Computational Dialectics for Arguing Agents

Hajime Sawamura

Department of Information Engineering and Graduate School of
Science and Technology, Niigata University
8050, 2-cho, Ikarashi, Niigata, 950-2181 JAPAN
sawamura@cs.ie.niigata-u.ac.jp

Abstract. In this paper, we extract its computational content from Hegelian Marxist dialectics and consider the utilization in agents' world. This is a novel approach to conflict resolution, cooperation, reconciliation, negotiation and so on that are main concerns in agent-oriented computing. We first examine two approaches to static dialectical logics: the dialectical logics **DL** and **DM** by Routley and Meyer, and the paraconsistent dialectical logic by da Costa. Then, we consider how to render those dialectical logics dynamic, introducing some dialectical inference rules on top of **DL** and **DM** and the definitions of Aufheben. We also discuss the meaning and utilization of the law of the negation of the negation in agents' world as well. In order to realize those aspects of dialectics computationally, we built the argument-based agent systems in which dialectics plays an important role in decision-making, attaining agreements and reaching an understanding among agents. We illustrate two applications of those systems.

1 Introduction

Our world and reality are full of inconsistencies as can be seen in our everyday life and society. In fact we human beings have lived in inconsistent situations. It could be argued that fights and wars are an outgrowth of inconsistencies. Traditional logics are intolerant of the existence of inconsistencies in data and knowledge. People have had a fear of having a nonsense theory that everything becomes true or theorems and much effort to remedy inconsistencies and maintain consistency has devoted to so far in the various fields of computer science [15][29].

However, there is one thought that accepts the view that reality is inconsistent and that there are true contradictions, whether our world is western or eastern. It is 'dialectic(s)' and we have been forgotten it for a long time without exploiting it in the fields of science and engineering and discussing its role. We have become aware of its significance in the world of agents that are interacting with each other in a computer-networked environment as well as in our world [23][30][22][24].

The starting point of dialectics is that the concept and phenomena expressed in terms of conflict, contradiction, opposite, difference, etc. in thought, nature, and society are the motive force both of nature and of human history, leading

to a further phase of development. We think that these are also one of the primitive driving force of reflection and consciousness residing in our brain, and of meditation to remove internal conflicts and transcend to a higher position or vanity

Differently from the approaches and attitudes to inconsistencies that much effort has been devoted to in artificial intelligence and computer science, we take a stand that we should be more tolerant of inconsistencies and our world is inherently inconsistent. We will pay attention to dialectics, aiming at a new interpretation and treatment of inconsistencies. The more closely and widely our world is informationalized and interconnected by the computer network, the more conflicts emerges. We would say that the computational globalization suffers the same influences and problems as those of the globalization of activities in business, economy, and politics. It, therefore, would be natural and reasonable to introduce dialectics into the computational world as well.

The paper is organized as follows. In Section 2, we first touch upon what dialectics is like. In Section 3, we outline two approaches to the static dialectical logics that seem to be representative ones as far as we know: the dialectical logics **DL** and **DM** by Routley and Meyer [20], and the paraconsistent dialectical logic by da Costa [3]. In Section 4, we consider how to render those dialectical logics dynamic, introducing some dialectical inference rules on top of **DL** and **DM** and the definitions of Aufheben. We also discuss the meaning and utilization of the law of the negation of the negation from a computational viewpoint. In Section 5, we outline two versions of our argument-based agent systems with dialectics incorporated. In Section 6, we illustrate two applications of those systems to a contemporary topic such as electronic commerce and a topic from software desigh. Final section includes concluding remarks and future work that needs further deep insights.

2 What is dialectics and why now dialectics?

According to the philosophy dictionary [6], the term 'dialectics' has a great variety of meanings. Among the more important meanings of the term, we are concerned with the meaning, the logical development of thought or reality through thesis and antithesis to a synthesis of these opposites (Hegel) since the Hegelian dialectic accepts the contradiction as a real aspect of the world, which is continually overcome and continually renews itself in the process of change.

