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Observer Patterns for Real-Time Systems

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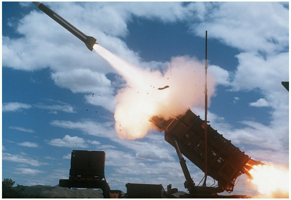
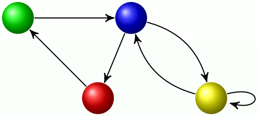
Context: Verifying Complex Timed Systems (1/2)

- Need for early bug detection
  - Bugs discovered when final testing: expensive
  - $\leadsto$ Need for a thorough modeling and verification phase



Context: Verifying Complex Timed Systems (2/2)

- Use formal methods

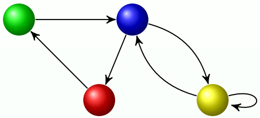


A model of the system

A property to be satisfied

Context: Verifying Complex Timed Systems (2/2)

- Use formal methods



$\overset{?}{\models}$

 is unreachable

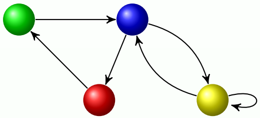
A model of the system

A property to be satisfied

- Question: does the model of the system satisfy the property?

Context: Verifying Complex Timed Systems (2/2)

- Use formal methods



$\overset{?}{\models}$

 is unreachable

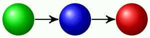
A model of the system

A property to be satisfied

- Question: does the model of the system satisfy the property?

Yes

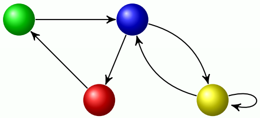
No



Counterexample

Context: Verifying Complex Timed Systems (2/2)

- Use formal methods



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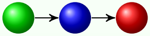
A property to be satisfied

- Question: does the model of the system satisfy the property?

Yes

No



Counterexample

Specifying Properties for Real-Time Systems

- (Timed) temporal logics [Pnueli, 1977, Baier and Katoen, 2008]
  - ☺ Very expressive
  - ☹ Not easy to handle by non-experts
    - EF((EX.P)U(AG.Q))
  - ☹ Expressiveness not often supported in full by tools
  - ☹ Requires complex model checking algorithms
  - ☹ Too expressive?

- Observer-based properties [Aceto et al., 1998b, Aceto et al., 1998a]
  - ☺ Quite expressive
  - ☺ Do not require complex algorithms
  - ☹ Not easy to handle by non-experts
  - ☹ Too expressive?

Outline

Outline

Goal

- Identify and express common properties met in the design and verification of complex real-time systems
- Define an associated formal semantics
- Shall be non-compositional
  - ☺ Avoids mistakes or ill-formed properties
  - ☺ Discards properties never or rarely met in practice
  - ☹ Non-complete

Patterns: Related Works

- Design patterns for software engineering [Gamma et al., 1995]
  - $=$ Non-original, non-compositional, non-complete
  - $\neq$ Can be inserted into freely written code
- Timed automata patterns [Dong et al., 2008]
  - $=$ Specification for real-time concurrent systems
  - $\neq$ Specify the model and not the property
  - $\neq$ Aim at completeness
- Other patterns for real-time systems
  - Dedication to scheduling problems [Khatib et al., 2001]
  - Specification using UML [Mekki et al., 2009]
  - Timed automata patterns generated from RTESMs [Han et al., 2013]

Observers: All is Reachability

- Observer: additional subsystem monitoring the system behavior
  - Synchronization with the system events
  - Definition of bad / good states
- Reduction to pure reachability properties
  Here, we consider 2 main kinds of properties:
  1. Never reach the bad state
  2. Always end in a good state
- Advantages
  - Any tool implementing (non-)reachability can implement such patterns

Our Approach

- A limited set of non-compositional patterns
  - Commonly used in practice
  - ⇝ Discards too complicated properties
- Expressed using an intuitive English-like syntax
  - Partially inspired by CASL-LTL [Reggio et al., 2003, Choppy and Reggio, 2006]
  - Described using a full English sentence
  - ⇝ Easy to understand by non-experts
- Associated with a formal semantics
  - Expressed using observers
  - ⇝ Does not require complex algorithms (only reachability)
    - Implemented in both timed automata [Alur and Dill, 1994] and Stateful Timed CSP [Sun et al., 2013]

Outline

Action Precedence: Acyclic Version (1/2)

Syntax:

if a_2 *then* a_1 *has happened before*

English description:

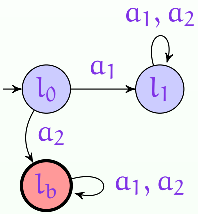
"If a_2 happens at least once, then a_1 has happened before the first occurrence of a_2."

