Coalition Strategy Logic

[redacted]

09 Oct 2024 (modified: 19 Dec 2024) Submitted to AAMAS 2025 Conference, Authors Revisions BibTeX

Submission Track: Representation, Perception, and Reasoning (RPR)
Keywords: Strategy Logic, Coalition Logic, Expressiveness, Model Checking, Completeness

Abstract:
We introduce Coalition Strategy Logic (CSL), which combines the intuitions behind Coalition Logic (CL) and Strategy Logic (SL). Specifically, CSL allows for arbitrary quantification over actions of groups of agents. The motivation behind CSL is two-fold. First, we show that CSL is strictly more expressive than other known coalition logics, and then we discuss its model-checking procedure. Second, we provide a sound and complete axiomatisation of the logic, which is, to the best of our knowledge, the first axiomatisation of any strategy logic in the literature.

Submission Number: 710

Paper Decision

Decision by Program Chairs 17 Dec 2024 at 17:06 (modified: 19 Dec 2024 at 19:58) Program Chairs, Senior Area Chairs, Area Chairs, Authors Revisions

Decision: Reject

Meta Review of Submission710 by Area Chair A9Bk

Meta Review by Area Chair A9Bk 11 Dec 2024 at 10:04 (modified: 19 Dec 2024 at 20:01) Senior Area Chairs, Area Chairs, Authors, Reviewers Submitted, Program Chairs Revisions

Metareview:
The paper introduces Coalition Strategy Logic (CSL), a logic designed for deterministic, serial, perfect information multi-agent systems. CSL incorporates an action diamond-type modality and quantification over actions, making it strictly more expressive than other single-step logics for multi-agent systems that lack explicit quantification. The authors present a PSPACE-complete model checking algorithm based on an alternating Turing machine. They also develop a complete axiomatization for CSL and establish its completeness through standard canonical model constructions.

The reviewer all agreed that the submission is not yet ready to be published for the following reasons:

- Missing comparison with existing literature (In particular, Hennessy-Milner paradigm and STIT)
- Low significance
- Low readability

Official Review of Submission710 by Reviewer NH82

Official Review by Reviewer NH82 23 Nov 2024 at 19:08 (modified: 19 Dec 2024 at 20:00) Program Chairs, Senior Area Chairs, Area Chairs, Reviewers Submitted, Reviewer NH82, Authors Revisions

Summary: They present Coalition Strategy Logic (CSL), a logic for deterministic, serial, perfect information multi-agent systems. The modalities are an action diamond-type modality, and quantification over actions. They show that this logic is strictly more expressive than several other single-step logics for multi-agent systems, without explicit quantification. They provide a model checking algorithm based on an alternating Turing machine, and show that model checking is PSPACE-complete. They provide a complete axiomatization for CSL and prove completeness using standard canonical model constructions.
Technical Quality: 3: Solid
Significance: 2: Unclear significance
Presentation Quality: 4: Good; clear presentation
Review:
In this paper, the authors present Coalition Strategy Logic (CSL), a logic for deterministic, serial, perfect information multi-agent systems. The modalities are an action diamond-type modality, and quantification over actions. They show that this logic is strictly more expressive than several other single-step logics for multi-agent systems, without explicit quantification. They provide a model checking algorithm based on an alternating Turing machine, and show that model checking is PSPACE-complete. They provide a complete axiomatization for CSL and prove completeness using standard canonical model constructions.

The logic presented in this paper is quite close to a quantified version of Hennessy-Milner logic for deterministic, serial systems. Using multi-agent systems as the models and the inclusion of quantifiers allows some interesting applications for the logic to game-type settings. The axiomatization is not surprising, given that in effect the logic only includes a single step, action-labelled operator and no other LTL-style operators. The authors consider an individual's choice of a single action to be a strategy, which to me seems to weaken the notion of strategy significantly. In particular, it is difficult to see how this notion of a strategy could be extended to the more realistic setting of partial information multi-agent systems. Nonetheless, it is valuable to see an axiomatization of a limited version of strategy logic. Overall the paper is clearly written and the proofs are presented well.

One of my concerns with this paper is that they seem to be unaware of the classic Hennessy-Milner logic, where the notion of bisimulation originated from, yet their work is quite close to an extension of HM logic with action quantifiers, applied to multi-agent systems.

I am not convinced that a single-step logic has many practical applications for model checking. Without modalities like G at least, my guess is that the logic is not practically useful. Adding relevant examples would strengthen the paper.

Extending the logic to imperfect-information systems would also be of interest.