It is well known that Hegel's dialectics led Marx to dialectical materialism in which dialectics is a means to explain a social development and a historical process from contradictions. In this paper we are going to take a more concrete view that dialectics is a method to discover or produce truth by dialogue. From this point of view, argumentation by dialogue (polylogue in general and monologue as a special case) may well be a process of inventing or creating higher-order agreements in conflicting situations from a higher stand. Thus, we are concerned with such an aspect of dialectics that recognition of conflicts and contradictions of information can bear new information. Put it differently, we should make in-

consistency respectable as a vital trigger for action and as an important source of direction in argumentation [8].

There, however, seems to be some difficulties attendant to dialectical reasoning. Two of the foremost are (i) the proper semantics whereby one can assign a sensible meaning to a proposition and its negation so that in some sense both are or can be true at the same time, (ii) the conceptual framework whereby one can capture more systematically what is meant by the phases, movement, or unfolding of a dialectical argument. In what follows, we will give a framework for computationally addressing these two difficulties. For (i), we introduce dialectical logics based on relevant logics or paraconsistent logics. The dialectical logics we notably consider in this paper are **DL** and **DM** by Routley and Meyer [20] that are subclasses of relevant logics[5], and are ones based on the paraconsistent logic by da Costa [3]. For (ii), we will pay attention to the most important aspects of Hegelian dialectics such as (1) Aufheben through synthesis from thesis and antithesis and (2) The law of the negation of the negation as a development process of thought, reality (nature, history), etc. where an operational force of development is viewed as negation. Negation plays a role of destruction and amplified renewal that lead to something better and more various.

However, unfortunately those underlying logics for logical dialectics are not dynamic so as to be able to overcome the difficulties. We will embody the dialectical dynamism in relation to argumentation since dialectics constitutes an important apparatus of argumentation. Put it differently, we will realize dialectics by incorporating it into argument-based agent systems. There are many good reasons to bring dialectics into the recent agent-oriented computing. Firstly, dialectics has many significant implications to the various societal view of computation in the agent world, such as negotiation, compromise/concession, cooperation, coordination, collaboration, conflict resolution, consensus attainment, etc. as we have discussed in [23][30][22][24]. Secondly, reaching an agreement or understanding through argumentation is a most important aspect of decision making in our real society. This would not be exceptional in a virtual society as well, which is now very rapidly being formed over the computer network. As a matter of fact, much attention has been paid to argumentation by researchers in computer science(e.g., [4] [10] [17] [11] [16] [22] [23] [24] [30]) as well as by informal logicians, philosophers, linguists, sociologist and so on [2] [7] [28] [19].

In the next section, we briefly outline two representative attempts to capture some aspects of dialectics in a logical setting such as relevant logics and paraconsistent logics. As far as we know, they seem to have been only logics that could successfully yield logical and static characterizations of dialectics, although they are remained static and very far from dynamic characterizations that should be inherent in dialectics. So in Section 4, we further proceed to take two typical aspects of dialectics in order to render it dynamic computationally by argumentation: Aufheben-like inferences and the law of the negation of the negation.

3 Formal dialectical logics

3.1 A relevant logic approach

The dialectical logics **DL**(Dialectical Logic) and **DM** (Dialectical Materialism) were originally proposed as logical and static dialectical logics by Routley and Meyer [20] in 1976. Then they formalizes them based on relevant logics [5], so that the important concepts in dialectics can be held. The following formulas hold in **DL** and **DM**, which deserve attention since they can be viewed as a characterization of the static dialectic logic. The semantic proofs of their validity are all given by using the higher-order logic theorem prover HOL [21].

Three fundamental principles for logic by Aristotle It is noteworthy that the dialectic logics are very normal in the sense that they keep these principles.

