Adding Branching Temporal Dimension to Qualitative Coalitional Games with Preference

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***Abstract*—Qualitative Coalitional Games (QCGs), as a variation of coalitional games, is to investigate agents' strategies and behaviors in cooperating games. Each agent has a set of goals as its desires and will be satisfied if at least one of its desires is achieved by executing some strategies in a coalition, otherwise be unsatisfied. After introducing QCGs, we add preference to QCGs framework to enable that every agent has the ability to join the best coalition for achieving its preferences goals (QCGPs). In order to make a formal description and reason about repeated coalitional games, the paper will study Branching Temporal Qualitative Coalitional Games with preferences. Computational Tree Logic (CTL) is used for QCGPs with complete axiomatisation of it, denoted as CTQCGPs. Further more, this paper analyses the expression power, complexity, and some characteristic of CTQCGPs.**

***Index Terms*—Coalition games, Multi-agents Systems, Modal logic, Artificial Intelligence.**

I. INTRODUCTION

The study of social software is a hot topic among research communities, including computer scientists, game theorists and philosophers. The key idea of it is regarding the social process as a computer program, and then using formal methods to analyze, design and validates social procedures just the same way in computer programs [1]. On the other hand, the multi-agents systems have gained the attention of game theory and artificial intelligence. So using formal methods, such as model and logic are an effective way for games which are often studied by mathematics tools. With the idea, coalitional Games (CGs) [2.3] are regarded as a natural tool for modeling goal-oriented multi-agents systems. When the goals of agents can be achieved with transferable payoffs of which the expression of payoff is not a numeric value, we have to use qualitative ways to solve the problem, Wooldridge.et.al[4] first introduces QCGs and pays an attention to the computation complexity of QCGs for decision problem and make the definition of the satisfaction of agents. In QCGs, each agent has a set of goals as its desires and will be satisfied in a coalition by performing some strategies. The means of an agent's satisfaction is that a coalition including that agent achieves a set of goals which at least include one of the elements of that agent's goals. [5, 6]Add preference to QCGs without temporal concept, what the means of preference of agent is that in any two goals of the agent, it prefers one to the other goal. In order to systematically study the multi-agents systems [7], repeated games [8] are an important way. Line Temporal logic(LTL) is used for repeated games in QCGs(TQCGs) by iterating games in time serial[9], but the expression power of LTL is only useful in universal quantifier. This paper will use CTL for QCGPs(CTQCGPs) for existential and universal quantifier.

This paper is organized as follows: Section Ⅱ introduces QCGPs with a formal description, section Ⅲ defines logic for expressing the properties of individual QCGPs, and the language for QCGPs is also given. In section Ⅳ we built CTQCGPs. Sone chatacteristic of CTQCGPs is given in Ⅴ. Conclusion and future work will be given in section Ⅵ.

II. QUALITATIVE COALITIONAL GAMES WITH PREFERENCES

Coalitional games were introduced in [4] for interpreting cooperative interactions in games, just like "which coalition I should join in". Although coalitional games are a very good model for numeric value in which every agent's payoff can be expressed as a numeric value, unfortunately, it can not enable the payoff of a goals set to be expressed in that way. The new situation assumes that every agent has a set of goals as its desires and achieves its desires by attending a coalition to get some goals. To a different agent, in two goals, it prefers a goal to the other between two goals. The abstract description of coalitional games is given in [8], the formal model of QCGs is first presented in [4], and QCGPs is introduced in [5]. These models pay attention to how the coalition can be formal without caring for the concrete strategy and how to compute the payoff of agents.

QCGPs include a non-empty, finite set $A=(1, \ldots m)$ of agents, each agent has a set of goals $G_i \subseteq G$. Here G is a goals set of all agents, and the elements of G_i has a partial order relation for interpreting the preference of agent i.

Definition 1 Qualitative Coalitional Games with Preferences (QCGPs) is a $2n+3$ tuple

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$$\Gamma=<A, G, G_1,\dots,G_n, V, \rhd_1,\dots,\rhd_n>$$

where. A is a finite, non-empty set of agents; $G=\{g_1,\dots,g_m\}$ is a set of possible goals; $G_i\subseteq G$ is the set of goals for agent $i\in A$; $V: 2^A \rightarrow 2^{2^G}$ is the characteristic function of the game which for every coalition $C\subseteq A$ determines a set $V(C)$ of choices, the intended interpretation being that if $H\in V(C)$ then one of the choices is available to coalition C is to bring about all the goals in H simultaneously. $\rhd_i\subseteq G_i\times G_i$, is a partial order over G_i representing i's preference relation, so that $g_r\rhd_i g_t$ indicates that i would rather have goal g_r satisfied than goal g_t

We say a set of goals H satisfies agent i if $H\cap G_i\neq\Phi$. We say that H satisfies $C\subseteq A$ if it satisfies every member of C. Also, we say that H is feasible for coalition C if $H\in V(C)$. The coalition preference which means the coalition likes one goal set more than the other goals set. We introduce the following definition.

Definition 2 A coalitions, called by C, can achieve all the goals sets of it and every members of it are satisfied in that sets.

$$X(C) = \{G'\subseteq G: (\wedge_{i\subseteq C}(G'\cap G_i\neq\Phi)\wedge(G'\in V(C))\},$$

$$\text{let } X^\Gamma=\cup_{C\subseteq A}X(C)$$

Definition 3 A coalition prefers a goals set than the other set of goals in X^Γ $C\subseteq A$, H, $H'\in X^\Gamma$, we say C strongly prefers the goal set H *to* H', *denoted as* $H\supset_c H'$ *if*

1 $H\in X(C)$,

2 $\forall i\in C$, $\exists r_i\in H\cap G_i$, $\forall s_i\in H'\cap G_i$, $r_i\rhd_i s_i$.

