A Standard Grammar for Temporal Logics on Finite Traces

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Abstract

The heterogeneity of tools that support temporal logic formulae poses several challenges in terms of interoperability. In particular, a standard syntax for temporal logic on finite traces, despite similar to the one for infinite traces, is currently missing. This document proposes a standard grammar for several temporal logic formalisms interpreted over finite traces, like Linear Temporal Logic (LTLf), Linear Dynamic Logic (LDLf), Pure-Past Linear Temporal Logic (PLTLf) and Pure-Past Linear Dynamic Logic (PLDLf).

Introduction

This section explains the motivations behind the existence of this standard, states the goals of the standard, describes the notation conventions used throughout the document, and lists the normative references\(^1\).

Motivation

Temporal logics have a long history \(^1\). One of the most influential formalisms is Linear Temporal Logic (LTL) \(^2\), which has been applied for program specification and verification. The variant with finite trace semantics, LTLf, has been introduced in \(^3\).

Linear Dynamic Logic (LDL) \(^4\); is the extension of LTL with regular expressions (RE). The idea behind LDL is to have a formalism that merges the declarativeness and convenience of LTL, as expressive as star-free RE, with the expressive power of RE. The variant over finite traces, LDLf, has been proposed in \(^3\). The syntax that naturally supports empty traces has been employed in \(^5\) for LTLf/LDLf.

Recently, a finite trace variant has been proposed also for the pure-past versions of LTLf and LDLf, namely Pure-Past Linear Temporal Logic (PLTLf) and Pure-Past Linear Dynamic Logic (PLDLf) \(^6\).

The topic has gained more and more attention both in academia and industry, also because such logics have been considered compelling from a practical point of view. Among areas of Computer Science and Artificial Intelligence, we encounter reactive synthesis \(^7\), model checking \(^8\), planning with temporal goal \(^9\), theory of Markov Decision Process with non-Markovian rewards \(^10\), business processes specification \(^11\), just to name a few. For what concerns industry applications, Intel proposed the industrial linear time specification language ForSpec \(^12\), and the IEEE association standardized the Property Specification Language (PSL) \(^13\). Both standards witness the need of specifications based on LTL and regular expressions. Also, the research community has proposed a plethora of software tools and libraries to handle LTL and/or LDL formulas for a variety of purposes: Spot \(^14,15\), Owl \(^16\), SPIN \(^17\) for the infinite-trace semantics, and Syft \(^18\), Lisa \(^19\), FLLOAT \(^20,21\), LTLf2DFA \(^22\), Lydia \(^23\) for the finite trace setting. Another related work is represented by TLSF v1.1 \(^24\), although its focus is on a format for LTL synthesis problems.

All these tools and formats assume the input formulae to be written in a certain grammar. Unfortunately, as often happens when dealing with parser implementations with lack of coordination, the grammars to represent the formulae have some form of discrepancies; e.g. different alternative ways to denote boolean conjunctions or temporal operators, different lexical rules to describe the allowed atomic propositions or boolean constants, underspecifications on how to handle special characters (linefeed, tab, newline, etc.), how to handle associativity of the operators.
Goals

To enhance interoperability between the aforementioned tools, this document proposes a standard grammar for writing temporal logic formulae. In particular, we specify grammars for:

- Linear Temporal Logic on finite traces (LTLf)
- Linear Dynamic Logic on finite traces (LDLf)
- Past Linear Temporal Logic on finite traces (PLTLf)
- Past Linear Dynamic Logic on finite traces (PLDLf)

Note that, despite the syntax is very similar between the finite trace and the infinite trace variants, it is not the same for some operators. For instance, in LTL there is no weak next operator, whereas in LTLf it is the dual operator (under negation) of the next operator.

We would like this standard to be:

- An open standard, fostering collaboration and contributions from the research community;
- As much compliant as possible to existing and widely used tools;
- Written by researchers, for researchers. In other words, this is not strictly tight to industrial needs; for instance, we deliberately dropped the modeling of multiple clock and reset signals of ForSpec and PSL, as these are constructs not relevant for domains outside formal verification.
- Tool-agnostic. Often, grammars are reported alongside software manuals and descriptions. Instead, our aim is to propose a common denominator for all the grammars in use.