- $A = A$ (Law of identity)
- $\neg(A \wedge \neg A)$ (Law of contradiction)
- $A \vee \neg A$ (Law of the excluded middle)

Proper requirements for the dialectical logics

- The refusal of the proposition $A \wedge \neg A \rightarrow B$ (ex falso quodlibet).
- The refusal of the proposition $A \rightarrow \neg\neg A$ (required only in **DM**). In **DL**, we have $\vdash A = \neg\neg A$. However, the converse $\vdash A \rightarrow \neg\neg A$ will be unacceptable to strict dialecticians who wish to take into proper consideration the dialectical law of the negation of the negation since the content of the negation of the negation of A is claimed to be logically richer than that of A alone [Edwards 67]. It would be worthy to note that the dialectical logic **DM** retains $D7$. $\neg\neg A \rightarrow A$ which intuitionism rejects, but rejects the converse $A \rightarrow \neg\neg A$ which intuitionism keeps.
- The admissibility of the proposition $p_0 \wedge \neg p_0$, for some propositional constants p_0 such as 'God exist' and 'God do not exist'. It should be noted that Irrespective of the presence of such a contradictory proposition, the absolute consistency is kept in **DL** and **DM**.

3.2 A paraconsistent logic approach

There has been one more approach as an alternative possibility to deal with dialectics in a logical manner. It is the paraconsistent logic approach to dialectics by da Costa [3] and Batens [1]. da Costa gives a dialectical logic as a sort of paraconsistent logic in which he claims that the study of dialectical logics is the study of those logics which formalize theories based on the ideas and principles introduced by Hegel and Marx and their followers. The dynamic dialectical logic by Batens is interesting in the sense that the semantics is extensional and not usual truth-functional one (or non Fregean), and it realizes such a dynamism of dialectics that allows to make a proposition defeasible by its negated one occurring in the later proof step. This might be viewed as a realization of the

law of the negation of the negation (to be discussed in the next section) with which Engels was mainly concerned in his dialectical materialism, but it is still static in the sense that in the new definition of a dynamic proof, it does not mention what a motive force for negating the proposition already asserted in the proof is.

The paraconsistent approach to (logical) dialectics never refuses the positive paradox ($A \rightarrow (B \rightarrow A)$) that is hated by relevant logicians. And the common property for both approaches is that a single contradiction does not spread into the absolute inconsistency (ex falso quodlibet) [18].

4 Rendering Dialectical Logics Dynamic by Argumentation

As have seen above, any of those approaches to dialectics does have no consideration on how to derive Aufheben-like dialectical conclusions from contradictory propositions and how inferences dynamically go. In this section, we will consider these problems so that they can be dealt with on a computer. In particular, we think that argumentation is a best place to render dialectical logics dynamic as can be seen in our society as well.

4.1 Aufheben: synthesis from thesis and antithesis

We here give a breath of dynamism to the static dialectical logics, **DL** and **DM** by introducing the following elementary dialectical inference rules with Aufheben flavor on top of **DL** and **DM**, as to the logical connective $\wedge$ (similarly for other connectives). These dialectical inference rules turn out to play a significant role in the argument-based agent system described later.

- $A\,,\ \neg A \Rightarrow A$
- $A\,,\ \neg A \Rightarrow \neg A$
- $A \wedge B\,,\ \neg B \Rightarrow A$
- $A \wedge B\,,\ \neg B \Rightarrow B$
- $A \wedge B\,,\ \neg B \Rightarrow A \wedge \neg B$
- $A \wedge \neg B,\ \neg A \wedge B \Rightarrow A \wedge B$
- $A(a)\,,\ \neg A(a) \Rightarrow A(a) \wedge \neg A(b)$, etc.

Readers might have noticed that these derived inference rules hold vacuously in classical logics and hence almost meaningless. They, however, have the so significant meanings within dialectical logics. Specifically they are considered to represent sort of compromise, concession, reconciliation and so on that constitute a part of the important computational concepts for multi-agent systems (cooperation, coordination, collaboration, competitiveness, conflict management, etc. are others). Generally these may be considered as elementary dialectical inferences in the sense that the consequent are sort of syntheses from confrontational antecedents: thesis and antithesis. Of course these might not really be so-called 'Aufheben' (transcend or lift up to a higher level in English) since they do not

provide something higher, but would be the best the present dialectical logics can bring about. An ideal dynamic dialectical logic (or a logic of discovery) if any could produce more novel or innovative consequences. Here we situate the significances of those dialectical inferences above by introducing the comprehensive definitions for Aufheben as follows.

