Larissa Aspects and Design-By-Contract

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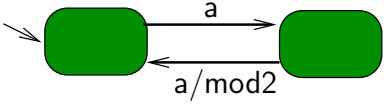
Introduction

- Reactive systems are systems which are in constant interaction with their environment
- Cross-cutting concerns exist in reactive systems
- Aspect-oriented programming modularizes cross-cutting concerns, but existing aspect languages cannot be used
- Larissa is an aspect language for the synchronous programming language Argos
- This talk :
  - present Argos and Larissa
  - combine design-by-contract with Larissa

Argos

- **Hierarchical, synchronous automata language**
- **Basic element : complete and deterministic Mealy automata**
- **Interface : a set of inputs, a set of outputs**



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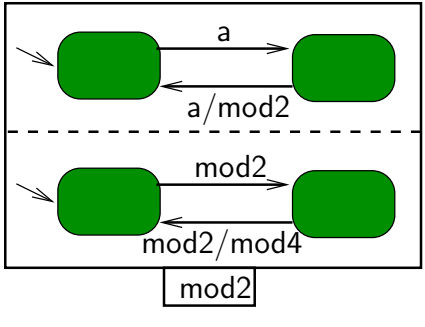
- Operators : parallel product, encapsulation



Argos

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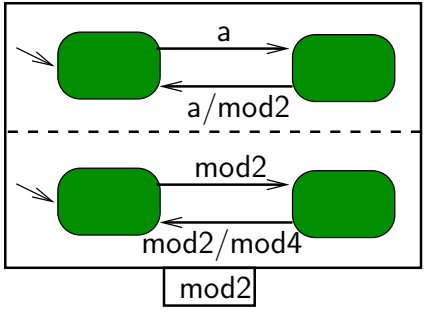
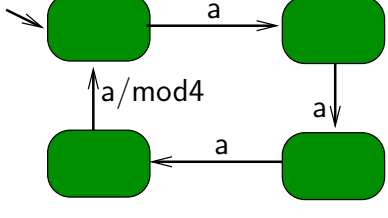
- Operators : parallel product, encapsulation
- Compiled into flat automata



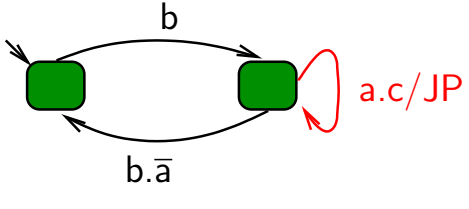


Larissa

- Aspect language for Argos
- Consists of pointcuts and advice :
  - a join point is a transition
  - pointcuts select transitions in automata
  - advice replaces these transitions
- This cannot be done with the existing operators
- We want to preserve semantic properties, e.g. preservation of equivalence

Pointcuts

- Observer automata which take as inputs the inputs and outputs of the program they observe
- Output JP is emitted when the program is in a join point
- Independent of the implementation of the program



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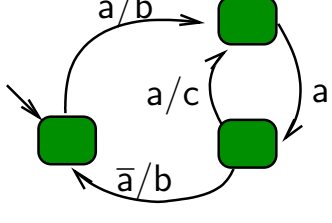

base program

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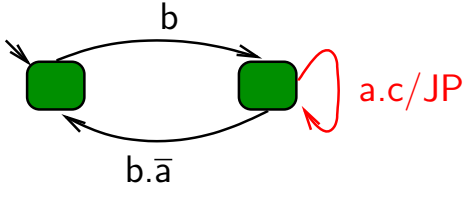

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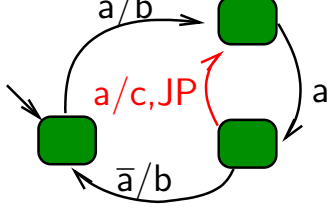
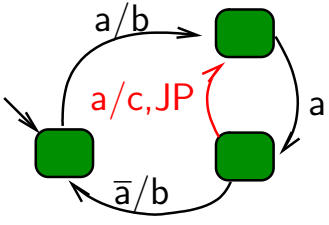


join point program

toInit Advice

- When a join point is passed, program execution is changed :
  - emit some outputs O
  - go to some target state
  - target state defined by a finite input trace
- Example advice : trace a.a, advice output d



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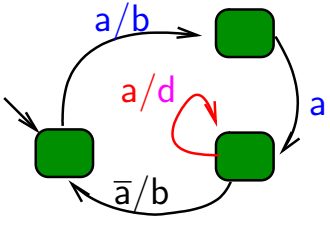