Notation

We describe the syntax in Extended Backus-Naur Form (EBNF) [25]. We follow the notation used for the specification of XML [26]; we discarded the EBNF standard version ISO/IEC 14977 [27], as it has been often rejected by the community of those who write language specifications for a variety of reasons [28, 29].

Normative

We refer to [30] for requirement level key words. We also refer to Unicode standard [31, 32] to define legal characters. For versioning this standard, we use SemVerDocs [33], inspired by SemVer [34].

Common definitions

In this section, we describe syntactic rules shared across every logic formalism.

Characters

Parsers MUST be able to accept sequence of characters (see definition below) which represent temporal logic formulae. A character is an atomic unit of text as specified by ISO/IEC 10646:2020 [31]. Legal characters are tab, carriage return, line feed, and the ASCII characters of Unicode and ISO/IEC 10646.

The range of characters to be supported is defined as:
That is, the character tabulation, line feed, carriage return, and all the printable ASCII characters.

**Boolean constants**

We use `true` and `false`, to denote *propositional booleans*, and `tt` and `ff`, to denote *logical booleans*. Note that `true` != `tt`, as `true` requires reading any symbol from the trace, e.g. in LTLf, whereas `tt` is the tautology. Similarly, `false` != `ff` as `false` requires reading no symbol, whereas `ff` is the contradiction. For `false` and `ff` the difference is a bit more blurred, but we considered it better to keep them for symmetry with the positive case.

```
True ::= true
False ::= false
TT ::= tt
FF ::= ff
PropBooleans ::= TRUE | FALSE
LogicBooleans ::= TT | FF
```

**Atomic Propositions**

An atomic proposition is a string of characters. In particular, it can be:

- any string of printable characters, excepted the quotation character used (see QuotedName)
- any string of at least one character that starts with `[a-z_]` and continues with `[a-z0-9_]`, and that is not a reserved keyword.

Unquoted strings with some upper-case characters are excluded. The reason is that some upper-case characters (e.g. `F` and `G`) are reserved keywords for LTL and PLTL operators, and for a more intuitive usage of the grammar it is preferred to forbid all of them instead of asking the user to remember the relatively few exceptions. Moreover, the grammar should be able to support constructs like `FGa`, i.e. no necessary spaces between operators and symbols, for better conciseness.

The reserved keywords are:

- `true`, `false`, `tt`, `ff`, the boolean constants;
- `last`, `end`, `first`, `start`, the temporal logic abbreviations;
- `F`, `G`, `H`, `M`, `O`, `R`, `S`, `U`, `V`, `W`, `X`, `Y`, the temporal operators.
Boolean operators

The supported boolean operations are: negation, conjunction, disjunction, implication, equivalence and exclusion.

Follows the list of characters used for each operator:

- negation: !, ~;
- conjunction: &, &&;
- disjunction: |, ||;
- implication: ->, =>;
- equivalence: <->, <=>;
- exclusive disjunction: ^;

Parenthesis

We use ( and ) for parenthesis.

White Spaces

It is often convenient to use “white spaces” (spaces, tabs, and blank lines) to set apart the formulae for greater readability. These characters MUST be ignored when processing the text input.

LTLf
In this section, we specify a grammar for LTLf.

**Atoms**

An LTLf formula is defined over a set of atoms. In this context, an atom formula is defined by using the `Atom` regular language defined above:

\[
\text{LTLAtom ::= Atom}
\]

**Temporal operators**

Here we specify the regular languages for the temporal operators.