Particular points: p. 1: is there another definition of countable? p. 3, footnote: these systems are not bisimilar according to Milner's original definition of bisimulation. They are bisimilar only wrt a particular notion of bisimulation defined for a particular logic, presumably without actions, but the original (and I would argue most general) definition of bisimulation includes action labels. It is important to be precise about what definition of bisimulation you are using, especially since the one you reference in the footnote would not be the appropriate notion of bisimulation for the logic you define here. p8: My guess is that it will be difficult to find an axiomatization for the logic if it is extended with more LTL operators.

Overall Rating: 5: Low borderline
Confidence: 4: The reviewer is confident but not absolutely certain that the evaluation is correct

Rebuttal by Authors

Rebuttal by Authors ([redacted] 29 Nov 2024 at 13:07
Program Chairs, Senior Area Chairs, Area Chairs, Reviewers, Authors

Rebuttal:
We thank the reviewer for their suggestions.

It is indeed an extension of multi-modal K logic (Hennessy-Milner logic) in which the frames are serial and functional with first-order quantifiers over components of the arrow labels (actions). This increases the expressivity of the logic dramatically compared to the standard multi-modal K. We will add a note specifying this fact.

Q1 Is there another definition of countable?

A1 No, but it has happened to us before that “countable” was understood by a reader as “infinitely countable” and we preferred to clarify this point.

Q2 On bisimulation.

A2 We mean here 'alternating bisimulation', defined in [3] of the submission. We will clarify this fact in the final version of the paper.

Q3 Extending CSL with LTL operators

A3 We conjecture that if the LTL connectives are always preceded by the strategic assignment operator (as in e.g. ATL), the axiomatization (and the completeness proof) would be non-trivial, but still feasible (Following, perhaps, the ideas from the ATL completeness proof).

Q4 Extending the setting to imperfect information

A4 We agree with that this will be interesting, but, as it always with various logics for strategic reasoning, having imperfect information makes the resulting logics considerably more complex (regarding axiomatisations, model checking, and satisfiability).

Q5 On the Next-time

A5 We choose this fragment as it allows us to isolate one of the features of strategy logic, namely arbitrary quantifier alternation, and thus prove the completeness of CSL, which is the first completeness proof of *any* strategy logic. In the future, we aim to extend the language of CSL with other temporal modalities, and try to establish the completeness of the resulting logic. However, even as a coalition logic, as we show in the paper, CSL is quite interesting in the sense that it is strictly more expressive than other coalition logics in the literature.

Official Review of Submission710 by Reviewer GdYF

Official Review by Reviewer GdYF 21 Nov 2024 at 16:52 (modified: 19 Dec 2024 at 20:00) Program Chairs, Senior Area Chairs, Area Chairs, Reviewers Submitted, Reviewer GdYF, Authors Revisions

Summary: The paper presents coalition strategy logic (CSL), a fragment of strategy logic (SL) that supports reasoning about arbitrary quantifications over the actions of agents. The main results of the paper are i) a PSPACE-completeness result for model checking and ii) a sound and complete axiomatization for the proposed logic.
Technical Quality: 3: Solid
Significance: 3: Significant for an important subfield
Presentation Quality: 3: Acceptable
Review:
Reasoning with strategy logic (SL) is notoriously difficult. The full SL language has a non-elementarily decidable model-checking problem and a highly undecidable satisfiability problem. Moreover, the proof-theoretic aspects of SL are far less studied and understood. So, the motivation of the paper (finding an axiomatizable and decidable fragment of SL) is perfectly well-justified and the topic of the paper very relevant for AAMAS. On the downside, I think the paper has some drawbacks at the conceptual level and presentation level.

I do not see in which sense CSL should be called a “strategy logic”. An essential feature of SL is the possibility of reasoning about agents’ strategies and their effects. This feature is removed altogether from CSL. In CSL, one can only reason about agents’ actions and their effects in the next state. From this point of view, it is conceptually misleading to use the term "strategy" to talk about the logic presented in the paper.

There is a mismatch between the definition of the language on page 1 (right column, Section 2) and the definition of the satisfaction relation on page 2 (Definition 2.6, left column, Section 2). In the definition of the language the authors introduce the construct ((t_1...t_k))phi as a primitive, where t_1,...,t_k are arbitrary terms and a term is either a constant in the set of constants C or a variable in the set of variables V. But the satisfaction relation (Definition 2.6) is only defined for sentences (formulas with no free variables). Only the case ((a_1...a_n))phi is treated, where a_1,...,a_k are arbitrary actions which are assimilated to constants (in Definition 2.5 it is assumed that the set of actions Ac and the set of constants C coincide). The case for the construct ((t_1...t_k))phi in which some terms in {t_1,...,t_k} are variables is not treated. So, something is missing either at the language level or at the model-theoretic level. Specifically, either the authors should explicitly define the grammar of the "no free variable" fragment of the language defined on page 1 they consider, or they should extend the definition of the satisfaction relation for formulas to cover formulas with free variables. In the latter case an assignment function mapping variables to actions should be added to the semantic interpretation of formulas (i.e., formulas should be evaluated wrt to a CGS, a state and an assignment function as usually done in SL).