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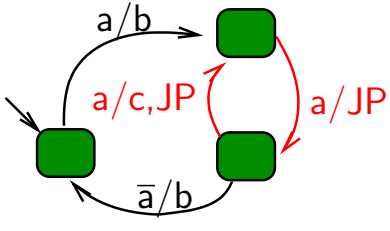

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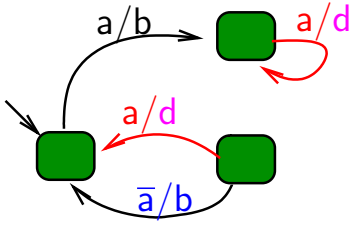

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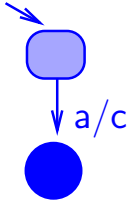
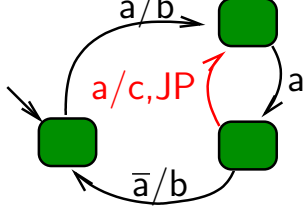
Advice Program

- **Add an automaton to the join point transition**
- **Example : tolnit advice, trace a.a, output d, inserted automaton**





inserted automaton **join point program**

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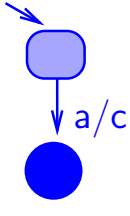

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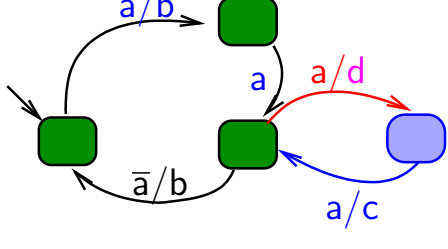

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Results

- Case study : modelling the interface of a complex wristwatch [Software Composition 06]
  - Quite complex base program in Argos and several aspects
  - Used aspects to build a product line

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- Implementation exists

Design by Contract

- Originally introduced by Bertrand Meyer for object-oriented programming
- A contract of a method consists of an assumption and a guarantee
- If the assumption holds when the method is called, the guarantee holds when the method returns
- Example :

```
/* @assume i ≤ 10 */
/* @guarantee \result ≤ 10 */
int m(int i){...}
```

Aspects Modify Contracts

– **Adding an aspect may invalidate the contract of a method**

```
int around(int i) : m(i){
  return 1 + proceed(i + 1);
}
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```

– **Sometimes, a new contract may be derived**