- (Weak) Next: `X`;
- Strong Next: `X[!]`;
- (Strong) Until: `U`;
- Weak Until: `W`;
- (Weak) Release: `R`, `V`;
- Strong Release: `M`;
- Eventually: `F`;
- Always: `G`;

In EBNF format:

```
WeakNext ::= "X"
Next ::= "X[!]
Until ::= "U"
WeakUntil ::= "W"
Release ::= "R" | "V"
StrongRelease ::= "M"
Eventually ::= "F"
Always ::= "G"
```

**Special Formulae**

Special LTLf formulae are:

- `last`, meaning “the last step of the trace”, semantically equivalent to `X(false)`;
- `end`, meaning “the end of the trace”, semantically equivalent to `G(false)`.

In EBNF format:

```
Last ::= "last"
End ::= "end"
```
For the semantics of these operators, we refer to [3] for the finite setting.

**Precedence and associativity of operators**

The precedence and associativity of the LTL operators are described by the following table (priorities from lowest to highest). For brevity, aliases for boolean operators are omitted.

| associativity | operators         |
|--------------|-------------------|
| right        | $\rightarrow$, $\leftrightarrow$ |
| left         | $\wedge$         |
| left         | $|$               |
| left         | $\&$             |
| right        | $U, W, M, R$     |
| right        | $F, G$           |
| right        | $X, X[!]$        |
| right        | $!$              |

**LDLf**

In this section, we specify a grammar for LDLf.

**Temporal operators**

LDLf supports two temporal operators:
• **Diamond operator:** `<regex>ldl_formula;`
• **Box operator:** `[regex]ldl_formula;

`regex` will be presented in the next paragraph.

```
LeftDiam ::=: "<"
RightDiam ::=: ">"
LeftBox ::=: "["
RightBox ::=: "]
```

In EBNF format, an LDLf formula is defined as follows:

```
ldl_formula ::= TT
         | FF
         | LeftParen ldl_formula RightParen
         | Not ldl_formula
         | ldl_formula And ldl_formula
         | ldl_formula Or ldl_formula
         | ldl_formula Impl ldl_formula
         | ldl_formula Equiv ldl_formula
         | LeftDiam regex RightDiam ldl_formula
         | LeftBox regex RightBox ldl_formula
```

**Regular Expressions**

In this section, we define the regular expression used by Diamond and Box operators.

A regular expression is defined inductively as:

- a *propositional formula* over as set of propositional atoms.
- a *test expression*: `ldl_formula?`
- a *concatenation* between two regular expressions: `regex_1 ; regex_2`
- a *union* between two regular expressions: `regex_1 + regex_2`
- a *star* operator over a regular expression: `regex*`

The symbols are listed below:

```
Test ::=: "?"
Concat ::=: ";"
Union ::=: "+
Star ::=: "*
```

The EBNF grammar for a regular expression is:
propositional ::= Atom
| True
| False
| LeftParen propositional RightParen
| Not propositional
| propositional And propositional
| propositional Or propositional
| propositional Impl propositional
| propositional Equiv propositional
| propositional Xor propositional

regex ::= propositional
| LeftParen regex RightParen
| regex Test
| regex Concat regex
| regex Union regex
| regex Star

For the semantics of the operators, we refer to [3].

**Precedence and associativity of operators**

The precedence and associativity of the LDL operators are described by the following table (priorities from lowest to highest). For brevity, aliases for boolean operators are omitted.

| associativity | operators |
|---------------|-----------|
| right         | $\rightarrow$, $\leftrightarrow$ |
| left          | $\land$ |
| left          | $\lor$ |
| left          | $\&$ |
| N/A           | $\langle$, $\rangle$, $[]$ |
| left          | $;$ |
| left          | $+$ |
| left          | $*$ |
| left          | $?$ |
| right         | $!$ |

**PLTLf**

In this section, we specify a grammar for PLTLf.

**Atoms**

A PLTLf formula is defined over a set of *atoms*. In this context, an atom formula is defined by using the *Atom* regular language defined above:
Temporal operators

Here we specify the regular languages for the temporal operators.

- Before: Y;
- Since: S;
- Once: O;
- Historically H.