It seems to me that there is a close connection between the logic CSL and STIT logic (the logic of “seeing to it that”). Surprisingly, STIT logic is not even mentioned in the paper despite the fact that several logicians from the AAMAS community are currently working or have worked on it in the past. Like CSL, the action-based version of STIT logic (in opposition to strategic STIT) supports reasoning about agents' actions and their effects. It enables existential and universal quantification over agents' choices, by keeping fixed the choices of the other agents. For example, the CSL formula given in Example 2.10 about Stackelberg equilibrium (i.e., \forall x_d \exists x_a \forall x_e ((x_d,x_a,x_e))win_a) can be naturally translated into the variant of STIT with groups, as follows:

[Agt\setminus {d}]<Agt\setminus {a}>[Agt\setminus {e}] X win_a

where Agt={1,...,n} is the set of agents, X is the “next” temporal modality of LTL, the "Box" modalities [Agt\setminus {d}] and [Agt\setminus {e}] are the so-called “Chellas” group STIT modalities, and the “Diamond” modality <Agt\setminus {a}> is the dual of the “Box” modality [Agt\setminus {a}]. Notice that the “Chellas” STIT modalities are S5 modalities. I think the authors should clarify the relationship between their logic and STIT theory, and not put it "under the carpet" and completely ignore it.

Overall Rating: 5: Low borderline
Confidence: 4: The reviewer is confident but not absolutely certain that the evaluation is correct

Rebuttal by Authors

Rebuttal by Authors ([redacted] 29 Nov 2024 at 14:28
Program Chairs, Senior Area Chairs, Area Chairs, Reviewers, Authors

Rebuttal:
Thank you for your review!

Q1 CSL as a strategy logic

We argue that CSL qualifies as a (variant of) strategy logic. The defining feature of SL is the quantification over strategies, and strategies for the Next-time operator are still strategies. Furthermore, CSL retains key characteristics of SL, like strategy sharing. Additionally, term 'strategy' is also used in central works on CL (like Pauly 2002), as well as in subsequent works (e.g., Goranko, Jamroga, Turrini 2013; Turrini, Ågotnes 2023 SEP). This follows the terminology in game theory (e.g., Osborne & Rubinstein), where 'strategy' is often understood in the same way as in our paper. Thus, we believe that our use 'strategy' is both accurate and consistent with established usage in the field.

Having a richer temporal language with quantification is interesting. In this case we will end up, essentially, with second-order quantification, and hence we suspect that the resulting logic will not be recursively axiomatisable. We leave this problem for future work. In this submission we focus on the arbitrary quantifier alternation feature of SL, which leads to the first axiomatisation of *any* strategy logic.

Q2 There is a mismatch...

We define truth solely for closed formulas. The truth of open formulas is reduced to the truth of the closed ones via closure (Definitions 2.7 and 2.8). Thus, the semantics of the whole logic is properly defined. This approach is fairly standard in first-order logic (e.g., Van Dalen's "Logic and Strucure"). We could define the truth of a formula wrt an assignment, but this would not affect our results. Our choice simplifies the formal machinery of the paper and makes it more readable. We will clarify this in the final version.

Q3 STIT

Thank you for pointing out the STIT logics! We believe that your formula for Stackelberg equilibrium could work. The main difference from CSL though is that explicit quantification over strategies (or actions) allows for more nuanced expressions, where, e.g., different agents use *the same* strategy. Also, our modalitity is not S5, but rather a KD! (! for functionality) modalitiy.

We are also aware of the translation of CL into discrete deterministic STIT (Broersen, Herzig, Troquard 2006) and into Chellas-STIT with next-time (Broersen, Herzig, Troquard 2007). Additionally, SAT for latter logic is undecidable (Herzig, Schwarzentruber 2008). We will add (an extended version of) this discussion in the paper with the appropriate references.

Discussion

Official Comment by Reviewer GdYF 03 Dec 2024 at 16:35 (modified: 03 Dec 2024 at 21:26) Program Chairs, Senior Area Chairs, Area Chairs, Reviewers, Authors Revisions

Comment:
Thanks for clarifying Q2. As for Q1 and Q2 I'm still not convinced. Let me explain why.

Q1. The essential aspect of a strategy in the SL and ATL sense is the fact of anticipating what an agent will do at every state in a CGS (memoryless strategy) or at end of every trace in the CGS (perfect recall strategy). This aspect is absent in CSL.

