Most General Property-Preserving Updates

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DB

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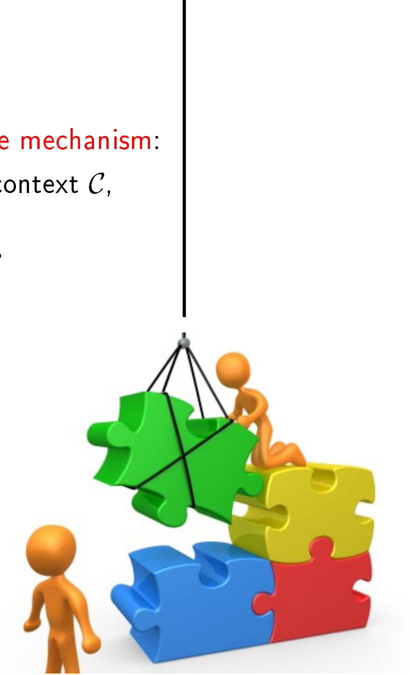
Motivation

- Modern applications are increasingly designed as distributed systems that cooperates to achieve a common goal.
- They must face dynamically changing requirements and unpredictable behaviour by the environment
- Applications and systems need to be updated, statically or dynamically:
  - changing business rules
  - changing environment conditions
  - bug fixes
  - specialize the application to user preferences
  - ...

Which Updates

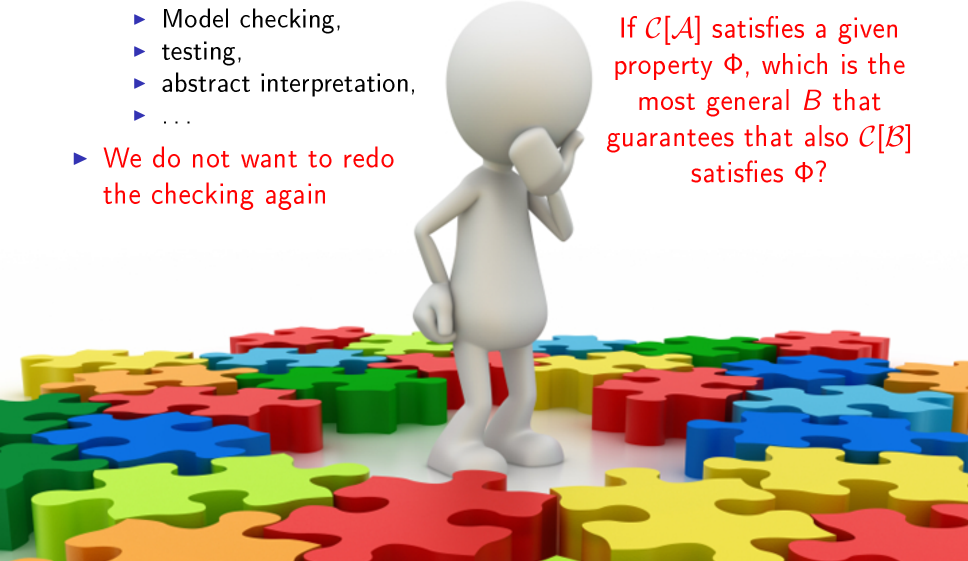
We consider a simple but general update mechanism:

- The application is composed by a context $\mathcal{C}$, and a component to be updated $\mathcal{A}$
- The component $\mathcal{A}$ is replaced by $\mathcal{B}$
- We go from $\mathcal{C}[\mathcal{A}]$ to $\mathcal{C}[\mathcal{B}]$



Property preservation

- Many approaches:
  - Model checking,
  - testing,
  - abstract interpretation,
  - ...
- We do not want to redo the checking again



If $\mathcal{C}[\mathcal{A}]$ satisfies a given property Φ, which is the most general B that guarantees that also $\mathcal{C}[\mathcal{B}]$ satisfies Φ?


One property
one context
All properties
one context
One property
all contexts
All properties
all contexts

Constraint Automata

We model contexts and components as constraint automata

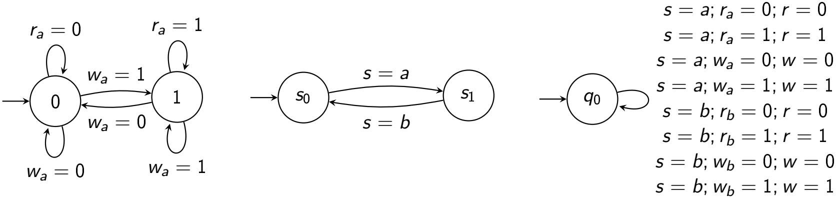
$$\mathcal{A} = \langle Q, N, q_0, \rightarrow \rangle$$

- Automata that communicates via (internal and external) nodes N
- Transitions are labelled with functions from N to $data \cup \{\perp\}$
- We consider embeddings:
  - The component communicates only with the context
- We consider both synchronous and asynchronous composition