We say C weakly prefers the goal H *to* H', denoted as $H\succ_c H'$ *if*

1 $H\in X(C)$,

2 $\forall i\in C$, $\forall s_i\in H'\cap G_i$, $\exists r_i\in H\cap G_i$: $r_i\rhd_i s_i$

The $H\supset_c H'$ means that coalition C can achieve H which will satisfy every member of it and every member has a goal in $H\cap G_i$ which is better than any other goals from $H'\cap G_i$. $H\succ_c H'$ indicates that for $\forall i\in C$, no matter which goals of $H'\cap G_i$, i will find a better goal in $H\cap G_i$. In this definition, H' is not required to be in $X(C)$; we use $\rhd_c$ to express $\supset_c$ or $\succ_c$ in the following paper

The following example is concrete description of the coalition with preference

Example1 let Γ_1 be a Qualitative Coalitional Games with Preferences (QCGPs)

$\Gamma_1=<A, G, G_1, G_2, G_3, V, \rhd_1, \rhd_2, \rhd_3>$, *where*

$A=(a_1, a_2, a_3)$, $G=(g_1, g_2, g_3, g_4, g_5. g_6)$

$G_1=(g_1, g_4)$: $g_1\rhd_1 g_4$

$G_2=(g_2, g_3, g_4)$: $g_2\rhd_2 g_3\rhd_2 g_4$

$G_3=(g_4, g_5, g_6)$: $g_4\rhd_3 g_5\rhd_3 g_6$

$V(a_1)=\{(g_1,g_2)\}$:

$V(a_2,a_3)=\{(g_1,g_3), g_6\}$:

$V(a_1,a_3)=\{(g_4, g_5), (g_1, g_4), (g_1, g_6)\}$:

We will make use of Γ_1 in later example

III. The Logic for QCGPs

Logic for expressing properties of individual of QCGs has been given in [9]; the key idea is that the language is defined in two parts: *Lc* is the satisfaction language, and is used to express properties of choices made by agents. The basic constructs in that language are of the form sat_i, meaning "agent i is satisfied". The overall language *L(QCGs)* is used for expressing properties of QCGs themselves. The main construct in that language is of the form $<C>\varphi$, where φ is a formula of the satisfaction language, and means that C have a choice such that this choice makes φ true. For example, $<3>(sat_1\wedge sat_4)$ will mean that agents *3* has a choice that simultaneously satisfies agents *1* and *4*, we add preferences to that language. So we improve the logic by adding preference operations

A. The formal expression of logic

Formally, the grammar φ_c defines the satisfaction language *Lc*, while φ_q defines the QCGPs language *L(QCGPs)*.

$\varphi_c ::= sat_i \mid \neg\varphi_c \mid \varphi_c\vee\varphi_c$

$\varphi_q ::= <C>\varphi_c \mid [C]\varphi_c \mid \rhd_C\varphi_c \mid \neg\varphi_q \mid \varphi_q\vee\varphi_q$

Here, $i\in A$, $C\subseteq A$, the other propositional connectives ($\wedge$, $\rightarrow$, $\leftrightarrow$) is also used in the language of *Lc* and *L(QCGPs)*, the $[C]\varphi$ means that no matter what strategy C take, φ will be true and can be written as $\neg<C>\varphi$.

When $\Gamma=<A, G, G_1,\dots,G_n, V, \rhd_1,\dots, \rhd_n>$ is a QCGPs, $H\subseteq G$, and $\varphi\in Lc$, $\Gamma. H \models_Q\varphi$ is defined as fellows.

$\Gamma. H \models_Q sat_i$ iff $G_i\cap H\neq\Phi$

$\Gamma. H \models_Q \neg sat_i$ iff not $\Gamma. H \models_Q sat_i$

$\Gamma. H \models_Q \varphi_1\vee\varphi_2$ iff $\Gamma. H \models_Q \varphi_1$ or $\Gamma. H \models_Q\varphi_2$

When φ is *L(QCGPs)* formula, $\Gamma \models_Q\varphi$ is defined as fellows

$\Gamma \models_Q <C>\psi$ iff there is a $H\in V(C)$, such that $\Gamma. H \models_Q\psi$

$\Gamma \models_Q \rhd_C\psi$ iff there is a $H\in V(C)$, $H'\in X^\Gamma$, $\Gamma. H \models_Q\psi$, $\Gamma. H' \models_Q\psi$ and $H \rhd_C H'$

$\Gamma \models_Q \neg\psi$ iff not $\Gamma \models_Q\psi$

$\Gamma \models_Q \psi_1\vee\psi_2$ iff $\Gamma \models_Q\psi_1$ or $\Gamma \models_Q\psi_2$

The preference of coalition of C means C has better choice to satisfy their goals. We will use the logic in section 4 to Branching Temporal framework.

Example 2: let Γ_1 be as in Example 1 Then

$\Gamma_1 \models_Q (a_1)(sat_1\wedge sat_2)$

$\Gamma_1 \models_Q (a_2,a_3)sat_1\wedge(a_2,a_3)sat_2)\wedge\neg((a_2,a_3)(sat_1\wedge sat_2))$

$\Gamma_1 \models_Q \neg ((a_1,a_3) sat_2)$

$\Gamma_1 \models_Q \rhd (a_1,a_3) sat_1$

B. Expressive power of L(QCGPs)

The Expresive power of *L(QCGs)* is given in [9] by analyzing some properties of it, we pay attention to the properties of the preference which means what *L(QCGPs)* can express is that coalition can prefer some set of agents concurrently, we are not interested in neither how and why the coalitions prefer some goals, nor why an agent prefer one goal to the other one. We will use QCGPs-simulation to show the properties of preference, In other words, the language can not differentiate the preference of two games Γ and $\boldsymbol{\Gamma'}$ iff QCGPs-simulate each other

A relation

$$Z \subseteq \bigcup_{c \in A} V(C) \times V'(C)$$

is a QCGPs-simulation between two QCGPs, $\Gamma = <A, G, G_1, \ldots, G_n, V, \rhd_1, \ldots, \rhd_n>$, and $\mathbf{\Gamma'} = <A, G', G_1', \ldots, G_n', V', \rhd_1', \ldots, \rhd_n'>$ iff the following conditions hold for all coalitions C.

