Smart Innovation, Systems and Technologies 306

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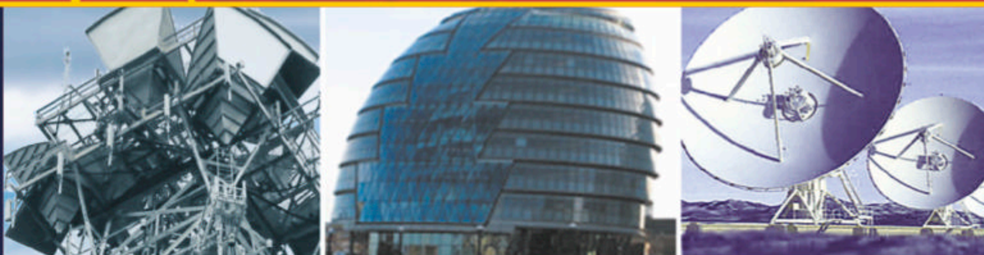
Lakhmi C. Jain *Editors*



Agents and Multi-Agent Systems: Technologies and Applications 2022

Proceedings of 16th KES International Conference, KES-AMSTA 2022, June 2022

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Preface

This volume contains the proceedings of the 16th KES Conference on Agent and Multi-Agent Systems—Technologies and Applications (KES-AMSTA 2022) held as a hybrid conference between June 20 and 22, 2022. The conference was organized by KES International, its focus group on agent and multi-agent systems and University of Zagreb, Faculty of Electrical Engineering and Computing. The KES-AMSTA conference is a subseries of the KES conference series.

Following the success of previous KES Conferences on Agent and Multi-Agent Systems—Technologies and Applications, held in St. Julians, Gold Coast, Vilamoura, Puerto de la Cruz, Sorrento, Chania, Hue, Dubrovnik, Manchester, Gdynia, Uppsala, Incheon and Wroclaw, the conference featured the usual keynote talks, presentations and invited sessions closely aligned to its established themes.

KES-AMSTA is an international scientific conference for discussing and publishing innovative research in the field of agent and multi-agent systems and technologies applicable in the Digital and Knowledge Economy. The aim of the conference is to provide an internationally respected forum for both the research and industrial communities on their latest work on innovative technologies and applications that is potentially disruptive to industries. Current topics of research in the field include technologies in the area of decision making, big data analysis, cloud computing, Internet of Things (IoT), business informatics, artificial intelligence, social systems, health, transportation systems and smart environments, etc. Special attention is paid on the feature topics: multi-agent systems and architectures, modelling and simulation of agents, business process management, agent negotiation and optimization, and intelligent agents applied to health and medicine.

The conference attracted a substantial number of researchers and practitioners from all over the world who submitted their papers for main track covering the methodologies of agent and multi-agent systems applicable in the smart environments and knowledge economy, and four invited sessions on specific topics within the field. Submissions came from 12 countries. Each paper was peer reviewed by at least two members of the International Programme Committee and International Reviewer Board. 26 papers were selected for presentation and publication in the volume of the KES-AMSTA 2022 proceedings.

The Programme Committee defined the following main tracks: Intelligent Software Agents and Optimization, and Multi-Agent Systems. In addition to the main tracks of the conference there were the following invited sessions: Agent-based Modelling and Simulation, Intelligent Agents in health, wellness and human development environments applied to health and medicine, Business Economics and Agent-based Modelling, and Multi-Agent Systems in Transportation Systems.

Accepted and presented papers highlight new trends and challenges in agent and multi-agent research. We hope that these results will be of value to the research community working in the fields of artificial intelligence, collective computational intelligence, health, robotics, smart systems and, in particular, agent and multi-agent systems, technologies, tools and applications.

The Chairs' special thanks go to the following special session organizers: Prof. Rosario Baltazar Flores, Tecnologico Nacional de Mexico/Campus Leon, Mexico, Prof. Arnulfo Alanis Garza, Tecnologico Nacional de Mexico/Campus Tijuana, Mexico, Prof. Hiroshi Takahashi, Keio University, Japan, Prof. Setsuya Kurahashi, University of Tsukuba, Japan, Prof. Takao Terano, Chiba University of Commerce, Japan and Dr. Mahdi Zargayouna, Université Gustave Eiffel, France, for their excellent work.

