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A Reasoning Method based on Spatio-Temporal Relevant Logic in Mobile Multi-Agent Systems (MMAS)

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Abstract
In this paper, we continued the preparatory works of Jingde Cheng in conjunction with spatio-temporal relevant logics, and proposed several epistemic spatio-temporal relevant logics as basic logics for Mobile Multi-Agent Systems (MMAS). To establish an inference system, important elements are: semantics and syntax appropriate to it include a language, axioms and inference rules. By proving the meta-logical properties such as soundness and consistency, completeness and decidability and etc., we have a method to test the reliability of the systems. Finally, we will have models and algorithms for the application of these logics in the MMAS.

Keywords: Relevant logic, Epistemic logic, Temporal logic, Spatial logic, Mobile Multi-Agent Systems, Reasoning.

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1. Introduction

The major subject of this paper is a new group of relevant logics that be usable in spatio-temporal information systems, and using this spatio-temporal relevant logic as basic logic in specification, verifying, and reasoning in Mobile Multi-Agent Systems (MMAS).

There has not been much formal work in this field, and only discussions under this heading are briefly cited in two articles by Jingde Cheng in 2004 and 2005, which are referred to in the sources of the article [4, 5 & 6]. Of course, there are many classical and modal logics for spatio-temporal systems, which are not suitable systems for our purpose, because of lack of capabilities such as truth-preserving, relevance implication and reasoning, ampliative reasoning, paracompleteness and paraconsistency. Also, relevant logics as the closest logics to the basic logic that considered in this article are not suitable for this purpose alone. Therefore, with the continuation of Cheng's work in two papers of 2004 and 2005, we are looking for the design, expansion, and development of the spatio-temporal logic for multi-agent mobile systems.

To clarify the subject, we firstly study about the keywords and basic concepts, including computer scientific concepts and logical concepts, in brief. Then by combining the Cheng’s strong relevant logics, Rc, Tc and Ec, with temporal logics (both predicate and modal approaches), make new strong temporal relevant logics (with suitable syntax and semantics). By Combining these logics with spatial logics (both predicate and modal approaches) and epistemic logic, we can create a new family of logics, as basic logic to Specify, verify, and reason in Mobile Multi-Agent Systems.

Finally, we introduce a suitable model and algorithm to use constructed logics in this paper, in MMASs.

2. Basic concepts

2-1. Computer sciences’ concepts

2-1-1. Spatio-temporal Information system

An information system is a computational system and a database for collecting, processing and analyzing data obtained from a segment of real world, and storing and distributing information (processed data) that is regularly retrieved, collected and updated. Also, feedback to evaluate and modify the input section of the system is one of the benefits of this system. Because of this, information systems are considered not only as a database, software and hardware, but as a larger system, which can help you to manage all the manual and machinery affairs and interpreting the communication systems easily.

Spatio-temporal Informational System is a type of information system that collects and processes spatio-temporal data, stores and distributes output information that is spatio-temporal and feedbacks from them. Many information systems have a spatio-temporal nature, such as spatio-temporal databases, geographic information systems (GIS), predictive systems, mobile multi-agent systems (MMAS), and so on.

In this research, we are looking for a basic logic for mobile multi-agent systems through the above spatio-temporal information systems. To define mobile multi-agent systems, we first need to define the concepts of “agent” and “mobile agent”:

Agent: An agent is a computer system capable of performing autonomous and automated actions on behalf of the user or the owner. The main thing about agents is their autonomy, in that agents are able to act independently and control their internal states. The main thing about agents is their autonomy, in that agents are able to act independently and control their internal states. In this way, another definition for an agent can be: An agent is a computer program that is capable of performing autonomous tasks in some environments.

Mobile agent: In computer science, the mobile agent is defined as a set of software and information. The mobile agent has the ability to transfer from one computer to another computer completely autonomous, and then continue its operation at the destination computer after this transfer. A mobile agent can be considered as a software agent that has properties such as independence, interaction, learning, and most importantly moving and transferring. In particular, it's a mobile-based processor that can change its location from one environment to another, while maintaining the accuracy of the data, and the agent can properly execute its tasks in the new environment. This is the mobile agent in itself that determines the transfer time. Transmission often involves RPC (Remote Procedure Call). When a user uses an Internet browser to visit a site, the browser downloads a copy or a version of the dynamic site exclusively. Similarly, the mobile agent uses copying information to perform a transfer. When a mobile agent decides to transfer, he first saves his current position, then transfers the saved state to the new host and continues the execution of the operation from the saved state.