1 if $HZ\mathbf{H}$ then if $H \cap G_i = \Phi$, iff $\mathbf{H} \cap G_i' = \Phi$ for all i (the satisfaction condition), if $H \cap G_i \neq \Phi$ and there is $H' \in X^{\Gamma}$, $H \rhd_i H'$ iff $\mathbf{H} \cap G_i' \neq \Phi$ and there is $\mathbf{H'} \in X^{\Gamma'}$, $\mathbf{H} \rhd_i \mathbf{H'}$ for all i (the preference condition),

2 for every $H \in V(C)$, there is a $\mathbf{H} \in V'(C)$ such that $HZ\mathbf{H}$ (Z is total)

3 for every $\mathbf{H} \in V'(C)$, there is a $H \in V(C)$, such that $HZ\mathbf{H}$ (Z is surjective)

If there is a QCGP-simulation between Γ and $\mathbf{\Gamma'}$, we write $\Gamma \rightleftharpoons \mathbf{\Gamma'}$

Example 3: Let $\Gamma_2 = <A, G', G_1', G_2', G_3', V', \rhd_1', \rhd_2', \rhd_3'>$ be the *QCG* with the same agents as in Γ_1

$A = (a_1, a_2, a_3)$, $G' = (f_1, f_2, f_3, f_4,)$

$G_1' = (f_1, f_3)$: $f_1 \rhd_1 f_3$

$G_2' = (f_1, f_4)$: $f_1 \rhd_2 f_4$

$G_3' = (f_2, f_3\ f_4,)$: $f_3 \rhd_3 f_4, \rhd_3 f_2$

$V(a_1) = \{(f_1)\}$:

$V(a_2, a_3) = \{(f_1), (f_2)\}$:

$V(a_1, a_3) = \{(f_1, f_3)\}$:

Then $\Gamma_1 \rightleftharpoons \Gamma_2$.*The relation* Z *consisting of the following pairs is a QCGP-simulation between* Γ_1 *and* Γ_2

$\{(g_1, g_2), (f_1)\}$: $\{(g_1, g_3), (f_1)\}$: $\{(g_1, g_4), (f_1, f_3)\}$: $\{g_6), (f_2)\}$

Note that Z not a function, nor the inverse of a function.

We can simulate any choice in one game with a choice in the other, and vice versa, if there is QCGPs-simulation for two games.

We write $\Gamma \equiv \mathbf{\Gamma'}$ iff $\forall_{\varphi \in L(QCGPs)} [\Gamma. H \models_Q \varphi \Leftrightarrow \Gamma'. \mathbf{H} \models_Q \varphi]$

Theorem 1.The preference is invariant under QCGPs-simulation: $\Gamma \rightleftharpoons \mathbf{\Gamma'} \Rightarrow \Gamma \equiv \mathbf{\Gamma'}$

Proof: let $\Gamma = <A, G, G_1, \ldots, G_n, V, \rhd_1, \ldots, \rhd n>$ and $\mathbf{\Gamma'} = <A, G', G_1', \ldots, G_n', V', \rhd_1', \ldots, \rhd_n'>$ with $\Gamma \rightleftharpoons \mathbf{\Gamma'}$, first, we show that

$$HZ\mathbf{H} \Rightarrow (\Gamma. H \models_Q \psi \Leftrightarrow \mathbf{\Gamma'}. \mathbf{H} \models_{Q'} \psi) \quad (1)$$

For any ψ by induction over ; For the satisfaction condition, $\Gamma. H \models_Q \psi$ iff $H \cap G_i \neq \Phi$, iff, $\mathbf{H} \cap G_i \neq \Phi$ iff $\mathbf{\Gamma'}. \mathbf{H} \models_Q \psi$. For the preference condition, there is $H' \in X^{\Gamma}$, $\Gamma. H \models_Q \psi$, $\Gamma. H' \models_Q \psi$, $H \rhd_i H'$ iff $\mathbf{H'} \in X^{\Gamma'}$, $\mathbf{\Gamma'}. \mathbf{H} \models_Q \psi$, $\mathbf{\Gamma'}. \mathbf{H'} \models_Q \psi$, $\mathbf{H} \rhd_i \mathbf{H'}$. The inductive step (negation and disjunction) is straightforward. We now show that

$$\Gamma. \models_Q \varphi \Leftrightarrow \mathbf{\Gamma'}. \models_Q \varphi$$

for any φ by induction on φ For the base case, let $\varphi = \rhd_C \psi$, for the direction to the right, if $\Gamma. H \models_Q \psi$ then there is a $H \in V(C)$, $H' \in X^{\Gamma}$, such that $\Gamma. H \models_Q \psi$, $\Gamma, H' \models_Q \psi$ and $H \rhd_C H'$ by totality of Z, there is a $\mathbf{H} \in V'(C)$ such that $HZ\mathbf{H}$, by (1) then $\mathbf{\Gamma'}. \mathbf{H} \models_Q \psi$ and $\mathbf{H'} \in X^{\Gamma'}$, $\mathbf{\Gamma'}. \mathbf{H'} \models_Q \psi$, $\mathbf{H} \rhd_i \mathbf{H'}$. The direction to the left is symmetric: if $\mathbf{\Gamma'}. \mathbf{H} \models_Q \psi$, there is $\mathbf{H} \in V'(C)$, $\mathbf{H'} \in X^{\Gamma'}$, $\mathbf{\Gamma'}. \mathbf{H} \models_Q \psi$, $\mathbf{\Gamma'}. \mathbf{H'} \models_Q \psi$, $\mathbf{H} \rhd_i \mathbf{H'}$ by surjective of Z, there is a $H \in V(C)$ such that $HZ\mathbf{H}$, by (1) then $\Gamma. H' \models_Q \psi$ and $H' \in X^{\Gamma'}$, $\Gamma. H \models_Q \psi$, $H \rhd_i H'$, the step (negation and disjunction) is straightforward. The proof of invariant of satisfaction is given in [9] ■