```
/* @assume i ≤ 9 */
/* @guarantee \result ≤ 11 */
```

Generating New Contracts

– **Idea : apply an aspect asp to a contract C, and obtain a new contract C' fulfilled by any $P \triangleleft$ asp, such that P fulfills C**

$$P \models C \Rightarrow P \triangleleft \text{asp} \models C'$$

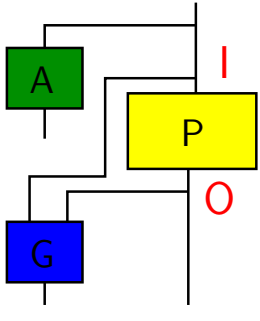
– **Goal : find a way to build C' automatically from C and asp**

Ways of Modifying Contracts

- Aspects can modify contracts in multiple ways
- Refinement : If aspects weaken the assumption and reinforce the guarantee the new program can replace the old one and can also be used in other contexts
- If aspects reinforce the assumption or weaken guarantee, or modify them completely, $P \triangleleft$ asp must be considered a new program

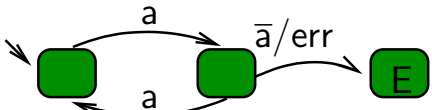
Contracts for Reactive Systems

- **Assumptions** constrain the inputs from the environment
- **Guarantees** ensure properties on the outputs
- Example :
  - **Assumption** : input **a** always occurs in pairs
  - **Guarantee** : input **a** is immidiatly followed by output **b**
- Guarantee may not constrain inputs more than the assumption

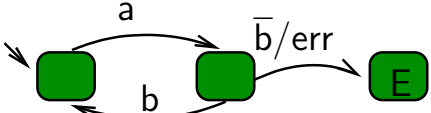


Expressing Contracts with Observers

- Properties of reactive programs can be expressed with observers with a single output err
- A program fulfills a contract if, for any execution, the guarantee only emits err if the assumption emits err or has done so previously



Assumption



Guarantee

Constructing a new Contract

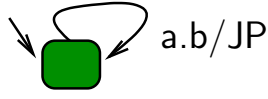
- How can we obtain a new contract $C' = (\mathbf{Ass}', \mathbf{Gu}')$ such that

$$P \models (\mathbf{Ass}, \mathbf{Gu}) \Rightarrow P \triangleleft \mathbf{asp} \models (\mathbf{Ass}', \mathbf{Gu}')$$

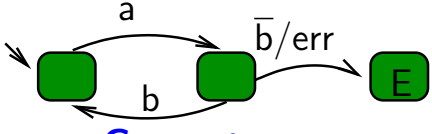
- Simulate the effect of the aspect on the program as far as possible on the assumption and the guarantee
- However, aspects cannot be applied to observers
- Transform observers into generator automata
- Apply aspect to generators
- Transform generators with aspects back to observers
- $\mathbf{Ass}' = obs_{\mathbf{Ass}}(gen(\mathbf{Ass}) \triangleleft \mathbf{asp})$
- $\mathbf{Gu}' = obs_{\mathbf{Gu}}(gen(\mathbf{Gu}) \triangleleft \mathbf{asp})$

Example

– **Example aspect : advice output b, trace a**



Pointcut



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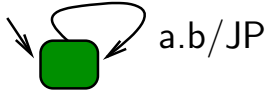

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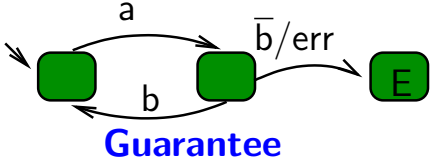

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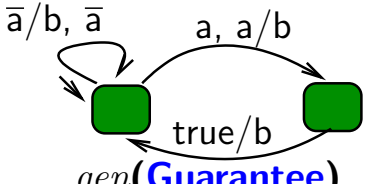

gen**(Guarantee)**

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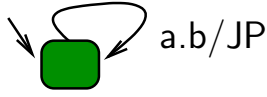

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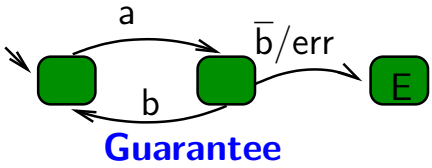

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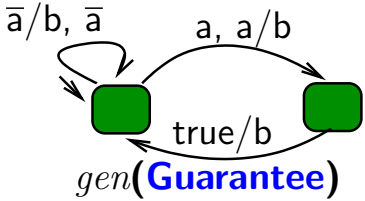

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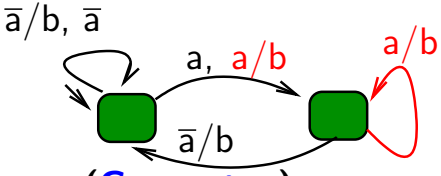

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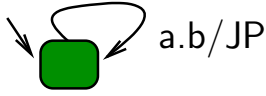

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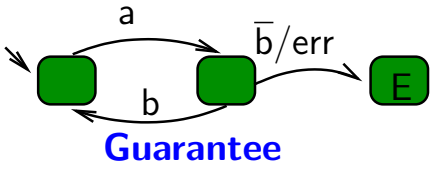

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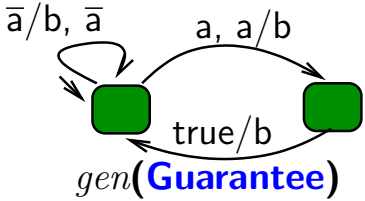

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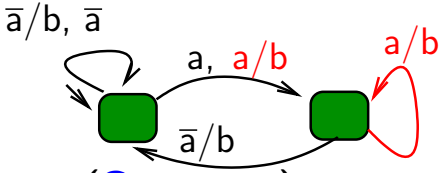

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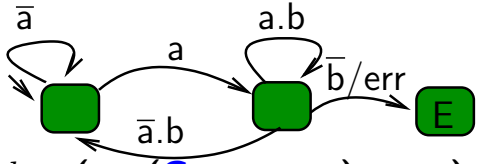

$obs_{\mathbf{Gu}}$(gen(**Guarantee**)◁ **asp**)

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- Transformation into generators is standard
- Generators have the same interface as the program, plus output err, and are non-deterministic
- Aspects can be woven into generators, but trace may lead to several target states