Multi-agent system: A multi-agent system is a system composed of a number of factors, each of which, in turn, has the ability to operate independently and autonomously to a certain degree, as well as the ability to interact and communicate (including co-operation, co-ordination, and two-sided exchange of views) with each of the other agents to succeed in their tasks.

Mobile Multi-Agent System (MMAS): A MMAS is a multi-agent system that each of agents has the ability to move or transfer from a location to another location, in an arbitrary period in a communication system such as a computer network. .

2-2. Logical concepts

To specification, verifying, and reasoning in Mobile Multi-Agent Systems (MMAS), we need a basic logic that gives us the criteria for validating and deciding about the behaviors of multiple mobile agents with uncomplete or even inconsistence epistemic behaviors. Such logic, as mentioned earlier, must have capabilities such as truth-preserving deduction, relevance implication and reasoning, ampliative reasoning, paracompleteness and paraconsistency. In order to develop or design such logics (whose history only limits to Cheng's 2004 and 2005 articles), which have relevant, and spatio-temporal entity, we firstly describe relevant logics, spatial logics and temporal logics, in brief; Then we study about their relation to concepts Such as truth-preserving, relevance-preserving, ampliative reasoning, paracompleteness and paraconsistency.

Relevant logic as a non-classical logic, has a great influence on logical and philosophical discussions, and recently on basic sciences, such as mathematical sciences and computer sciences, and even on applied sciences. Classical logic (or standard logic) is involved with some of the paradoxes, and relevant logics have been established to eliminate them. The most fundamental paradoxes in classical logic are material paradoxes; Both the C. I. Lewis's strict implication logic and the relevant logic have worked to eliminate these paradoxes. Pierce's paradox (P^+), negative Pierce's paradox (P^-), disjunctive syllogism (Disj.), EQT and EFQ are the most important of these paradoxes:

1. Positive paradox (P^+): $\phi\supset(\psi\supset\phi)$
2. The paradox of EQT: $\phi\supset(\psi\vee{\sim}\psi)$ (And in argument form: $\Sigma \vdash(\psi\vee{\sim}\psi)$)
3. Negative paradox (P^-): ${\sim}\phi\supset(\phi\supset\psi)$.
4. The paradox of EFQ: $(\phi\wedge{\sim}\phi)\supset\psi$. (And in argument form: $\phi,{\sim}\phi\vdash\psi$)
5. Disjunctive syllogism: $[{\sim}\phi\wedge(\phi\vee\psi)]\supset\psi$ (And in argument form: ${\sim}\phi, \phi\vee\psi\vdash\psi$)

Relevant logic (from 1950s) is an extension of classical logic that challenges the classical logic presuppositions by introducing the concept of relevance in implication and inference. In non-classical logics with a review on assumptions of classical logic, we are looking for solutions to precision and comprehensiveness of classical logic. The main assumptions of classical logic include [2, p.251-252]:

1. **Abstractness**: logic concerns only on study of a proposition's form and its value.
2. **Fregean assumption**: Value of a proposition determines by its form's value and its components.
3. **The common definition of Validity**: an argument is valid, iff it is not the case that all premises are true and the conclusion is false.
4. **The principle of bivalence**: there are only two values: "true" and "false". Each proposition has only one truth-value, and cannot has two values simultaneously.

Relevant logics with challenging the first three assumptions have associated relevance concepts into logic. Relevant logics by possible world semantics, firstly don't limit logic to form of proposition and its value; Secondly, implication and the consequent in this logic isn't truth-functional and therefore, value of a molecular proposition don't only depend on value of its components, but relevance between antecedent and consequent in conditional propositions and relevance between premise and conclusion in arguments must be considered.

3th, relevance logic challenges the common definition of validity ,that depends on material implication, and with introducing the relevance conditional and argument, refutes the third assumption above. Therefore, relevant logics are both truth-preserver and relevance-preserver.