Definition 1 (Aufheben). *Given two conflicting propositions, A and B, a proposition C is said to be a higher-order agreement (Aufheben) lifted up from A and B (diagrammatically see Figure 1) if (i) neither* $\vdash A \rightarrow C$ *nor* $\vdash B \rightarrow C$*, and (ii) C shares some atomic propositions with A or B.*

The condition (i) is placed to represent that the content of the synthesis from the thesis and antithesis in the dialectical inference is supposed to be logically richer than the thesis and antithesis alone. The condition (ii) is placed to represent the relevance of the thesis and antithesis to the synthesis, similarly to the variable sharing property in relevant logics[5].

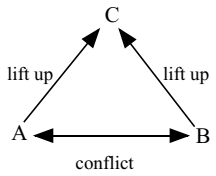

Fig. 1. Aufheben scheme

For example, (1) $A \wedge B$ is Aufheben from $A \wedge \neg B$ and $\neg A \wedge B$ (see Figure 4). Actually, it is not the case that $\vdash A \wedge \neg B \rightarrow A \wedge B$ and $\vdash \neg A \wedge B \rightarrow A \wedge B$ in the dialectical logics DL and DM, and even in classical logic. Note that the Aufheben shares the atomic propositions A and B with the two contradictory propositions respectively.

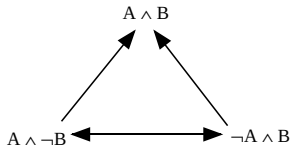

Fig. 2. An example of Aufheben

Definition 2 (Weaker Aufheben). *Given two conflicting propositions, A and B, a proposition C is said to be a higher-order agreement lifted up from A and B if (i) it is not the case that* $\vdash A \rightarrow C$ *and it is the case that* $\vdash B \rightarrow C$*, or it is the case that* $\vdash A \rightarrow C$ *and it is not the case that* $\vdash B \rightarrow C$*, and (ii) C shares some atomic propositions with A or B.*

For example, (2) A is an agreement lifted up from $A \wedge B$ and $\neg B$ (see Figure 2). Actually, it is not the case that $\vdash \neg B \rightarrow A$ but it is the case that $\vdash A \wedge B \rightarrow A$, in the dialectical logics DL and DM, and even in classical logic.

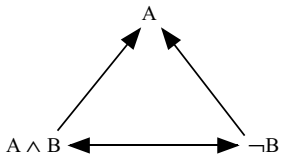

Fig. 3. An example of Weaker Aufheben

With the advance of the internet, we now live in a networked computational world where a large number of software agents may be working on behalf of their principals. They may be acting on searching for data and knowledge, making decision, purchasing good and services, etc. The static dialectical logics we have seen above are tolerant of inconsistency in data and knowledge base. This is extremely suitable for dealing with the computer-networked world as well as our actual and dynamic world, in which our knowledge is incomplete, contradictory, not closed, distributed, always changing, developing and so on. In order to see some implications and utilizations of the dialectical inference rules, let us consider the following simple knowledge base: the knowledge base of agent a $KB_a = \{bird(x) \rightarrow fly(x), bird(penguin)\}$ and the knowledge base of agent b $KB_b = \{\neg fly(penguin)\}$. Then obviously, we have two contradictory propositions: fly(penguin) and ¬fly(penguin). But, thanks to the refusal of the proposition: $A \wedge \neg A \rightarrow B$, our world never lead to a logical catastrophe full of all propositions. By the dialectical inference rules above, we can make a choice of either A or $\neg A$ positively. The choice should be made depending on which proof or argument on either A or $\neg A$ is better, stronger or more persuasive. We think that it should be determined by a defeat relation, argument strategies or outer criteria beyond the formal logic how an appropriate conclusion is chosen or which argument for contradictory conclusions is considered better. In the next section, we will describe our argument-based agent systems in which the dialectical inferences are to be accomplished in one way or another.

