Dialogue on Logic, Information, and Dynamics

Fenrong Liu with Johan van Benthem

Chinese translation: Wenfei Ouyang

Spring 2026

I. Prelude

Liu: Our earlier interviews were about your technical work. This time, I want to probe the philosophy behind it and the main themes in your total perspective. What drives you, how do philosophy and mathematics interact in your work?

Thank you Fenrong. I am not a person who started out with a grand philosophical vision which I then developed systematically in all its aspects and consequences. In my academic life I constantly run into new ideas from colleagues and students which affect my thinking. It is only afterwards, looking back at my activities, that I see stable lines through my work. Thus, this interview is a welcome chance to learn more about myself, perhaps even reinvent myself a bit.

II. Information and logic

Liu: You started with technical contributions in modal logic, the semantics of natural language, the philosophy of science, and the philosophy of time. But over the years you have also become known for general philosophical themes. One theme I see running through your work is information. You even invented a public slogan: "Information is the only resource that grows with use". What did you mean?

Slogans need not be deeply reflected. They occur to you in a flash of inspiration, like lines of poetry. In 1996, the University of Amsterdam asked me for a thought for a publicity campaign with postcards and posters on bus shelters. My flash was this. We all know the dark prospect of using up the finite resources of this planet. But universities provide information, and unlike other resources, this one stays fresh in use, and the more you use it, the more it accumulates. That's the thought. And the slogan caught on. The library of Delft University commissioned a large handwritten version which I ceremonially inscribed on the wall of their building.

Liu: But how did the information theme become prominent in your thinking?

Much of my work is indeed about information that humans can use: how we represent it, how it affects us through changing our knowledge and beliefs, and how we live with it when we act and, in particular, interact with others. And since these topics occur in many disciplines, information is a useful unifying perspective for my interdisciplinary interests in philosophy, computer science, and the like.

This theme was not originated by me. In the 1960s just after finishing high school, I read a book by three Dutch philosophers giving a broad perspective, since major advances in human history such as the invention of writing are all about information. Later, around 1980, students and colleagues in Amsterdam proposed viewing the essence of linguistic meaning as its role in information exchange between language users, an approach now called Dynamic Semantics. Another influence in the 1980s was the Situation Theory of Jon Barwise and John Perry at Stanford. It views our world as a network of situations connected by information channels. That information was a unifier in my environment also shows in the "Institute for Logic, Language and Computation" (ILLC) that we founded in 1991 in Amsterdam. It started in 1987 as an informal "Institute for Logic, Language and Information": 'Computation' replaced 'Information' to please some hard-core computer scientists joining later.

In all then, in my information theme, I was just a child of my times.

Liu: You are one of the editors of the "Handbook of the Philosophy of Information", which presents a variety of perspectives on the nature of information. For instance, Shannon viewed information as a measure of uncertainty reduction, emphasizing signals and probability, while Floridi sees it as well-formed, meaningful, and true data. Could you share your thoughts on these differing views?

This is a perennial question. Information means different things in different fields. In the scientific or engineering tradition it is a numerical quantity measured in bits and bytes. Mathematical theories making this precise are Statistical Mechanics, Information Theory and Kolmogorov Complexity. These offer quantitative insights on efficient coding, information channels, and processing by physical devices.

On the other hand, there is the qualitative notion of meaningful information pervading human life, studied in linguistics, philosophy and other humanities. In the Introduction to the Handbook we point at two of its crucial features: it is always about something, and for someone. This brings in the world as well as the agents using the information, their purposes and their ways of obtaining or modifying it.

The two views are not in conflict. Human agents can only pick up compressed information about the complex reality around us that fits our bounded cognitive capacities, and compression can be measured by Information Theory. But I doubt if there is one unified definition of information covering all its senses. As with probability, such a definition need not exist, and is not needed for serious uses.

Liu: But how does logic help us study the notion of meaningful information? Logic is about valid inference, right? How does information enter there?

The chapter 'The Stories of Logic and Information' in the Handbook you cited uses logic to study meaningful information. It distinguishes several basic senses, based on what happens in logical inference. Perhaps I can best introduce these senses with a simple example of the inference patterns that logic is after.

Suppose your doctor tells you: "If you take my medicine, you will get better. But you are not taking my medicine. So you will not get better." This has the general pattern "If M, then B. Not M. So: Not B". Clearly this inference is incorrect: you might also get better by taking a rest or avoiding bad food. But now change just a little bit in the pattern: invert the second M and B, and turn it into "If M, then B. Not B. So: Not M". You are not getting better, so the doctor infers that you did not take the medicine. In contrast with the first, this is definitely a correct conclusion. It is patterns like this that have been a core subject of logic throughout its history: we want to find the correct ones and stay away from the incorrect ones.

What does this have to do with information? One can think of what is happening in the correct inference of the doctor as follows. Initially, we know nothing, so all four possible true-false combinations for M and B occur in the range of options that we see, we have no specific information. Now consider the assertion "If M, then B". Once we learn this, it rules out the case of M true and B false, leaving three options. This smaller range means more information. Next consider the further information that "Not B". This rules out the two options where B is true, and we are left with just one: B false, M false. This outcome explains why the conclusion "Not M" was correct: it is enforced by the information in the two assumptions.

Here is one more illustration. Consider the incorrect inference. We start again with the first assertion, leaving three options MB, (not-M)B, (not-M)(not-B). If we now get the information that "Not M", only the option MB is ruled out, and we are left with the two options (not-M)B, (not-M)(not-B), so the conclusion "Not B" does not follow. We just do not have enough information to draw this conclusion.

The sense of information involved here is as a range of options for what the actual world is like. This notion is sometimes called `semantic information'. We also see how it is constantly updated as new information comes in. By the way, in practice, information ranges can be large, and a process of successive updates need not end up with just one option where we know all relevant facts about the world.

But this cannot be all. The range view does not explain why logical conclusions can be informative. This, too, is illustrated by our simple example of a correct inference. The information in the two premises reduced the range to just one option. But then, if I update that range with the conclusion "Not M", nothing is ruled out, the range stays the same, so no semantic information is added But we do draw logical conclusions all the time, and they are helpful with many tasks. How can this be?