Thanks are due to the Programme Co-chairs, all Programme and Reviewer Committee members and all the additional reviewers for their valuable efforts in the review process, which helped us to guarantee the highest quality of selected papers for the conference.

We cordially thank all authors for their valuable contributions and all of the other participants in this conference. The conference would not be possible without their support.

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Zagreb, Croatia — Mario Kusek
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April 2022

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Part I
Agent and Multi-Agent Systems

Chapter 1
Temporal Logic in Multi-agent Environment

Vladimir V. Rybakov

Abstract This paper studies temporal multi-agent's relational models with distinct time accessibility relations for agents. Distinct valuations of truth values for agents' are also allowed, and a global valuation is the one which in a sense summarizes the opinion of agents. Some illustrating examples are provided (cf. displayed in paper below formulas (1.2), (1.3)). From mathematical point of view, we deal with satisfiability problem for formulas, and we construct a mathematical algorithm (cf. Theorem 1.3) verifying satisfiability. Also we prove that the problem of admissibility for inference rules in some such logics is decidable. Open problems from the area are proposed.

1.1 Introduction

Working with information, each agent updates it and checks it for reliability, safeness, truth, always being during work in some temporal environment.[1] Therefore, instrument of temporal logic is rather popular in such kind of research and usually to be combined with elements of multi-agency, parallel computing, and multi-agent logics (in a sense a multi-modal logics). It seems the first substantive example of a two-modal logic is Arthur Prior's tense logic, with two modalities, F and P, corresponding to "sometime in the future" and "sometime in the past". A logic with

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infinitely many modalities is dynamic logic, introduced by Vaughan Pratt in 1976, it has a separate modal operator for every regular expression.

In multi-agents' logic, modalities are interpreted often as agent's temporal accessibility operations, or the ones oriented to model checking. They were used widely for study interaction and autonomy, effects of cooperation (cf. e.g. Babenuschev and Rybakov [1–4], Rybakov [20], Woldridge and Lomuscio [28], Woldridge [29, 30], Lomuscio et al. [10], Rybakov [23, 25]).

Working with knowledge representation also often deals with analysis of information by logical instruments (e.g., description logics) close to temporal and modal logics (cf. Horrocks, Satler et al. [14–16], Baader et al. [7–9]). Representation of agent's interaction (as a dual of common knowledge) was suggested in Rybakov [20]; using as a base agent's knowledge (S5-like) modalities. Knowledge, as a concept itself, came from multi-agency, since individual knowledge may be received only from interaction of agents, learning.

As essential feature of multi-agent environment is the observation that receiving or knowledge, interaction of agents, cooperation occur during some intervals of time, and that the length of this interval might be of great importance. To capture this observation CS often use symbolic (mathematical) temporal logic. Historically investigations of temporal logic in the framework of mathematical/philosophical logic based on modal systems, as we know, was originated by Arthur Prior in the late 1950s.

Nowadays temporal logic highly developed area in mathematical logic, information sciences, AI , and CS overall (cf. e.g.—Gabbay and Hodkinson[11–13]). One of the important cases of such logics is the linear temporal logic $\mathcal{LTL}$, which was used for analyzing protocols of computations, verification of consistency. Automaton techniques to solve satisfiability in this logic were developed by Vardi [26, 27]). Further, to evolve mathematical tools of $\mathcal{LTL}$, the solution for admissibility problem for $\mathcal{LTL}$ was found in Rybakov [17], the basis for admissible rules of $\mathcal{LTL}$ was obtained in Babenyshev and Rybakov [5]. Recently modeling multi-agency in non-transitive time assumption was studied in Rybakov [21, 22].

This paper considers temporal multi-agent's relational models with distinct linear time accessibility relations for agents. Agents as well have their own valuations for truth values of letters (notations) and formulas, and models have a global truth valuation which in a sense summarizes opinion of agents. Illustrating examples and explaining discussions are provided. From the mathematical point of view, we investigate with satisfiability problem for formulas, we find an algorithm verifying satisfiability. Also we prove that the problem of admissibility for inference rules in some such logics is decidable. Open problems from the area are proposed.