4.2 The law of the negation of the negation

The second aspect of dialectical dynamism that we wish to deal with is the so-called the law of the negation of the negation which was more specifically emphasized by Engels [6]. According to him, it is the law of development of nature, history and thought, which holds good in the animal and plant kingdoms, in mathematics, in history, and in philosophy. As we have mentioned in Section 3, the dialectical logic **DM** retains $D7$. $\neg\neg A \rightarrow A$, but rejects the converse $A \rightarrow \neg\neg A$. The paraconsistent dialectical logic also rejects this [3]. This rejection reflects the law of the negation of the negation, satisfying that each pair of the following formulas is not equal: $A, \neg A, \neg\neg A, \neg\neg\neg A, \neg\neg\neg\neg A, \cdots$. Negating the old is a motive force of development and the progression of development is to be realized not in a trice, but in a whole process (see Figure 4).

We think that we could capture such dialectical movement by the law of the negation of the negation in the framework of argumentation. In an agent society, each agent generally has its own goal and does its own thing acting independently from other agents as far as it does not need any interaction with its environment. Intelligence -even human intelligence-, for example, of an agent society or agents in it emerges and develops as a result of the interactions with other agents and the environment. An agent can acquire truth and decision only through interaction in the competitive or cooperative environment. It would be natural to think that the typical form of interaction must be argumentation just like in our actual society. The results of the interactions, however, are not absolute but tentative and temporal, and may always have a fate of being negated. We would say a motive force of the development form of this kind is the law of the negation of the negation we can see in the philosophy of dialectics. Even agents grow according to Engels just as oats grow according to Engels! The importance of the process of argumentation has been much emphasized by Loui [13].

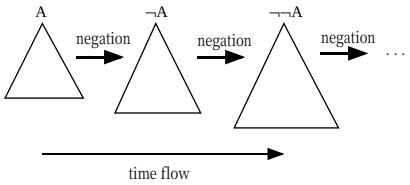

Fig. 4. The law of the negation of the negation

For example, let us see a series of arguments on the pros and cons of gene-altered crops and foods, such as genetically modified corn.

Example.(A scientific argument development along the law of the negation of the negation)

1. A biological scientist first publicized a result on advantages of gene-altered corn, based on biotechnology.
2. A few months later, some scientists and general people argued against it with the grounds of the harmful effects to other life forms such as monarchs (milkweed butterfly) as well as nature.
3. Further later on, some biologists publicized some studies that ease gene-altered corn fears, with new data collected in actual field conditions.
4. In the present day, the argument is still going on in the form of the negation of the negation of ... of the first issue and not yet settled if bio-technology corn is a threat to monarchs or not.

In this scientific argument, it can be seen that the content of the argument (of $\neg\neg A$) at the stage 3, for example, is richer than that of the former stage 1 since we must be getting more data and knowledge as the arguments are developing (refer to the subsection 3.1).

5 The dialectically arguing agent systems

So far, in order to make dialectics feasible computationally, we have examined DL and DM by Routley and Meyer and the paraconsistent logic by da Costa, and discussed a possibility of realizing dialectics within argumentation. Conclusions (sort of agreements or consensus among agents) obtained by the dialectical logics are valid, but not simply accepted by agents concerned. We have proposed that the acceptance of dialectical conclusions should be justified by argumentation among agents concerned. That is, we have considered dialectical dynamism of inferences in relation to argumentation.

The considerations and results so far provide a logical basis for our argument-based agent systems [23] [30][22] that enable us to promote dialectical reasoning. We have built three types of argument-based agent systems so far by taking into account dialectics. Here we describe two approaches to the incorporation of dialectics to the argumentation framework and features attained.