At work here is a more refined notion of information, making relevant aspects of our range-style information explicit for a given task, or directing our attention to new topics. Think of Bob Dylan's famous line "When you've got nothing, you've got nothing to lose." This is a logical consequence, but somehow also an informative reminder of what is true in life, it may even be a consoling thought. In my high school days I would listen to Dylan's songs at the home of a friend, and we would copy their memorable lines on the wall of his room: including this one.

More generally, this more subtle second sense of information through inference essentially involves syntactic code: how we phrase the information in natural or formal languages, and how it can be grasped, modified, and communicated.

Both range and code senses of information can be studied in Epistemic Logic, an area where I have done a lot of work, but I will not go into technical details here.

Liu: But does all this really cover the notion of information in the Situation Theory that you mentioned? That is a framework which I really like.

It does not. Situation Theory introduced a third sense of information in terms of correlation between different situations. For instance, by looking at a mobile phone in my hand, I can find out what the weather is like in Beijing, through a complex network of channels running from the actual weather events in China to the visual representation in my wechat app here in Holland.

I have struggled for years to find a logical framework for studying this third notion. Its mature version is my work in recent years with Alexandru Baltag on logics of dependence between variables in universes of states (standing for the relevant

situations) that have correlated values. The resulting abstract theory unifies Epistemic Logic and Situation Theory. We are now pushing this view of information flow through correlation in many concrete directions.

I also had the privilege of publishing a mathematical logic paper with Jon Barwise shortly before his passing on how his philosophical idea of information as correlation affects logic. Here going mathematical improves precision. Classical logical consequence is about one situation: if the premises A are true there, then so must the conclusion B. But we defined a broader notion of cross-situational consequence: if A is true in situation s and s is suitably connected to situation t, then B must be true in t. (This cross-situational view already shows in ancient Indian Logic with its "Smoke means fire" example, where learning facts on the ground can lead me to conclusions about facts on some inaccessible mountain top.) But to show that a proposed new notion has real content (and frankly also, to support one's craving for mathematical depth and elegance), the best way is often proving a theorem. Barwise and I used theorems about our new notion of 'from here to there' consequence to discover new properties of basic logical systems.

Liu: Your inference example was clear, but it is just a very simple piece of reasoning. You have explored many kinds of logic — modal, epistemic, dynamic, and more. What do these richer logical systems reveal about your theme of information?

Classical logical systems describe what is the case: in terms of facts about the world. Next, modal logics move from what is the case to what could be the case: opening up the space of possibilities and formulating the reasoning governing that wider space. These models arise naturally with semantic information which, as we discussed, leaves a range of viable options for what the actual world might be. But the modal open space view also fits dynamic or temporal logics of action, which go from being to becoming. Their models represent what the state of the world might be now, but also what that state can become over time as events take place. Still my work on these multiple richer systems of reasoning has a clear unity because they can all be studied with the same formal tools and logical mindset.

III. Representation and invariance

Liu: You said that the how of expressing information matters. How do we actually represent information and what representations do you find most revealing?

Every language is a medium for representing thoughts, and for parts of the world that are the contents of thoughts. Since I cannot transmit my thoughts directly, I also need language to communicate. Having language as a go between is all for the best. Transmitting our thoughts directly is a recipe for warfare. Language allows us to select parts of our thoughts, keeping society civilized and livable.

Of course, natural language is also a powerful medium for conveying emotions and synchronizing feelings, and it is even a source of beauty and creativity in its own right – but let's stick to information and logic in this interview.

To me, one major aspect of natural language is that it can represent information at different levels: in great detail, or at a higher abstraction level. I can spell out a professional article for you line by line, but I can also paraphrase it to give you the gist. All these levels may be appropriate and show our grasp of text or speech.

Liu: But there are also formal languages, and these seem what most logicians love.

Yes, humans developed cultural artefacts like mathematical or logical formalisms that represent information sharply in formal patterns to facilitate specialized tasks such as computing or problem solving. Just think of the number notations that we all use in daily life: they are an artificial formal addition to natural language.

These formal languages can differ greatly in the level of detail they provide. For instance, there is a lot more structure to the doctor's sentence than my "If M, then B" pattern. If we focus on the flow of time, it also has a transition from taking the medication now to getting better later. Reasoning about that transition needs the richer language of 'temporal logic'. Such levels and their connections can be made precise. This reflects a general interest in logic in matters of definability and expressive power of formal languages for describing structures in the world.

Liu: But how do natural and formal languages live together?

Some famous philosophers have argued for the superiority of formal languages over natural ones, given their precision and clarity – others the other way around. I myself see formal languages like Gottlob Frege did in a famous metaphor in his 1879 book "Begriffsschrift", the birth certificate of modern logic. Frege compares formal languages with microscopes: very precise, but with limited applications. By contrast, he sees natural language to the human eye: not as precise as a microscope, but much more flexible and with an almost boundless range of applications.

By the way, in Frege's day, university professors were seriously underpaid. Throughout his academic life, his salary was supplemented by a subsidy from Carl Zeiss, the son of a poor weaver and founder of the still existing precision optics industry that made Frege's university town of Jena famous. Zeiss wanted to give back all the money he had made as an industrialist to society, but unlike modern sponsors of universities, he insisted on his donations being kept anonymous.

But this may still make the two species too different. What most intrigues me today are mixtures of natural and artificial languages. This happens in mathematics which adds symbolic notation to natural language, but also with new symbols on your mobile phone in the information technology that pervades our society. These mixtures work, and we still do not understand well enough why. I even think that we do not really understand a complex mathematical proof unless we are able to paraphrase it in natural language, elucidating its key points and flow patterns.

Liu: Language is not the only form of representation used in logic. Logicians also use models to represent the reality that their languages are talking about.

There is an interesting historical transition here. For a long time, languages were seen as automatically interpreted: each sentence comes with its links to the world attached, so to speak. But gradually philosophers and logicians separated syntax (grammatical form) of a language from its semantics (interpreting the syntactic forms in terms of what they describe). For the latter purpose they invented mathematical models consisting of objects and their properties and relations as independent structural representations of the world. Compare how a map with cities and roads can represent the actual topography of a country, or how a family tree represents the living persons in a family and their actual blood ties.