Two register example

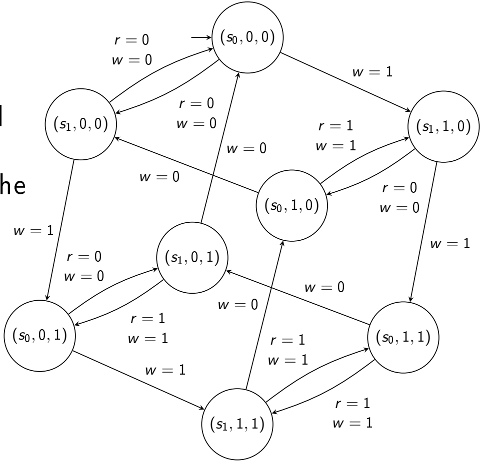
Consider a system composed by two 1 bit registers, A and B

- Registers can be read and written
- A scheduler decides which register can be accessed from outside
- A synchronizer that exposes to the outside world the nodes r (read) and w (write) to access the active register



The complete system

- We consider the Scheduler as the component to be updated
- The contex is then given by the Registers and Synchronizer
- The complete system is obtained by asynchronous composition



Properties

We adopt a general definition of **property**. . .

- for us, a property is a prefix-closed sets of traces . . .
- . . . that can be accepted by some Constraint Automaton
- we represent a property by the automaton Φ that accepts it
- $\mathcal{A}$ satisfies the property Φ iff $\mathscr{L}(\mathcal{A}) \subseteq \mathscr{L}(\Phi)$

. . . to exploit the link between **automata and logic:**

- Constraint Automata are as expressive as the safety linear μ-calculus
- our approach can cope with any safety property written in some temporal logic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One property, one context

Problem

Given a context $\mathcal{C}$, a component $\mathcal{A}$ and a property Φ, find a most general $\mathcal{B}$ such that if $\mathcal{C}[\mathcal{A}]$ satisfies Φ, then also $\mathcal{C}[\mathcal{B}]$ satisfies Φ.

- This is equivalent to finding the largest $\mathcal{B}$ (w.r.t. language containment) that solve the equation

$$\mathscr{L}(\mathcal{C}[\mathcal{B}]) \subseteq \mathscr{L}(\Phi)$$

- We know from automata theory that

$$\mathscr{L}(\mathcal{B}) = \overline{\mathscr{L}(\mathcal{C}[\overline{\Phi}])}$$

One property, one context

We cannot directly apply the equation:

- The solution may not be prefix-closed
  - we restrict to prefix-closed solutions
- Constraint Automata are not closed under complementation
  - we need to add final states and an acceptance condition
- We are dealing with infinite traces, where complementation is expensive
  - can we avoid Safra's construction?
  - what about determinization and subset construction?

A (somehow) simpler way to the solution

1. Φ can be easily complemented:
   - all states of Φ are final
   - complete the automaton and add a unique, non-final, sink state
   - determinize with the subset construction
   - complement by switching final and non-final states

$$\overline{\Phi} = \text{Switch}(\text{Subset}(\Phi))$$

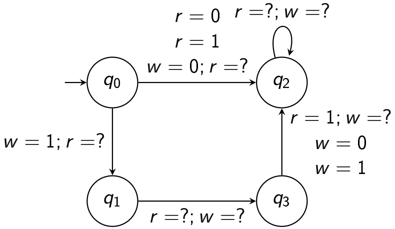
2. Then the maximal prefix closed $\mathcal{B}$ is

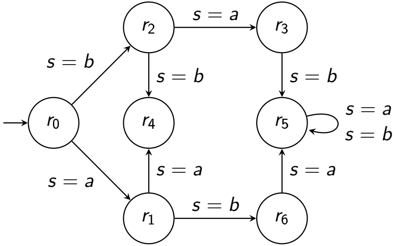
$$\mathcal{B} = \text{Prefix}(\text{Switch}(\text{Subset}(\mathcal{C}[\overline{\Phi}])))$$

   - this is a solution of the equation, but non necessarily the most general one
   - every other prefix-closed solution is contained in $\mathcal{B}$

One property, one context – example

P1: "if *w=1* is executed at the first step, then at the third step *r=0* cannot be executed"





- The solution accepts traces that ends before the third step, or longer traces that starts with either $s = a, s = b, s = a$ or $s = b, s = a, s = b$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All properties, one context

Problem

Given a context $\mathcal{C}$ and component $\mathcal{A}$, find a most general $\mathcal{B}$ such that for every property Φ, if $\mathcal{C}[\mathcal{A}]$ satisfies Φ, then also $\mathcal{C}[\mathcal{B}]$ satisfies Φ.

- This is equivalent to finding the largest $\mathcal{B}$ (w.r.t. language containment) that solve the equation

$$\mathscr{L}(\mathcal{C}[\mathcal{B}]) \subseteq \mathscr{L}(\mathcal{C}[\mathcal{A}])$$

- We know from automata theory that

$$\mathscr{L}(\mathcal{B}) = \overline{\mathscr{L}(\mathcal{C}[\overline{\mathcal{C}[\mathcal{A}]}])}$$

All properties, one context

Problem

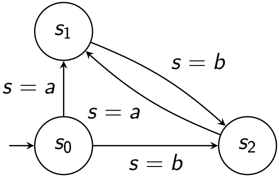
Given a context $\mathcal{C}$ and component $\mathcal{A}$, find a most general $\mathcal{B}$ such that for every property Φ, if $\mathcal{C}[\mathcal{A}]$ satisfies Φ, then also $\mathcal{C}[\mathcal{B}]$ satisfies Φ.