The underlying logic for the argument-based agent system actually consists of two logics: the logic of the extended logic programming with which arguments and counterarguments are formed, possibly producing contradictory propositions, and the dialectical logics above where existence of conflicting arguments are justified from scratch and they turn out to trigger dialectical reasoning. The co-existence of two logics may be well characterized as a problem solving by multi-paradigm logic where two logics interplay, switching one to another and vice versa. The similar idea can be seen in [9]. This reminds us of multi-paradigm programming in software development. We naturally can see such a phenomenon in our brains and society as well very often.

5.1 Argument-based agent system with dialectic reasoning

We have realized an argument-based agent system with such an argumentation protocol that integrates three reasoning methods into the argumentation protocol: conflict resolving reasoning, cooperative reasoning and dialectical reasoning

[30]. Arguments usually proceeds with mutually casting arguments and counterarguments, resulting in 'justified' (sort of 'win') or 'overruled' (sort of 'lose') of the either side. However, if an argument has not been settled, it might be better or necessary for the both sides to attain an agreement (consensus) satisfactory to some extent rather than leaving it unsettled. Our argument-based agent system invokes the Aufheben and Weak Aufheben process in this situation and proposes a dialectical consensus. They are obviously a way to reach truth by arguments (dialogue), and are sort of inventive and/or creative social processes in the sense that they cannot be attained by other types of reasoning such as deduction, induction, abduction and analogy. For example, suppose that the issue is of the form $A \wedge B$, and the first part A is justified by the argument, but the second part B is overruled by the argument. Then if $\neg B$ is justified by an opponent's argument, the Aufheben process (a sort of oracle) lifts up the conflict and proposes $A \wedge \neg B$ as a dialectical agreement.

5.2 Argument-based agent system for reconciliatory or negotiatory dialogue

The argumentation protocol used in this argument-based agent system allows for reaching an understanding with other agents concerned, through argumentative dialogue. Reaching an understanding is attained by allowing for changing issues to be settled alternatively [22]. The final issue (consensus) is agreed by agents under the dialectical inferences of **DL** and **DL**. The argumentation protocol devised here is not simply a protocol for arguing with other agents, but one for reaching an understanding with them. In a sense, we think that it might reflect an eastern way how talking with persons about matters and doing things. We might well say that we here presented such a protocol that avoids confrontational situations as possible as we can. We would say agents couldn't help but involving culture. East vs. West is a typical one. Western culture tends to begin with discussing a matter by making conflicting points thoroughly explicit, as seen in formal debate.

6 Dialectical argument examples

We have dealt with various kinds of realistic argument examples that cannot go well without dialectical resolution, and are not easy for us to foresee which side is predominant, immediately from the knowledge bases. They include an argument on right and wrong or propriety of the nuclear power plant, an argument on design choices occurring in the software design, an argument on the scheduling of the time and place for a meeting, a traveling salesman agent who negotiates by argumentation, and so on.

6.1 Dialectical argument in e-commerce

Here we describe an application to e-commerce of our agent system with dialectical reasoning. It would be an intriguing question how the argument-based

agent system can be applied to such a contemporary topic as electronic commerce with a high demand. Here let us take up the following argumentative dialogue between a salesclerk and a customer at a PC shop. Note that in our actual implementation, the dialogue is dealt with in terms of facts and rules in the extended logic programming.

1. (Issue) Customer: I want to buy a pc with 700 Mhz cpu ($1,500) and a 17-inch monitor ($500).
2. (Counter-argument) Salesclerk: That type of a pc is now out of stock.
3. Customer: No counter-argument and hence the issue is overruled.
4. (Issue change) Salesclerk: What about a popular 19-inch monitor ($1,500) and a pc with 600 Mhz cpu ($600)?
5. (Counter-argument) Customer: The total price is two high and I can't afford it.
6. Salesclerk: No counter-argument and hence the issue is overruled.
7. (Issue compromised) Customer: I will take such a combination of a pc with 600 Mhz cpu (a part of the clerk's suggestion) and a 17 inch monitor (a part of the customer's original desire) because it does not exceed my estimate.
8. Salesclerk: No counter-argument and the customer's issue have been justified. Both will be happy, reaching an agreement!