Of course, this again creates a distance: we are not grasping the world directly, but through its representations in models, and just as with languages, these models can be richer or poorer. And in doing so, the main semantic notion in logic becomes that of a formula (the representation of some thought) being true in a model (a representation of the world). Thus, precision is bought at the price of distance. The interplay of language and models is crucial to the working style of modern logic.

Even other forms of representations, say, gestures, images, or music, fall within the scope of logic, since its formulas and models admit of many interpretations.

Liu: Representation may be needed, but it also hides the reality that it represents. When we compare two different ways of representing the same thing, we often invoke notions of invariance to capture what it means to get at "the same structure." How does this work for language in your information-theoretic perspective?

Indeed, one should always look for the underlying structure, asking the question when two representations 'stand for the same thing'. Such 'criteria of identity' make sense not just in logic, but also in philosophy and any systematic discipline.

With formal languages, logic has precise ways of determining when two formulas are logically equivalent, sharing the same 'logical form'. For instance, logical laws often state that two expressions have the same information. A famous example is the beautiful De Morgan Law saying that "Not (A or B)" and "Not-A and Not-B" are equivalent (it also works with "or" and "and" interchanged). This intimately ties together negation, conjunction and disjunction: notions that you can find in every sort of reasoning. However, in modern logic, there is no unique answer to the question of equivalence: it depends on one's perspective or purpose. And so, you can find different logical equivalences in different logical systems. Even basic laws of the De Morgan kind can be given up if required in a special reasoning practice.

Liu: Fine, logical laws state equivalence of information content for certain types of users. But how does this work with models, which are not linguistic entities?

With models, the issue is when they stand for the same structure. Answers then come in the form of a relation of 'invariance'. For instance, the widespread relation of mathematical isomorphism demands that two models are literally the same up to renaming of objects, properties, and predicates. But there are also natural less strict invariance relations such as bisimulation, first introduced in my dissertation. For instance, your watch may bisimulate with your heartbeat, though these two processes are dissimilar otherwise. A choice again depends on one's purpose. Logic has many invariances, each representing a 'zoom level' for structure.

Invariance thinking connects to the sciences in general: just look at the many symmetries pervading physics, chemistry, and other sciences. This goes back to the work of great thinkers in the 19th century such as von Helmholtz. In particular, he noted the role of invariances in the ways we represent space: for instance, moving objects along a straight line or rotating them does not change their shape. Moreover, for Helmholtz, invariances were correlated with the origins of language.

These arise when humans find the need to describe and communicate the invariant structure that remains the same as they move through space. Von Helmholtz was not a logician, but I see him as an important ancestor.

Thinking in Helmholtz' way, representation in models and in language are not disjoint topics. The invariances in the universe of models correspond with logical languages. For instance, consider the bisimulation invariance theorem in my dissertation. It determines exactly which language can express the properties of models that are preserved across models connected by a bisimulation. That language is that of the basic modal logic that we talked about earlier. I see this theorem as backing up my philosophical interest in using modal logic. But also, once published, this theorem has kept generating new mathematical research.

By the way, the science connection here may not be accidental. I started out as a physics student, switching only later to philosophy and mathematics. The decisive push occurred when I joined a mixed-gender student club. We used to have heated discussions about lots of topics which I always lost. An opponent said this was because I could not think logically. In arguing for a claim, at some point, I would assume that claim itself and run in circles. I bought a logic textbook in a cheap student edition (my government scholarship was modest and money was tight) by a 19th century author called Stanley Jevons, and I was hooked immediately. It's like Alice stepping through the looking glass: now into a deeper world of patterns behind the reasoning that we all do unconsciously in daily life. And I have stayed there ever since, since that world has an abstract structure and beauty of its own.

Liu: You painted a complex picture of varieties of information and representation in logic. But what does all this mean for your grand picture of the field?

Fellow logician Larry Moss once called me a 'landscapist', dreaming away in large landscapes of concepts. To me, we all live in a rich Information Landscape running from concrete to abstract, where different levels of representation or 'zoom', each with their own notion of invariance and matching language for expressing invariant structure, serve different purposes. This landscape is where logicians design and study their theories of reasoning, so it is our common playground.

In philosophical logic today, the dominant direction in this landscape is zooming in, making languages and models ever more elaborate. This is often the easy thing to do, by thinking of some surplus in the never-exhausted sea of concrete examples. Much harder is finding useful higher abstraction levels using creative information

reductions. There are spectacular examples of this in the history of mathematics and the sciences, and I think one of the key tasks of logic is offering more of these. I even think that our mental activity consists of information reductions on the vast boiling cauldron of our brain, so in a sense we are living families of abstractions.

IV. Dynamics and agency

Liu: One of the main themes you have emphasized since the late 1980s is that information is not static—it changes and evolves. You have coined the term Logical Dynamics for this perspective. What does this move from statics to dynamics mean?

Around 1990, I was struck by a pervasive duality in language between 'product' and 'process'. "Dance" is a verb denoting an activity, but it is also a noun denoting a particular form or product of that activity, say, the tango. This process-product duality occurs in many natural languages (I guess also in Chinese). It also occurs in our standard logical terminology: say, "argument" is an activity one can engage in, but 'an argument' is also one of the products or ingredients of that process.

Once you see this, action and change become crucial aspects of the world and our lives that should be treated on an equal footing with static properties. "Becoming" is as important as "being", or in terms of logical systems, the dynamics is at least as important as the statics. I see this dynamic move as akin to the 17th century turn in physics from statics to dynamics. We understand the mass of a particle in terms of what it does in motion, including its interactions with other particles.

Again my early years as a physics student may have something to do with this turn in my thinking. And like information, dynamic themes were coming up at various places in the 1980s, so the influences leading to the above ideas are surely complex.