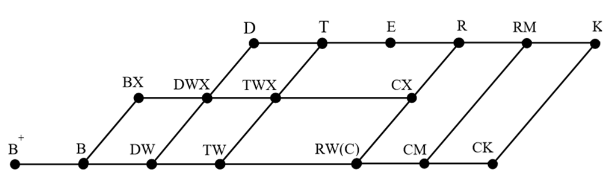
Paraconsistent logic, like relevant logic, denies triviality (EFQ). All relevant logics, are paraconsistent, But the Paraconsistency of relevant logics is not mean that their followers were dialetheist, and many of relevant logicians do not consider him/his as dialetheist.[1] In fact, paraconsistent logic, unlike classical logic, intuitionistic logic and more of the other logics that see inconsistent sets as trivial and results them every consequence, does not see these sets as trivial and therefore, says inference everything from them is impossible.

Relevant logic by changing the meaning of implication and inference from material to relevant and substituting De Morgan negation rather than Boolean negation accepts a new interpretation of bivalence principle and so rejects EQT. In other words, in paracomplete logics we cannot achieve from arbitrary set of promises to tautologies [14].

Relevant logic in addition to the classical truth-functional value (including conjunction (∧), disjunction (∨) and Boolean negation (~)), has also intensional connectives, such as intensional conditional (→), De Morgan negation (¬), intensional conjunctions (fusion) (∘), and intensional disjunction (fission) (+) (Of course, it should be noted that in positive relevant logics such as B^+, T^+, E^+ and R +, there are no Boolean and De Morgan negation.) [10].

Now, since the concept of the entailment in relevant logic is represented with the intensional conditional (and not the material conditional), relevant reasoning are ampliative, not circular and / or tautological.

The basic relevant logic is B +, which all other relevant logics are extensions of this system. The following diagram illustrates the most important extensions of B^+ [11]:



1. Relevant Logicians distinguish between truth and falsehood of φ together in one world, and being true of ~φ and φ in that world, and consider the first as contradiction and wrong, and accept the latter only in impossible worlds. But dialetheists but dialetheists accept truth and falsehood of φ together in the real world, and accept in principle the possibility of the inconsistency and contradiction in every possible world [12, p. 174].

Among the relevant logics above, "Entailment logic"(E), "Relevance logic" (R) and "Ticket entailment logic" (T) are the most important and most relevant logics.

3. Spatio-temporal logics

"Can a system be established that both includes relevant reasoning and is a suitable logical system for spatio-temporal information systems?" And "Can such logical systems be considered as the basis of the spatio-temporal information systems like Mobile Multi-agent systems?"

The answer to the above two questions is positive.

Jingde Cheng claims that so far there has been no computational system for spatio-temporal systems that can be considered as a basis for spatio-temporal information systems such as mobile multi-agent systems. In his 2004 and 2005 papers [4, 5 & 6], he designed the spatio-temporal relevance logic. In Cheng's view, this basic logic to provide specification, verifying, and reasoning for mobile multi-agent systems must have four fundamental conditions:

1) **The criterion of validity and provability of reasoning** (Truth-preserving and relevant-preserving): For any valid argument in this logic, if its premises are true (in the sense of conditional), the conclusion must be relevant to the premises and also to be true (in the sense of conditional).

2) **The ampliative reasoning**: The truth of the conclusion must be understood after the full process of reasoning; However it should also be noted that should not be cited in deciding about the truth of premises of reasoning. In other words, the conclusion is derived from certain premises, is a new conclusion, and therefore such an argument is ampliative, not circular and/or tautological.

3) **Paraconsistency and paracompleteness:** the rejection of the EFQ paradoxes (the explosive principle of classical logic) and the EQT, guarantee paraconsistency and paracompleteness properties for this logic, respectively. The basic logic for mobile multi-agent systems should be paraconsistent and paracomplete, since we deal with inadequate and/or inconsistence knowledge in everyday life, and in almost all branches of science, and mobile multi-agent systems are not exception.

4) **Support for temporal and spatial reasoning:** Basic logic should also support temporal and spatial reasoning and inferences. Because, as noted earlier, in a mobile multi-agent system, agents generally act in various spatial regions under time, and their tasks, knowledge, and behavior are related to temporal and /or spatial objects.