Formally this paper is structured as follows. Section 1.1—Introduction—comments on the historical state of existing research in the area and the aim of this paper; Sect. 1.2—Notation, Preliminary Facts—introduces accepted notation and briefly recall necessary for reading known facts; Sect. 1.3—Rules for computation truth values for formulas—formally and detailly describes algorithmic (mathematical) rules for computation; Sect. 1.4—Satisfiability Problem—recalls basic notation and facts concerning satisfiability problem in logics and then precisely enumerates all main obtained results formulated as mathematical theorems.

1.2 Notation, Preliminary Facts

Since we will use elements of multi-modal (temporal) logic we first recall necessary definitions and facts. As model theory for such logic usually to be used relational models which may be viewed as tuples $\langle W, \{R_i \mid i \in I\}, V\rangle$ with a base set W—the set of worlds (or states) in these models. A set of binary relations $\{R_i \mid i \in I\}$ on these worlds (any R_i is a subset of W x W) represent current time events in perception of agents i. Here V is a valuation of a set of propositional statements (letters) in this model.

That is, for any $p \in P$, $V(p) \subseteq W$. Then if $w \in W$ and $w \in V(p)$, we say p is true at the world w w.r.t V. As a logical language, it usually to be based on Boolean logic and uses special additional logical operations. Special rules defining computation of the truth values logical formulas are introduced, and the logic is usually defined as the set of all formulas which are true in any world of such specified models.

In order to embed the multi-agent approach, we consider individual valuations—$V_1, \ldots, V_k$ for agents in such models instead of only one unique fixed one. Then any V_i represents viewpoint of the agent i on truth of the atomic statement—propositional letters, and $w \in V_i(p)$ would mean that the agent i accepts the statement p to be true at the world w.

Besides differently from our previous works in that direction, we consider different time accessibility relations $\leq_j$ for different agents $j \in Ag$.

So, relational models of our paper look as follows; assume that a set of propositional letters $Prop$ be given.

Definition 1.1 A temporal k-model with agents' multi-valuations is the structure $\mathcal{M} := \langle \mathcal{N}, \leq_j, \text{Next}, V_1, \ldots, V_k, V_0\rangle$, where

(i) $\mathcal{N}$ is the set of all natural numbers;
(ii) Each $\leq_j$ (for $j \in Ag$) is a linear order which is a subset of usual $\leq$ on $\mathcal{N}$ (that is it is a linear order coinciding with $\leq$ on some subset of $\mathcal{N}$);
(iii) Next is the binary relation, where a Next b means that b is the number next to a;
(iv) any V_j is a valuation of $Prop$ (that is for any $p \in Prop$, $V_j(p) \subseteq \mathcal{N}$).

These models have a good range of applications, as researchers viewed earlier: they may represent (i) computational multi-agents runs (in particular—threads, as often for usual linear temporal logic), (ii) surfing via networks, internet, databases collections ($\mathcal{N}$ then will represent sequence of steps in the search), (iii) sequences of queries for relational databases, (iv) evolutions of social objects in time, etc. But now our semantics also includes different time relations for agents which give more ways for applications. To fix notation, for all $a \in \mathcal{N}$ and any $p \in Prop$ we write $[(\mathcal{M}, a) \Vdash_{V_j} p \Leftrightarrow a \in V_j(p)$, and say that the letter p is true at a w.r.t. V_j.

The valuation V_0 is a special one—global one—accepted in these models to fix objective truth relation. This valuation, in a sense, have to summarize opinions of all agents. Ways to construct V_0 out of all V_j may be different. For example, we may consider $(\mathcal{M}, a) \Vdash_{V_0} p \Leftrightarrow ||\{j \mid (\mathcal{M}, a) \Vdash_{V_j} p, j \neq 0\}|| > ||\{j (\mathcal{M}, a) \nVdash_{V_j} p, j \neq 0\}||$, This means the majority of agents believe that p is true. There are very many ways to express what means global valuation and what indeed means the dominant part of agents.

Maybe the agent's opinion may be considered with an appropriate weights prescribed, maybe depending on different states the rules to compute global valuation may be different, etc. At the very limit point, we may assume V_0 to be arbitrary, which does not depend on all V_j—it is opinion of a total dominant—the only true what V_0 think to be true. In this paper, we do not fix rigidly the rules for computation V_0 (they may be any ones chosen).