What they have finally attained in the argumentative dialogue is such a dialectical agreement, CPU(600Mhz) $\wedge$ Monitor(17-inch) that neither $\vdash \neg$Monitor(19-inch) $\rightarrow$ CPU(600Mhz) $\wedge$ Monitor(17-inch) nor $\vdash$ CPU(600Mhz) $\wedge$ Monitor(19-inch) $\rightarrow$ CPU(600Mhz) $\wedge$ Monitor(17-inch), subject to the variable sharing condition.

Diagrammatically, we can depict it as in Figure 5. Note that the dialectical dialogue for purchasing and selling computers proceeds by piling up the dialectical triangles that represent dialectical inferences given in Section 3. The lowest triad represents the dialogue from the dialogue step 1 to 4 above and the intermediate one represents the dialogue from the dialogue step 4 to 7. The final agreement: a pc with 600 Mhz cpu and a 17 inch monitor is constructed by employing a pc with 600 Mhz cpu, a part of the clerk's suggestion in the dialogue step 4, and a 17 inch monitor, a part of the customer's original desire in the dialogue step 1. The issue modification mechanism of agents that appears in these triads is based on the two ideas: The first one is the dialectical inference rules of compromise (Aufheben) and concession (Weaker Aufheben) in Section 3, and the second one is that the top propostions lifted up from two conflicting ones come partly from them and partly from propositions in the precedent dialogues steps. For example, Monitor(17 inch) in Step 7 is a constituent in Step 1. This is a sort of learning process in the sense that agents modify issues and propose new ones by using their own knowledge and the other party's knowledge acquired or learned from his arguments in the dialogue process. In this manner, dialectical inferences allow agents to attain agreements when they confront with conflicting information in negotiatory or reconciliatory argumentative dialogues. Sycara [27]

introduces an idea similar to our issue modification in persuasive argumentation to change the other party's mind.

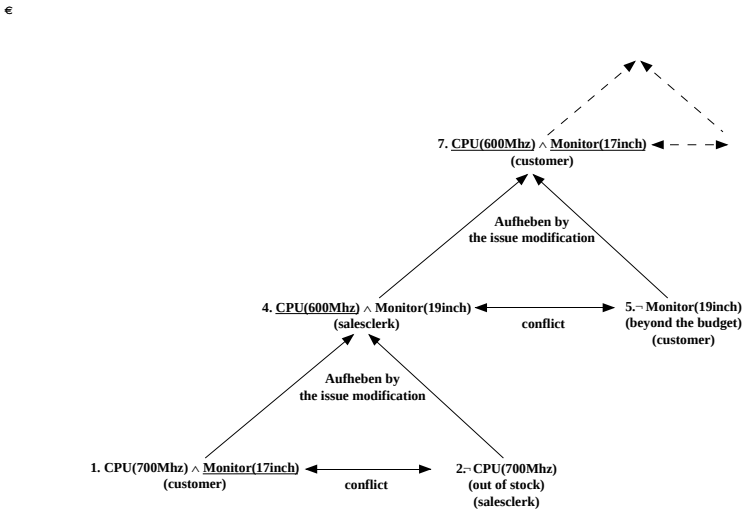

Fig. 5. The dialectical development of a reconciliatory dialogue

6.2 An actual dialectical development of programming languages

A lot of decisions are made in the process of software design and programming language desigh, and hence software designers and programmers are to be involved in arguments on those decisions. Here we illustrate a simple but actual dialectical development of programming languages that we have seen in a recent historical process of programming language development. Figure 6 shows a dialectical development by a series of Aufheben to a unity of opposites, where at the moment, a programming language Minerva is recognized as a good choice in implementing such argument-based systems that need both the agent interaction and symbol manipulation. In the second stage of the development, $Java \wedge Prolog$ was an agreement lifted up from $Java \wedge Lisp$ and $Prolog$, under the assumption of $Lisp = \neg Prolog$.