Theorem 2. Let Γ, Γ' be defined over the same set of agents: $\Gamma \rightleftharpoons \mathbf{\Gamma'} \Leftarrow \Gamma \equiv \mathbf{\Gamma'}$

Proof Let $\Gamma = <A, G, G_1, \ldots, G_n, V, \rhd_1, \ldots, \rhd_n>$ and $\mathbf{\Gamma'} = <A, G', G_1', \ldots, G_n', V', \rhd_1', \ldots, \rhd_n'>$ with $\Gamma \equiv \mathbf{\Gamma'}$, with any coalition C and any choice $H \in V(C)$, associate the set $S^C_H = \{i: H \cap G_i \neq \Phi, \exists H' \in X^{\Gamma}, H \rhd_i H'\}$ of agents satisfied if C prefers H to H'. Similarly for $\mathbf{\Gamma'}$: $T^{C'}_{\mathbf{H}} = \{i: \mathbf{H} \cap G_i' \neq \Phi, \exists \mathbf{H'} \in X^{\Gamma'}, \mathbf{H} \rhd_i \mathbf{H'}\}$. For any $\mathbf{H} \in V'(C)$. We define a QCGPs- simulation Z: $\Gamma \rightleftharpoons \mathbf{\Gamma'}$ as follows: for every coalition C and pair of choices $H \in V(C)$, $\mathbf{H} \in V'(C)$,

$$HZ\mathbf{H} \Leftrightarrow S^C_{H'} = T^{C'}_{\mathbf{H}}.$$

We must show that Z is total, i.e., that if $H \in V(C)$ then there is $\mathbf{H} \in V'(C)$, such that $S^C_{H'} = T^{C'}_{\mathbf{H'}}$. Suppose not: assume that $i \in S^C_{H'}$ and $i \notin T^{C'}_{\mathbf{H}}$, for all $\mathbf{H} \in V'(C)$ Then $\Gamma. \models_Q \rhd_C sat_i$, and $\mathbf{\Gamma'}. \models_Q \neg \rhd_C sat_i$ which contradicts the fact that $\Gamma \equiv \mathbf{\Gamma'}$ the same is to $i \notin S^C_{H'}$, $i \in T^{C'}_{\mathbf{H'}}$. Similarly, we must show that Z is surjective, the proof is the same as Z is total. Finally, we show that the satisfaction condition holds if. $HZ\mathbf{H}$, then $H \cap G_i \neq \Phi$ iff $i \in S^C_{H'}$, iff, by the definition of Z, $i \in T^{C'}_{\mathbf{H'}}$ iff $\mathbf{H} \cap G_i' \neq \Phi$ ■

C. Axiomatisation for QCGPs

We give the axiomatisation of qualitative coalitional games, and show its soundness and completeness. We use K(QCGPs) to express the axiomatisation for QCGPs for close resemblance to the modal system K, which also indicates that our logic, is in a sense, a weakest basic system for QCGPs, The system K(QCGPs) over the language *L(QCGPs)* is defined as follows, where φ, ψ are arbitrary *L(QCGPs)* formulae, α, β are arbitrary *Lc* formulae and C is an arbitrary coalition:

Prop If φ is an *L(QCGPs)*-instance of a propositional tautology, then φ is provable

K $[C](\alpha \rightarrow \beta) \rightarrow ([C]\alpha \rightarrow [C]\beta)$ is provable. $\rhd_C (\alpha \rightarrow \beta) \rightarrow (\rhd_C \alpha \rightarrow \rhd_C \beta)$ is provable

MP If $\varphi, \varphi \rightarrow \psi$ are provable, then ψ is provable

Nec If α is an (*Lc*) instance of a propositional tautology, then $[C]\alpha$, $\rhd_C \alpha$ are provable

It is easy to see that the deduction theorem holds for K(QCGPs).We will need the following properties of

K(QCGPs). The proofs are straightforward for readers familiar with modal logic

LEMMA 1. $\alpha,\beta \in Lc$:

1 $\models_{K(QCGP)} \langle C\rangle(\alpha\wedge\beta) \rightarrow \langle C\rangle(\alpha)$

2 $\models_{K(QCGP)} \langle C\rangle(\alpha\vee\beta) \rightarrow (\langle C\rangle(\alpha) \vee \langle C\rangle(\beta))$

3 $\models_{K(QCGP)} (\langle C\rangle(\alpha)\wedge[C](\alpha\rightarrow\beta)) \rightarrow \langle C\rangle(\beta)$

4 $\models_{K(QCGP)} \rhd_C(\alpha\wedge\beta) \rightarrow \rhd_C\alpha$

5 $\models_{K(QCGP)} \rhd_C(\alpha\vee\beta) \rightarrow (\rhd_C\alpha\vee \rhd_C\beta)$

Theorem 3 (SOUNDNESS & COMPLETENESS)

For any $\Omega\subseteq L(QCGPs)$, $\varphi\in L(QCGPs)$,

$$\Omega\models_Q\varphi \Leftrightarrow \Omega\models_{K(QCGPs)}\varphi$$

Proof: For soundness (the direction to the left), it is easy to see that the axioms are valid, and that the rules preserve logical consequence. For completeness, let $\psi\subseteq L(QCGPs)$ be K(QCGPs) consistent. We show that ψ is satisfied by some QCGPs. Let A be the set of agents and let n = $|A|$,. Let Δ be a $L(QCGPs)$ maximal and K(QCGPs) consistent set containing ψ. We now construct $\Gamma=\langle A, G, G_1,\ldots,G_n, V, \rhd_1,\ldots,\rhd_n\rangle$ intended to satisfy ψ. as follows:

$G = \{ sat_1, \ldots, sat_n\}$

$G_i = \{ sat_n, sat_i \}$ $sat_n \rhd_i sat_i$ for each i

$H\in V(C) \Leftrightarrow \rhd_c \mathcal{E}H\in\Delta$ for any $H\in G$ where

$\mathcal{E}H= \bigwedge_{sat_i\in H, sat_n\in H} sat_i \wedge \bigwedge_{i\in A, sat_i\notin H} \neg sat_i$, we show that

$$\text{Gamma} \models_Q \gamma\Leftrightarrow\gamma\in\Delta$$

For any γ by structural induction over γ For the base case, $\gamma=\rhd_c\alpha$, $\alpha\in L_c$, Again, we use induction on the structure of α, For the (nested) base case, let α=sat$_i$, For the direction to the right, if $\Gamma \models_Q \gamma$ then there is an $H\in V(C)$, and $\exists \boldsymbol{H}\in X^\Gamma$ and $\Gamma.\ H \models_Q \gamma$, $\Gamma.\ \boldsymbol{H} \models_Q \gamma$, $H\rhd_c\boldsymbol{H}$, then $sat_i\in H$, and by Lemma 1.4, $\gamma=\rhd_c sat_i\in\Delta$. For the direction to the left, Let $\rhd_c sat_i\in\Delta$, $S\subseteq G$, $S'\subseteq G$ let

$$X_i= \bigvee_{S\subseteq G} \mathcal{E}H(S\cup sat_i, sat_n)$$

$$\mathbf{X_i}'= \bigvee_{S'\subseteq G} \mathcal{E}\boldsymbol{H}(S'\cup sat_i).$$

$sat_i\rightarrow X_i$, $sat_i\rightarrow \mathbf{X_i}'$ is a Lc instance of a propositional tautology, by Nec $\rhd_c(sat_i\rightarrow X_i)\in\Delta$, $\rhd_c(sat_i\rightarrow \mathbf{X_i}')\in\Delta$, then $\exists S,S$ $\Gamma.(S\cup\{sat_i, sat_n\})\models_Q\gamma$, $\Gamma.(S'\cup\{sat_i\})\models_Q\gamma$, and $(S\cup\{sat_i, sat_n\})\rhd_c(S'\cup\{sat_i\})$, so $\Gamma \models_Q \rhd_c sat_i$ which concludes the proof of the direction to the left in the innermost induction proof. Both the inner and the outer induction steps (negation and disjunction) are straightforward. The proof about $\gamma=\langle C\rangle\alpha$ is be given in [9]■

Ⅳ. BRANCHING TEMPORAL QCGPS

Using temporal method is an effective ways for repeated games, to CTL, at each node of it, a (possibly different) QCGPs Γ is played. A Branching temporal qualitative coalitional games (CTQCGPs) is then a triple M =<S, R, Q> where:

S: is a set of states;

R: is a total binary relation $R\subseteq S\times S$. i.e.. $\forall s\in S$, $\exists t\in S$, $\langle s, t\rangle\in R$, and

Q: $S\rightarrow Q$, where Q is the class of all QCGPs, is a function associating a qualitative coalitional games Q(S) $=\langle A, G, G_1,\ldots,G_n, V, \rhd_1,\ldots \rhd_n\rangle$with every state $s\in S$.

A. A Logic for CTQCGPs

In this section we provide the formal syntax and semantics for representative systems of Branching Temporal QCGPs propositional by branching time temporal logics, CTL (Computational Tree Logic) allows basic temporal operators of the form: a path quantier−either A (for all futures pathe) or E (for some future path) followed by a single one of the usual linear temporal operators G (always), F (sometime), X (next time) or U (until).Formally, the language of $L(CTQCGPs)$ is defined by the grammar φ_t

$$\varphi_t ::= \langle C\rangle\varphi_t|\neg\varphi_t|\rhd_c\varphi_t\ |\varphi_t\vee\varphi_t \mid E(\varphi_t U\psi_t) \mid EX\varphi| \ EG\varphi|$$

The remaining temporal operators to express eventuality and universality can be derived in standard way, for instance: $EF\varphi_t = E(\mathbf{T}\cup\varphi_t)$, and $AG\varphi_t = \neg EF\neg\varphi_t$. CTL formulae are interpreted in *Kripke* models. When M =<S, R, Q>is a CTQCGPs，A path $\pi =\langle\pi_0, \pi_1, \pi_2, \cdots\rangle$ of M is an infinite sequence of states in s such that $(\pi_i, \pi_{i+1})\in R$ for all $i\geq0$. $s\in S$, φ is a $L(QCGPs)$ formula, the satisfaction relation. M.s $\models_T \varphi$, is defined as follows (the cases for negation and disjunction are defined as usual).

M. s $\models_T \varphi$ iff Q(s) $\models_Q \varphi$ when $\varphi\in L(QCGPs)$

M. s $\models_T E(\varphi_t U\psi_t)\varphi$ iff there exists a path π such that π_0 =s and a $k\geq0$. Such that $\pi_k \models_Q \psi$ and $\pi_i \models_Q \varphi$ for all $0\leq i< k$, $Q(\pi_i)\models_Q \varphi$, φ, $\psi\in L(QCGPs)$.

M. s $\models_T EX\varphi$ iff there exists a path π such that π_0 = s and $Q(\pi_1) \models_Q \varphi$, $\varphi\in L(QCGPs)$

M. s $\models_T EG\varphi$ iff there exists a path π such that π_0 = s and $Q(\pi_i) \models_Q \varphi$ for all $i\geq0$.

We will henceforth use $L(CTQCGPs)$ to refer to both the language, and the logic we have defined over this language.

B. Expressive Power of CTQCGPs

The notion of simulation for QCGPs (Section 2.2) can be naturally used to the branching temporal case. When M = (S, R, Q) and M'= (S', R', Q') are CTQCGPs and s $\in S$, s'$\in$S' we define.

$M.s \risingdotseq_T M'.s' \Leftrightarrow Q(s) \risingdotseq Q'(s')$,

$M.\risingdotseq_T M'$, $\Leftrightarrow$ $\forall s$, $\exists s'$ $M.s\risingdotseq_T M'.s'$, and $\forall s'$, $\exists s$, $M.s\risingdotseq_T M'.s'$

The notion of elementary equivalence for CTQCGPs over the language $L(CTQCGPs)$ can be defined as follows. M.s≡ M'.s' iff, for every $\varphi\in$L(CTQCGPs), M. s $\models_T \varphi$ iff M' s' $\models_T \varphi$ M≡M', iff for $\forall$S', $\exists$S, M.s$\equiv_T$ M'.s' and $\forall$S', $\exists$S, M.s≡M'.s'. Note that in the branching temporal case, the fact that M,s $\rightleftharpoons_T$ M',s' is not sufficient for M,s≡M',s' to hold.