In Logical Dynamics, the structure of actions is as basic as that of propositions. I recently looked at lecture notes for my logic course as a beginning teacher in Amsterdam in 1975. They had examples viewing static consequence relations dynamically, using the sort of updates that I gave for the inference from "if M, then B, Not B" to "Not M" when discussing information as range. Back then, this was just a didactic device to enliven a routine course, but the seed was there.

Liu: But how can this logical dynamics be implemented in logical systems?

My main tool since 2000 for studying information in action has been Dynamic-Epistemic Logic. This framework, which I cannot go into here, can be used to model

many subtleties of information flow, also in social settings with more agents interacting where some information is public and other information is private. Moreover, dynamic-epistemic logic offers a clean way of stating the laws of how knowledge and beliefs change under the influence of new information. But other people may prefer other logical systems for highlighting dynamics. You can find a lot on my approach, but also on alternatives pursued by colleagues, in the volume "Johan van Benthem on Logic and Information Dynamics" published in 2014.

Still on the topic of alternatives, one also finds dynamics in other areas of logic. For instance, Proof Theory studies actions that shape reasoning. And since computing is also an activity, Computational Logic is another locus for dynamics. I find these alternative approaches congenial, but my main focus has been semantics.

Liu: Your dynamics program applies not just to knowledge, but also to beliefs. How should we understand your famous slogan "Logic is the Immune System of the Mind"? What sort of mental health does such an immune system protect?

One function of logic is facilitating growth of information by correct inferences and reliable information updates. It is a sort of 'accelerant for knowledge'. And my first slogan about information might suggest that this is all there is to it.

But logic has a second, equally important, critical function: exposing defective information and refuting invalid claims by deriving consequences that are patently false. In this way, logic can signal mismatches between our beliefs and new information about reality, or spot internal contradictions lurking in our system of beliefs. This critical function is essential to the way we learn from experience, where errors are frequent, and progress involves facing problems and revising beliefs. Dynamic-Epistemic Logic can also describe belief revision and the laws governing it. But these laws do not predict the outcome: learning remains open-ended, and no method will guarantee correctness of our beliefs once and for all.

And this is the point of my slogan about the immune system. The human body may never develop one defense against every disease. But we have a sophisticated immune system, constantly detecting and helping us overcome health threats. Likewise, logic offers no total safety, but it assists our mental vigilance. And given this, here is what we should do: be courageous, guess, and intuit toward better theories which we can then pursue by logical means again until the next failure.

In some areas consistency may be overrated. As a kid of 15, I loved the novels of famous Dutch author Simon Vestdijk. They are wide-ranging, but a common trait

is their atheist spirit. But Vestdijk's greatest novel, "The Waiter and the Living" has a religious flavor. This disturbed me, so I bicycled all the way to his home, and rang the bell. The great man opened and I asked why this novel was so inconsistent with the rest of his books. Had he given up his atheist stance? His answer: "Not at all. But this was what the novel wanted me to do, so how could I refuse?"

Liu: One thing that strikes me in your writings on logical dynamics is that there is a lot of talk about "we", "us humans" and "agents". Does not this shift logic away from what is true in the world to what people do?

As the editors say in the "Handbook of the Philosophy of Information", meaningful information is always for someone, and humans are information-processing beings. In this light, the inferences that got me into logic as a student are just one of many information-processing skills we have. I often quote the view of the ancient Mohists in China that knowledge has three sources: hearing from others (think: communication), demonstration (inference and proof) and experience (things: observation, memory, and so on). These span a much wider range of things to study than inference, and the dynamic-epistemic logics that I use enable us to do so. By the way, I may be creating a bit of a myth here: whether the Mohists really said this in Ancient China, I leave for a historical expert like you to decide.

Have I now descended into the noisy world of agents (human or artificial) and just become a participant? I do not think so, I am still after the laws that govern this wider. family of processes. And there is still a lot more to be learnt here, even mathematically, about the reach of our usual logical systems when we combine them with models of agents performing tasks these systems were designed for.

Liu: On a more philosophical note, some of your writing suggests that action and information might be two sides of the same coin. Could you elaborate on that idea?

I find this idea intriguing, since it fits with my process-product duality. I first heard it from colleagues in the foundations of computing. But in dynamic-epistemic logics statics and dynamics co-exist, they are not two sides of the same coin. This bothers me. I do feel that information and action are close in the basic conditional sentences in my first example of logical patterns in reasoning. I can see them as rules triggering actions, but also as propositions about the effects of actions.

I have long tried to make the analogy work, even moving from semantics to proof theory, like in my 1980s work on the Lambek Calculus which is a system of laws for both syntactic combination of linguistic expressions and composing actions.

But I still cannot connect this to my current logical ways of modeling dynamics. I have played with Category Theory as well (using Chu spaces), but again no success.

In summary, I think that the information - action duality is such a beautiful idea that it ought to be true. The task still before me is just to see how.

Liu: I find it inspiring to think about the dance of information and action, but do you think logic today has really embraced your dynamic turn?

Logical Dynamics has not transformed logic and philosophy as I may have hoped. A few people saw it as an eye-opener and a fresh look at traditional topics, but other reactions have been hostile. Critics feel that 'dynamic logics' are in fact static, since they have unchanging laws for effects of actions. But this is just as expected. The dynamics in physics obeys static laws and yet it is was a crucial innovation. The discovery that dynamic activities themselves obey general static laws is in fact a natural outcome of the reflective stance in logic.

Anyway, my mind has been rewired, and I see process-product dualities all around. But what the verdict of history will be, I do not know, and I will not live to see.

V. From individuals to society

Liu: Much of your work brings logic into the social realm — dialogue, games, communication. How does logic help us understand interaction among people or agents?

Until the 1990s, I had focused on information and reasoning for single agents, and even more for reflection on their practices (something I find impossible to do with other people around). But logical notions are often social, starting with argumentation in the history of the discipline: in my student days, I lost against others, not myself. Also, the communication in the Mohist view is multi-agent. I coined one more slogan for this social turn around 2010, again for an outreach campaign of the University of Amsterdam, viz. "Intelligence Seldom Comes Alone."