- Typical use: avoid false positives for alarms
  - "An alarm must ring only if an intrusion has happened before"
- Does not mean that the intrusion will always lead to an alarm!

Action Precedence: Acyclic Version (2/2)

if a_2 *then* a_1 *has happened before*

Timed automaton observer:



Stateful Timed CSP:

$P_{obs} \doteq (a_2\{v_{bad} := \top\} \rightarrow P_S) \,\square\, (a_1 \rightarrow P_S)$

Action Precedence: Cyclic Version

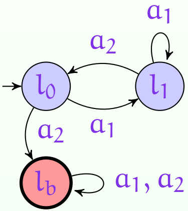
Syntax:

every time a_2 *then* a_1 *has happened before*

English description:

"Every time a_2 happens, then a_1 has happened before, since the last occurrence of a_2 (if any)."

Timed automaton:



Stateful Timed CSP:

$P_{obs} \doteq P_1$

$P_1 \doteq (a_2\{v_{bad} := \top\} \rightarrow P_S) \,\square\, (a_1 \rightarrow P_2)$

$P_2 \doteq (a_1 \rightarrow P_2) \,\square\, (a_2 \rightarrow P_1)$

Action Precedence: Strict Cyclic Version

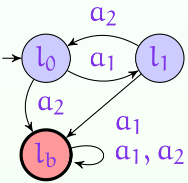
Syntax:

every time a_2 *then* a_1 *has happened exactly once before*

English description:

"Every time a_2 happens, then a_1 has happened before, exactly once since the last occurrence of a_2 (if any)."

Timed automaton:



Stateful Timed CSP:

$$
\begin{aligned}
P_{obs} &\doteq P_1 \\
P_1 &\doteq (a_2\{v_{bad} := \top\} \rightarrow P_S) \,\Box\, (a_1 \rightarrow P_2) \\
P_2 &\doteq (a_1\{v_{bad} := \top\} \rightarrow P_S) \,\Box\, (a_2 \rightarrow P_1)
\end{aligned}
$$

Eventual Response: Acyclic Version (1/2)

Syntax:

if a_1 *then eventually* a_2

English description:

"If a_1 happens, then a_2 eventually happens."

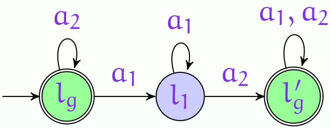
- Typical use:
  - "Every time access is requested, then access is eventually granted"
  - "Every time an intrusion occurs, then the alarm eventually rings"
- Does not require a_1 to happen!
- Typical liveness property[1]

[1] Cf. https://cs.nyu.edu/acsys/beyond-safety/liveness.htm

Eventual Response: Acyclic Version (2/2)

if a_1 *then eventually* a_2

Timed automaton:



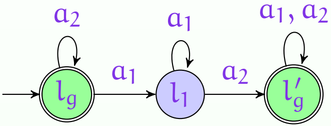
Stateful Timed CSP:

$$P_{obs} \doteq (a_2 \rightarrow P_{obs}) \,\Box\, (a_1\{v_{good} := F\} \rightarrow P_1)$$
$$P_1 \doteq (a_1 \rightarrow P_1) \,\Box\, (a_2\{v_{good} := T\} \rightarrow P_S)$$

Eventual Response: Acyclic Version (2/2)

if a_1 *then eventually* a_2

Timed automaton:



Stateful Timed CSP:

$P_{obs} \doteq (a_2 \rightarrow P_{obs}) \,\square\, (a_1\{v_{good} := F\} \rightarrow P_1)$

$P_1 \quad \doteq (a_1 \rightarrow P_1) \,\square\, (a_2\{v_{good} := T\} \rightarrow P_S)$

Also exists in “cyclic” and “strict cyclic” versions (cf. paper)

Action Before Deadline (1/2)

Syntax:

a no later than d

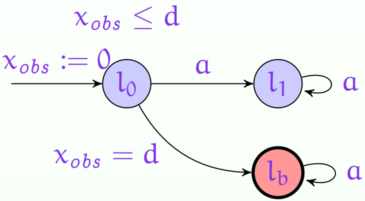
English description:

"a will happen no later than d units of time after the system start."