Definition 1.2 To fix language, the set of all formulas for our multi-agent logic (the set For) contains $Prop$ and is closed w.r.t. applications of Boolean logical operations $\wedge, \vee \neg, \rightarrow$, the unary operation N (next) and the binary operations U_j $j \in Ag$ (until, each one for each agent j).

The formula $N\varphi$ has meaning: φ holds in the next time point (state); $\varphi U_i \psi$ can be read: φ holds until ψ will be true in the opinion of the agent i.

1.3 Rules for Computation Truth Values for Formulas

Rules for computation truth values at our models for compound, complected formulas are as follows. Let a temporal linear k-model with agent's multi-valuations

$$\mathcal{M} := \langle \mathcal{N}, \leq_j, j \in Ag, \text{Next}, V_1, \dots, V_k, V_0 \rangle,$$

be given. That is, for any letter $p \in Prop$ $V_i(p) \subseteq \mathcal{N}$. If $a \in \mathcal{N}$ and $a \in V_i(p)$ we write $(\mathcal{M}, a) \Vdash_{V_i} p$ and say that p is true at a w.r.t. the valuation V_i.

Definition 1.3

$$\forall p \in Prop\ (\mathcal{M}, a) \Vdash_{V_j} p \Leftrightarrow a \in \mathcal{N} \wedge a \in V_j(p);$$

$$(\mathcal{M}, a) \Vdash_{V_j} (\varphi \wedge \psi) \Leftrightarrow (\mathcal{M}, a) \Vdash_{V_j} \varphi \wedge (\mathcal{M}, a) \Vdash_{V_j} \psi;$$

$$(\mathcal{M}, a) \Vdash_{V_j} \neg\varphi \Leftrightarrow not[(\mathcal{M}, a) \Vdash_{V_j} \varphi];$$

$$(\mathcal{M}, a) \Vdash_{V_j} N_i\varphi \Leftrightarrow \forall b[(a \text{ Next } b) \Rightarrow (\mathcal{M}, b) \Vdash_{V_i} \varphi];$$

$$(\mathcal{M}, a) \Vdash_{V_j} (\varphi U_j \psi) \Leftrightarrow \exists b[(a \leq_j b) \wedge ((\mathcal{M}, b) \Vdash_{V_j} \psi) \wedge$$

$$\forall c[(a \leq_j c < b) \Rightarrow (\mathcal{M}, c) \Vdash_{V_j} \varphi]].$$

There are various ways to define other logical operations using the postulated ones. In particular, the modal operations $\Box_i$ (necessary for agent i) and $\Diamond_i$ (possible for agent i) might be defined via temporal operations as follows: $\Diamond_i p := \top U_i p$, $\Box_i p := \neg\Diamond_i\neg p$. It might be easily verified that then

$$(\mathcal{M}, a) \Vdash_{V_j} \Diamond_i\varphi \Leftrightarrow \exists b \in \mathcal{N}[(a \leq_i b) \wedge (\mathcal{M}, b) \Vdash_{V_j} \varphi];$$

$$(\mathcal{M}, a) \Vdash_{V_j} \Box_i\varphi \Leftrightarrow \forall b \in \mathcal{N}[(a \leq_i b) \Rightarrow (\mathcal{M}, b) \Vdash_{V_j} \varphi];$$

Now we pause briefly to discuss why we cannot look at it as simply a mechanical combination of k—examples of the standard linear temporal logic. That all is a consequence the fact that in our definition of rules for computation truth values of formulas, cf. above, recall:

$$(\mathcal{M}, a) \Vdash_{V_j} (\varphi U_i \psi) \Leftrightarrow \exists b[(a \leq_i b) \wedge ((\mathcal{M}, b) \Vdash_{V_j} \psi) \wedge$$

$$\forall c[(a \leq_i c < b) \Rightarrow (\mathcal{M}, c) \Vdash_{V_j} \varphi]].$$

So, we switch the valuation for temporal operations: if the valuation is some V_j and we compute truth value for a temporal operation with index i we switch j to i and use further the valuation V_i. That is seemed as very correct and well justified: if a temporal statement refers to an agent i, the opinion about truth for future to be its one.