- Solution : add several advice transitions, introducing additional non-determinism
- Transformation into observers different for assumption and guarantee
- Different handling of introduced non-determinism :
  - Assumption rejects all traces that can be rejected
  - Guarantee produces all traces that can be produced

Related Work

- Closest related work : Goldman and Katz, "Modular Generic Verification of LTL Properties for Aspects" (FOAL '06)
  - If a base program P verifies a LTL property ψ, then $P \triangleleft$ asp verifies ϕ
  - ϕ build by weaving the aspect into ψ
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  - If a base program P verifies a LTL property ψ, then $P \triangleleft$ asp verifies ϕ
  - ϕ build by weaving the aspect into ψ
  - generic aspect model, restricted class of aspects
- Several approaches restrict the influence of aspects on the program, e.g.
  - Curtis and Leavens, "Behavioral Subtyping Analogy" Aspects must not violate the contract of a method
  - Dantas and Walker, "Harmless Advice" : Aspects must not influence the final result of the program

Conclusion

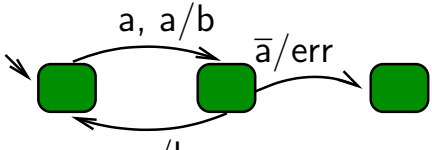
- **Larissa : an aspect language with strong semantic properties**
- **Contracts : exploit semantic properties**
- **We have shown**

$$P \models (\textbf{Ass}, \textbf{Gu})$$
$$\Rightarrow P \triangleleft \textbf{asp} \models (obs_{\textbf{Ass}}(gen(\textbf{Ass}) \triangleleft \textbf{asp}), obs_{\textbf{Gu}}(gen(\textbf{Gu}) \triangleleft \textbf{asp}))$$

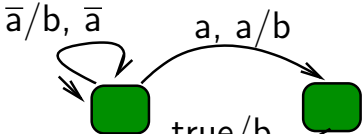
- **Approach works on small examples**
- **Further work :**
  - **Validate approach on larger example**
  - **Extend approach to valued signals**

Non-Deterministic Automata

- **Aspects cannot be woven into observers**
- **Idea : use non-deterministic automata instead**
- **Same inputs as the program and same outputs plus err**
- **err signals that a input trace is not accepted**
- **NDAs are equivalent to observers**



gen(**Assumption**)



gen(**Guarantee**)

Weaving aspects into NDA

- **Problem with weaving aspects : trace may lead to more than one state**
- **Solution : add an advice transition to every possible target state**
- **This introduces additional non-determinism**
- **Aspect can be woven into NDAs**

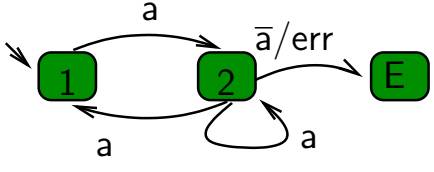
$$P \models (\textbf{Ass}, \textbf{Gu}) \Rightarrow P \triangleleft \textbf{asp} \models (\textbf{Ass} \triangleleft \textbf{asp}, \textbf{Gu} \triangleleft \textbf{asp})$$

Weaving Aspects into Contracts

- Weaving aspects into NDAs introduces additional non-determinism
- For the modular verification theorem to hold, this non-determinism needs different treatment for pre- and guarantee
  - Assumption must reject all traces that can possibly be rejected
  - Guarantee must produce all traces that can possibly be produced
- This difference is taken into account during the transformation from NDA to observer

onverting NDAs into Observers – Assumptions

- Assumption must reject all traces that can possibly be rejected
- Remove all outputs, except err
- Determinize the automaton, but do not consider non-error transitions if an error transition is available



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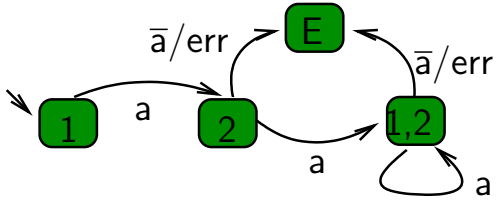
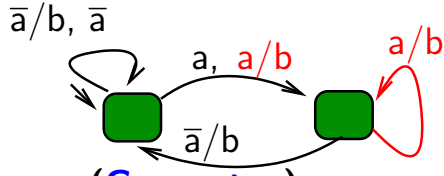


$obs_{\textbf{Ass}}(gen(\textbf{Assumption}) \triangleleft \textbf{asp})$

Converting NDAs into Observers – Guarantees

- Guarantee must produce all traces that can possibly be produced
- Convert the NDA into an observer which accepts exactly the traces the NDA produces
- Determinize the observer, but do not consider error transitions if a non-error transition is available



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