- Typical use: signal changes in hardware verification
- Similar to the "deadline" pattern in [Dong et al., 2008]

Action Before Deadline (2/2)

a no later than d



Stateful Timed CSP:

$P_{obs} \doteq (a \rightarrow P_S)$ $\texttt{timeout}[d]$

$\big((e_{obs}\{v_{bad} := \top\} \rightarrow P_S) \setminus \{e_{obs}\}\big)$

Time-Bounded Action Precedence

Syntax:
if a_2 *then* a_1 *has happened at most* d *units of time before*

English description:
"If a_2 happens at least once, then a_1 has happened at most d units of time before the first occurrence of a_2."

- Timed extension of the "Action precedence" pattern
- Also exists in "cyclic" and "strict cyclic" versions

Time-Bounded Response

Syntax:

if a_1 *then eventually* a_2 *within* d

English description:

"If a_1 happens, then a_2 will eventually happen within d units of time."

- Typical use:
  - "If an intrusion occurs, then the alarm eventually rings within 2 seconds"
- Also known as time-bounded liveness [Behrmann et al., 2005]
- Timed extension of the "Eventual response" pattern
- Also exists in "cyclic" and "strict cyclic" versions

Sequence

Syntax:

sequence $a_1, \ldots, a_n$

English description:

"Actions $a_1, \ldots, a_n$ must occur in this order."

- Imposes an order, but does require the actions to happen
- Also exists in "cyclic" version

Use of the Patterns in a Set of Case Studies

Pattern	Nb	Applications		
Non-reachability	9		Prtc	
Always end in good state	2	HW	Prtc	
Action precedence	2	HW		
Eventual response	5		Prtc	
Action before deadline	1	HW		
T-bounded action precedence	1			
T-bounded response	3	HW	Prtc	Sched
Sequence	1	HW		
Combinations	3		Prtc	Sched
Others	2		Prtc	

Based on 29 case studies (real-time systems)

Outline

Conclusion

- Observer patterns
  - Common properties
  - Intuitive syntax
  - Reachability-based formal semantics
  - Limited expressiveness
- Extends to parameter synthesis
  - Parameterized version of the patterns
    - E.g.: "if a_1 then eventually a_2 within p", with p a parameter
  - Implemented in IMITATOR [A., Fribourg, Kühne, Soulat, 2012]
- Extends to state- and variables-based properties?
  - So far: action-based
  - No theoretical problem for state and variables
    But what about synchronization?

Perspectives

- What about liveness?
  - Requires Büchi conditions in the observers
- Add a limited dose of compositionality
  - Combination of patterns
    - Example: “[sequence a, b, c] within 10 seconds” (Sequence + new “within” pattern)
  - Propose a bounded depth for well-formedness?
- Semantic equivalence between the implementation of the patterns in timed automata and Stateful Timed CSP respectively
- Reuse some of the most common existing “patterns” [Khatib et al., 2001, Mekki et al., 2009]
- Improve the English description
  - Take compositionality into account

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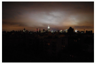
Additional explanation

Explanation for the 4 pictures in the beginning



Allusion to the Northeast blackout (USA, 2003)
Computer bug
Consequences: 11 fatalities, huge cost
(Picture actually from the Sandy Hurricane, 2012)

Allusion to any plane crash
(Picture actually from the happy-ending US Airways Flight 1549, 2009)

Allusion to the sinking of the Sleipner A offshore platform (Norway, 1991)
No fatalities
Computer bug: inaccurate finite element analysis modeling
(Picture actually from the Deepwater Horizon Offshore Drilling Platform)

Allusion to the MIM-104 Patriot Missile Failure (Iraq, 1991)
28 fatalities, hundreds of injured
Computer bug: software error (clock drift)
(Picture of an actual MIM-104 Patriot Missile, though not the one of 1991)

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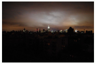

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