As you may see truth values during computations are switching valuations. Therefore, the standard technique cannot be directly applied. That is in particular because the standard rule of exchanging equivalents does not work here.

Indeed if for a model $\mathcal{M}$, it may happen

$$\forall a, (\mathcal{M}, a) \Vdash_{V_0} \Box_0((p \to q) \wedge (q \to p)),$$

but it does not imply generally speaking that

$$\forall a, (\mathcal{M}, a) \Vdash_{V_0} \Box_1((p \to q) \wedge (q \to p)).$$

Assume a class $\mathcal{K}$ of described models is given. We may assume that the rules of definition of the global valuation V_0 via agent's valuations V_i, $1 \leq i \leq k$ are fixed and are the same for all models and all states of these models. Though the agent's valuations themselves may be various (that looks as the most general case) but the rules imposed on the agent's valuations are the same for all states. For example, rules for agent's valuations may be with the limitation: for all states a,

$$[||\{i \mid (\mathcal{M}, a) \Vdash_{V_i} p\}|| > k/2 + 1] \Rightarrow \tag{1.1}$$

$$[\forall i (1 \leq i \leq k \Rightarrow (\mathcal{M}, a) \Vdash_{V_i} p)].$$

This means a uniform opinion—if a majority of agents believe that a fact is true then all of them think it is true.

Definition 1.4 A formula φ is said to be satisfiable in a class of models $\mathcal{K}$ if there is a model $\mathcal{M} \in \mathcal{K}$ and a state $a \in \mathcal{M}$ such that $(\mathcal{M}, a) \Vdash_{V_j}$ for some j.

Satisfiability problem for $\mathcal{K}$ is to resolve for any given formula if it is satisfiable in some model from $\mathcal{K}$. Assuming that a class of models $\mathcal{K}$ is chosen we may define the logic $\mathcal{L}(\mathcal{K})$ of this class as follows.

$$\mathcal{L}(\mathcal{K}) := \{\varphi \in Form \mid \forall \mathcal{M} \in \mathcal{K},\ \forall a \in \mathcal{M}, \forall j [(\mathcal{M}, a) \Vdash_{V_j} p]\}.$$

In this definition we may use only global valuation or a dominant part of all valuations. So the definition depends on the aim of our description of information inside models. For brevity in the sequel we write $\mathcal{L}$ instead of $\mathcal{L}(\mathcal{K})$ if we assume that $\mathcal{K}$ is fixed.

Assuming that all V_j are equal and V_0 being the same as any V_j and all of them to be arbitrary, we may obtain the limit point—to obtain that $\mathcal{L}(\mathcal{K})$ is just the standard linear temporal logic LTL itself. Bigger than this—then any j-fragment of any logic $\mathcal{L}(\mathcal{K})$ for the valuation V_j to be arbitrary is again LTL itself. But if combinations of different temporal and modal operations for distinct agents are allowed, the possibility to describe properties of multi-agent reasoning is much wider.

We briefly illustrate which formulas could more plausibly describe the postponed decision of agents. The background idea here is to say that the agents need time to think of indeed necessary particular properties, their safety and other qualities, and that need time for verification, comparison, etc. So, the idea is to postpone the taking decision for a reasonable time. That from technical viewpoint may be made in various ways and via distinct technique. For example, we could consider the formulas: $m \in N$,

$$DF(\varphi) := \bigwedge_j \Diamond_j \mathcal{N}^m \varphi. \tag{1.2}$$

That means that any agent always in future may use reasonable time (m steps) to wait for verification if the statement φ will be true; that is to postpone taking decision for reasonable time.