C. Satisfiability

The satisfiability problem for L(CTQCGPs) is as follows: given a formula $\varphi\in$ *L(CTQCGPs)*, does there exist a *CTQCGPs* M and s∈S, such that M. s $\models_T \varphi$?

Theorem 4. The sat. probl. for L(CTQCGPs) is a PSPACE-complete problem.

The satisfiability problem of TQCGs in [9] is given by LTL+K_m(the fusion of LTL and multi-modal K),so the same method is for CTL+K_m, in [12,13]pointing that the complexity of CTL+K_m is PSPACE-complete problem. The detail context to translate *L(CTQCG)* formula to LTL+K_m is in [9], so the same method can be used for CTL+K_m

D. Satisfiability

The system K(CTQCGPs) over the language *L(CTQCGPs)* is defined as follows, where φ,ψ are arbitrary *L(CTQCGPs)* formulae, *A,B* are arbitrary *L(QCGPs)* formulae, α β are arbitrary *Lc* formulae and *C* an arbitrary coalition. For simplicity, we write T instead of K(TQCGPs) for derivability in K(CTQCGPs).

Prop If *A* is an *L(QCG)* instance of a propositional tautology, then $\vdash_T A$

K $\vdash_T[C](\alpha\rightarrow\beta)\rightarrow[C](\alpha)\rightarrow[C](\beta)$

MP if $\vdash_{K(QCGPs)}A$ and $\vdash_{K(QCGPs)} A\rightarrow B$, then $\vdash_T B$

Nec If α is an (Lc) instance of a propositional tautology, then $\vdash_T[C]\alpha$, $\vdash_T \rhd_c\alpha$

A1 $EX(\varphi\vee\psi)\leftrightarrow(EX\varphi\vee EX\psi)$

A2 $AX\varphi\leftrightarrow\neg EX\neg\varphi$

A3 $AG(\varphi\rightarrow(\neg\psi\wedge EX\varphi))\rightarrow(\varphi\rightarrow AF\psi)$

A4 $AG(\varphi\rightarrow(\neg\psi\wedge AX\varphi))\rightarrow(\varphi\rightarrow EF\psi)$

A5 $AG(\varphi\rightarrow\psi)\rightarrow(EX\varphi\rightarrow EX\psi)$

U1 $E(\varphi U\psi)\leftrightarrow(\psi\vee(\varphi\wedge EX(\varphi U\psi)))$

U2 $A(\varphi U\psi)\leftrightarrow(\psi\vee(\varphi\wedge AX(\varphi U\psi)))$

Prop if φ is an (*L(CTQCGPs)*) instance of a propositional tautology, then $\vdash_T\varphi$

Nec If $\vdash\varphi$ then $\vdash AG\varphi$

MP If $\vdash\varphi$ and If $\vdash\varphi\rightarrow\psi$ then $\vdash\psi$

Axioms Prop and K and rules MP and Nec say that every K(CTQCGPs)-theorem is also a K(CTQCGPs)-theorem. The subsystem consisting of axioms A1–U2 and rules Prop–Nec is a version (with *L(QCGPs)* formulae in place of atomic propositions) of an axiomatisation of branching time logic proved to be sound and complete in [10].

Theorem 5 (SOUNDNESS & COMPLETENESS). For any $\varphi\in$*L(TQCGPs)* $\vdash_T\varphi\Leftrightarrow\models_T\varphi$

Proof: The logic K(CTQCGPs) is a temporalisation of K(QCGPs): the language of K(CTQCGPs) has atomic K(QCGPs) formulae in place of atomic propositions; the semantic structures of K(CTQCGPs) identifies a semantic structure for K(QCGPs) by using *Kripke* model for interpreting K(QCGPs) formulae; and the rules of K(CTQCGPs) are the rules of the temporal logic for temporal formulae in addition to axioms/rules of K(QCGPs) formulae. Finger [11] show that the temporalisation of a sound and complete system is sound and complete. The theorem thus follows immediately from Theorem 3. ■

E. An Example

We add Branching Temporal dimension with preference to the example given in [9]. There are there agents and server providing web service, all agents needs to access the server from time to time, There are three basic action for agents, read access, write access and wait, For the integrity, web service is violated if two agents write access are granted (inconsistent writes) or read and write access are granted (inconsistent reads), or no action for any agents (inefficiency) at the same time

Let M =<S, R, Q> be a CTQCGPs where S is some infinite set of states, and R is total binary relation over S×S and Q are holds for Q(s: s∈S)=$<A, G, G_1, G_2, G_3, G_{ser}, V, \rhd_1, \rhd_2\ \rhd_3\ \rhd_{ser}>$

A={1,2,3,ser}, We model the agents as players 1, 2 and 3, and the server as player ser

G=$\{s_1,s_2,s_3,s_4,s_5,s_6,s_7\}$*, That each of these goals are achieved means that right now.*

s_1*: every agent is granted read access*

s_2*: agent 1 is granted write access*

s_3*: agent 2 is granted write access*

s_4*: agent 3 is granted write access*

s_5*: Server prefer write access agent 1 to agent 2*

s_6*: Server prefer write access agent 1 to agent 3*

s_7*: Server prefer write access agent 2 to agent 3*

for the preference of every agent, for example, players 1 more like *(s1, s2)* than *(s1)*, Notice that when players 1 get the goal (s1, s2) that means he can read or write, not that read and write at the same time.