Most dynamic-epistemic logics are about information exchange, and this social dimension fits with the logic-friendly area of 'multi-agent systems' in computer science. Logic can model social scenarios and bring to light subtle features, it discovers laws that govern social interaction, and it can study how individual intelligence interacts with group intelligence. Of course, there are dangers in the social setting, such as being swept along by blind currents of public opinion, but these phenomena are being studied by other logicians, including you, Fenrong..

FR: One of your main social themes is games and game theory. How come?

Games are a wonderful medium for studying dynamics in social settings. As shown in my 2014 book "Logic in Games", they illustrate most of Philosophical Logic. In a game, players may have partly aligned and partly contradictory preferences between possible outcomes, and they plan their actions keeping in mind what they think other players will do when it is their turn to move. Just think of recreational games like Chess, or games modeling economic scenarios as studied in Game Theory. In such scenarios we can study how information flow entangles with action, how players' knowledge and beliefs change during a game, and we can analyze the role of longer-term strategies. Also, bringing in preferences, we can study types of rational behavior for agents as choosing actions that they believe to be best for them qua outcomes.

So far I talked about logical analysis of games. Conversely, games can also be used to analyze key notions of logic like truth, consequence, invariance between models, argumentation, and more. For instance, argumentation about a claim is a game between the proponent and one or more critics, each with options for defending and attacking. And as anyone knows who has lost debates (like my young self as a student before I turned to logic), in such games there are winners and losers.

My book also discusses the mutual relations between these two ways of interfacing logic and games, which is still in need of a deeper understanding.

Liu: I get what you said earlier about looking for valid laws that hold regardless of empirical facts. Still, let me press you a bit further on cognitive reality. A lot of your writing on social dynamics tries to model what people actually do, or at least, your concrete scenarios often sound like that. How do you see logic relating to actual human reasoning—how people think, communicate, and understand the world?

I fell in love with logic by seeing patterns behind human reasoning practices. And yet the relation of logical laws to human behavior is a bit loose: logic is not cognitive psychology. If it just described what we do, it would not have the authority it has in endorsing conclusions, suggesting corrections and improving our practices.

Even so, if logic deviated completely from human reasoning practices, it would be a miracle how these can be so successful. (Of course, calling ourselves 'successful' in what we do is like 'recommended by owner'.) I am drawn to an evolutionary explication. The laws of logic are valid universally. So, if our species deviated systematically from these laws, its survival would be a miracle.

If one starts thinking that way, facts from cognitive science do become of interest to logicians, at least as a challenge. For instance, given the huge role of memory in human cognition, it is strange that memory is absent from current logical systems. Also, it is clear that communication is not pure transfer of information, but also involves resonance between participants, which requires some sort of emotional synchonization around a shared purpose. I would like to understand this better.

Vice versa, logic can inform cognitive science. While some psychologists gloat over deviations from logic in experiments, their subjects often agree with what logic says if given more time to think. Moreover, the emergence of logic is a striking cognitive phenomenon in itself, which should be taken as seriously as what people do in short-term tasks in an artificial lab setting.

VI. The interdisciplinary position of logic

Liu: To some people, you are interdisciplinarity incarnate, since your work gets referred to in philosophy, linguistics, computer science, game theory, and other fields. And you have been involved in setting up several academic organizations with this broad outlook. How do you see the interdisciplinary position of logic?

Logic shares many themes with other disciplines. And as such, it can suggest analogies, build bridges, and contribute insights. Vice versa, many disciplines also offer new themes and challenges for logic, and both directions play in my work. What I do not claim is that logic is the leader of the pack. Even for my information topic, philosophy has often been an indispensable source of ideas, and on the technical side, there are other perspectives like computational complexity or probability. The keyword to interdisciplinary success is modesty. But logic does sit at a cross-roads of the university, so being there will offer you great views.

Liu: What about the relation of logic to philosophy? You have even been critical of philosophy's tendency toward prophets. What kind of culture do you prefer?

First of all, an apology. This critical talk of mine was truly infelicitous. Different communities have different habits, and one should describe them without value judgments. Also, there are simply different character types. Logic in Amsterdam started with L.E.J. Brouwer, a prophet with sweeping dogmas and followers. But the founder of the stable milieu was E.W. Beth, more down-to-earth, broad and eclectic in his modus operandi. I am more like Beth, but we also need the Brouwers.

I see lots of interfaces between logic and philosophy, and it would be tedious to enumerate all of these. So, sometimes, I just point my students to role models:

people who contributed significantly to both fields, such as Rudolf Carnap, Saul Kripke, David Lewis, or Robert Stalnaker. That should be enough to make the point. In my own work, it should be obvious how it connects to the philosophy of information, but also to epistemology, the philosophy of science, and much more.

But a confession is in order. Speaking for myself, as a logician I have a detached attitude. While logical systems are often designed with a specific motivation, good theories have interpretations and new uses beyond what their originators foresaw. This mathematical tendency toward abstraction clashes with philosophical views that insist on knowing just what the objects in a theory are, and that demand to know whether the theory is true under this concrete interpretation. Putting the contrast vividly, my Stanford colleague Krista Lawlor once said that my questions after seminars always stood out: the philosophers asked whether what the speaker had said was true, I asked if what the speaker had said was interesting and could trigger new ideas. (Since some philosophers like labels, I guess that makes me an 'instrumentalist'.) I am often inspired by ideas from philosophy, in particular, in my ongoing work on epistemology, but whether the philosophers that I admire are right or wrong does not play a major role.

Perhaps the best way of fostering the logic-philosophy contact is by historical case studies of successful cooperation where the two sides retain their own identity. I have published several such studies, and am continuing to do so.

Liu: Do your new perspectives on dynamics, information, and action offer insights into traditional issues in the philosophy of logic, such as the normativity of inference?

Some people find dynamic logics of social agents descriptive, given the vividness of their scenarios. But to me, their laws of information and action seem as objective as those governing the usual static notions in logic. Whether that means that, normatively, people 'should' use them is a further matter. But as I said earlier about cognitive reality, perhaps they had better, if they do not want to fail in life.