To say that the property encoded by a formula φ is very safe—conclude that φ will be true and in remaining future, and we may repeat that verification again and again, that is

$$Safe(\varphi) := \bigwedge_j [\Diamond_j \mathcal{N}^m \varphi] \wedge [\bigwedge_j [\Box_j \Diamond_j \mathcal{N}^m \varphi]. \quad (1.3)$$

1.4 Satisfiability Problem

Here, we turn to describe our new results for satisfiability problem. To recall, a formula φ is said to be satisfiable w.r.t. a valuation V_j in a class of models $\mathcal{K}$ if there is a model $\mathcal{M} \in \mathcal{K}$ and a state $a \in \mathcal{M}$ such that $(\mathcal{M}, a) \Vdash_{V_j}$ for some j. We may differ the problem by asking only for satisfiability formulas w.r.t. the global valuation., or alternatively all of them, or just some of them. More general case is—all of them, and we consider later this case. For any class of models $\mathcal{K}$ the logic $\mathcal{L}(\mathcal{K})$ of this class is defined as follows. $\mathcal{L}(\mathcal{K}) := \{\varphi \in Form \mid \forall \mathcal{M} \in \mathcal{K},\ \forall a \in \mathcal{M}, \forall j[(\mathcal{M}, a) \Vdash_{V_j} p]\}$. So the logic is all formulas which are true everywhere w.r.t. any valuation.

Differently from our earlier research in this area, we here consider models with distinct agents' linear time-accessibility relations.

So, as axillary instruments, we will need special models $\mathcal{M}(\Uparrow, C)$ aiming to distinguish special finite models. Recall that for $n, m, i \in \mathcal{N}$ with $n < m$ $[n, m]$ denotes the closed interval of all numbers situated between n and m and these numbers n, m themselves.

Definition 1.5 So let a model $\mathcal{M}$ for our logic defined as earlier to be given. Any $\mathcal{M}(\Uparrow, C)$ model has the following structure. For $n, c(m), m \in \mathcal{N}$, where $0 < n < c(m) \leq m$,

$$\mathcal{M}(\Uparrow, C) = \langle [0, m], \leq_j, j \in Ag, \text{Next}, V_1, \ldots, V_k, V_0 \rangle),$$

where $\text{Next}(m) := c(m)$ and

(i) C is a loop on a final part of [0,m] w.r.t. an external time order;
(ii) Any $\leq_j$, is the linear order on an interval of C coinciding with the original $\leq_j$ on the states belonging to the domain of $\leq$;
(iii) before C any $\leq_j$ acts as in the original model;
(iv) The valuations V_j are taken from the model $\mathcal{M}$ itself.

The rules for computation of the truth values of formulas in such model w.r.t. any V_j are defined similarly to as earlier in the models, simply for states bigger than $c(m)$ the order $\leq$ to be replaced by appropriate $\leq_j$ in C. More precisely, we define $(\mathcal{M}(\Uparrow, C)a) \Vdash_{V_j} (\varphi U_j \psi)$ as follows. If $a \in [0, c(m)]$ the definition is as earlier, if $a > c(m)$,

$$(\mathcal{M}(\Uparrow, C), a) \Vdash_{V_i} (\varphi U_j \psi) \Leftrightarrow \exists b\big[[(a \leq_j b \leq c(m)) \wedge (\mathcal{M}(\Uparrow, C), b) \Vdash_{V_i} \psi) \wedge$$

$$\forall c[(a \leq_j c < b) \Rightarrow (\mathcal{M}(\Uparrow, C), c) \Vdash_{V_i} \varphi]] \bigvee$$

$$\exists d\big[(b > c(m)) \wedge (\mathcal{M}(\Uparrow, C), , b) \Vdash_{V_i} \psi) \wedge$$

$$\forall c[(a \leq_j c < m) \Rightarrow (\mathcal{M}(\Uparrow, C), c) \Vdash_{V_i} \varphi]] \wedge$$

$$\forall c[(c(m), \leq_j c < b) \Rightarrow (\mathcal{M}(\Uparrow, C), c) \Vdash_{V_i} \varphi]].$$

So introduced rules act in accordance with our previous intuition of what is circled bypath by $Next$. For any formula φ, we denote by $Sub(\varphi)$ is the set of all its subformulas.

Let for any formula φ, $Tm(\varphi)$ be the temporal degree of φ; the temporal degree of formulas is defined inductively: (i) temporal degree of letters is 0, (ii) temporal degree of any formula with a temporal operation as the main one is the maximal temporal degree of the components plus 1; (iii) temporal degree of any formula with a Boolean logic operation as the main one is the maximal temporal degree of the components. Recall that k is the number of agents in our models. Denote $f(\varphi) := 2 \times 2^{2^{||Sub(\varphi)|| \times k+3}} + 5$. By the size of a model, we agree to call the number of states in this model.