In the three papers [1, 3, 4], Cheng proposed three strong relevant logic Rc, Ec and Tc, which are respectively free from the conjunction-implicational and disjunction-implicational paradoxes of the relevant logics R, E, and T . In his view, the premises of their reasoning should not include any unnecessary conjuct, and the result of the argument should not include any unnecessary disjunct. "The strong relevance principle" makes these systems stronger than R, E, and T systems: “If A is a Theorem of Rc, Ec or Tc, then every propositional variable in A, should occur at least once as an antecedent part and at least once as a consequent part” [15]. These three logics, in addition to the material implication paradoxes, resolve the conjunction-implicational and disjunction-implicational paradoxes that other relevant logics have given up them.

But with all these benefits, These Three strong logic, i.e. Rc, Ec and Tc, despite satisfying the first three conditions of the four basic constraints of the basic logic for mobile multi-agent systems, do not satisfy the fourth condition. To achieve such a basic logic, we must combine the three strong logic with spatial logics and temporal logics. for this purpose, Cheng combined the temporal relevant logic proposed in [4] (three logic T0RcQ, T0EcQ and T0TcQ, that are the conservation extentions of Rc, Ec and Tc) with the first-order predicate spatial logic Rcc (Randall (1992), Goetz (1996), and Bennett (1994, 1995), and therefore, he proposed a new family of relevant logics that are both spatial and temporal, as the basic logic for mobile multi-agent systems, in which all four above conditions meet. These three Axiomatic systems are: ST0RcQ, ST0EcQ and ST0TcQ [7, 8, 9, 13].

To study merely the spatio-temporal characteristics of these logical systems, Cheng have not introduced the epistemic operators and axioms of epistemic logic. But in order to achieve the main goal of research and construct deductive machine for mobile multi-agent systems based on these logics, this is necessary.

The spatio-temporal relevant logics have the following possible applications: First, because the logics can underlie relevant, truth-preserving, ampliative, paracomplete, paraconsistent, spatial, and temporal reasoning, they provide us with criteria of logical validity for reasoning out new spatio-temporal knowledge with incomplete or sometime even inconsistent knowledge. This is in fact the major purpose to propose and develop the logics. Second, once we modelled a part of the real world, represented the nod el by a spatio-temporal information system, and specified desirable with the formal language of the spatio-temporal relevant logics, we can verify the properties based on the logics. Third, the spatio-temporal relevant logics provide us with a foundation for constructing more powerful logic systems to deal with other issues in spatio-temporal information systems [5].

Cheng's works (as he himself admits) is incomplete and despite many efforts, there are the following disadvantages:

(1) Cheng merely proposed axiomatic systems for these logics, and he did not propose any semantics and other syntactic systems used in computer science (such as tree systems).

(2) He gives the logic of the predictive spatial logic RCC as basic spatial logic. While this logic isn't complete and decidable in all two-dimensional and multi-dimensional spaces, because we can found consistent formulas in its language, with no model in its semantics. While there are a lot of complete and even decidable spatial logic with modal approach (such as Dlm, S5, DLm + $\sim\Gamma_{3,3} + \Gamma_5$, and S4 unextended), which may be easier in order to achieve our goal.

(3) He considers the predicate temporal logic T0Q as the basic temporal logic, which is based on a predicate approach and is incomplete and undecidable. This is despite the fact that we have a large number of temporal logics with modal approach, which, in combination with strong relevant logics, could lead us to a simpler way to achieve the goal of this paper.

(4) Cheng has not provided a model for how these logics are used in mobile multi-agent information systems.

(5) These logics are not adequate alone, and we must add to them the epistemic operators and axioms.

4. Conclusion

Spatio-temporal relevant logics as conservative extensions of strong relevant logics satisfying the strong relevance principle. These logics can underlie relevant reasoning as well as truth-preserving reasoning in the sense of conditional, ampliative reasoning, paracomplete reasoning, and paraconsistent reasoning.

The Spatio-temporal relevant logics have all fundamental conditions to provide specification, verifying, and reasoning for spatio-temporal information systems, and therefore can be considered as basis for mobile multi-agent systems. We can select any one of them according to our purpose in an application from various aspects of relevance, temporality, and spatiality. However These logics are not adequate alone, and to prove this problem, we must add the epistemic operators and axioms to them. Also, using of complete spatial and temporal logics with modal approach, instead of incomplete spatial and temporal logic with predicative approach, could lead us to an easier way to achieve the goal of this paper, and guarantee decidability of these logics and automata based on them.

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