Even so, I am interested in agent-dependent aspects of normativity. The laws of dynamic-epistemic logic only hold for ideal agents with perfect memory who learn only by making observations. They fail for agents with bounded memory or other cognitive limitations. I think we should tease out such agent assumptions before we assign normative force to a logical system. Or, but I have not thought this through yet, the truly universal laws of information flow and action should include the type of agent involved. I would like to discover the laws of this 'super-logic'.

But frankly, I want to turn your question on its head. The point is not if Logical Dynamics throws new light on traditional concerns in the philosophy of logic. It is rather how the philosophy of logic can enrich its agenda with new issues raised by the dynamic perspective. These include the role of information versus truth, the impact of bringing agents into logic, and a host of further issues in this interview.

Liu: Let us turn to the interface of logic and mathematics. What remains of the grand foundations program of Frege, Hilbert and Gödel?

I have been an anti-foundationalist since my student years. It was bad that I lost discussions, but I also learnt enormously from the experience. I do not see logic as providing foundations for mathematics in any non-circular and epistemologically relevant sense. In fact, in line with my "Immune System of the Mind", I think that mathematics needs no foundations. The main force for stability in the exact sciences is our creative ability to repair, or replace, theories that turn out to be inconsistent. Frege's idea that mathematics would collapse 'like a house of cards' if a contradiction were found seems based on exactly the wrong metaphor. Mathematics is a galaxy of systems, and its stability lies in their interconnections.

Another radical view came up in my recent work on 'Logic and Counting' with Thomas Icard. Logical and mathematical abilities live on a par in natural reasoning: one is not foundational or explanatory for the other. For instance, understanding logical syntax is dependent on some degree of competence in arithmetic, and vice versa, arithmetic can be facilitated by logic. What we should understand is how the two combine, and support each other, letting each side do what it is best at.

Liu: You have also engaged deeply with computer science. What draws you to this more technical interface?

My interests in computer science go back a long time, since its subject includes representation and processing of information. This is not just a technological fashion, since, as I said, algorithmic considerations have played throughout the history of logic. The interface has the two strands. In a participating stance, logical tools are widely used in working computational systems. But at a greater reflective distance, logic probes how we can prove correctness of programs or system behavior, and even on what we can and cannot achieve at all with computation. The variety of contacts between logic and computer science is amazing, and most logic worldwide is currently being developed there.

Conversely, readers of my work on dynamics will see influences from computer science. These are not in the form of programming or implementing my systems, but in terms of fundamental notions and insights into computing that make sense for information and action more generally. This role of computer science as a fundamental conceptual discipline seems underestimated in philosophical circles.

Liu: Looking at a relative of computer science, with today's rapid progress in AI, we often hear that the days of logic are over there. How do you see this?

In its classical phase, AI had seamless contacts with logic in areas such as agent systems, default reasoning, and knowledge representation. A slogan of mine in that happy period (the fourth in this interview, I apologize) paraphrased Clausewitz: "AI is the Continuation of Logic by Other Means". AI founding father John McCarthy adopted this as an author in our "Handbook of the Philosophy of Information".

Nowadays AI is data- and technology-driven machine learning. This is an exciting challenge for logic. Old concerns still make sense. Logic plays a role in 'hybrid systems' boosting machine learning systems qua reliability and explainability. And more at a distance, logic analyzes machine learning systems for what they achieve just as it did for classical models of computing, and find limits to what they can do. Work in both veins is thriving today, belying narratives of the demise of logic in AI.

But more intriguing are new questions emerging at this interface. One eye-opener to me are causally faithful information reductions of the huge state spaces of machine learning systems to known logical or linguistic models. This opens up a whole new perspective on where logic lives compared to current AI systems. It might even reveal new humanly graspable levels with laws not yet discovered in the history of logic. A sample of these topics will appear in a book on interfaces of Logic and AI I am editing with some colleagues (including you, Fenrong).

But there are also further challenges. Think of how we humans display intelligent behavior with only a fraction of the resources needed by modern AI systems, no matter how intelligent these energy-guzzling systems appear to behave. (This is the real challenge today, not the traditional Turing Test.) It might be that this is because our information comes from combining what is in our individual brains in sophisticated ways with those in the vast social network around us.

VII. Becoming a logician

Liu: You often describe yourself as a logician, which is actually a label for just a small group of experts worldwide, and a term which many people find unfamiliar or even intimidating. How did you become a logician?

Yes, this label is unusual. Once, Jon Barwise, a colleague and friend, organized a meeting of mathematical and philosophical logicians at Stanford and asked us to write down our primary self-identification. Only two wrote 'logician' (Barwise and me), the others divided neatly into 'mathematician' and 'philosopher'.

How did my self-identification arise? As a high school student I soaked up everything that was taught (one teacher called me a 'sponge'). But what I liked most in each subject were general patterns, which I would write down in a small notebook that I could carry with me: grammar rules, mathematical formulas, principles. But the decisive push was the one I described earlier when buying my first logic book after the so-manieth defeat in our student circle. The book showed me that underneath the stream of our daily inferences there are patterns, and once we see them, we can study them as such. And, just as rearranging atoms in a molecule can lead to very different physical behavior, even small changes in patterns can have dramatic effects on whether a piece of reasoning is correct.

So I entered a new world outside of daily life, and learnt about its further beauties. For instance, De Morgan's Law that I mentioned is just one of many discoveries. The general system of patterns of reasoning underneath our daily activities has its own mathematical features for us to discover. Modern logic constructs 'logical systems' that decribe the patterns underlying various reasoning practices in daily life, but also helps us see surprising structure in how these patterns relate.

Liu: So now you had stepped through the looking glass, like you said earlier. But I still do not see what was so exciting about that world of patterns and systems that you wanted to stay there. After all, Alice came back.

The next book I read as a student was by two authors Nagel and Newman called "Gödel's proof". It explained all the deep ideas in the proof of the 'incompleteness theorem' by Kurt Gödel, the greatest 20th century logician. This theorem states an impossibility and limits what logical systems can do. No logical system can prove all and only the truths of mathematics. (I omit details, Gödel's Theorem is still the subject of whole courses today.) But the innovative proof of the theorem also led

to a century of new positive results, since finding an impossibility also sharpens our sense of what is possible. Seeing the rocks allows the sailor to navigate safely. Reading this book was an almost religious experience for me. The new world behind daily reasoning and language use turned out to be full of beauty and magic. To me, entering it was a transcendent experience which changed my life.