7 Concluding remarks and future work

As a new approach to inconsistency handling or conflict resolution, we have aroused Hegelian and Marxist dialectics and considered how to shed light on such a philosophical but typical dialectical reasoning as Aufheben and the law

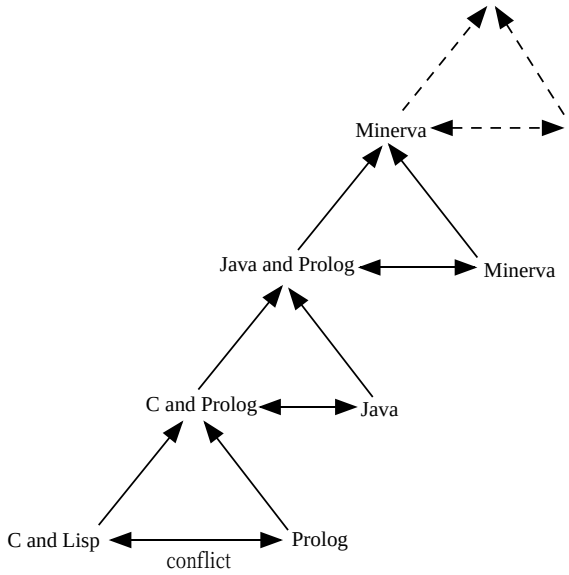

Fig. 6. An example of a dialectical development by Aufheben to a unity of opposites

of the negation of the negation. We gave a promising approach to render them dynamic by argumentation, and realized them in argument-based agent systems. We think that dialectics is the fourth types of reasoning to be added to others: deduction, induction, abduction and analogy, and has significant roles in the virtual society of interacting agents. Our approach is characterized, in a word, as not dialogical but logical in the sense that we have based our ideas on a formal logic.

What we have attempted in this paper, of course, may be said to be still in its infancy, compared with the original Hegelian and Marxist dialectics with a long tradition and history. This paper, however, is interested in not a full range of their philosophy but their computationally significant and tractable contents. There are many important directions to be pursued further. We will touch upon some of them below.

Social validation As far as we confine ourself to logical dialectics, validation of dialectical conclusions is guaranteed. However, this is not sufficient for agents situated in an environment interacting with other agents. The problem of social validation emerges and we are particularly interested in dealing with it in relation to argumentation [31].

Nature of opposites, conflicts and differences All the logics mentioned above are only concerned with negation-inconsistency in the sense of strict opposites. As a matter of course, there seems to be opposites with other meanings, as discussed in [14], where the principle of the unity of opposites is interpreted in six ways. Likewise, there can be seen many aspects of conflicts in the daily life, which are not necessarily of the sense in formal logics [15]. Being influenced

by these insights, we think that we have to proceed to computational dialectics that takes into account these concepts, for a fruitful theory and practice of argument-based agent with dialectics. And at the same time we come to feel the need to capture information 'content' rather than information 'form' for allowing reasoning like dialectical inferences.

Eastern dialectics Dialectics is a thought not only in western philosophy but also in eastern philosophy (India , China and Japan). It rather has a longer history in eastern philosophy, and it appears to be a much more common and recurrent view in eastern philosophy than in the West, for example, N$\bar{\text{a}}$g$\bar{\text{a}}$rjuna and Vasubandhu's dialectics in ancient India [25] and Japanese Zen [26][18]. We can also observe similar concepts of Aufheben in other more specific terms such as sublime, enlightenment in Buddhism, nirvana or vimukti in Sanskrit (meaning 'isolate oneself from all trouble'), 'gedatsu' in Japanese [25] that may be interpreted as eastern counterparts of Aufheben in Western dialectics. They deserve special attention, and we belive they could bring a new insight to computationally capturing inconsistency, dialectics, argumentation, and so on.

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