciences. 1. An increasing attention to the interpersonal/social aspects of reasoning. Of course there is a long tradition in this regard, tracing back to Lorenzen's work on dialogical logic in the 1950s and Hintikka's game theoretic semantics from the 1970s onward. Still, the recent attention to games in the economist's sense, especially on epistemic game theory, adds a whole new quality to this approach. 2.

The game-theoretic take on reasoning and rationality is closely connected to a new focus on learning and evolution. Real people are not the perfectly rational agents of traditional logics and classical decision theory – far from it. Recent work in evolutionary game theory and related approaches show, though, that what looks like highly rational reasoning and decision making can be causally explained as the outcome of a trial-end-error style learning process plus selection in the Darwinian sense. 3. One of the classics of modern Bayesian statistics, Jaynes' "Probability Theory: The Logic of Science" aptly made a connection between subjectivist statistics and logic. Recent advances in empiricist inference (due both to breakthroughs in the computational implementation of empirical inference patterns and in the availability of "Big Data") are a healthy challenge to deductive logic which promises to yield exciting new insights in the imminent future.

Hannes Leitgeb, Center for Mathematical Philosophy, Ludwig-Maximilians-Universität München

Within philosophy, logic has always had a double role to play: on the one hand, as a tool that is to be used to improve our philosophical reasoning; on the other hand, as a part of philosophy that is concerned with topics such as consequence or truth.

This also carries over to the role of logic education within philosophy curricula: to teach our students how to think and talk straight; but also to let them participate in the fascinating developments of philosophical logic. We need to make sure that we keep the healthy balance between these two aims also in the future: to be relevant to other philosophical areas; and at the same time to value logic as a philosophical discipline in itself.

Christian List, Departments of Government and Philosophy, London School of Economics

On the question regarding the relevance of logic to the social sciences, I think logic is relevant in at least two respects:

(i) Social scientists engage in reasoning, argumentation, inference, and theory/model construction. All these activities involve logic and can benefit from an upgrade in logical techniques and sophistication.

(ii) The "objects" of study in the social sciences, i.e., the agents involved in social phenomena, are users of logic themselves, typically of course implicitly. They, too, engage in reasoning, argumentation, inference, and so on. Logic can offer us great tools for modelling and analysing their intentional agency, rationality, and related phenomena.

In this spirit, my own work—both on judgment aggregation and on reason—based choice-aims to bring together ideas from logic and ideas from rational and social choice theory.

Hiroakira Ono, Japan Advanced Institute of Science and Technology

(1) *What is the role of logic in your research area, and what are major developments?*

In the last 20 years, people started to see topics with a broader view and to try to understand them in a unified way. In my research area, this has caused substantial collaborations with algebraists and topologists. It is surprising for me to see, for instance, that algebraists sometimes discuss cut elimination theorems.

(2) *What broader logic outreach efforts are you involved in?*

These years, I have been working as an academic advisor of the project called "Alliance for Breakthrough between Mathematics and Sciences", which is financed by the Japan Science and Technology Agency, a major funding agency in Japan. This is the first big project on mathematics in Japan (http://www.jst.go.jp/crest/math/en/index.html). The perspective of the project is as follows. "It is designed in particular for research by mathematical scientists that is motivated by social needs, conducted in cooperation with scientists in non-mathematical fields, and that is expected to make a scientific breakthrough. It may be viewed as attempting to integrate the rationalism of Descartes and the empiricism of Bacon in the 21st century. The program will cover studies of mathematical problems in diverse fields of science: materials science, life science, environmental science, information science, telecommunication science, financial engineering, etc. Research activities in other fields will also be within the scope of the program if those activities propose new research topics arising from social needs, and explore mathematical approaches to those topics. Priority will be given to research that develops new mathematical ideas through the study of natural or social phenomena in a field of science while applying existing mathematical methods to that study. The program therefore emphasizes research which contributes to the integration of mathematical and experimental sciences. "

I think that the project has been quite successful and has made a contribution to a change of attitudes of mathematicians in Japan toward other sciences and also to society in general.