$G_1=\{(s_1), (s_1, s_2)\}\quad (s_1, s_2)\rhd_1(s_1)$

$G_2=\{(s_1), (s_1, s_3)\}\quad (s_1, s_3)\rhd_2(s_1)$

$G_3=\{(s_1), (s_1, s_4)\}\quad (s_1, s_4)\rhd_3(s_1)$

$G_{ser}=\{(s_1), (s_5), (s_6), (s_7)\}$

It is assumed that for *ser,* its preference will be changed with time: Given the symbol t (minute) for time with the state changes, *ser* has different preference.

If t mod 2 = 0 $(s_5)\rhd_{ser}(s_6)\ \rhd_{ser}(s_1)$

If t mod 3 = 0 $(s_6)\rhd_{ser}(s_7)\ \rhd_{ser}(s_1)$

If t mod 5 = 0 $(s_7)\rhd_{ser}(s_5)\ \rhd_{ser}(s_1)$

otherwise $(s_1)\ \rhd_{ser}(s_5)\rhd_{ser}(s_7)\rhd_{ser}(s_6)$

$V(1, ser)=\{(s_1), (s_1, s_2)\}$,

$V(2, ser)=\{(s_1), (s_1, s_3)\}$

$V(3, ser)=\{(s_1), (s_1, s_4)\}$

$V(1,2,ser)=\{(s_1), (s_1, s_2, s_5)\}$,

$V(2,3,ser)=\{(s_1), (s_1, s_3, s_6)\}$,

$V(1,3,ser)=\{(s_1), (s_1, s_4, s_7)\}$,

$V(1,2,3,ser)=\{(s_1,s_2,s_3,s_4,s_5,s_6,s_7)\}$,

The following properties hold in the system

1 EF<*ser*>($sat_1\wedge sat_2\ \wedge sat_3$) all agents will be satisfied in sometime at some future path just like t=30

2 AG <*ser*>($sat_1 \vee sat_2 \vee sat_3$) for all future path, there is at least a agent will be satisfied

3 E [<*ser*>($sat_1 \vee sat_3$) U <*ser*>(sat_2)] agent 1 or 3 will be satisfied in some future path until agent 2 is satisfied.

V. CHARACTERIZING CTQCGPS S

In this section, we investigate the axiomatic characterizations of various classes of CTQCGPs., We pay attention to the preference characteristic with time. As usual, when saying that a formula scheme' characterizes a property *P* of models, we mean that φ is valid in a model M iff M has property *P*; if only the right-to-left part of this biconditional holds, then we say property *P* implies φ.

A. Basic Correspondences

Let $h^s(C)$ denote the set of all agents that could possibly be satisfied (not necessarily jointly) by coalition *C* in state s:

$$h^s(C) = \{ i: i \in A \ \& \ \exists H \in V^s(C), G^s_i \cap H \neq \Phi \}$$

The "h" here is for "happpiness": We regard $h^s(C)$ as all the agents that *C* could possibly make happy in s. Thus the semantic property $i \in h^s(C)$ is a counterpart to the syntactic expression <*C*>sat_i [9], we use $hp^s(C)$ to denotes the $h^s(C)$ with preference.

$hp^s(C) = \{i: i \in A \ \& \ \exists H \in X^s(C), \forall \boldsymbol{H} \in X^s(C)/G$, there is no such that case $(\boldsymbol{H} \cap G_i) \rhd_i (H \cap G_i)\}$ which means *C* have realized a preference set of goals in s.

$\forall s \in S$, for all path from s,

$s \to s', (i \in hp^s(C)) \to (i \in hp^{s'}(C))$ (AXHP)

if means *C* have realized a preference set of goals.in all the state immediately following s.

$\forall s \in S$, for a path from s,

$s \to s', (i \in hp^s(C)) \to (i \in hp^{s'}(C))$ (EXHP)

if means *C* have realized a preference set of goals in a state immediately following s.

Lemma 2. $\rhd_C sat_i \to AX \rhd_C sat_i$ characterizes AXHP, $\rhd_C sat_i \to EX \rhd_C sat_i$ characterizes EXHP

We also characterise the unperference property

$\forall s \in S$, for all state immediately following s,

$s \to s', (i \notin hp^s(C)) \to (i \notin hp^{s'}(C))$ (AXUP)

$\forall s \in S$, for a state immediately following s,

$s \to s', (i \notin hp^s(C)) \to (i \notin hp^{s'}(C))$ (EXUP)

Lemma 3. $\neg \rhd_C sat_i \to AX \neg \rhd_C sat_i$ characterizes AXUP , $\neg \rhd_C sat_i \to EX \neg \rhd_C sat_i$ characterizes EXUP,

To the time of future, eventually, *C* will be able to make *i* happy with preferences.

for all path $\exists s \in S, (i \in hp^s(C))$ (AFEH)

for a path $\exists s \in S$ in the path $(i \in ph^s(C))$ (EFEH)

for all path $\exists s \in S, (i \notin hp^s(C))$ (AFEU)

for a path $\exists s \in S$ in the path $(i \notin hp^s(C))$ (EFEU)

Lemma 4 $AF \rhd_C sat_i$ characterizes AFEH, $EF \rhd_C$ sati characterizes EFEH

$AF \neg \rhd_C sat_i$ characterizes AFEU $AF \neg \rhd_C sat_i$ characterizes EFEU

Finally, we consider safety properties. Which means *C* always have realized a preference goals set and *C* never can have realized a preference goals set

for all path $\forall s \in S, (i \in hp^s(C))$ (AGPH)

for a path $\forall s \in S$, in the path $(i \in hp^s(C))$ (EGPH)

for all path $\forall s \in S, (i \notin hp^s(C))$ (AGPU)

for a path $\forall s \in S$ in the path , $(i \notin hp^s(C))$ (EGPU)

Lemma 5 $AG \rhd_C sat_i$ characterizes AGPH, $EG \rhd_C sat_i$ characterizes EGPH

$AG \neg \rhd_C sat_i$ characterizes AGPU, $EG \neg \rhd_C sat_i$ characterizes EGPU

B. Basic Properties of preference Choice Sets

We consider whether a coalition has a preference set of goals in a state and whether it has a best choice.