Of course, I did not really just stay in that abstract world. Ever since, I have seen my life in terms of combining two stances. In the 'participating stance', logic is at work in our daily reasoning and can be used to draw correct conclusions or criticize wrong ones. But in the 'reflective stance', we step outside this daily practice and examine it for its limitations and strengths. I see this stance switching as a major talent, which also occurs, in different ways, in other intellectual fields. Of course, the stances can influence each other: logicians are not schizophrenic.

Liu: Good, that is a personal conversion in your student days by reading two books. But now you had to learn serious logic. The Amsterdam environment has long been famous for this, starting with great names like Brouwer, Heyting and Beth. Can you tell us something about your education there and how it shaped you?

After my conversion to logic, I switched from physics and pursued joint degrees in mathematics and philosophy. I felt that logic was right in between these two fields. This was exactly the atmosphere of the "Institute for Logic and Foundational Research into the Exact Sciences" created by Professor Beth in the mid 1950s. Beth had already passed away, but not before educating a generation of incredible talents, several of which are great names in logic today. I felt immediately at home in this environment and had found my natural habitat.

Beth's work had a deep impact on me because of his broad interests. He pioneered logical systems for use in computation (still a flourishing branch of computer science) and he brought modern Chomsky-style linguistics to his institute. What also shaped my mindset was Beth's ideal of a 'scientific philosophy' combining philosophical analysis with mathematical precision. For Beth, who had a broad historical erudition, this meant giving up philosophical questions such as "What is X?" where X can be possible worlds or broader concepts such as knowledge or justice. Beth saw the ubiquity of such questions in philosophy as remnants of Aristotelean 'essential properties' that had been abandoned in the 17th-century scientific revolution in favor of mathematical laws that govern the evolution of physical properties. So, he advocated a focus on logical laws governing concepts. I feel a clear continuity here since I succeeded Beth on his chair in 1986.

Incidentally, Beth started out as a competent, but not all that distinguished philosopher in the style of neo-Kantianism. His major mathematical results in logic (including a famous theorem named after him) were only discovered when he was well over 45. When I became a teaching assistant around 1971, I once asked his widow how come. She smiled, and said: "Johan, just check our wedding date."

Liu: But how did you yourself start your career as a professional logician?

Of course, as a student I did not know if I had the talent to do creative research. And what did not help that there was no PhD program in Amsterdam (all this only came in the 1980s), I was out on my own. So how to find a research topic?

What struck me in my courses was a divide between 'mathematical logic' as a study of proof in mathematics and 'philosophical logic' as a study of basic notions in philosophy. A staple of the latter were modal expressions such as "possibly" and "necessarily", studied since Antiquity. Modal expressions go beyond mere truth such as "Den Haag is the seat of government in Holland". They express what could have been otherwise (other Dutch cities might have won this honor in history) or what could be changed. (When sea levels rise too far, we have to move our country and its capital to higher ground, perhaps applying for a place to resettle in China.)

But then I noted that there were strong similarities between the philosophical and the mathematical face of logic. For instance, a statement that P is possible can be seen as saying that P is true in some other situation then the current one, related through some leap of the imagination or even a physical action. Now such "there exists" statements are common in mathematical reasoning as well, and I found a translation from modal reasoning into that of standard mathematical logic. This created a bridge between what were often seen as different fields, and from there on, the ball kept rolling. I found new notions and proved new theorems, and pursued the trails of elegance and beauty that run across this conceptual world. And my results turned out to be publishable in international journals.

This got me in touch with a worldwide community of logicians, who corresponded by airmail in those days. I still have cherished letters on their lightweight paper. I had now joined an international brotherhood, regardless of nationality, culture or race, which had existed for many centuries. That is still my self-image today.

My papers turned into a dissertation "Modal Correspondence Theory" that got me the doctoral degree in mathematics in 1976. But actually, I had already been appointed as an assistant professor of philosophy in 1972 on the recommendation

of professor Martin Löb who saw promise in me, to teach logic to revolutionary philosophy students who were critical of the subject. But the challenge was exciting, the environment with gifted students (my own age) in Amsterdam was amazing, and teaching them helped me immensely in finding out who I was and what I wanted to say. Research without teaching has never worked for me.

Liu: Many people see you as the prototype of a logician with a broad view of the field. Maybe you are even a spokesman for it. How broadly do you see the field?

The term 'logic' is as multi-interpretable as 'information'. In its colloquial use it is about correct inferences in daily life. And about practical virtues of thinking things through, organizing well, and a willingness to yield to the force of arguments.

In its more academic sense logic is about finding patterns in reasoning, but also about designing complete logical systems containing many such patterns for a host of different notions in reasoning, modal or not. In this second sense, 'logic' can be seen as the total of all formal systems that we have right now. We can keep exploring this rich intellectual construction and try to understand its evolution.

But yes, we should also think dynamically and socially over time. Logic is also a general style of thinking and investigating transmitted to new generations of students based on the best practices of logicians. Of course this is circular, as I have not defined 'logicians' and 'best practices'. But as a prominent philosopher of science once said to me, "We can debate forever about an essential definition of the field of 'physics'. But in the final analysis, the best definition is historical: 'Physics is what has been studied by the best physicists'." I could not agree more.

Liu: But where is this community heading? Many people feel that logic is on a trajectory of creating a jungle of formal systems where no one has a general view any more. You are into dynamics. How do you see the development of logic itself?

I would find it tedious to discuss where logic should be heading. I remember how, as a youngster, I was not interested in sweeping views from an older generation. Let me just say a bit about my general working style and attitudes towards my field.

I am a coherentist trying to connect different logical systems to see their analogies and differences as inhabitants of my grand information landscape. My dissertation connected modal logic to standard first-order logic, my recent work connects current hyper-intensional logics in philosophy to classical modal logics, and so on.