Ramaswamy Ramanujam, Institute of Mathematical Sciences, Chennai

The agenda of logic needs to be broadened to include methods that are termed classically as "analysis", so that not only the logical foundations but also methodological issues in the natural sciences can be given a logical basis.

(1) *What is the role of logic in your research area, and what are major developments?*

Logic has tremendous applications in computer science, has been remarkably successful in hardware and software verification, in security policies and protocols, and in database systems. The very popular database query language SQL is first-order logic.

(2) *What broader logic outreach efforts are you involved in?*

The work on large games that I have been involved in, with some colleagues, addresses social situations such as the effects of imitation on herd behaviour, which some biologists have pointed out as having parallels in animal behaviour. Similarly work on games where players' choices change during play have led to some applications in social infrastructure.

A separate line of work has been in school education, where I have been involved in mathematics curriculum design: one important element has been incorporating formal logic, patterns of reasoning and types of proofs in the Indian national higher secondary mathematics curriculum. I have also been involved in mathematics workshops for high school teachers where logic is one main component. Current work includes a formulation of a logic component for inclusion in the teacher education curriculum, as a part of mathematics pedagogy.

Jeremy Seligman, Department of Philosophy, The University of Auckland

I am sure I share with many of the conference participants a sense of excitement that logic can have some creative interaction with the social sciences. In my own work on logics of social networks, I am increasingly aware of social phenomena that call out for logical analysis. Examples that have received recent attention include peer pressure, the way in which social structures mediate the transmission of opinion, pluralistic ignorance (when every member of a group does not know something but believes that every other member knows it) and information cascades (when the mechanism of transmission of opinion blocks a group from combining their opinions in an effective way). Our evolving understanding of the two-way relationship between game theory and logic also promises to be a valuable tool in thinking about social networks, which are already studied by economists and social psychologists using the concepts and central theorems of game theory.

For the past thirty years or so, logicians have been moving away from the traditional area of application in mathematics, through computer science, to a range of interesting new topics. And yet logic education lacks behind to a great degree. Within many universities, logic is still regarded as either a small component of theoretical computer science, a specific topic in mathematics or minority interest, or a rather boring and not really necessary service course in philosophy. Although there are many examples of contributions of logical analysis to philosophy at the highest levels, only the most ambitious philosophy programmes insist on training their students even to be able to read and understand this work. In my view, the greatest challenge for contemporary logicians working on new areas of application is to find a way to convey their excitement to students at every level, to show the value and fascination of examining a diverse range of problems through the clear lens of logical formalism.

Su Kaile, Department of Computer Science, Griffith University and Peking University

(1) *What is the role of logic in your research area, and what are major developments?*

My research area is the field of model checking. Given a model of a computational system and a specification (usually in temporal logic), the model checking problem refers to checking whether this model meets the given specification. One major development in the field of model checking is symbolic model checking, that is, using symbolic techniques such as SAT (Satisfiability) and BDD (Binary Decision Diagrams) for overcoming the major so-called 'state explosion problem' in model checking.

(2) *What broader logic outreach efforts are you involved in?*

Our current outreach effort is model checking epistemic logic, i.e., checking whether a model of a multi-agent system (such as a game) meets stated specifications concerning also epistemic properties pertaining to agents' information. In doing so, we also study and improve symbolic techniques like SAT and BDD.

Paolo Turrini, Department of Computer Science, Imperial College, London

What logicians should do if they do not want to be useful for other disciplines that study human reasoning is:

(i) To keep the reasoning structure implicit in their languages, as happens for instance with various logics for strategic ability, which never really show how strategic reasoning actually develops: "If my opponent cooperates, I had better defect. If he defects, I had better defect. Therefore, I had better defect. " This is an inference!

(ii) Not to read literature in psychology, experimental economics, etc., and still aim at building formal theories of beliefs, preferences and so forth. Realistic properties of reasoning (human or not) should be investigated in logic, even if complex.

Logic is the science of reasoning. The kind of reasoning studied in psychology and economics is something that logic should study. And it should study it explicitly, both in its outcome and in its process, in a complex enough way to be of interest for the more applied sciences.