In EBNF format:

```
Before ::= "Y"
Since ::= "S"
Once ::= "O"
Historically ::= "H"
```

Special Formulae

Special PLTLf formulae are:

- `first`, meaning “the first step of the trace”, semantically equivalent to !B(true);
- `start`, meaning “the start of the trace”, semantically equivalent to H(false).

In EBNF format:

```
First ::= "first"
Start ::= "start"
```
For the semantics of these operators for the finite setting, we refer to [6].

**Precedence and associativity of operators**

The precedence and associativity of the LTL operators are described by the following table (priorities from lowest to highest). For brevity, aliases for boolean operators are omitted.

| associativity | operators |
|---------------|-----------|
| right         | $\rightarrow$, $\leftrightarrow$ |
| left          | $\wedge$ |
| left          | $\mid$ |
| left          | $\&$ |
| right         | $S$ |
| right         | $O$, $H$ |
| right         | $B$ |
| right         | $!$ |

**PLDLf**

In this section, we specify a grammar for PLDLf.

**Temporal operators**

PLDLf supports two temporal operators:

- Backward diamond operator: $\ll<\text{regex}>\text{pldl\_formula};$
- Backward box operator: $\ll<\text{regex}>[\text{pldl\_formula};$

$\text{regex}$ is the same as defined for LDLf.
In EBNF format, a PLDLf formula is defined as follows:

\[
\text{pldl\_formula ::= } \text{TT} \\
| \text{FF} \\
| \text{LeftParen pldl\_formula RightParen} \\
| \text{Not pldl\_formula} \\
| \text{pldl\_formula And pldl\_formula} \\
| \text{pldl\_formula Or pldl\_formula} \\
| \text{pldl\_formula Impl pldl\_formula} \\
| \text{pldl\_formula Equiv pldl\_formula} \\
| \text{LeftBackwardDiam regex RightBackwardDiam pldl\_formula} \\
| \text{LeftBackwardBox regex RightBackwardBox pldl\_formula}
\]

For the semantics of the operators, we refer to [6].

**Precedence and associativity of operators**

The precedence and associativity of the LDL operators are described by the following table (priorities from lowest to highest). For brevity, aliases for boolean operators are omitted.

| associativity | operators     |
|---------------|--------------|
| right         | \( \rightarrow, \leftrightarrow \) |
| left          | \&           |
| left          | |             |
| left          | \&           |
| N/A           | \( \leftarrow\rightarrow, \llbracket\llbracket \) |
| left          | ;             |
| left          | +             |
| left          | \^            |
| left          | ?             |
| right         | !             |

**Future work**

In future versions of this standard, we would like to add:

- Spot-like syntactic sugars for regular expressions (SERE) and temporal operators [14,24];
- Compatibility with the PSL standard [13];
• Support full Unicode characters, so to use UTF-8 characters like ⊕ (U+25CB) for the Next operator and ◇ (U+25C7) for the Eventually operator etc. as alternative symbols.
References

1. **A Survey on Temporal Logics**
   Savas Konur
   (2010-05) [http://arxiv.org/abs/1005.3199v3](http://arxiv.org/abs/1005.3199v3)

2. **The temporal logic of programs**
   Amir Pnueli
   *18th Annual Symposium on Foundations of Computer Science (sfcs 1977)* (1977-10)
   [http://dx.doi.org/10.1109/sfcs.1977.32](http://dx.doi.org/10.1109/sfcs.1977.32)
   DOI: [10.1109/sfcs.1977.32](http://dx.doi.org/10.1109/sfcs.1977.32)

3. **Linear Temporal Logic and Linear Dynamic Logic on Finite Traces**
   Giuseppe De Giacomo, Moshe Y. Vardi
   *Proceedings of the Twenty-Third International Joint Conference on Artificial Intelligence* (2013)
   [http://dl.acm.org/citation.cfm?id=2540128.2540252](http://dl.acm.org/citation.cfm?id=2540128.2540252)
   ISBN: [978-1-57735-633-2](http://dl.acm.org/citation.cfm?id=2540128.2540252)

