A Temporal Logic For Network Flow Analysis

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Overview

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Motivation

Clarify timing relationships
Formalize analysis semantics
  • Clearer discussions
  • Enhance automation & frameworks
  • Combining analyses
Avoid over-specification of timing
Support reasoning about analysis tasks
Access temporal logic methods
Temporal Logic

Logic with explicit inclusion of time

Classically, first-order logic, could be any logic form

Temporal interpretation: Instantiating circumstances

- Linear time with rollback on contradiction
- Branching time with branch termination on contradiction
- Advantage to linear: simpler structure, no worry over paths
- Advantage to branching: can express path-related conditions
Temporal Logic Operators

Next(\(t, p\)) – \(p\) is true in the instant after \(t\)

Global(\(p\)) – \(p\) is true independent of time

Following(\(t, p\)) – \(p\) is true at some instant after \(t\)

Until(\(t, p, q\)) – \(p\) is true at each instant after \(t\) until \(q\) is true

Forall (\(p\)) – \(p\) is true along all paths

Exists (\(p\)) – \(p\) is true along at least one path
Adaptation to Flow

Description first, then reasoning

Iterative semantics – suitable for filter-like processing

Specific semantics:

• 5-tuple
• Ordinal time (inexact comparisons)
• Related flows
Adapted semantics

R($f_1,f_2$) relation – flow-flow connection

$p(f,…), q(f,…)$ – logic predicates on flow records/fields

Enable reasoning using Horn clause resolution and backtracking
Temporal Operators for Flow

Globally:
\[ \text{G}(p) : \forall (R(f,f') \rightarrow p(f) \text{ and } p(f')) \]

Next:
\[ \text{N}(f,f') : \text{iff } R(f,f') \text{ and } f'.stime > f.stime \text{ and } \text{does not exists (} R(f,f'') \text{ and } f'.stime > f''.stime > f.stime) \]
\[ \text{N}^*(f,f') : \text{transitive relation on } N \]
\[ \text{X}(f,p) : \forall (R(f,f') \rightarrow p(f')) \]

Following:
\[ \text{F}(f,p) : \exists (\text{N}^*(f,f') \text{ and } p(f')) \]

Until:
\[ \text{U}(f,p,q) : \exists (\text{N}^*(f,f'') \text{ and } q(f''), \forall (\text{N}^*(f,f') \text{ and } f''.stime > f'.stime \rightarrow p(f') \text{ and not } q(f'))) \]
Descriptive Temporal Example

Spam(s,f):

\[ R(f,f') : f.sip = f'.sip = s \text{ and } s \text{ not on whitelist} \]

If and only if

\[
| \{ f', \text{Following}(f,f', f'.stime < f.stime + 5\text{min} \text{ and } f'.dport=email) \} | > 15 \text{ and }
| \{ f', \text{Following}(f,f', f'.stime < f.stime + 5\text{min} \text{ and } f'.dport=email) \} | \geq
| \{ f', \text{Following}(f,f', f'.stime < f.stime + 5\text{min}) \} | \ast 0.1
\]
Implementation

Use temporal logic to express analysis criteria

Prolog-based (GNU-Prolog)
- Logic programming, incorporating time in resolution
- Initial prototype to refine semantics
- Construct interface to analysis tools (plugin)

Python-based (PySiLK)
- Declarative programming, incorporate limited resolution mechanism
- Secondary prototype to demonstrate applicability

Eventually construct reasoning rules for analysis relationships or proof
Conclusions

Temporal logic adaptation of flow analysis offers opportunity to encompass large literature of pre-existing methods

Formalization of time relationships offers opportunity to improve flow analysis methods

More formal reasoning on flow analysis?