Simple Temporal Networks: A Practical Foundation for Temporal Representation and Reasoning

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Abstract

Since Simple Temporal Networks (STNs) were first introduced in 1991, there have been numerous theoretic and algorithmic advances that have made them practical for a wide variety of applications. However, the presentation of most of the important advances have been scattered across numerous conference papers and journal articles. As a result, it is too easy for even experienced researchers to be unaware of results that could positively impact their work. In this talk we review the most important results about STNs for researchers in Artificial Intelligence who are interested in incorporating the management of time and temporal constraints into their projects.

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1 Extended Abstract

Temporal networks are data structures for representing and reasoning about temporal constraints on activities. The most basic kind of temporal network is a Simple Temporal Network (STN) which can accommodate such constraints as release times, deadlines, precedence constraints, and duration constraints [16]. The fundamental computational tasks associated with STNs – checking consistency and managing execution – can be done in polynomial time [16, 40].

STNs are used as temporal reasoning tools in numerous research projects and applications. Currently, there are more than 2400 research papers in Google Scholar (more than 1200 in Scopus) that employ STNs, either as the main temporal reasoning model or as the basis for more expressive models. Considering only the most cited papers (more than 30 citations in Scopus) that present a tool or a methodology based on STNs, the use of STNs falls into the following two macro areas:

- *planning for robots* [30, 10, 25, 19, 1, 24, 27, 8, 7, 26, 31, 21],
- *industrial, business and health-care management systems* [17, 3, 2, 45, 37, 20, 5, 12, 11, 9]

An STN contains a set of real-valued variables, called *time-points,* that typically represent the starting or ending times of actions, together with a set of constraints on those time-points. Each constraint in an STN has the form, $Y - X \leq \delta$, where X and Y are time-points, and δ is a real number. Despite their limited form, the constraints in an STN can represent release times, deadlines, precedence constraints, and duration constraints. For example, if X and Y are the starting and ending times of an action, then $Y - X \leq 10$ represents that the duration of that action must be no more than 10. One advantage of STNs over earlier approaches is that they allow flexibility: time-points need not be assigned values in advance, but may be assigned in real time, during execution. In addition, STNs have an equivalent graphical form that enables the use of algorithms from the vast literature on labeled, directed graphs.

The *Simple Temporal Problem* (STP) is the problem of determining whether a given STN has a solution (i.e., is *consistent*, when viewed as a constraint satisfaction problem). Many polynomial algorithms have been presented for solving the STP, their performance differing depending on the structure of the STN graph. However, there are many other computational problems that users of STNs need to be able to solve. For example, in most applications, constraints are frequently inserted into the network incrementally, over time. The incremental STP checks the consistency as new constraints are inserted [36, 18, 34]. In addition, to take advantage of the flexibility offered by STNs, a system managing real-time execution needs to be able to quickly determine when to execute each time-point while preserving the network's consistency. And, in cases where spurious events introduce an inconsistency into the network, a system must be able to figure out modifications that will restore a network's consistency [14, 33]. For another example, in multi-agent scenarios with limited communication, temporal networks may need to be *decoupled* to enable agents to operate independently [22, 35, 4, 44]. All of these, and many other problems associated with STNs have polynomial algorithms for solving them, making STNs a practical temporal reasoning model for many real-world applications.

Because many real-world scenarios involve features that are not representable in STNs, the STN model has been extended in many different ways. For example, an STNU accommodates actions with *uncertain* durations (e.g., a taxi ride) [42, 43, 28], a CSTN accommodates *conditional* constraints and test actions that generate information in real time [41, 13, 23], and a DTN accommodates *disjunctive* constraints (e.g., action A must finish before action B starts *or* vice-versa) [38, 39, 32]. Other extensions of STNs accommodate probabilistic constraints [29, 15] and decisions (or choice points) [6].

Typically, the increase in expressiveness introduces a significant computational cost. (The main exception is the STNU, for which many polynomial algorithms exist.) However, recent advances have begun to make these extensions viable for practical applications. In each case, the techniques applied to the more expressive networks builds on the theory and algorithms for STNs.

This talk surveys the 30-year development of the theory and algorithms for Simple Temporal Networks for researchers and application developers interested in incorporating STNs into their projects.

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