- By the same argument of the "one property, one context" case we can show that the maximal prefix closed $\mathcal{B}$ is

$$\mathcal{B} = \mathrm{Prefix}(\mathrm{Switch}(\mathrm{Subset}(\mathcal{C}[\overline{\mathcal{C}[\mathcal{A}]}])))$$

All properties, one context – example

We can apply the construction to obtain the most general scheduler that replaces the original one.



- The solution accepts only traces of the form
  $s = a, s = b, s = a, s = b, \dots$ or
  $s = b, s = a, s = b, s = a, \dots$

Complexity

- The same construction can be used for both the "one property, one context" and "all properties, one context" cases
- The problem is in 2-EXPTIME, since it requires a double complementation
  - even though the final result may be much smaller in practical cases
- Solving the "one property, one context" case is EXPSPACE-hard
  - Proved by reducing a suitable three-player game to it
  - The component and the property play against the context
  - Hardness of the "all properties, one context" case is open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One property, all contexts

Problem

Given a component $\mathcal{A}$ and a property Φ, find a most general $\mathcal{B}$ such that for all contexts $\mathcal{C}$, if $\mathcal{C}[\mathcal{A}]$ satisfied Φ then also $\mathcal{C}[\mathcal{B}]$ satisfies Φ.

- For asynchronous embedding, unless the formula is true or false, we need:

  $$\mathscr{L}(\mathcal{B}) \subseteq \mathscr{L}(\mathcal{A})$$

  and thus we have that $\mathcal{A}$ is the most general solution we are looking for

One property, all contexts

Problem

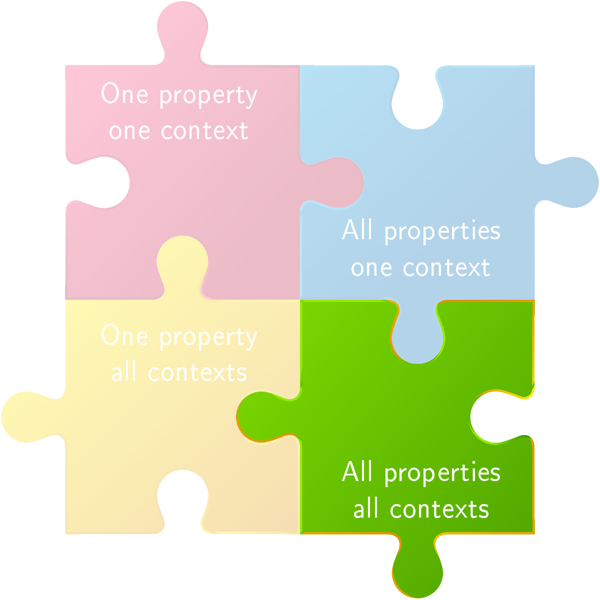
Given a component $\mathcal{A}$ and a property Φ, find a most general $\mathcal{B}$ such that for all contexts $\mathcal{C}$, if $\mathcal{C}[\mathcal{A}]$ satisfied Φ then also $\mathcal{C}[\mathcal{B}]$ satisfies Φ.

- For synchronous embedding we need:

$$\mathscr{L}(\mathcal{B}) \subseteq \mathscr{L}(\mathcal{A}) \cup \overline{\mathcal{R}(\Phi)}$$

  where $\mathcal{R}(\Phi)$ is the observation-point language of Φ that contains all the words of lengths n such that there exists zc of length n such that z is in Φ and zc is not in Φ.

- Once again, the most general solution $\mathrm{MGU}(\mathcal{A}, \Phi)$ can be built by a double complementation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All properties, all contexts

Problem
Given a component $\mathcal{A}$, find a most general $\mathcal{B}$ such that for all contexts $\mathcal{C}$ and for all properties Φ, if $\mathcal{C}[\mathcal{A}]$ satisfied Φ then also $\mathcal{C}[\mathcal{B}]$ satisfies Φ.

- Given two distinct $\mathcal{A}$ and $\mathcal{B}$, it is always possible to find a context and a property that distinguish them
- Hence, we need:

$$\mathscr{L}(\mathcal{B}) \subseteq \mathscr{L}(\mathcal{A})$$

  and thus we have that $\mathcal{A}$ is the most general solution we are looking for


One property one context
All properties one context
One property all contexts
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Conclusions

Results:

- We studied under which conditions updates preserve properties
- We have show how to build a most general update
- We generalized to all properties and/or all contexts

Future Work:

- Consider the same problem in different settings
  - More expressive automata automata
  - More expressive properties
  - More efficient constructions
- What happens when multiple updates are considered?