Moshe Vardi, Department of Computer Science, Rice University

(1) *What is logic about, and what role does it play in your research?*

During the past fifty years there has been extensive, continuous, and growing interaction between logic and computer science. In many respects, logic provides computer science with both a unifying foundational framework and a tool for modeling computational systems. In fact, logic has been called "the calculus of computer

science". The argument is that logic plays a fundamental role in computer science, similar to that played by calculus in the physical sciences and traditional engineering disciplines.

(2) *What are the uses of logic, inside the university, but also outside in society?*

Indeed, logic plays an important role in areas of computer science as disparate as machine architecture, computer-aided design, programming languages, databases, artificial intelligence, algorithms, and computability and complexity.

(3) *What do you see as the most exciting future developments in the field?*

One of the most fundamental challenges of computer science is to bridge the gap between people and computers. People communicate best in high-level languages. Computers ultimately execute only low-level programs. Thus, we need a bridge between high-level and low-level languages. Logic offers such a bridge. The most exciting development is the attempt to be able to communicate with computers in languages that are much more high level than today's programming languages.

Dag Westerståhl, Department of Philosophy, Stockholm University

In the study of how people communicate via language, the use of logic is by now a commonplace. But although the roots go back to Aristotle, it is only with the most recent advances that science is beginning to shed some real light on the extremely complex, yet seemingly effortless, process by which *my* thoughts or desires, through the media of sound or writing, result in appropriate responses and perhaps action on your side. Logic plays an important role here (as do linguistics, computer science, psychology, and neuroscience), in particular for efficient representation of the content of thoughts and the mechanisms of human information processing. To a logician interested in language, these are exciting times. Logic is a toolbox as well as a means of making ideas clearer, and even discovering new ones. The purpose of logic teaching is not to describe these tools but to enable the student to use them. In logic, teaching is never far from research, as witnessed by the many LLC—logic, language and computation—summer schools and the like now taking place across the world, where students as well as researchers participate. I have recently been involved in several such schools in China, where the demand for logic teaching is growing and the enthusiasm of the students is truly inspiring.

Xiong Minghui, Institute for Logic and Cognition, Sun Yat-sen University, Guangzhou

As Rescher has said, a legal trial is not concerned with the "real truth for the matter"—else why have categories of "inadmissible" evidence?—but for making a legally proper case (*Dialectics*, 1977). Legal logic refers to the logic for legal argumentation, which should be the reasonable warrant for judges and attorneys to make

a legally correct decision. Its task is to distinguish good legal arguments from bad ones. And its aim is to help a judge to make a reasonable and just judicial decision in court, an attorney to engage reasonably in a lawsuit, or a knowledge engineer to model legal argumentation.

When I say to somebody my research area is legal logic, I am normally asked to answer the following question: How do you evaluate Jr. Holmes' well-known saying that "the life of the law has not been logic; it has been experience" (*The Common Law*, 1881). Some people indeed misunderstand Holmes' expression as rejecting logic in the law. But if we check his subsequent paper *The path of the law* (Jr. Holmes, 1897), it is not difficult to find formulations such as "the training of lawyers was indeed a training in logic" and "the language of judicial decision was mainly the language of logic." Obviously Holmes did not reject logic in the law but wanted to show how it is misused and misconceived by lawyers. In his own words, the fallacy to which he refers is the notion that the only force at work in the development of the law is logic.

With the development of artificial intelligence, nowadays legal logic must be geared to the need of two "brains"—human brains and robot brains—as well as logic. For legal logic, the human brain facing it is that of a judge or an attorney while the robot brain is that of a computer. It is the former that leads legal logic to an informal perspective and the latter that pushes legal logic into formalizing legal argumentation. Throughout history, the study of legal logic has been typically based on mainstream logic(s) at the time, therefore a logical tool for legal argumentation always varies from time to time.

