# A Bitvector Encoding for Satisfiability Checking of Temporal Logic

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## Background

Cyber-physical systems interact with the real-world and are thus often safety critical. Consider, for example, an autonomous vehicle that needs to comply with traffic rules in order to safely participate in traffic. Temporal logics have emerged as a powerful language to formally specify these requirements. Building upon propositional logic, temporal logics can not only describe the current state of the world, but also express properties about its future development. For example, we can require that an autonomous vehicle *always* keeps a safe distance to preceding vehicles. In particular, mission-time temporal logic (MLTL) is well suited for specifying the requirements of cyber-physical systems, as it allows for precise timing constraints [2].

When formally specifying the requirements of a system in MLTL, it is crucial that the specification is *consistent*, i.e., that there exists at least one possibility to satisfy it. An unsatisfiable specification indicates a problem with the requirements and calls for "debugging." Since the specifications for real-world cyber-physical can quickly become very large and complex, tool support for satisfiability checking is required. In [2], the authors compare several approaches for MLTL satisfiability checking and conclude that a method based on satisfiability modulo theories (SMT) [1] is most efficient.

## Description

Recent work has proposed a bitvector encoding of the semantics of linear temporal logic (LTL) [4]. This encoding leverages bitwise operations to determine the satisfaction of an LTL formula at multiple time steps at once. Thus, it enables efficient and highly parallelized monitoring of LTL formulas on a GPU. Since the semantics of MLTL is very similar to that of LTL, we want to adapt this method to MLTL semantics. With this, we can encode the MLTL satisfiability problem as an SMT problem over the theory of bitvectors. Consequently, we can construct a quantifier-free encoding of MLTL without the drawback of significantly increasing the encoding size as mentioned in [2]. Moreover, our novel encoding will allow us to leverage highly optimized SMT solvers specialized to the theory of bitvectors like Bitwuzla[1] [3].

## Tasks

- Familiarize with temporal logic and SMT solvers
- Review literature on satisfiability checking for MLTL
- Adapt the bitvector encoding of [4] to the semantics of MLTL
- Implement the developed encoding to solve the satisfiability problem for MLTL
- Evaluate the developed approach on several benchmark problems collected from the literature and compare its performance to existing methods
- Optional: Compare the performance of different SMT solvers as backend

## References

[1] A. Biere, M. Heule, H. van Maaren, and T. Walsh. *Handbook of Satisfiability*, volume 185 of *Frontiers in Artificial Intelligence and Applications*. IOS Press, Amsterdam, 2009.

[2] J. Li, M. Y. Vardi, and K. Y. Rozier. Satisfiability checking for mission-time LTL (MLTL). *Information and Computation*, 289:104923, 2022.

[3] A. Niemetz and M. Preiner. Bitwuzla. In *Computer Aided Verification*, pages 3–17, 2023.

[4] M. Valizadeh, N. Fijalkow, and M. Berger. LTL learning on GPUs. In *Computer Aided Verification*, pages 209–231, 2024.

[1] `https://bitwuzla.github.io/`

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**Research project:**
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**Type:**
BT/GR

**Research area:**
Formal Methods

**Programming language:**
Python
SMT-LIB v2

**Required skills:**
Interest in Formal Methods
Software Development

**Beneficial skills:**
Experience with SMT Solvers
Experience with Temporal Logic

**Language:**
English, (German)

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