Definition 4 for $C \subseteq A$, the maximal strongly preferred goal sets with respect to *C*, denoted $\mu^{\sqsupset}$ are defined through

$\mu^{\sqsupset}(C) = \{H \in X(C), \forall \boldsymbol{H} \in X(C)$, it is not the case that $H \sqsupset_c \boldsymbol{H}\}$ the maximal weakly preferred goal sets with respect to C, denoted

$\mu^{\succ}(C) = \{H \in X(C): \forall \boldsymbol{H} \in X(C)$, it is not the case that $\boldsymbol{H} \succ_c H\}$ In the event of $\mu^{\sqsupset}(C) = \mu^{\succ}(C)$ we write simply $\mu(C)$. To avoid excessive repetition, we use the relational symbol $\rhd$ to indicate either $\sqsupset$ or $\succ$

$\forall s \in S \ \mu_s^{\rhd}(C) = \Phi$, *C* never has preference choice.

$\forall s \in S \ \exists H \in \mu_s^{\rhd}(C) \neq \Phi, H \neq \Phi$, *C* has preference choice

$\forall s \in S \ \exists H \in X^s(C), \forall \boldsymbol{H} \in X^s(C)/H, H \rhd_C \boldsymbol{H}$, *C* has a best preference choice

C. Static preference Goal Sets and Choices

The goal sets with preference for each agent and the choice sets for each coalition are guaranteed to remain unchanged.for all path(existential quantifier is easy for reader to built)

$\forall s,s' \in S \ (H_i^s = H_i^s \ \& \ \rhd_i^s = \rhd_i^{s'})$ (ASGS)

the goal set with preference is static for agent *i*.

$\forall s,s' \in S \ (V(C)^s = V(C)^{s'} \ \& \ \rhd_i^s = \rhd_i^{s'})$ (ASC)

coalition *C*'s preference choices remain static

$\forall s,s' \in S , \mu(C)^s = \mu(C)^{s'})$ coalition C's maximal strongly preferred goal sets remain static

Lemma 6. Any model satisfying both ASGS and ASC also satisfies AXHP and AXUP, and as a consequence, ASGS and ASC together imply $\rhd_C sat_i \leftrightarrow AXPH \rhd_C sat_i$,

D. Dynamic preference Goal Sets of individual agent

Considering agent *i*'s goals set with preference is guaranteed to monotonically decrease over time. Roughly, this condition means that every agent is guaranteed to get no easier become to satisfy his preference over time. Formally a agent *i*'s preference goal sets in state s is better than all the immediately following s (existential quantifier is easy for reader to built)

$\forall s \in S$, for all path from s, $s \to s', \exists H \in \mu_s^{\rhd}(C)$,

$\forall \boldsymbol{H} \in \mu_{s'}^{\rhd}(C), \forall g_2 \in (\boldsymbol{H} \cap G_i), \exists g_1 \in (H \cap G_i), g_1 \rhd g_2$

The monotonically increasing over time is:

$\forall s \in S$, for all path from s, $s \to s', \forall H \in \mu_s^{\rhd}(C)$,

$\exists \boldsymbol{H} \in \mu_{s'}{}^{\rhd}(C)$, $\exists g_2 \in (\boldsymbol{H} \cap G_i)$, $\forall g_1 \in (H \cap G_i)$, $g_2 \rhd g_1$

E. Dynamic preference Choices

We also investigate the coalition's choice in time, which say that the sets of choices available to coalition C monotonically increase or decrease respectively. (existential quantifier is easy for reader to built)

$\forall s \in S$, for all path from s, s→s', $\mu_s{}^{\rhd}(C) \subseteq \mu_{s'}{}^{\rhd}(C)$ the coalition C' preferred goal sets are monotonically increase

$\forall s \in S$, for all path from s, s→s', $\mu_s{}^{\rhd}(C) \supseteq \mu_{s'}{}^{\rhd}(C)$ the coalition C' preferred goal sets are monotonically decrease

F. Solution Concept

Definition 5 Let $\Gamma = \langle A, G, G_1, \ldots, G_n, V, \rhd_1, \ldots, \rhd_n \rangle$ For a coalition $C \subseteq A$ the core of C denoted $K^{\rhd}(C)$, is the set $\{ H \in \mu^{\rhd}(C)$:, $\forall C' \subset C$, $\forall \boldsymbol{H} \in \mu^{\rhd}(C')$, it is not the case that $\boldsymbol{H} \rhd_C H \}$,then the coalition C is core sets.

To an agent, perhaps the key problem is whether at every time point there is some stable coalition, containing this agent.

stable(i)= AG $\bigvee_{C \in A, i \in C} K^{\rhd}(C)$, if there is a coalition satisfying the stable of agent i. which means, to agent i, there is a stable solution for it. More characteristics of QCGPs can be seen in [5]

VI. CONCLUSION

QCGs were introduced in [4] as a model for coalition games with non-numeric values payoff, it score how a coalition can be formed, to a agent. Although it has many goals as its desire, it can't be get all the goals in games, so preference goals is effective ways for an agent's strategy.

Formal coalition cooperating games is a hot point in social software and multi-agents systems, in this paper we introduce the problem from QCGPs and CTL, we investigate the basic concept and model of QCG with preference and give a logic language for it by using simplest modal logic K, and we talk about the expression power and axiomatisation of the logic. The CTL is used for the repeated games and some characteristic of CTQCGPs, such as realizing preference goals sets, best strategy of coalition, the stabilization of coalition and so on, are given

The further researches are multiple. First are the properties of CTQGCPs some principium investigations were made in [5], but considering the repeated games, more work should be taken. Second, temporalising QCGPs also has many ways, just like ATL and CTL*, The LTL and CTL are only reflects a simple case. The more complex temporal structure should be used for deeper percipience to coalition games. In addition, the dynamic goals and preferences are also important problems, in practice application, the goals and preferences of an agent are not static, for example, with the resource loss, a agent will decrease its goals and preferences or after by getting some goals, an agent will increase its goals for being unsatisfied in existing goals. So those factors will influence the structure and strategy of the coalition in games.

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