Ye Feng, Department of Philosophy, Capital Normal University

My research area is philosophy of mathematics, which is very closely connected with logic. In the past couple of decades, the most significant developments in logic closely related to philosophy of mathematics are perhaps the following two. First, W. H. Woodin and some other set theorists tried to realize Gödel's program of extending ZFC to settle ordinary mathematical problems, including the Continuum Hypothesis and perhaps even all 'natural' mathematical problems in some appropriate sense. Second, in a program called 'reverse mathematics', H. Friedman, S. Simpson, and other logicians explored the exact mathematical axioms required to prove a specific ordinary mathematical theorem (that is, instead of deriving theorems from the axioms, they reverse the process). Besides, a new direction in philosophy of mathematics, the new Fregean approaches to foundations of arithmetic and analysis, heavily rely on logical technical results about subsystems of second order arithmetic and systems of arithmetic and analysis based on non-classical logics. Personally, I am involved in developing a very weak and strictly finitistic mathematical system as a tool for explaining the applicability of classical mathematics to this finite physical world.

Zhou Beihai, Department of Philosophy, Peking University

Cognitive science is emerging today. It is a family of many subjects, including psychology, brain sciences, linguistics, computer science, philosophy of science, and logic. Around cognition, there has been new development in linguistics and computer science. For instance, cognitive linguistics started from the 1980s. In computer science, in particular, in AI, we have seen AGI (artificial general intelligence). Logic traditionally has close connections with linguistics and computer science; however, it has not been as active as those two fields. Though there has been epistemic logic since the 1960s, there is no cognitive logic yet. People suspect whether there will be something called cognitive logic at all. Cognitive linguistics has not caught much attention from the community of logicians. In current interdisciplinary studies, there is no influential work concerning cognitive linguistics. One of the founders of cognitive linguistics, George Lakoff once concluded that "Formal logic has no resources for characterizing any of the aspects of human concepts and human reason discussed so far in this book. The reason is that formal logic is disembodied, literal, nonimagistic, and nonmetaphorical" (Lakoff and Johnson, *Philosophy in The Flesh: the Embodied Mind and its Challenge to Western Thought*. Basic Books, 1999, pp. 128). I agree with many of his ideas on cognitive linguistics, but do not agree on this opinion. In my view, logic can play a critical role in the study of cognition, for instance, to establish a formal theory of concepts based on logic, in order to get a formal characterization of metaphor. I believe that introducing cognition will bring new concepts and vitality to the studies of natural language.

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I do interdisciplinary research on logic, language and computation. We have achieved some preliminary results, involving the following ideas:

(i) According to Fillmore's Case Grammar in which verbal-head has been emphasized, a new kind of categorical type logic has been established based on polychotomy (a method of syntactic analysis), that can be used to analyze ditransitive sentences and multiple prepositional phrases.

(ii) We intend to adopt Morrill's discontinuous Lambek Calculus to deal with multiple quantified expressions in natural language, and even improve Morrill's discontinuous categorical logic.

(iii) We have thought about extensions of the categorical symmetry logic which was investigated by Moortgat and his disciples. If the so-called "product" operator means "concatenation" in categorial grammar, we can create a "non-concatenation" operator that can explain asymmetry phenomena in Chinese.

In the field of computational linguistics, the logical approach is not in a dominant position like the statistical approach. Although there are plenty of irregularities

in natural language, however, its basic framework can be regulated by logic. What seems to be non-standard phenomena that cannot be solved by old logical rules may be solved using new criteria of logic. This is the inducement that drives logicians to explore the mysteries of natural language and develop new tools.

Concluding remark

The many interesting experiences of doing logic expressed here, and the rich spectrum of views that practitioners have of its future, clearly show the importance of logic today, its exciting role across a broad range of the university, and its potential outreach to society. Many more statements could be collected adding to this picture, but we hope that the present collection carries its own weight. Of course, where all this ferment is leading precisely may not be obvious at this stage, and indeed, our authors may not all agree on where best to mine right now for logical gold or related intellectual currencies. This diversity of views invites careful thought and analysis. It also invites discussion, and readers of this journal may feel inspired to formulate further views of their own. What should be clear, however, is that the voices heard here are not in conflict: they represent a community of people that can and do talk to each other in fruitful ways.

Our role as editors for this panorama of thoughts and opinions has come to an end. We leave the follow-up discussion to others—and in the end, to that final arbiter of all things: where modern logic is heading, time will tell.

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