Theorem 1.1 *If a formula φ is satisfiable in a model $\mathcal{M}$ at a state by a valuation V_j, then there exists a finite model of kind $\mathcal{M}(\Uparrow, C)$ with size at most $f(\varphi)$ satisfying φ at the world 0 by its own V_j.*

Theorem 1.2 *If a formula φ is satisfiable in a finite model $\mathcal{M}(\Uparrow, C)$ then it is satisfiable in some k-model $\mathcal{M}$.*

Recall that a logic $\mathcal{L}(\mathcal{K})$ is decidable if for any formula φ we may compute if $\varphi \in \mathcal{L}(\mathcal{K})$. Observe that $\varphi \in \mathcal{L}(\mathcal{K})$ iff $\neg\varphi$ is not satisfiable in $\mathcal{L}(\mathcal{K})$. From Theorems 1.1 and 1.2 we immediately obtain

Theorem 1.3 *The satisfiability problem for $\mathcal{L}(\mathcal{K})$ is decidable (so the logic $\mathcal{L}(\mathcal{K})$ is decidable). For a formula φ to be satisfiable it is sufficient to check its satisfiability at all models $\mathcal{M}(\Uparrow, C)$ of size at most $f(\varphi)$.*

We are also interested to consider the problem of recognizing rules admissible in our logic. Though we can do it now only for a restricted case—when the valuation in models is only single—the final global one, and when the operation $Next$ is deleted from the models (denote the resulting logic by L_{Ag}).

Theorem 1.4 *The admissibility problem for the logic L_{Ag} is decidable. There exists an algorithm recognizing rules admissible in L_{Ag}.*

1.5 Conclusion

There are several interesting open problems in this area. For example, to consider models with distinct rules of computation global valuation depending at which state the computation is to be done. Next one is the case when the operation NEXT STATE is different for distinct agents. That looks like a reasonable approach—agents may be distinct in perception when next time will come depending on, e.g., their accessibility restrictions, etc. The extension that results in branching time logic is very interesting and actual. The investigation of admissibility for rules for all logics from thew related area is interesting, many things are already done for non-classical logics (cf. [17–19]) and many strong results about admissibility and unification were obtained by distinct researchers. But for multi-agent logics the amount of such results is not too big as the area is very technical (cf. from Recent results [24] Rybakov 2020.). To consider technique from this paper in a combination with the fuzzy logic also looks interesting.

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Chapter 2
Cost-Aware Dynamic Task Sharing Among Decentralized Autonomous Agents: Towards Dynamic Patient Sharing Among Hospitals

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Abstract In the COVID-19 pandemic era, hospitals tend to be crowded with patients. Dynamic task sharing is becoming an important research theme and can be applied to patient sharing among hospitals. Unlike in standard task scheduling, the tasks are created dynamically and asynchronously, and each agent (hospital or region) is independent. Hence, we previously designed and compared the decentralized algorithms for dynamic task sharing. However, in these algorithms, the cost of task transfers was not considered. The cost of transferring a patient to a distant hospital is high and cannot be ignored. In this paper, we present new decentralized algorithms for dynamic task sharing that consider the cost of task transfers.

2.1 Introduction

As the COVID-19 pandemic continues, hospitals tend to be crowded and might refuse admission. To accommodate more patients, hospitals need to cooperate, and patients must be transferred from busy hospitals to less busy hospitals.

Therefore, we need to find effective task-sharing algorithms. Most task-allocation algorithms previously applied are centralized algorithms wherein a single agent allocates the tasks to other agents. However, in the task (patient) sharing problem, each hospital is independent and pursues its own profit. In other words, hospitals generally do not transfer patients to other hospitals, unless their beds are full. Therefore, we need decentralized task-sharing algorithms.

Furthermore, patient sharing among hospitals needs special consideration because patients appear dynamically and asynchronously, and some patients need to be treated urgently. From this perspective, we previously evaluated and compared six decentralized task-sharing algorithms using patient sharing scenarios [10]. The algorithms were designed considering the urgency of patients. Thus, we found that the CSRN

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(continual or single random negotiation) algorithm was the best among the six algorithms proposed, for increasing the number of executed tasks before the deadline. But multiple negotiations for the transfer of the same task were not effective.