4. **The rise and fall of LTL**
   Moshe Y Vardi
   *GandALF* (2011)

5. **LTLf/LDLf Non-Markovian Rewards**
   Ronen Brafman, Giuseppe De Giacomo, Fabio Patrizi
   (2018) [https://www.aaai.org/ocs/index.php/AAAI/AAAI18/paper/view/17342](https://www.aaai.org/ocs/index.php/AAAI/AAAI18/paper/view/17342)

6. **Pure-Past Linear Temporal and Dynamic Logic on Finite Traces**
   Giuseppe De Giacomo, Antonio Di Stasio, Francesco Fuggitti, Sasha Rubin
   *Twenty-Ninth International Joint Conference on Artificial Intelligence and Seventeenth Pacific Rim International Conference on Artificial Intelligence IJCAI-PRICAI-20* (2020-07)
   [http://dx.doi.org/10.24963/ijcai.2020/690](http://dx.doi.org/10.24963/ijcai.2020/690)
   DOI: [10.24963/ijcai.2020/690](http://dx.doi.org/10.24963/ijcai.2020/690) · ISBN: ['9780999241165']

7. **Synthesis for LTL and LDL on Finite Traces**
   Giuseppe De Giacomo, Moshe Y. Vardi
   *Proceedings of the 24th International Conference on Artificial Intelligence* (2015)
   [http://dl.acm.org/citation.cfm?id=2832415.2832466](http://dl.acm.org/citation.cfm?id=2832415.2832466)
   ISBN: [978-1-57735-738-4](http://dl.acm.org/citation.cfm?id=2832415.2832466)

8. **Automatic Verification of Finite-State Concurrent Systems Using Temporal Logic Specifications**
   E. M. Clarke, E. A. Emerson, A. P. Sistla
   *ACM Trans. Program. Lang. Syst.* (1986) [https://doi.org/10.1145/5397.5399](https://doi.org/10.1145/5397.5399)
   DOI: [10.1145/5397.5399](https://doi.org/10.1145/5397.5399)

9. **Planning for temporally extended goals**
   Fahiem Bacchus, Froduald Kabanza
   *Annals of Mathematics and Artificial Intelligence* (1998)

10. **Rewarding behaviors**
    Fahiem Bacchus, Craig Boutilier, Adam Grove
11. *Enacting declarative languages using LTL: avoiding errors and improving performance*
Maja Pešić, Dragan Bošnački, Wil MP van der Aalst
*International SPIN Workshop on Model Checking of Software* (2010)

12. *The ForSpec temporal logic: A new temporal property-specification language*
Roy Armoni, Limor Fix, Alon Flaisher, Rob Gerth, Boris Ginsburg, Tomer Kanza, Avner Landver, Sela Mador-Haim, Eli Singerman, Andreas Tiemeyer, others
*International Conference on Tools and Algorithms for the Construction and Analysis of Systems* (2002)

13. *IEEE Standard for Property Specification Language (PSL)*
IEEE
*IEEE* (2010) [http://dx.doi.org/10.1109/ieeestd.2010.5446004](http://dx.doi.org/10.1109/ieeestd.2010.5446004)
DOI: 10.1109/ieeestd.2010.5446004 · ISBN: ['9780738162553']

14. *Spot’s Temporal Logic Formulas*
Alexandre Duret-Lutz
*Tech. rep. Available online: https://spot.lrde.epita.fr/tl.pdf* (2016)

15. *Spot 2.0A Framework for LTL and 19970\backslash 19970-Automata Manipulation*
Alexandre Duret-Lutz, Alexandre Lewkowicz, Amaury Fauchille, Thibaud Michaud, Etienne Renault, Laurent Xu
*International Symposium on Automated Technology for Verification and Analysis* (2016)

16. *Owl: A Library for omega-Words, Automata, and LTL*
Jan Kretinsky, Tobias Meggendorfer, Salomon Sickert
*Automated Technology for Verification and Analysis - 16th International Symposium, ATVA 2018, Los Angeles, CA, USA, October 7-10, 2018, Proceedings* (2018) [https://doi.org/10.1007/978-3-030-01090-4\textbackslash{}\_34](https://doi.org/10.1007/978-3-030-01090-4\textbackslash{}\_34)
DOI: 10.1007/978-3-030-01090-4\textbackslash{}\_34