Q3 I find authors' reply not to the point. I strongly suspect that the group STIT logic of Horty's (Horty, 2001), namely, the STIT logic including the group (Chellas stit) agency modalities of the form [C] with C a coalition of agents can be polynomially embedded in the CSL logic presented in the paper. As the authors correctly argue, given the explicit quantification over actions, CSL allows for more nuanced expressions than STIT. If my conjecture is true, then the logic CSL is undecidable since, as shown in (Herzig & Schwarzentruber, 2008), the group STIT logic is undecidable. Some decidable fragments of group STIT logic are studied in (Lorini & Schwarzentruber, 2011). There are non trivial issues like the previous ones about the connection between CSL and group stit logic and about the decidability of CSL (in relation to the known undecidability of full group STIT logic and the decidability of some of its fragments) that are simply ignored in the paper. In my opinion, the logic CSL should be better related to group STIT logic to better assess its significance.

References:

- A. Herzig and F. Schwarzentruber. Properties of logics of individual and group agency. In Proc. of Advances in Modal Logic 2008, pages 133–149. College Publ., 2008.
- E. Lorini and F. Schwarzentruber. A logic for reasoning about counterfactual emotions. Artificial Intelligence, 175, 3-4, 2011.
- J. Horty. Agency and Deontic Logic. OUP, 2001.

Replying to Discussion

Official Comment by Authors

Official Comment by Authors ([redacted] 04 Dec 2024 at 13:12
Program Chairs, Senior Area Chairs, Area Chairs, Reviewers, Authors

Comment:
Q1. We believe that an essential aspect of Strategy Logic is the quantification over strategies treated as first order objects. This is exactly what we do in our paper and in a similar way as it has been done in the original Strategy Logic paper. Strategies in Strategy Logic work as placeholders (which is a key feature of Strategy Logic), in other words, one can define Strategy Logic by using different strategy definitions, including the "one-step" one we consider in our paper, which we agree is different from the one used in ATL and the original work introducing SL. Clearly, the strategy definition affects the expressiveness of the logic, which we are aware of and not hiding in our paper. Notice however that we fully capture essential properties of SL, like the ability to refer to particular strategies through variables and arbitrary quantification prefixes. In this sense, CSL to CL is what SL to ATL*. As we mentioned before, we suspect that quantifying over ATL-like strategies will lead to a logic lacking recursive axiomatisation. In this work, we provide an axiomatisation of a variant of SL. This, in conjunction with the fact that the whole SL is highly undecidable (Σ_1^1-hard), and thus not recursively axiomatisable, establishes the two borderline cases when it comes to axiomatisability. We leave it for future work to explore the existence of recursive axiomatisations of logics 'in between' CSL and SL.

Q2. Thank you for the interesting discussion on the relationship of CSL and STIT. We will add some highlights of it in the final version with the recommended references. In the future, we are excited to investigate embeddings of various STIT logics into CSL. In this paper, our goal was to provide a complete axiomatisation of a (variant of) strategy logic. Observe that providing a complete axiomatisation of *any* SL has been an open problem since the inception of the logic.

Official Review of Submission710 by Reviewer PStS

Official Review by Reviewer PStS 16 Nov 2024 at 17:45 (modified: 19 Dec 2024 at 20:00) Program Chairs, Senior Area Chairs, Area Chairs, Reviewers Submitted, Reviewer PStS, Authors Revisions

Summary: The paper proposes Coalition Strategy Logic, a modal logic that extends CL with arbitrary, explicit action quantification. The paper introduces the syntax and semantics of CSL, and proves that it is strictly more expressive than other known coalition logics. The complexity of model checking is proven to be PSPACE-complete, where the lower bound is given by a reduction from QBF. Finally, an axiomatization of CSL is given, and is proven to be sound and complete.
Technical Quality: 3: Solid
Significance: 3: Significant for an important subfield
Presentation Quality: 4: Good; clear presentation
Review:
The paper proposes a novel combination of the ideas behind CL (Coalition Logic) and SL (Strategy Logic) to strike a balance between expressivity and axiomatizability. The paper obtains technical results on expressivity, complexity of model checking, and axiomatization. Especially, as the authors suggest, the axiomatization of CSL could serve as a foundation for axiomatizing more complex fragments of SL. Thus, the proposed logic has potential significance. The paper is well-written, and related works are well-cited. A limitation of the paper is that the complexity of satisfiability is not addressed.

After Author Response: I have read the other reviews, and I have lowered my scores.

Overall Rating: 5: Low borderline
Confidence: 3: The reviewer is fairly confident that the evaluation is correct

Rebuttal by Authors

Rebuttal by Authors ([redacted] 29 Nov 2024 at 13:01
Program Chairs, Senior Area Chairs, Area Chairs, Reviewers, Authors

Rebuttal:
Thank you for your review! Indeed, we leave the satisfiability problem for future work due to strict page limit of AAMAS.