Our earlier topic of representations of the same underlying structure also applies to the many logical systems discovered since Frege, no matter how different they look qua notations and motivations. Here the proper notion of invariance has to do with inter-system translations, a complex topic that I keep thinking about, but which has not yet led to a final theory of when two logics are the same or truly different. To me this search is a force for unity in the field of logic. Translations do not just connect systems, but also agendas and insights of communities using them.

Well, I guess one can overdo this irenic view. Removing all competition, including a ban on unfair propaganda, can block intellectual progress. But competitors should still see the unity of their field, just as one would want for society.

Liu: You are passionate about logic. Should we all learn to think in logical terms?

Not at all, logic only works for those who are sensitive to it. And it can also distort or leave out important aspects of reality. I have never claimed it is the only game in town. A mathematician, statistician, philosopher, or economist may look at one and the same phenomenon and see completely different patterns. We should be aware of a Rashomon effect: relevant structure can be in the eye of the beholder.

This said, I do not really have to argue for the attractions of at least including logic in one's intellectual repertoire, it pretty much speaks for itself.

Liu: Now let us move to the broadest circle in your activities, the outside world. If you explain logic to a lay audience in your public lectures, how do you describe it?

In public outreach lectures. I give concrete samples of the logical point of view. I display common inference patterns, update scenarios, strategic games, and so on. Especially with lectures for young children, getting through to their world is a creative challenge, but we have played logical games with 6-year olds, where we make sure that their over-eager and competitive parents are kept at a safe distance. (Fenrong, I now suddenly realize that I have to leave soon and play soccer with my own 6-year old grandchildren.)

Actually, many audiences also want to hear about the limitative meta-theorems of Gödel and others from the golden age of the 1930s. Many of these results are about impossibilities. Perhaps this resonates with the public since we all like being lectured about our sins and inadequacy. These results showcase logical reflection at its best, even though they have no direct impact on concrete reasoning practices.

As an aside, lay audiences associate logic with stern and cold reasoning from data, and they see this as excluding feelings, emotions, and unfettered creativity. I then explain that all these further layers are integral parts of human intelligence. In fact, logic can help trigger emotions, like when we deduce unexpected bad news from our medical test results, and vice versa, emotions can be powerful drivers for doing well in logical debates. I also explain how logical analysis helps clarify which parts of thinking can be understood formally, and by that very fact, show where other aspects become important: chance, serendipity, and of course, emotions.

Liu: But more down to earth, can logic really help people reason better?

Focusing only on reasoning seems too narrow. In the history of logic, three themes have always been entangled: definition, proof, and algorithm. This is much richer than 'reasoning'. And my agenda for logic includes even further information-producing actions, including observing the world and consulting others.

So, in teaching basic logic, I aim for a spectrum of skills: seeing reasoning patterns, manipulating formal proofs, modeling serious scenarios (more exciting than 'translating' natural language sentences). A pilot course showing how this can be done is 'Logic in Action', available at the website https://www.logicinaction.org. By the way, in the Middle Ages, logic exams would even test argumentation skills, I am not sure how well logic students (or professors) would do on these today.

Does all this help us reason better? Logic has helped machines to reason to some extent. What about humans? I would hope so, but the few experiments I have seen about effects of logic teaching seemed inconclusive: it can do good when taught in the right way, but it can do harm and make enemies when taught the wrong way. Anyway, many school topics do not have direct benefits, but society considers education as valuable, not just for picking up skills, but also developing the mind.

VIII. The road ahead

Liu: And finally—after so many decades of exploring logic and information—what questions still fascinate you the most today?

The issues mentioned in my answers to your questions in this interview still occupy me, as you can see in my recent papers. But beyond these I am increasingly intrigued by the role of probability and chance and the way their 'blind rationality' of a physical or biological nature interfaces with the conscious rationality of logic. We steer our little ship, but at the same time, we are swept along by ocean currents.

Now I have mostly worked on logical theories whose core laws were qualitative, and viewed probability as a mere lubricant to connect with empirical facts. But probability may be much more essential. It can refine notions of knowledge and belief, and it can extend single actions to mixtures of actions. And also importantly, probabilistic notions may be just what is needed to describe the salient emergent patterns in the behavior of groups and societies that single agents function in.

A bit fancifully, I sometimes think of the sphere of logic, traditional or in my version, as a thin layer sandwiched in between two realms where probability reigns. 'Above' us is the huge aggregate of Society and the flows of public opinion. And 'below' us is the teeming activity in our brains which seems largely a probabilistic machine. The logic layer is as thin as the soil on this earth in between the rocks and the air, which yet nourishes all of us. Perhaps the same is true for logic.

Also, returning to my student experience of joining a long historical stream across cultures, space and time, I am more and more interested in the history of logic in other cultures, as part of the onward march of our curious species Homo Sapiens.

Liu: So, any final words to conclude this interview?

A pleasant aspect of getting older is recalling one's youth. Maybe this is an influence of having worked for so long in China, but I see myself more and more as a product of my parents (I am not yet into deeper historical ancestor worship). Neither had any affinity with logic (they preferred poetry and painting). Therefore, the conversion of my stepping into a world of logical abstractions was alien to them, and they saw it as crossing over to the 'dark side'. But there are other ways of stepping out of our daily world and suddenly seeing familiar things differently.

Let's close a circle in our conversation. My dissertation defense was the ceremonial start of my career as a logician which you have traced in this interview. It took place in the beautiful and stately Lutherse Kerk in Amsterdam on the same podium where you have stood, 31 years later, to defend your thesis, Fenrong. That evening, there was a party for fellow students and university colleagues where my parents attended. Like all young people (I was 25 at the time) I was anxious about what they would say, especially, the usual anecdotes that proud parents tell about how special their gifted child was already at an early age. So I told my father that he could say something, but only if he kept it extremely short. Here is what he said:

"Ladies and gentlemen, I have been asked to keep this very short, and so I will just make some introductions. (Pointing at himself:) I am Johan's father. (Pointing at a young girl next to him:) This is Johan's sister. And finally (pointing at my mother:) This is the woman with whom Johan has been happily married for 25 years now."

Humor achieves transcendence in a flash where logic needs to labor.