



# A Temporal Logic For Network Flow Analysis

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# Overview

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Motivation

Temporal Logic

Application to Flow

Example

Implementations

# Motivation

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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

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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

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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

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Description first, then reasoning

Iterative semantics – suitable for filter-like processing

Specific semantics:

- 5-tuple
- Ordinal time (inexact comparisons)
- Related flows

# Adapted semantics

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

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

Enable reasoning using Horn clause resolution and backtracking

# Temporal Operators for Flow

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## Globally:

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

## Next:

$N(f,f')$ : iff  $R(f,f')$  and  $f'.stime > f.stime$  and  
does not exists (  
 $R(f,f'')$  and  $f'.stime > f''.stime > f.stime$ )

$N^*(f,f')$ : transitive relation on  $N$

$X(f,p)$ :  $\text{forall}(N(f,f') \rightarrow p(f'))$

## Following:

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

## Until:

$U(f,p,q)$ :  
exists  $(N^*(f,f'') \text{ and } q(f''))$ ,  
forall  $(N^*(f,f') \text{ and } f''.stime > f'.stime \rightarrow p(f') \text{ and not } q(f'))$

# Descriptive Temporal Example

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Spam(s,f):

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

If and only if

$|\{f', \text{Following}(f, f', f'.\text{stime} < f.\text{stime} + 5\text{min} \text{ and } f'.\text{dport} = \text{email})\}| > 15$  and

$|\{f', \text{Following}(f, f', f'.\text{stime} < f.\text{stime} + 5\text{min} \text{ and } f'.\text{dport} = \text{email})\}| \geq$

$|\{f', \text{Following}(f, f', f'.\text{stime} < f.\text{stime} + 5\text{min})\}| * 0.1$

# Implementation

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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

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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?