17. *The SPIN Model Checker: Primer and Reference Manual*
Gerard Holzmann
*Addison-Wesley Professional* (2011)
ISBN: 0321773713

18. *Symbolic LTLf Synthesis*
Shufang Zhu, Lucas M. Tabajara, Jianwen Li, Guguang Pu, Moshe Y. Vardi
*Proceedings of the Twenty-Sixth International Joint Conference on Artificial Intelligence* (2017-08) [http://dx.doi.org/10.24963/ijcai.2017/189](http://dx.doi.org/10.24963/ijcai.2017/189)
DOI: 10.24963/ijcai.2017/189 · ISBN: 9780999241103

19. *Hybrid Compositional Reasoning for Reactive Synthesis from Finite-Horizon Specifications*
Suguman Bansal, Yong Li, Lucas M. Tabajara, Moshe Y. Vardi
*The Thirty-Fourth AAAI Conference on Artificial Intelligence, AAAI 2020, The Thirty-Second Innovative Applications of Artificial Intelligence Conference, IAAI 2020, The Tenth AAAI Symposium on Educational Advances in Artificial Intelligence, EAAI 2020, New York, NY, USA, February 7-12, 2020* (2020) [https://aaai.org/ojs/index.php/AAAI/article/view/6528](https://aaai.org/ojs/index.php/AAAI/article/view/6528)

20. *RiccardoDeMasellis/FLLOAT*
Riccardo De Masellis
21. Reinforcement learning for LTLf/LDLf goals: Theory and implementation  
Marco Favorito  
*Master's thesis. DIAG, Sapienza Univ. Rome* (2018)

22. LTLf2DFA  
Francesco Fuggitti  
*WhiteMech* (2018) [https://github.com/whitemech/LTLf2DFA](https://github.com/whitemech/LTLf2DFA)

23. Compositional Approach to Translate LTLf/LDLf into Deterministic Finite Automata  
Giuseppe De Giacomo, Marco Favorito  
*Proceedings of the International Conference on Automated Planning and Scheduling (to appear)*  
(2021)

24. A high-level LTL synthesis format: TLF v1.1  
Swen Jacobs, Felix Klein, Sebastian Schirmer  
arXiv preprint arXiv:1604.02284 (2016)

25. The syntax and semantics of the proposed international algebraic language of the Zurich ACM-GAMM conference  
John W Backus  
*Proceedings of the International Conference on Information Processing, 1959* (1959)

26. Extensible Markup Language (XML) 1.0 (Fifth Edition)  
W3C  
(2008) [https://www.w3.org/TR/xml/](https://www.w3.org/TR/xml/)

27. ISO/IEC 14977: 1996 (E)  
Extended BNF ISO  
ISO: *Geneva* (1996)

28. Don't Use ISO/IEC 14977 Extended Backus-Naur Form (EBNF)  
David Wheeler  
(2020) [https://dwheeler.com/essays/dont-use-iso-14977-ebnf.html](https://dwheeler.com/essays/dont-use-iso-14977-ebnf.html)

29. BNF was here: what have we done about the unnecessary diversity of notation for syntactic definitions  
Vadim Zaytsev  
*Proceedings of the 27th Annual ACM Symposium on Applied Computing* (2012)

30. Key words for use in RFCs to Indicate Requirement Levels  
Scott Bradner  
*RFC2119* (1997)

31. Information technology—Universal coded character set  
ISO/IEC  
*International Organization for Standardization* (2020)

32. The Unicode Standard, Version 13.0.0  
The Unicode Consortium  
(2020) [https://www.unicode.org/versions/Unicode13.0.0/](https://www.unicode.org/versions/Unicode13.0.0/)  
ISBN: 978-1-936213-26-9
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