Although our conclusion in the previous study is extremely useful for patient sharing among hospitals, we would like to improve the CSRN algorithm further, considering more constraints in the real world. An important constraint is the distance between hospitals. It is expected that hospitals tend to avoid transferring their patients to distant hospitals because this process requires time and money. Therefore, we extended the CSRN algorithm and introduced two new algorithms taking the transfer cost into account. We evaluated and compared the two new and improved algorithms with the CSRN algorithm by multi-agent simulation. The results have been reported in this paper.

The rest of this paper is organized as follows. In Sect. 2.2, related work is discussed. In Sect. 2.3, the problem is described. In Sect. 2.4, two new algorithms are presented. In Sect. 2.5, simulation settings are explained in detail. In Sect. 2.6, simulation results are presented and discussed. In Sect. 2.7, concluding remarks and future works are summarized.

2.2 Related Work

Dynamic task allocation is an important research subject and is applied in areas such as coordination of robots [13, 24], allocation of taxis [6, 21] and ride-share cars [27, 28] to passengers, coordination of IoTs [22], coordination of non-playing characters in computer games [4, 11, 14, 23, 25], weapon-target assignment [2, 12, 26], and disaster relief [5, 15–17]. Owing to the COVID-19 pandemic, task sharing among hospitals has now become important.

As discussed in [3, 16], there are two types of task-allocation algorithms: centralized and decentralized. Centralized combinatorial optimization (such as maximum weight matching [20]) or auction (such as parallel auction [1]) are also related to task-allocation problems. As aforementioned, most algorithms are centralized, wherein a single agent allocates the tasks to other agents. In decentralized algorithms, however, each agent must individually negotiate with other agents to transfer tasks. As explained in the previous section, in the case of the task sharing among hospitals, decentralized algorithms are needed. Auctions can be decentralized. However, they need many communications among agents, which is not acceptable when human operators are involved in each negotiation.

Decentralized algorithms for dynamic task allocation were studied for different scenarios in [7–9]. In these studies, the task is always allocated to the agent who can handle it best, provided there is enough time. The task is handled locally only when the time is limited. These algorithms can be applied to applications such as disaster response and defense. In the case of task sharing among hospitals, the task is always handled locally when there are adequate resources, and this requires different algorithms.

Decentralized human resource sharing among companies was studied in [18, 19] where less busy companies send their employees to busy ones to level the busyness among companies. Although resource sharing is different from task sharing, the aim of human resource sharing is similar to that of task sharing among hospitals. However, in the case of task sharing among hospitals, critical tasks must be handled immediately.

2.3 Problem Description

We consider a multi-agent system in which each **agent** is given **tasks** dynamically and asynchronously, and handles the tasks using its own **resource**. The **agent** takes time (**execution time**) to finish a task, and occupies the **needed resource** when committed to the task. We assume that tasks must be commenced before the (start) **deadline**. In the case of medical tasks, tasks correspond to the treatment of ill patients, agents correspond to hospitals or regions, and resources correspond to medical staff or beds. Unexecuted tasks by the deadline correspond to the death of persons and will be removed after the deadline.

In our problem setting, to level the number of tasks among agents, we allow **transfer of tasks** among agents, if they agree. Through task transfers, busy agents can reduce the number of tasks. In the case of the COVID-19 pandemic, many people are hospitalized in some areas, whereas the other areas are relatively available.

One of the important factors to consider is the cost of task transfers. For example, when a hospital transfers a patient to another hospital, the cost increases with distance. Another important factor is the urgency of tasks. For example, we must start treatment tasks before it's too late.

In our study, we aim to minimize the **cost of task transfers** and the **number of tasks that missed the (start) deadline**. We assume that each agent cannot know the values of internal variables of the other agents, including available resources and waiting tasks.

2.4 Method

In this section, we introduce the task-sharing framework and the algorithms of simulation cycle, handling waiting tasks, and replying for a task transfer. To deal with the problem defined in the previous section, we try to improve the algorithms for handling waiting tasks that were introduced in [10], to minimize the cost of task transfers. Because our previous algorithms were incrementally defined, they are easily understandable. We recommend the interested readers to read our previous paper [10].